FINAL REPORT
ECONOMICS OF DIRECT HYDROGEN POLYMER ELECTROLYTE (PEM) MEMBRANE FUEL CELL SYSTEMS

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Table of Contents

Project Summary..... 2

Appendix A - Alternative Futures for the Prevailing Applications, Customers, and Markets of PEM Fuel Cells used for Stationary Power Generation in the United States by the Year 2015…….A

Appendix B: Analysis of Stakeholder Feedback on Polymer Electrolyte Membrane Fuel Cells for Stationary Applications…….B

Appendix C: Interim Report on the Economics of Stationary Proton Exchange Membrane Fuel Cells…….C

Appendix D: Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets…….D

Appendix E: Interim Report on the Market Opportunity Assessment of PEM Fuel Cell Applications at the Federal Aviation Administration……..E

Appendix F: Interim Report on the Market Opportunity Assessment of PEM Fuel Cell Applications at the Defense Logistics Agency……F

Appendix G: Analysis and Opportunity for Fuel Cell Application at Data Centers and Wastewater Treatment Plants……..G

Appendix H: The High Volume Manufacture Cost Analysis of 5 kW Direct Hydrogen Polymer Electrolyte Membrane (PEM) Fuel Cell for Backup Power Applications……..H

Project Summary

The DOE/EERE through the Fuel Cell Technologies Program (FCTP) is focused on providing a portfolio of energy technology solutions to meet energy security challenges of the future. Fuel cells particularly Polymer Electrolyte Membrane (PEM) fuel cells are a part of this portfolio of technology offerings. One focus of the FCT Program is on developing and deploying fuel cell systems in near term markets to enable the development of a manufacturing base for fuel cells, to lower the cost of fuel cells, and to build a track record for the performance and durability of fuel cell systems.

Battelle's ***Economic Analysis of PEM Fuel Cell Systems*** project was initiated in 2003 to evaluate the technology and markets that are near-term and potentially could support the transition to fuel cells in automotive markets. The objective of Battelle's project was to assist the DOE in developing fuel cell systems for pre-automotive applications by analyzing the technical, economic, and market drivers of direct hydrogen PEM fuel cell adoption. The project was executed over a 6-year period (2003 to 2010) and a variety of analyses were completed in that period. Analyses completed were –

- Commercialization scenarios for stationary generation through 2015 (2004)
- Stakeholder feedback on technology status and performance status of fuel cell systems (2004)
- Development of manufacturing costs of stationary PEM fuel cell systems for backup power markets (2004)
- Identification of near-term and mid-term markets for PEM fuel cells (2006)
- Development of the value proposition and market opportunity of PEM fuel cells in near-term markets by assessing the lifecycle cost of PEM fuel cells as compared to conventional alternatives used in the marketplace and modeling market penetration (2006)
- Development of the value proposition of PEM fuel cells in government markets (2007)
- Development of the value proposition and opportunity for large fuel cell system application at data centers and wastewater treatment plants (2008)
- Update of the manufacturing costs of PEM fuel cells for backup power applications (2009).

Battelle's research has enhanced DOE's understanding of the likely markets that should be a focus of early market transformation efforts. The project has identified the markets where PEM fuel cells offer a considerable advantage over competing alternatives in cost and performance and has built the case for deployment and adoption of these fuel cell systems. The project has defined the operational and performance requirements for near-term markets based on end-user inputs which can provide a sound basis for designing the fuel cell systems. Battelle has developed stack and system designs, bill of materials, manufacturing process models, capital equipment cost estimates, and economic and sensitivity models for total system cost and total cost of ownership that can be leveraged for future analysis. Battelle's approach to conducting manufacturing and lifecycle cost analysis has received approval from peer reviewers evaluating our existing projects as a valid, reasonable, and appropriate approach.[1] In addition Battelle has demonstrated the ability to involve a wide variety of stakeholders to provide input and vet the assumptions and design of the systems. For example, the total cost of ownership analysis performed by Battelle for use of fuel cells in backup power and lift truck applications has been

widely cited and has also assisted the DOE in decision making regarding market transformation activities in near-term markets.[2]

The cost analysis has helped the Fuel Cell Technologies Program and the fuel cell industry prioritize investments in research and development of components (e.g., metal bipolar plates vs. composite graphite plates in PEM fuel cells for low volume markets) to reduce the costs of fuel cell system while considering systems optimization. The cost analyses has also provided information on types of manufacturing processes that must be developed to commercialize fuel cells and the optimization needed for use of off-the-shelf components in fuel cell systems. Battelle through this project has provided the fuel cell industry with valuable competitive intelligence on the cost and performance drivers for the development and deployment of fuel cell systems. The project has also provided the public particularly end users an independent view of the value proposition for fuel cell systems thus facilitating the adoption of fuel cell systems. The project activities varied each year during the period of performance based on input received from the FCT Program. The reports produced for the various analyses undertaken are attached in Appendix A through Appendix H of this report. A number of publications and presentations were made as a part of the technology transfer activities required by the contract. A listing of these publications and presentations are provided in Table 1.

Table 1. Listing of Publications and Presentations.

Reports
K. Judd, K. Mahadevan, J. Amaya, J. Upton, T. Peterson, E. Zell, and G. Hund. 2004. Economic Analysis of Polymer Electrolyte Membrane Fuel Cells, Interim Report: Analysis of Stakeholder Feedback on Polymer Electrolyte Membrane fuel Cells for Stationary Applications. Contract No. DE-FC36GO13110.
S. Millett and K. Mahadevan. 2005. Alternative Futures for the Prevailing Applications, Customers, and Markets of PEM Fuel Cells Used for Stationary Power Generation in the United States by the Year 2015. Contract No. DE-FC36GO13110.
H. Stone, K. Mahadevan, K. Judd, H. Stein, V. Contini, J. Myers, J. Sanford, J. Amaya, and D. Paul. 2006. Economics of Stationary Proton Exchange Membrane Fuel Cells. Contract No. DE-FC36GO13110.
K. Mahadevan, K. Judd, H. Stone, J. Zewatsky, A. Thomas, H. Mahy, and D. Paul. 2007. Identification and characterization of near-term direct hydrogen proton exchange membrane fuel cell markets. Contract No. DE-FC36GO13110.
Battelle. 2010. The High Volume Manufacture Cost Analysis of 5 kW Direct Hydrogen Polymer Electrolyte Membrane (PEM) Fuel Cell for Backup Power Applications.
Publications
S. Millett and K. Mahadevan. Commercialization Scenarios of Polymer Electrolyte Membrane Fuel Cell Applications for Stationary Power Generation in the United States by the Year 2015. Journal of Power Sources, June 2005.
K. Mahadevan, H. Stone, K. Judd, and D. Paul. Identification and Characterization of Three Near-Term Direct Hydrogen PEM Fuel Cell Markets. Fuel Cell Seminar Conference Proceedings, 2006.
K. Mahadevan, H. Stone, J. Zewatsky, A. Thomas, K. Judd, and D. Paul. Market Opportunity Assessment of PEM Fuel Cells in Federal Markets. Fuel Cell Seminar Conference Proceedings 2007.
K. Mahadevan, H. Stone, K. Judd, and D. Paul. 2007. Identification and Characterization of Three Near-Term Direct Hydrogen PEM Fuel Cell Markets. ECS Transactions. Volume 5, Issue 1.
Presentations
K. Mahadevan and S. Millett. Scenario Analysis of the Commercialization of Proton Exchange Membrane (PEM) Fuel Cells for Stationary Applications in the U.S. by the Year 2015. Fuel Cell Seminar, San Antonio, November 2004.
K. Mahadevan, H. Stone, K. Judd, and D. Paul. Identification and Characterization of Three Near-Term Transitional Direct Hydrogen Fuel Cell Markets. Poster Presentation, Fuel Cell Seminar, Honolulu, Hawaii 2006.
K. Mahadevan, H. Stone, K. Judd, and D. Paul. Economic Analysis of Direct Hydrogen PEM Fuel Cells in Three Near-Term Markets. Hydrogen and Fuel Cells Trade Show, Vancouver, British Columbia, April 2007.
K. Mahadevan, H. Stone, J. Zewatsky, A. Thomas, K. Judd, and D. Paul. Market Opportunity Assessment of PEM Fuel Cells in Federal Markets. Fuel Cell Seminar, San Antonio, 2007.
K. Mahadevan, A. Thomas, J. Zewatsky, and H. Stone. Near-Term Market Opportunity Assessment of PEM Fuel Cells in Federal Markets. NHA 2008, Sacramento, CA, March 2008.
K. Mahadevan. Commercial Markets for PEM Fuel Cells in Backup Power, Portable Power, and Specialty Vehicle Applications. Fuel Cell 2008, Long Beach, CA, 2008.
K. Mahadevan. Market Opportunities for Fuel Cells in the United States Today. F-Cell 2008, Stuttgart, Germany, 2008.
K. Mahadevan. Analysis and Opportunity for Fuel Cell Application at Data Centers and Wastewater Treatment Plants. Fuel Cell Seminar 2008, Phoenix, Arizona.

Appendix A: Alternative Futures for the Prevailing Applications, Customers, and Markets of PEM Fuel Cells used for Stationary Power Generation in the United States by the Year 2015

DRAFT FINAL REPORT

ALTERNATIVE FUTURES FOR THE PREVAILING APPLICATIONS, CUSTOMERS, AND MARKETS OF PEM FUEL CELLS USED FOR STATIONARY POWER GENERATION IN THE UNITED STATES BY THE YEAR 2015

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TABLE OF CONTENTS

TABLE OF CONTENTS ii
1.0 Introduction 1
2.0 Scenario Methods and Interactive Future Simulations™ (IFS) 1
3.0 Methodology 3
3.1 Topic Question 3
3.2 Three Expert Focus Groups 3
3.3 Descriptors and Cross-Impact Analysis 5
4.0 Five Principal Scenarios 5
4.1 Scenario A: Slow Market Development 6
4.2 Scenario B: Qualified Success in Residential and Light Commercial Applications 8
4.3 Scenario C: Roaring Success 9
4.4 Scenario D: Success with a Hydrocarbon Infrastructure 11
4.5 Scenario E: Qualified Success in Commercial and Light Industrial Applications 11
5.0 Disruptive Events 12
6.0 Interpolation of Trends and Scenarios from 2005 to 2015 13
7.0 Implications of the Scenarios 16
8.0 Prevailing Applications and Customers of PEM Fuel Cells 18
9.0 Potential Benefits of Scenario Analysis 19
10.0 Conclusions 20
11.0 References 21
Appendix A: First Expert Focus Group on Drivers of the Stationary PEM Fuel Cell Market .. A-1
Appendix B: Second Expert Focus Group on Inputs to the PEM Fuel Cell Scenarios 2010 .... B-1
Appendix C. Third Scenarios 2015 Workshop on the Furture of Stationary PEM Fuel Cell C-1
Appendix D: Descriptors (From IFS) D-1
Appendix E: Cross-Impact Guides E-1
Appendix F: Cross-Impact Matrix (From IFS) F-1
Appendix G: Scenario Results (From IFS) G-1
Appendix H : Calculation of IFS Scenario Probabilities for Descriptor States and Scenarios .. H-1

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has the mission to stimulate the development and commercialization of hydrogen as a national energy source. One component of this mission is the successful commercialization of the polymer electrolyte membrane (PEM) fuel cell for the stationary generation of electricity. While PEM fuel cells will work technically and are being deployed among electricity consumers today, too many uncertainties still remain to determine with confidence what commercialization strategies and investments in them today will lead to their substantial market penetration over the next 10 years or so.

This document reports on the results of the scenario analysis conducted during Fiscal Year 2004 and Fiscal Year 2005 as part of a larger project to provide a long-term economic and market analysis of PEM fuel cells. The scenarios that are presented here are based on information and expert judgment generated in 2004 and early 2005 and are, of course, subject to change due to events, new information, and revised judgments. The forecast based on scenario analysis is conditional upon existing trends and known facts, all of which are subject to change. *The resulting scenarios and their probabilities of occurrence are hypothetical, as indeed are all forecasts.* The scenarios, therefore, should be viewed as a work in progress with potentially alternative futures emerging as new circumstances arise.

2.0 SCENARIO METHODS AND INTERACTIVE FUTURE SIMULATIONS™ (IFS)

Scenarios provide an alternative approach to econometric and statistical models and forecasts. They present alternative outcomes in the future that range from subtle to starkly different points of view. They are highly dependent upon qualitative information and expert judgment rather than historical data. Scenarios are not linear trend projects and statistical forecasts. Rather than the point forecasts produced by actuarial, econometric, and financial models, scenarios are really stories about how the future may evolve and why. Scenarios place more emphasis on the specific conditionality of outcomes rather than specific outcomes. Therefore, the results of scenario analysis can be very different in form and substance from econometric and statistical forecasts.

Scenarios are used when the future is highly uncertain and when various outcomes appear possible if not equally likely. They are used often as the beginning of a process that reduces uncertainty of a forecast through stages moving from the most general to the specific. Scenarios are used often as explicit pre-conditions for running alternative statistical modes for point forecasts.

The word “scenario” has at least two different meanings. One is a hypothetical or planned sequence of events from the present to a specified date in the future. This is the meaning of the term in the context of theatrical scripts and military planning. The other definition, as developed in the early 1970s by General Electric and Shell for long-term strategic business planning, is an internally consistent but different sets of outcomes by a specified date in the future. The method may generate any number of alternative future descriptions, typically numbers from two to five. This report employs the second meaning of the word “scenario.”

Since the 1970s, when scenarios were initially used for long-term business planning, two major alternative methods emerged. One is the well-known intuitive scenario writing method developed at Shell and made famous by such practitioners as Pierre Wack and Peter Schwartz. The other is the cross-impact method developed at the RAND Corporation and the business school of the University of Southern California (USC). The Battelle approach, which is used to generate the scenarios in this report, is an adaptation of the RAND-USC approach.[1]

Battelle created a proprietary scenario method and software program to support it in the 1980s. It has been applied to about 60 major projects with corporate and government clients around the world. The method and software tool was called BASICS, until it was substantially revised and reformatted for Microsoft Windows in 1998. They are now called Interactive Future Simulations (IFS). IFS combines expert judgment techniques with the cross-impact analysis method developed by RAND and USC to produce computer-generated probabilistic scenarios. It is essentially an analytical, as opposed to strictly intuitive, approach to constructing logically consistent scenarios and alternative futures. The method is further explained below.

Expert judgment is used to craft the topic question and to identify the descriptors, which are the issues, trends, and variables most important to the topic question. This step, in the language of systems analysis, is called the specification of the model. The descriptors cover technological, economic, financial, marketing, regulatory, policy, and consumer behavioral issues and trends. Each descriptor is distinctly different and must have at least some interconnections with other descriptors. In the course of IFS projects, the descriptors must be defined and documented.

Each descriptor has two, three, or four likely alternative outcomes by the target year (2015). These alternative outcomes are mutually exclusive and exhaustive of all reasonable outcomes. They are typically expressed as general ranges of high, medium, and low relative to the definition of the descriptor. Descriptor states, like the descriptors themselves, may be expressed either qualitatively or quantitatively (but as ranges rather than points). Each descriptor outcome is given an *a priori* probability of occurrence (as determined by the experts subject to peer review). The *a priori* probabilities, in language of Bayesian statistics, are initial judgment probabilities of a future occurrence based on current information and expectations. The sum of the *a priori* probabilities for each descriptor is 1.0.

A cross-impact matrix is set up on the IFS computer software program and the cells of the matrix are filled, using expert judgment subject to peer review, by index values (a surrogate for conditional probabilities) ranging from +3 to -3. The cross-impact values represent how the occurrence of one descriptor (and its alternative outcomes) would directly impact the occurrence

of all other descriptors (and their alternative outcomes). The IFS algorithm calculates the adjusted probabilities and drives each descriptor outcome to 1.0 (occurs) or to 0 (does not occur) and generates clusters of coincident occurring descriptor outcomes (scenarios).[2]

The purpose of the scenarios is to bound the uncertainties surrounding the commercialization and market penetration by framing reasonable (likely) expectations for PEM fuel cells used for stationary applications in the U.S. by 2015. The scenarios are by definition conditional, so the alternative scenarios represent alternative outcomes of descriptors by the target date. The cross-impact model not only provides the foundation for the scenarios, it also provides a model for simulating different descriptor outcomes and *a priori* probabilities and disruptive events. IFS may be used as a strategy simulation as well as a scenario generation tool. The scenarios provide different alternative futures that will be further used as inputs to more detailed economic analysis of each of the alternative likely applications, customers, and market sizes.

3.0 METHODOLOGY

3.1 TOPIC QUESTION

After consultation with DOE, the topic question was determined to be "What will likely be the principal applications, customers, and market sizes of stationary PEM fuel cells in the range of 1 kW to 250 kW in the U.S. by the year 2015?" DOE showed a particular interest in what sizes, applications, and customers of PEM fuel cells were most likely to prevail in the future, and why, in order to achieve the best potential long-term returns on DOE investments made today.

3.2 THREE EXPERT FOCUS GROUPS

Having established with DOE the topic question, Battelle conducted three expert focus groups to gather the judgments of various experts on the most important descriptors to be included in the scenario analysis. The first expert focus group was held at Battelle in Columbus, Ohio, on December 12, 2003. It included 16 participants from the fuel cell industry, electric utilities, universities, national laboratories, Battelle, and state government. The group identified 65 potential descriptors and ten major themes. (See Appendix A for the documentation of the first expert focus group). The ten major themes were as follows:

1. System costs and unit prices of PEM fuel cells relative to energy alternatives – both the retail prices of fuel cells and operating costs, including fuels

2. Sufficient investment capital for development and commercialization of PEM fuel cells
3. Technology advancements in PEM fuel cells relative to advancements in fossil fuel technologies
4. Environmental laws, regulations, taxes, etc.
5. Federal, state, and local energy policies and programs that favor PEM fuel cells
6. Hydrogen or hydrogen-rich fuels and infrastructure to support PEM fuel cells
7. Reliability and quality of the electric grid in regard to growth in electric demand
8. Performance quality of PEM fuel cells, including energy efficiency, reliability, safety, service, etc.
9. Successful early deployments of PEM fuel cells (including applications abroad and in automotive applications)
10. Increased consumer confidence in and benefits and value from PEM fuel cells as stationary generators of electric power.

Following the first expert focus group, the Battelle scenario project team derived 20 different descriptors and prepared draft definitional white papers for them. The team also identified the alternative outcomes and *a priori* probabilities for them for each descriptor. In addition, an initial quantitative cross-impact matrix was generated using qualitative cross-impact guides.

The second expert focus group was held in Washington, D.C., on May 12, 2004. It included 22 participants from the fuel cell industry, companies that are either potential producers or users of PEM fuel cells, energy companies, and DOE. The group reviewed, commented upon, and in many incidents revised the initial set of descriptors, alternative outcomes, and *a priori* probabilities derived from the first expert focus group. (For the documentation of the second expert focus group, see Appendix B.) Participants were also encouraged to review the cross-impact guides and values and submit alternative judgments.

As a result of the second expert focus group, the Battelle scenario project team increased the number of descriptors from 20 to 26 and revised the alternative outcomes and *a priori* probabilities of 15 of the previous 20 descriptors. The team also carefully reviewed and revised the cross-impact matrix. Revised inputs were made to the IFS software program and a new set of scenarios were generated based on them.

The third expert focus group was held at Battelle in Columbus on August 5, 2004. It included 19 participants from the fuel cell industry, companies that may produce or use PEM fuel cells, electric utilities, Battelle, and state and Federal governments. The group reviewed all the inputs and the resulting scenarios. They suggested the addition of one more descriptor and revisions to 14 of 28 descriptors. In addition, eight participants submitted detailed suggestions and revisions to the descriptor alternative outcomes, *a priori* probabilities, and cross-impact values in writing following the workshop.[3] Finally, the third expert focus group generated an initial list of implications of the scenarios for corporate and DOE investments, which appears at the end of this report. (For the documentation of the third expert focus group, see Appendix C.)

3.3 DESCRIPTORS AND CROSS-IMPACT ANALYSIS

As described above, the descriptors were derived by the Battelle scenario project team following each of the three expert focus groups. The process was iterative and the determination of the descriptors, their alternative outcomes, and *a priori* probabilities progressed through reviews by the participants of the expert focus groups. As mention above, the set of descriptors was set at 28. The descriptors, alternative outcomes, and *a priori* probabilities appear with definitions as Appendix D.

In addition to the descriptor definitions, the Battelle team completed a cross-impact guide for each descriptor. The line of inquiry is whether or not and how each descriptor impacts all the other descriptors. The sequence of questions and judgments is as follows:

a) Is there a direct cause-and-effect impact of each descriptor (and its alternative outcomes) on all other descriptors (and their alternative outcomes)?
b) If there is an impact, is it positive or negative? Would the impact adjust the *a priori* probabilities of other descriptor outcomes up, positively, or down, negatively?)
c) How large is the impact (strong = 3, medium = 2, and low = 1)? A zero value means that there is no known direct impact relationship or no net impacts.
d) Why? A brief narrative explanation is required to document the judgment made.

More precisely stated, if each descriptor state (alternative outcome) were to occur (with an *a priori* probability set to 1.0), then how would that adjust all the other descriptor alternative outcomes' *a priori* probabilities? This procedure provides the means of integrating all of the descriptors in net outcomes, or scenarios, of occurring and non-occurring outcomes for each descriptor. In Bayesian terms, the adjusted probabilities are called *a posteriori* probabilities of occurrence.

The cross-impact values were reviewed by the participants of the expert focus group and revised when necessary. The cross-impact guides were completed using the IFS software, which converted the guides into a numerical cross-impact matrix. The cross-impact guides for all 28 descriptors appear in Appendix E and the numerical matrix appears as Appendix F.

4.0 FIVE PRINCIPAL SCENARIOS

The IFS algorithm calculates the scenarios by setting each descriptor outcome to 1.0 (occurs) and to 0 (does not occur) as the initial starting point. It proceeds down each column of the cross-impact matrix adjusting other descriptor outcome *a priori* probabilities up or down according to

the positive or negative values in the cells of the matrix. Once a descriptor outcome has its *a priori* probability adjusted to 1.0 or to 0, it remains so until all descriptor outcomes are so adjusted. Then the algorithm sorts through all the single scenarios and groups them into identical types (clusters) of occurring and non-occurring descriptor outcomes, or scenarios.

In this study, there were 28 descriptors with a total number of descriptor outcomes equaling 92. The total number of single scenarios (which are calculated as sequential scenarios of occurring and non-occurring descriptor outcomes) equaled 184. Of these 184, only 17 scenario types (or just "scenarios") had a frequency of occurrence of two or more. The top ranked 17 scenarios had a combined frequency of occurrence of 58 (out of the total of 184 scenarios). The remaining 126 scenarios occurred only once. For the purposes of the analysis and scenario forecast, the Battelle project team considered only the top ranked 17 scenarios, which were consolidated further into five principal scenarios.[4]

The full array of scenarios appears as Appendix G. A full explanation of how the top five scenarios and their *a posteriori* probabilities of occurrence were determined appears as Appendix H.

The five principal scenarios, based on current trends and knowledge, barring unforeseen disruptive events, are as follows:

1. Scenario A: Slow Market Development
2. Scenario B: Qualified Success in Residential and Light Commercial Applications
3. Scenario C. Roaring Success
4. Scenario D: Success with a Hydrocarbon Infrastructure
5. Scenario E: Qualified Success in Commercial and Light Industrial Applications

Each of these five scenarios in terms of consistently occurring sets of descriptor outcomes is described below.

4.1 SCENARIO A: SLOW MARKET DEVELOPMENT

The most likely scenario (with an *a posteriori* probability of 15%) portrays a future in which both the technological and commercial developments of PEM fuel cells will most likely be characterized as incremental, as opposed to breakthrough, improvements over time. PEM fuel cell technology will likely progress beyond the state of the art of 2004 and sales will substantially increase over what they are today, but the PEM fuel cell product will face a tough market and experience slow market penetration.

In this scenario, the retail prices for PEM fuel cells will most likely be in the range (expressed in constant 2004 dollars) of $1,000 to $3,000 per kW capacity. The prevailing architecture of the PEM fuel cell will be the stack with controls and balance of plant, but it will have to be assembled with various peripherals required for specific applications and it will have to be professional installed, perhaps by the manufacturer. The PEM fuel cell will have the market

image as little more than an electric generator competing with other sources of electricity. In general, performance benefits will fail to consistently meet customer expectations, which may be higher for PEM fuel cells than for conventional gasoline and diesel generators. PEM fuel cell operating costs, including fuels and maintenance, will be in the middle range of 10-20 cents per kWh.

Investments in both mobile and stationary PEM fuel cells in the U.S. will average less than $1.0 billion a year, or essentially the same if not less than investments made today.

PEM fuel cell manufacturing will progress slowly and by 2015 will still require significant manual labor in the assembly process.

There will be technological advances in PEM fuel cells, primarily in the areas of materials and controls. PEM fuel cells will require a hydrogen fuel of high purity that will most likely be centrally produced and packaged in canisters and tanks. The implication is that hydrogen will be seen as expensive relative to the commodity fuels of gasoline, diesel, methane, and alcohols.

In the meanwhile, advances in fossil fuel and internal combustion engine technologies will not progress much further than the state-of-the-art today. There will be marginal improvements in electric storage technologies. Fossil fuel prices will be in the range of one to two times base 2004 prices. Environmental regulations will require lower levels of emissions, but carbon management will be voluntary. In general, the hydrocarbon-combustion energy paradigm will remain strong and competitive between now and the year 2015.

Public sector support of PEM fuel cells will be limited to specific tax breaks and R&D. The state and Federal governments will likely play a passive role relative to the primary leadership in the development and commercialization of PEM fuel cells by entrepreneurs, venture capitalists, and corporations. The national energy policy will emphasize free market dynamics and deregulation of the electric utility industry. Major gaps will remain between the evolving codes and standards for PEM fuel cells and the changing technologies and products on the market.

The country's electric power grid will be characterized as basically sound but with reliability and quality inconsistencies (marked by periodic power failures and voltage irregularities). The structure of the U.S. electric utility industry will remain essentially as it is today. Grid electric prices will rise to a high level (in the range of 11-15 cents per kWh as an average of all customers across the U.S.). Grid electricity, although prices may rise, will generally be viewed as good value for consumers and will not likely stimulate a consumer shift to alternative sources of electric power. Distributed generation will be largely customer-driven, with an emphasis on customers buying and operating their own generators.

PEM fuel cells will be used primarily in isolated locales unconnected, underserved, or overpriced by the utility electric grid or in especially high value applications (in which the failure of the grid would be seen as virtually catastrophic by customers). They will be seen as electric generators in competition with internal combustion engines or advanced batteries. The prevailing customers for PEM fuel cells will be commercial and light industrial. By implication, the prevailing size of PEM fuel cells in this market will be in the range of about 50-200 kW capacity.

The most likely market for PEM fuel cells in the U.S. by the year 2015 will be less than $5 billion sales per year for stationary power generation. The commercialization of PEM fuel cells will require time to penetrate substantially the stationary power market in the U.S.

4.2 SCENARIO B: QUALIFIED SUCCESS IN RESIDENTIAL AND LIGHT COMMERCIAL APPLICATIONS

The second scenario, which has a probability of 10%, portrays a more optimistic future for PEM fuel cells than provided by Scenario A. In Scenario B, PEM retail prices, unit architecture, and operating costs are the same as in Scenario A, but installation will be characterized as easy ("plug-and-play" by the customer) or relatively easy by local contractors. Performance benefits will consistently meet customer expectations. PEM fuel cell technology advances will be substantial, reflecting system-wide innovation and optimization. The stack will be designed to handle hydrogen even with some impurities, thereby negating the need for expensive, chemically-pure hydrogen. The stack will also likely meet exacting technical specifications and consumer expectations for performance reliability and longevity. A fuel processor in addition to the stack will likely not be required.

Investments in PEM fuel cells will increase to the range of $1-$2 billion a year by 2015, more than in Scenario A. Manufacturing of PEM fuel cells will progress to semi-automated assembly, improving product quality consistency and reducing production costs. The PEM fuel cell product will enjoy a "high tech, high gloss" market image – "the next best thing to sliced bread" (meaning a highly differentiated product with elements of glamour and brand name recognition like other types of high-end consumer products).

In Scenario B, PEM fuel cells will likely use hydrogen (or hydrogen-rich) commodity fuels. These hydrogen fuels will be as widely available as gasoline is today from retail outlets across the country. By implication, the hydrogen infrastructure will be in place to support PEM fuel cell commercialization, perhaps in parallel with the current hydrocarbon infrastructure. The hydrogen would be produced in high volumes with high purity and in forms that would be relatively easy to store and transport. It is also possible that the hydrogen may come from hydrogen-rich (but not pure) fuels, perhaps hydrocarbons with particularly rich and accessible hydrogen. This would permit the continued use of the hydrocarbon infrastructure of today. In either possibility, the fuel for PEM fuel cells will be, in this scenario, widely available and priced as a commodity fuel.

The public policy in support of PEM fuel cell development and commercialization will be characterized as providing numerous subsidies, credits, tax breaks, and other types of financial incentives offered by both the Federal and state governments. In other words, the public sector will help write off many of the exceptional expenses associated with PEM fuel cells and will thereby make fuel cells more competitive with traditional sources of stationary power generation.

The national energy policy will be driven primarily by concerns of national security and homeland defense.

Codes and standards for PEM fuel cells will exist, but they will be not be comprehensive and only partially aligned with changing technologies and fuel cell products. Code and standards gaps will remain.

The national electric grid will be highly reliable, with only occasional exceptions. Large power failures will be relatively brief and localized. Grid electricity prices will be in the medium level of 7-10 cents per kWh as a national average across all customers. Given these conditions, PEM fuel cells will increase their market penetration largely due to value attributed to lower installation costs, the meeting of customer expectations, PEM fuel cell system innovation and optimization, and the availability of commodity priced hydrogen fuels.

Distributed generation will grow as a cooperative and combined effort of customers and electric utilities. In this context, PEM fuel cells will increase in popularity as energy efficient and environmentally friendly power generators for both backup and grid load management (peak-shaving) applications. The growth of distributed generation will provide auxiliary power sources for customers and for the grid, thereby increasing grid reliability and lowering average grid costs. The prevailing customers for PEM fuel cells will be residential and light commercial. Residential customers might include a broad range of private residences, including individual homes, neighborhoods or subdivisions, apartment and condominium complexes, gated communities and cooperatives. By implication the prevailing PEM fuel cell unit successful in the marketplace will be of relatively small sizes (less than 50 kW capacity).

The market size for PEM fuel cells will be in the medium range of $5-$8 billion sales per year by the year 2015. By this time, PEM fuel cells will be seen as a qualified commercial success – products will be produced and sold and customers will be happy, but the market sales will not be as high as expected by the most avid product champions and investors.

4.3 SCENARIO C: ROARING SUCCESS

The third scenario, which has a probability of 4%, is characterized by relatively rapid market penetration and the growing demand for PEM fuel cells. In this scenario both the technological developments and the market commercialization meet high expectations for producers, customers, and investors.

PEM fuel cell product prices will be in the range of $2,000 to $3,000 per kW capacity. The architecture will be a fully integrated unit requiring no further modifications or adaptations for customers. Installation will be easy and inexpensive (plug-and-play). Technological advances will be substantial with system-wide innovation and optimization. Operating costs will be in the range of 10-20 cents per kWh.

As in Scenario B, PEM fuel cell performance benefits will consistently meet customers' expectations, and it will enjoy the market image of a high-tech, high-gloss product.

PEM fuel cell investments will be in the high range of more than $2 billion a year by 2015.

PEM fuel cells will be mass produced with high quality control and in high volumes, greatly improving product quality while reducing costs.

As in Scenario B, the principal fuel source will be hydrogen (or hydrogen-rich) commodity fuels with an infrastructure adequate to support the extensive commercialization of fuel cells. Hydrogen will be widely available and commodity priced. But unlike Scenario B, the public sector will become a lead buyer and customer of fuel cells. National energy policy will stress both energy sufficiency and national security. Codes and standards will be comprehensive and fully aligned with changing fuel cell technologies and products.

The national electric grid, also as in Scenario B, will be highly reliable, but with occasional exceptions and grid prices will be in the high range of 11-15 cents per kWh across the country and across all customers. Distributed generation will be a combined and cooperative endeavor of customers and electric utilities. In this scenario, unlike Scenario B, fuel cells will be used for more than just distributed generation – PEM fuel cells will be used on a continuous bases for premium power with great flexibility for backup, peak shaving, and optimal electric load management synchronized with the electric grid. This will likely also include the option of selling electricity from PEM fuel cells back to the grid.

The prevailing applications and customers for PEM fuel cells will be residential and light commercial (with units of less than 50 kW capacity) and the market size will be in the high range of more than $8 billion in sales per year by 2015.

A comparison of Scenario C with Scenario B suggests what descriptors and states separate the middle range from the high range market sizes for PEM fuel cells:

- PEM fuel cell architecture must be a fully integrated unit requiring no customization or adaptations for customers
- Installation must be plug-and-play
- Investments must rise to the high level
- Codes and standards must be comprehensive and fully aligned with changing fuel cell technologies and products
- The public sector must provide leadership by being a buyer and early adopter of PEM fuel cell products -- not just for space and military applications, but widely for public buildings and facilities
- National energy policy must stress both energy sufficiency and security
- National electric grid prices must be high
- PEM fuel cells must be used for continual if not continuous premium power generation for base load power as well as backup and peak-shaving power applications.

4.4 SCENARIO D: SUCCESS WITH A HYDROCARBON INFRASTRUCTURE

The fourth scenario, which has a frequency of 2%, is very similar to Scenario C, but with one major difference: the fuels for PEM fuel cells will be hydrocarbons requiring an additional fuel processor (including fuel reformer). The PEM fuel cell can experience a high level of commercial success even within the current structure of the hydrocarbon (oil, gasoline, diesel, and natural gas/methane) infrastructure. Also in this scenario, retail prices must be low, less than $1,000 per kW capacity. Another way to say this is that fuel cell unit prices might be higher with a hydrogen infrastructure than with a hydrocarbon infrastructure. One obvious reason is that in Scenario D the customer will have to buy and install a fuel processor in addition to the fuel cell unit. In all other aspects, Scenario D is identical with Scenario C. It should be remembered that the probability of Scenario D is less than half of the probability of Scenario C, suggesting that commercial success of the PEM fuel cell depends more upon commodity hydrocarbon or hydrocarbon-rich fuels than on lowest PEM fuel cell unit prices.

4.5 SCENARIO E: QUALIFIED SUCCESS IN COMMERCIAL AND LIGHT INDUSTRIAL APPLICATIONS

The fifth scenario, which has a probability of just 1%, is similar in many ways to Scenario B. In both Scenarios B and E, the market size will be in the middle range of $5-$8 billion a year by 2015. The difference, however, is that in Scenario B the principal applications and customers will be residential and light commercial, whereas in Scenario E they will be commercial and light industrial (with units in the range of 50-200 kW capacity).

In Scenario E, retail prices will be in the range of $1,000 to $2,000 per kW capacity. Installation will be achieved with the use of local contractors (with few or no plug-and-play options). Unlike Scenario B, the market image of a PEM fuel cell will be that of an effective electrical generator and heat appliance (but not that of the high-tech, high-gloss consumer product). Also, electric grid prices will be in the high range of 11-15 cents per kWh averaged across the country and across all customers.

The point must be made again that the scenarios and their probabilities of occurrence by the year 2015 are entirely predicated upon inputs made to the cross-impact model. It is not an immutable forecast of a predetermined future. In Bayesian fashion, revised inputs based upon recently occurring events, changed trends, and new information will result in revised scenarios. Having no data today from the future, the scenarios must be viewed as conditional, provisional, and hypothetical. Furthermore, to the extent that one can influence events in the future, the scenarios and their probabilities of occurrence can actually be changed due to the analysis of them. In other words, one may use scenario analysis to an extent to change potential future outcomes.

5.0 DISRUPTIVE EVENTS

As discussed above, the five principal scenarios were generated from the cross-impact model based on currently known trends and issues playing out into the future as expected today. Yet, there will always disruptive events (or "wild cards" or "black swans") that impose discontinuities upon trends. A consideration of disruptive events is a form of sensitivity analysis to the baseline model and resulting baseline scenarios.

This study considered two disruptive events between now and 2015: a significant increase in natural gas prices and a carbon management regime (including the possibilities of carbon emission restrictions and carbon taxes). In the first case, the disruptive event was introduced as a new descriptor with just one state (occurs) with an *a priori* probability of 1.0. The cross-impact analysis is performed with the disruptive event impacting all other descriptors, but it is not impacted by any of the other descriptors (because it is predetermined to occur as a disruptive event). In the second case, the possibility of a carbon regime was already in the baseline scenario model as the first alternative future (state) of Descriptor 13, Environmental Regulations. As a sensitivity analysis, this state was assigned an *a priori* probability of 0.98 in place of its baseline a priori probability of 0.15. The cross-impact matrix remained as before.

The first disruptive event was a long-term tripling of natural gas prices in real dollars from 1995 prices. This disruptive event might occur as the result of sharply increased demand for natural gas and/or a dramatic decline in supplies. The overall effect of the disruptive event would be to frustrate the successful commercialization of PEM fuel cells. Higher natural gas prices, and higher hydrocarbon prices in general, would likely increase grid electricity prices, and that condition would encourage the use of PEM fuel cells as in the mode of distributed generation to supplement or even replace grid electricity. However, high natural gas prices would in general increase the fuel costs, and thereby the operating costs, of PEM fuel cells, making them appear as a questionable value to customers.

In the prevailing scenario resulting from the disruptive event, the electric grid will be have reliability and power quality, but with periodic exceptions (particularly at times of peak load). Distributed generation will be primarily customer driven. Grid electric prices will be very high, which in general would make PEM fuel cells appear more attractive as an alternative, except the technical and performance expectations for PEM fuel cells will not likely be met. PEM fuel cells will be used primarily in isolated, high power value situations by commercial and light industrial customers.

The second disruptive event was a carbon management regime, including restrictions on carbon dioxide emissions, carbon credits, and carbon taxes. Such a disruptive event would have profound impacts on fuels for gasoline- and diesel-burning automotive vehicles and coal-burning electric utilities. The general impact would be to raise prices and restrict usage of hydrocarbon fuels, unless the carbon dioxide emissions could be captured and sequestered. The prevailing

scenario with a carbon management regime results in PEM fuel cells achieving sales in the range of $5-$8 billion by 2015. The prevailing customers will be residential and light commercial customers who will use PEM fuel cells in parallel with the grid. Distributed generation in general will be a coordinated endeavor of customers and electric utilities.

In the carbon management scenario, PEM fuel cells appear more attractive as an environmentally friendly technology for generating electricity. New environmental regulations on carbon emissions would most likely raise the prices of most forms of hydrocarbon fuels (especially oil and coal). To the extent that PEM fuel cells will use hydrocarbons as fuels, any disruptive event that raises the price of hydrocarbon fuels will raise the operating costs of PEM fuel cells.

6.0 INTERPOLATION OF TRENDS AND SCENARIOS FROM 2005 TO 2015

The five baseline and two disruptive event scenarios discussed above represent alternative futures for PEM fuel cells used for stationary power generation that are likely to occur in the U.S. by 2015. They are static scenarios in the sense that they present internally consistent sets of outcomes without representing specific paths across time. By knowing where we are today and by considering the alternative futures, one can use hypothetical, sequential scenarios as a method of interpolation of likely events over the next 10 years.

According to a recent market study, the number of PEM fuel cells sold for stationary power generation rose from 15 units in 2000 to a projected 1,379 units in 2004. The sales volume likewise rose from about $400,000 in 2000 to a projected $66 million in 2004. Another study estimates that total fuel cell sales (of all kinds for all applications) in the U.S. reached $118 million in 2004. Retail prices for PEM fuel cells vary greatly, ranging from $3,000 to $6,000 per kW depending upon the supplier and specifications. Installation has to be done by professionals and it can cost as much as or even more than the unit itself. Besides being generally viewed as expensive, PEM fuel cells have had issues with reliability and durability. PEM fuel cells can fail unexpectedly and require maintenance, often involving the replacement of individual cells or whole stacks. While the goal of durability is 40,000 continuous hours of operation, PEM fuel cells today generally run for less than 10,000 hours. In addition, the fuels used have been primarily high quality hydrogen available in canisters and tanks.[5]

Scenario A, Slow Market Development, presents a continuation of current market trends. Technology improvements and performance enhancements are likely to occur, although there may still be reliance and durability issues even after another 10 years of R&D. A major development that would set Scenario A in motion would be technical advancements, if not breakthroughs, in membrane and electrode materials and controls. With superior performance at lower costs, unit prices would decline to the range of $2,000 to $3,000 per kW capacity. Yet, the market size (volume of unit sales in dollars) will likely be less than $5 billion, which would still be substantially more than it is today. Even in Scenario A, there will likely be considerable

growth in PEM fuel cell sales over the next 10 years. However, in this scenario the market size for PEM fuel cells is not expected to exceed $5 billion by 2015.

Another trend that would set Scenario A into motion would be increases in the prices of grid electricity and an increase in customer self-generation of power. In Scenario A, the principal users of PEM fuel cells will be commercial and light industrial customers in situations where grid electricity is viewed as too expensive, unreliable, or simply unavailable. In this scenario, PEM fuel cells will most likely be adopted in relatively isolated and electric high-value places and circumstances in the mode of user-initiated distributed generation (for either premium or backup power) by commercial and industrial entities. This profile appears to be consistent with what is known about the current customers of PEM fuel cells. Scenario A, however, suggests that by 2015, the prevailing unit size of sold PEM fuel cells for the applications described above will likely be larger than 50 kW, whereas today the prevailing size is in the 1-10 kW capacity range.[4] There may be market opportunities for the smaller units, especially for telecommunication applications, but the larger market opportunity would be in the larger units.

Perhaps Scenario A will occur, but it will occur sooner than expected. If the conditions of Scenario A were to occur as early as 2010, then further technical advancements and market opportunities may lead to conditions described in Scenarios B and E.

In Scenario B, technical achievements will likely attract more investment and public policy commitments to PEM fuel cells, which in turn will further stimulate market penetration. The design of the stack will advance to the state of a fully integrated unit including the stack, controls, and power electronics. The unit will be easy and inexpensive to install. The performance questions of 2005 will be resolved, so that customer expectations for PEM fuel cells will me consistently met. This condition improves the benefits and value of PEM fuel cells to customers. In addition, government policy will provide incentives through subsidies, including credits and tax breaks and other possible economic incentives.

The technology advances described in Scenario B could occur as early as 2010. The technical successes would lead to the market size of $5-$8 billion by 2015, with much of the market penetration occurring in the period of 2010-2015.

Another key factor in Scenario B would be a national trend for electric utilities to actively participate and cooperate with customers in the deployment of distributed generation. This is occurring today in some parts of the country. Electric utilities are especially interested in distributed generation for load management with their leading industrial and commercial customers. Some electric utilities have also realized that distributed generation is a form of back up power for the grid as well as for customers. By 2015, according to Scenario B, the trend will shift to a prevailing customer base of residential and light commercial customers. The prevailing customers will most likely use PEM fuel cells (which consistently perform according to expectations) for backup power and peak shaving (peak load management) and for the additional benefits of CHP. The prevailing PEM fuel cell size will be less than 50 kW capacity.

In many respects, Scenario E is much like Scenario B, and may develop in very similar ways over the next 10 years. Technical advances in PEM fuel cells generally occur consistent with

Scenario B. The technical and performance enhancements are absolutely critical for market growth, and they will likely occur in the period of 2005-2010. One major difference, however, is that PEM fuel cells will have a market image of an effective electric generator with heat benefits in Scenario E and not the "high gloss, high tech" consumer product image in Scenario B. Another major difference in the two scenario paths is that high electric utility rates occur in Scenario E (when they were moderately priced in Scenario B). Therefore, the prevailing customers for PEM fuel cells will be, as the trend is today, will be commercial and light industrial (not residential and light commercial as in Scenario B). The trend today will continue for another 10 years for electric utilities to work with customers for distributed power generation; however, in Scenario E, this trend will take a shift toward distributed generation becoming grid parallel for the optimization of both the electric utility and customers. This shift is likely to occur from 2010 to 2015. The prevailing size of PEM fuel cells will be 50 kW or larger, fitting the needs of commercial and light industrial customers better than the smaller sizes, which better fit the residential and light commercial customers.

In Scenarios C and D, major technology breakthroughs will occur no later than 2010 and perhaps as early as 2006. The PEM fuel cell will be designed as a fully integrated and whole-system optimized unit with easy and inexpensive installation. The basic unit retail price will be in the range of $2,000-$3,000 per kW. It will acquire a "hi tech, hi gloss" market image and it will perform consistently in ways that meet customers' expectations. This will likely occur by 2010. Hydrogen will be readily available and commodity priced. This must occur no later than 2012. The great acceleration in sales is likely to occur from 2010 to 2015. Electric utilities by 2010 will be working with residential and light commercial customers in addition to commercial and light industrial customers in creating distributed generation choices by 2010. PEM fuel cells will be used by residential and light commercial customers in parallel with the grid and also benefiting from waste heat. The prevailing size of market-popular PEM fuel cell units will be relatively small, certainly 50 kW or less and perhaps as small as 3, 5, and 10 kW capacities. By 2015, the stationary market for PEM fuel cells will exceed $8 billion a year, with most of the market growth occurring after 2012.

In Scenario C, the public sector will emerge as lead buyers and users of PEM fuel cells. This means that governments will do much more than provide R&D funding and various types of economic incentives. The Federal, state, and local governments will purchase PEM fuel cells for many of its own electric power generation needs, potentially including public housing, municipal buildings, county courthouses, office buildings, police and fire stations, parks and recreational areas, postal service offices, and military installations. Many of these governmental users of PEM fuel cells would be included in a definition of light commercial, if not also residential. The public sector will stimulate the market greatly by making product purchases that will increase production volumes (and thereby lowering unit costs) and provide leadership by example to the private sector (especially the residential and light commercial markets).

Scenario D is much like Scenario C and will likely occur in similar ways. Major technological and performance improvements will occur no later than 2010. The PEM fuel cell will be a fully integrated unit that will be easy to install. This unit, however, in contrast with Scenario C, will require a fuel processor to extract hydrogen from hydrocarbons at points of use. This means that the existing hydrocarbon infrastructure will be able to support the fuel needs of PEM fuel cells.

Also, unlike Scenario C, the unit price of the PEM fuel cell (not including the additional fuel processor) will be less than $1,000 per kW.

As in Scenario C, grid prices will be high, distributed generation will be a cooperative effort of utilities and customers, and PEM fuel cells will be used in a grid parallel mode with additional heat benefits in Scenario D. The prevailing customers will be residential and light commercial customers. The prevailing unit size will be relatively small and the market size will be large (exceeding $8 billion a year by 2015). Substantial technology, performance, and market image advances are expected to occur no later than 2010 and substantial sales growth will occur between 2010 and 2015.

Also, in Scenario D as in Scenario C, the public sector emerges as a lead user of PEM fuel cells.

7.0 IMPLICATIONS OF THE SCENARIOS

The results of scenario analysis, as performed by cross-impact analysis and the IFS software program, can be read in at least two different ways. One form of analysis, as shown above, is to look at the rank order of most likely scenarios (as determined by *a posteriori* probabilities and scenario type clustering). This is a passive and reactive approach to scenarios, as though they captured a predetermined future. Another way, however, is to look at the scenario that is most desired, regardless of how likely it may seem today, and identify what conditions (descriptor outcomes) would need to occur in order to achieve desired results. This approach leads to an analysis of strategies and investments that may in part determine future outcomes. It is a proactive approach to scenarios and what they say about the future.

In this study, from the perspective of market penetration and sales, the most desirable scenarios would be Scenario C, Roaring Success, and Scenario D, Success with a Hydrocarbon Infrastructure, both of which contained a PEM fuel cell market size in the high range exceeding $8 billion annual sales by 2015. Understanding the differences between Scenarios C and D and Scenario A, Slow Market Development, leads to an understanding of what conditions will likely lead to commercial success as opposed to disappointment. Also, the differences between Scenarios C and D with Scenarios B and E show the differences between high and medium levels of market success. This analysis began with the narrative of the individual scenarios above.

The key elements of success for the commercialization of PEM fuel cell commercialization include the following considerations:

1. Fuel cell prices will most likely be in the $2,000 to $3,000 per kW range, except in the scenario of success with the hydrocarbon infrastructure, in which they must be in the low range of less than $1,000 per kW. With hydrocarbon fuels available and priced as commodities and with a fully integrated unit with the capacity for plug-and-

play installation (meaning, little or no addition installation costs to the consumer), a PEM fuel cell can be successful in the price range of $2,000 to $3,000 per kW capacity. Obviously, a lower price would appear more attractive to consumers, but the lowest price may not be the best value. One must look at the total price of the installed system and the benefits gained by the customer to determine the best value.

2. The PEM fuel cell architecture must be fully integrated, including within one packaged unit the stack, controls, power electronics, balance of plant, fuel handling, and all peripherals.
3. The installation of a PEM fuel cell must be as simple and as inexpensive as possible. It must be close to the ideal of "plug and play."
4. The market image must be high-tech, high gloss, "best thing since sliced bread." The PEM fuel cell must be an exciting appliance in order to achieve high levels of sales. The market positioning as an electric generator, even with ancillary heat, may be appealing to a narrow market of technically knowledgeable buyers, but may be less than compelling to a broader consumer base.
5. Customer benefits and expectations must be consistently met. Whatever the product claims and customer expectations may be, the fuel cell will have to meet or exceed them.
6. Technical advances must be substantial and achieve system-wide innovation and optimization (parallel with integrated architecture).
7. Hydrogen (or hydrogen-rich) fuels must be widely available and priced like commodities. This may require a hydrogen infrastructure, although other possibilities are emerging. If the stack were more efficient and forgiving of fuel impurities, then the quality of the hydrogen fuel going into it would not have to be as pure (or as expensive) as today. It is possible that through stack design and/or fuel processing technologies, the current hydrocarbon infrastructure could provide fuels for PEM fuel cells.
8. Codes and standards must be updated continually and they must be comprehensive and aligned well with changing PEM fuel cell technologies and products.
9. Public sector support must be substantial, including being a lead buyer and customer of PEM fuel cells.
10. National energy policy must emphasize both energy sufficiency and security.
11. Distributed generation must be a combined and cooperative endeavor of both electricity consumers and electric utilities.
12. Electric grid prices must be in the high range of 11-15 cents per kWh averaged across the U.S. and across different types of customers.
13. PEM fuel cells must be able to run continually or continuously as generators of premium power for base, backup, and peak-shaving loads in cooperation with the electric grid.
14. PEM fuel cell operating costs must be in the middle range of 10-20 cents per kWh.
15. To achieve the high range of sales, the PEM fuel cell must be attractive to residential and light commercial customers. This suggests a unit size of less than 50 kW capacity. However, some success is also to be expected in the isolated, high-value

electric power niches of large commercial and office building applications (most likely in the 50 -200 kW capacity sizes). The analysis supports the conclusion that if the PEM fuel cell cannot progress beyond the niches to the broad residential and light commercial market, it will not likely go beyond the middle level market size.

8.0 PREVAILING APPLICATIONS AND CUSTOMERS OF PEM FUEL CELLS

The scenarios indicate that three clusters of prevailing customers for PEM fuel cells will emerge in the U.S. stationary power market over the next 10 years, as follows:

- Scenario A: Commercial and light industrial consumers of electricity where the customers have a need (and a willingness to pay) for high quality and highly reliable power when the electric grid is not available, not reliable, or not attractively priced. One group of commercial customers might be in isolated places where the grid is not available. Examples would include hotels, motels, lodges, and recreational facilities in deserts, mountains, or wilderness areas. Other examples include remote and rural distribution centers, warehouses, and telephone relay towers and stations. Another group would be commercial and office building customers whose operations depend upon consistent quality and absolute availability of electricity. These would include hospitals, radio and TV stations, computer centers, computer server farms, FAA traffic control towers and facilities, the National Weather Service, military and police forces, and large department stores and malls where customer comfort and service depends upon highly reliable power. This category of customers also includes modern, relatively small scale but high throughput manufacturing enterprises.

  By implication, the PEM fuel cells attractive to this market segment will likely be in the middle range of 50-200 kW capacity. There may well be market niches for smaller units, depending upon specific customers, needs, and locales.

  These customers will define their own power needs and provide their own power resources. They will work with PEM fuel cell product companies to get the products that they want. Their units, like typical backup generators, will be off the grid and will not in most cases involve any electric utility.

  One can easily see Scenario A as the scenario of initial market penetration and success. Scenario A, however, says that if the market does not expand beyond the customers identified above, PEM fuel cells in general will experience slow market penetration.

- Scenarios B and E: Residential and Light Commercial customers who have access to the electric grid but who need both backup power and load management capabilities to

control potentially large electric bills. These customers need high quality and highly reliable power, which they usually get from the grid – but they have to have backup power, too. They worry about the potential affects of grid black outs and brown outs. They also have concerns about electric grid prices, especially at peak load times of day. They will deploy distributed generation in cooperation with the electric utility so that they will have power options partly determined by themselves and partly determined by their electric supplier.

Residential customers will be those who have a need for power quality and reliability, such as those where there are residents in need of electric medical support equipment and people who work by computer, telephones, and fax machines from their homes. The residential purchasers of PEM fuel cells may be neighborhoods, apartments and condominiums, and cooperatives in addition to individual residences.

Light commercial customers will likely have distributed generation units operated in cooperation with the grid. They need PEM fuel cells for high quality, highly reliable, and affordable power – they will use the PEM fuel cell as a generator for backup and peak-shaving (grid parallel) applications. These customers include all kinds of shops and stores, branch banks, restaurants, dry cleaners, movie theatres, small malls, post offices, etc.

By implication, the prevailing PEM fuel cell size will be relatively small in size with less than 50 kW capacity.

- Scenario C and D: customers will include a broad range of residential and commercial power consumers. This will be the energy mass market extending from individual homes to moderately sized commercial establishments. The prevailing PEM fuel cell size will be less than 50 kW.

  It seems plausible that if Scenario A may be the initial market for PEM fuel cells then Scenarios B and E reflect the intermediate markets and Scenarios C and D show the advanced, mass markets.

9.0 POTENTIAL BENEFITS OF SCENARIO ANALYSIS

Scenario analysis can provide the following benefits to strategy-making and investments:

1. Scenarios make explicit the sets of conditions associated with most likely and most desirable outcomes in the future. The sets of conditions become objects of strategy-

making and investment to the extent that one has proactive control of variables (descriptors) in future markets.

2. Scenarios challenge orthodox wisdom and forces participants to rethink their strategies based on alternative futures.
3. Scenarios identify most likely trends and outcomes, providing a context for trend monitoring. Scenario analysis is a continuous process of thinking about the future, so descriptors must be monitored to see what scenario is actually playing out.
4. Scenarios provide macroscopic inputs to microscopic models and analysis, such as economic and financial forecasting models and programs.

10.0 CONCLUSIONS

This report has presented five principal alternative futures (scenarios) for the prevailing applications, customers, and markets for PEM fuel cells used for stationary generation in the U.S. from today to the year 2015. These scenarios are based on a proven method, a broad sampling of expert judgments, trend research, and extensive vetting with DOE and stakeholders.

The final conclusions are offered as guidance toward the future:

1. A high priority is merited for technology advancements and performance improvements in PEM fuel cells. Satisfying customer expectations for benefits and performance quality will generate unit sales. If technical and performance milestones are not met by 2010, there is little chance that PEM fuel cells will enjoy strong sales by 2015. Technical improvements are being achieved today, but breakthroughs are still required.
2. In addition to performance improvements, to provide sufficient value to PEM fuel cell buyers, the prices of PEM fuel cells will have to drop. Significant cost reductions can be achieved through innovations in membrane materials, catalytic materials, cell and stack assembly techniques, and controls. In addition, the cost and complexity of installation must also be reduced.
3. PEM fuel cells must be designed as complete and optimized products with a strong market image and market positioning. Marketing strategies need to be crafted in parallel with technological development.
4. PEM fuel cells as stationary power generation will evolve as a mode of distributed generation. In many regards, PEM fuel cells may have to compete with the availability, reliability, quality, and prices of grid electricity. There will be market opportunities for PEM fuel cells, if competitive with alternatives, where the grid is not available, not reliable, not of consistent quality, and not affordable. There is a potentially significant market for PEM fuel cells where they are distributed in conjunction with the grid for back up, peak load shaving, and premium power. The benefits and economics of PEM fuel cells will likely be more attractive for a large market in conjunction with, not separate from, the electric grid.

5. PEM fuel cells will require fuels that are widely available and commodity priced. They will require hydrogen, but from where will the hydrogen come? Developing sources of hydrogen are just as important are developing the PEM fuel cell itself. One possibility is that hydrogen will be mass produced, stored, transported, and retailed in a business paradigm much like gasoline (in a liquid form) or like bottled gases (in a gaseous form). Another possibility is that the hydrogen will come from hydrocarbons, for which there is already an extensive infrastructure. In this case, PEM fuel cells will require effective fuel processors (reformers).
6. The public sector should emerge as leader users of PEM fuel cells.

11.0 REFERENCES

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among Battelle Geneva, Battelle Frankfurt (Germany), and Battelle Columbus Operations. The BASICS algorithm and mainframe computer software program were developed at Battelle Geneva. The BASICS personal computer software program was developed and released in 1986 by the Battelle staff in Columbus. The first-generation scenario practitioners included Dr. Gary Stacey, Dr. Bill Huss, Mr. Edward J. Honton, Ms. Sherry Richards, and Dr. Steve Millett.

3. Several industry representatives who participated in the expert focus groups were particular generous in providing information and insights into the commercialization challenges of PEM fuel cells.

4. Scenario A is a synthesis of Scenario Type 1 (with a frequency of 10), Scenario Type 4 (frequency of 4), Scenario Type 5 (frequency of 3), Scenario Type 6 (frequency of 3), Scenario Type 7 (frequency of 3), Scenario Type 10 (frequency of 2), and Scenario Type 15 (frequency of 2). Scenario A had a total frequency of 27. Scenario B is a combination of Scenario Type 3 (frequency of 6), Scenario Type 9 (frequency of 3), Scenario Type 11 (frequency of 2), Scenario Type 13 (frequency of 2), Scenario Types 14 (frequency of 2), Scenario Type 16 (frequency of 2), and Scenario Type 17 (frequency of 2). Scenario B had a total frequency of 19. Scenario C is a stand-alone Scenario Type 2, with a frequency of 7. Scenario D is a stand-alone Scenario Type 8 (frequency of 3), and Scenario E is Scenario Type 12 (frequency of 2). The top 17 scenario types had a combined frequency of 58 out of 184 single scenarios. The a posteriori probabilities can be calculated in at least two different ways. One would be as a percentage of all scenario types, including those with a frequency of only one. Another way would be to calculate the probabilities based on a total frequency of 58, the combined total for 17 scenarios that had a frequency of two or more. The scenarios with a frequency of just one might be dropped from the analysis as being statistical outliers or pre-determined starting points for the algorithm. The two methods produce the following results:

Scenario (frequency)	*A Posteriori Probability based on all 184 scenarios*	*A Posteriori Probability based on 17 scenario types with a total frequency of 58*
A (27)	15%	47%
B (19)	10%	33%
C (7)	4%	12%
D (3)	2%	5%
E (2)	1%	3%

5. Frost & Sullivan, "North American Stationary Fuel Cell Markets," 2003; data collected by Battelle in preparation of the "First Interim Report on the Economics of Stationary Proton Exchange Membrane Fuel Cells," Draft Submitted for Review and Comment, May 16, 2005; "Fuel Cell Trends," *Technology Forecasts and Technology Surveys*, July 2005, pp. 14-16, reporting on a market study released by the Freedonia Group, *World Fuel Cells* (2005).

APPENDIX A: DOCUMENTATION OF FIRST EXPERT FOCUS GROUP ON DRIVERS OF THE STATIONARY PEM FUEL CELL MARKET

DECEMBER 12, 2003

First Expert Focus Group on Drivers of the Stationary PEM Fuel Cell Market

Date: Friday, December 12, 2003

Place: Conference Room B, Battelle (Columbus, OH)

Topic Question: What will likely be the most important drivers impacting the market for stationary PEM fuel cells (in the range of 1-250 kW) in the U.S. by the year 2015? (And, what will be the most likely applications and markets for stationary PEM fuel cells?)

"driver" is a trend, issue, or factor (such as technological, regulatory, economic, political, or whatever) that will shape the market (including applications), whether it be large or small, for PEM fuel cells in the U.S. between now and the year 2015.

Method: Nominal Group Technique

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Drivers Generated in Response to the Topic Question:

1. Development of competitive technologies [alternatives to fuel cells], especially clean diesel for co-generation, back-up, etc. that are 10kW and larger
2. Product reliability for warranties
3. Comprehensive national energy policy
4. Funding for fundamental and applied engineering (Federal, state, industrial, etc) -- lots of basic issues need addressing, like durability and failure mechanisms
5. Availability of high temperature membranes greater than 150 C – membranes with high performance in the range if 175-200 C -- currently available membranes operate at about 80 C
6. Hydrogen fuel infrastructure (including hydrogen production and delivery)
7. Breakthroughs in manufacturing technologies for fuel cells – Six Sigma will not be adequate – more like Nine to Twelve Sigma quality for the mass production of the cells in the stack
8. Cost: fully valuated, systemic, life-cycle cost of PEM fuel cells versus costs of generating, transmitting, and delivering electrons by the grid to the load – environmental costs must be included, too
9. Fuel Cell system controls and diagnostics
    - Whole FC system controls
    - Self diagnosing systems: keep healthy requirements
10. Environmental demands, requirements, and legislation – one example: California rules on diesel trucks – primarily NO_x issues
11. Combined heat and power (CHP) technologies -- manufacturing and infrastructure issues should be integrated to address CHP, as in Europe.
    - More infrastructure for CHP products needs to be developed.
12. Success of PEM in the auto industry before stationary markets -- the auto industry will drive new technical developments and actual demonstrations – PEM fuel cell successes in the automotive sector would greatly encourage PEM FC applications for stationary power generation
13. Fuel cell safety
    - Guards against stack failure
    - Must be idiot proof
14. Size of the market to be captured.
    - Lots of disagreement on the size of the markets for fuel cells
    - Initial successful application will probably be distributed resources by utilities (energy producers) to meet load demand without building new transmission and central station generation
15. Overall increase in power availability
    - Challenges to meet increasing demand for electricity

16. Cost, availability, security, and sensitivity of hydrocarbon fuels, like coal, oil, natural gas, to support power generation
17. Success or failure of the first mass market applications of fuel cells
    - Residential DG
    - Commercial DG
18. Carbon tax: existing hydrocarbon-based technologies may find it difficult to survive due to treaties like Kyoto and other future agreements to be developed managing and/or taxing carbon emissions
19. Consumers extracting further value from fuel cells from transportation acceptance to home acceptance [concept that the automotive fuel cell may generate power for the home when the car in parked in the garage but connected to the home power system]
20. Societal acceptance of fuel cells in general.
21. Low cost conversion technology
    - For reforming biomass, coal, gasoline, natural, gas, etc. [reforming as localized refining]
22. Renewable Portfolio Standard (RPS) – states could mandate that 20% of power generation must be from renewable sources – California now requires 10% -- Ohio does not have such a requirement now
23. "Proton Valley": Economic incentives to attract fuel cell companies to a particular location
24. Aging utility infrastructure: majority of the power plants are 50 plus years -- Major considerations at power utilities are
    - Prohibitive cost of putting up new plants. Cinergy, AEP and FirstEnergy have power plants that are 50 years old and older -- now they are upgrading them, but in another 15-20 years they will have to address infrastructure issues and new technologies.
    - What will be the technologies of the next generation of power generation?
25. Dual use technologies – fuel cell technologies for both automotive and stationary applications – synergies of complementary technologies
26. Federal and state tax credits and other incentives
27. Energy storage technologies
    - Ancillary storage devices
    - Fly wheels
    - Ultra-capacitors
    - Batteries
    - Fuel cell itself as a power storage unit
28. Economics of utilities, which is largely driven by regulated prices and rate bases; the regulated prices could be shifted up from the standard $1600 kW capacity – rate bases and rate cases could be changed to accommodate the higher costs of fuel cells -- higher cost technologies need to slowly offset the older technologies –roll new technology costs into the existing average rates
29. Fuel cells integrated with the grid
30. Regenerative applications
    - House to recharge car
    - Wind power
    - Fuel reformer at home

31. Operating costs of fuel cells are sensitive natural gas prices -- hard to sell PEM fuel cells if natural gas prices are volatile and go way up [there are data where 25 homes with fuel cells showed good operating costs but one summer the natural gas prices increased and as a result the costs of fuel cell operations skyrocketed]
32. Attainment of worldwide oil pumping capacity (1015-2020 according to Rifkin) – consequent steep increases in oil prices
33. Markets outside the US may develop and have successes that will facilitate the fuel cell market in the U.S. – future market successes most likely in Japan, China, and maybe India
34. Grid reliability and quality.
    - Increasing sophistication of electronics and business require higher power quality
    - Grid friendly appliances – more and more technologies increasing the electricity load
35. Federal government provides PEM fuel cells to schools (like computers donated to schools)
36. New hydrogen storage and transport method and technologies, like cryogenic technologies
37. Cost structure for the consumer
    - Incentives, financing, loans, rental options, etc.
    - Need to find a business model for the fuel cell
38. Recycling fuel cell components and sub-systems, especially the membranes and rare metals for the electrodes
39. Consumers recognize the benefits in return for the costs of PEM fuel cells -- V=B/C [value to the consumer = benefits/costs -- is there sufficient value in fuel cells for consumers?]
40. Development of enabling technologies
    - Efficient compressors
    - Balance of plant
    - Heat exchangers
    - Balance of plant
41. Military needs and markets for fuel cells
    - Demonstrations and fulfillment of needs for auxiliary power units (APUs)
42. Federal buildings buy and use PEM fuel cells.
43. Issue of PEM stack performance – problems of sulfur and CO contamination
44. Fuel clean up for hydrogen pure enough for fuel cells
45. Use PEM fuel cells for peak load management
    - Night power inexpensive, so use it for electrolysis of water to create hydrogen for fuel cells, then use the fuel cells for peak loads
    - Need for 10 MW units with inexpensive stacks
46. Source of <u>big</u> capital for the commercialization of fuel cells -- private capital? -- where will the investment money come from?
47. First emerging market is non-continuous use -- emergency backup and stand-by power for computer center, banks, telecommunications, etc.
48. Breakthrough discontinuity – terrorist attack or some catastrophic event that will jump start the fuel cell market
49. Availability and prices for precious metals [for electrodes]

50. Political upheavals in Russia and South Africa
51. Competition to PEM fuel cells from other fuel cells (particularly solid oxide fuel cells)
52. Trading/commodity markets for carbon, hydrogen, etc.
53. Carbon capture and sequestration technology development.
54. Hot gas clean-up and effective coal gasification.
55. Building codes for hydrogen.
56. Popular images of science and technology and fuel cells
57. Improved efficiencies of PEM fuel cells
58. Reforming a renewable fuel (biofuels)
59. New computational and modeling technologies
60. Testing standards for fuel cells
61. How to value distributed generation, especially fuel cells – build a regulatory framework for distributed resources (generation) and fuel cells
62. Transmission and distribution of the grid and distributed generation.
63. If there is no progress on the regulation of the grid, there will be more blackouts, which in turn will drive the market for fuel cells
    - Lack of regulatory leadership
64. Who will champion the commercialization of PEM fuel cells?
    - Lack of leadership at the Federal level
    - Presently the leadership is GM, Toyota, and Honda
65. Service infrastructure for fuel cells -- maintenance and repair.

Voting:

Sixteen participants voted. Each participant selected the eight drivers from the master list that he thought were the most responsive to the topic question; each participant assigned to each of the eight selected drivers a point value ranging from eight points, high, to one point, low. The maximum number of votes that a driver could receive was 16 (one from each participant), and the maximum number of points that a driver could receive was 128 (16 X 8).

#	Driver	Votes with Point Values	Votes/Points	Rank
1	**Competitive technology development**	**8, 4, 4, 3, 2**	**5/21**	**8**
2	Product reliability	4, 8, 7	3/19	
3	National ongoing policy	1, 6, 2, 6	4/15	
4	Funding for research	4, 4, 1, 7	4/16	
5	High temperature membranes	6, 6	2/12	
6	**Fuel infrastructure**	**8, 5, 7**	**3/20**	**9**
7	**Manufacturing breakthrough**	**5, 5, 8, 6, 7, 3, 4, 4, 3**	**9/45**	**2**
8	**Cost - life cycle cost**	**7, 8, 7, 8, 8, 8, 7, 8, 8**	**9/69**	**1**
9	Fuel cell systems control	4, 6	2/10	
10	**Environmental demands/ regulations**	**1, 8, 2, 7, 5**	**5/23**	**6**
11	CHP incentives	2,3	2/5	
12	Success of PEM in automotive industry	1, 7	2/8	
13	Safety	3, 4, 4	3/11	

14	Operating costs		0	
15	Power availability	6, 3, 1	3/10	
16	Cost, availability and security of power generation	6, 1	2/7	
17	Success/failure of 1st mass market introduction	6, 8	2/14	
18	Carbon tax	4, 1	2/5	
19	Dual consumer use = higher value	3	1/3	
20	Social acceptance	4	1/4	
21	Low cost conversion for broad fuel flexibility	2, 7	2/9	
22	renewable portfolio standards	2	1/2	
23	Proton valley	1, 7	2/8	
24	**Aging utility infrastructure**	**3, 6, 2, 8**	**4/19**	**10**
25	Dual Use Technologies, automotive, stationary	2, 3, 4, 5	4/14	
26	**Fed/State tax credits/incentives**	**7, 2, 6, 1, 6**	**5/22**	**7**
27	**Energy storage technologies**	**2, 6, 5, 6, 5**	**5/24**	**5**
28	Economics for utilities regulatory rate of return	7, 4	2/11	
29	Integration into a dynamic grid	5, 8	2/13	
30	Regenerative Applications	1, 3	2/4	
31	Natural gas prices	6, 5	2/11	
32	Attainment of worldwide oil pumping capacity (2020		0	
33	Market outside of US	3, 2, 1, 2, 3	5/11	
34	Grid reliability	5, 1	2/6	
35	Federal incentives for PEM FC to schools		0	
36	H2 storage /T&D	2	1/2	
37	Cost structure for consumer burden model	7, 6	2/13	
38	Military uses	2, 7	2/9	
39	Consumer value propositions	3	1/3	
40	**Develop enabling technology (balance of plant?)**	**3, 5, 7, 2, 4, 5**	**6/26**	**4**
41	Military needs and markets.		0	
42	Federal buildings buy and use PEM fuel cells.		0	
43	Issue of PEM stack performance	5	1/5	
44	CHP technology infrastructure (ie Europe)	2	1/2	
45	Use PEM FC for peak load management		0	
46	**Source of big capital**	**8, 3, 8, 1, 1, 3, 5**	**7/29**	**3**
47	First emerging market is Non-continuous use		0	
48	Breakthrough discontinuity	1	1/1	
49	Availability and prices for precious metals		0	

50	Political upheavals in Russia and South Africa		0	
51	Competition from other FC	1, 5	2/6	
52	Trading/commodity markets for electrons and protons		0	
53	Carbon capture and sequestration technology development		0	
54	Hot gas cleanup technologies	4	1/4	
55	Building codes for hydrogen		0	
56	Popular images of S&T and FC		0	
57	FC efficiency	5	1/5	
58	Reforming a renewable fuel		0	
59	New computational and modeling technologies		0	
60	Testing standards		0	
61	How to value distributed generation especially fuel cells		0	
62	T&D of the grid and distributed generation		0	
63	If no progress on regulation of the grid, more blackouts will drive fuel cells.		0	
64	Who will champion the commercialization of PEMFC		0	
65	Service infrastructure for maintenance and repair		0	

Ranking is based on total points, number of votes, and number of 8's, in that order of importance.

Top 10 Ranked Drivers:

1st Fully valuated, systemic, life-cycle costs of PEM fuel cells, in both absolute terms and relative to competitive fossil fuels and other types of fuel cells (driver #8 with 9 votes/69 points)

2nd Breakthroughs in manufacturing technologies for PEM fuel cells (important for both reduced costs and improved product quality) (driver #7 with 9 votes/45 points)

3rd Source of big capital for the commercialization of PEM fuel cells (driver #46, with 7 votes/29 points)

4th Development of enabling technologies, especially balance of plant (driver #40 with 6 votes/26 points)

5th Energy storage technologies (driver #27 with 5 votes/24 points)

6th Environmental demands, requirements, and legislation (driver #10, with 5 votes/23 points)
7th Federal and state tax credits and other incentives (driver #26 with 5 votes/22 points)

8th Development of competitive technologies, especially clean diesel (driver #1, with 5 votes/21 points)

9th Hydrogen fuel infrastructure (driver #6, with 3 votes/20 points)

10th Aging utility infrastructure (driver #24, with 4 votes/19 points)

Principal Themes:

1. The system costs (retail price, operations, and maintenance) of PEM fuel cells relative to alternatives, both fossil fuel systems and alternative types of fuel cells (drivers #7*, 8*, 16, 26, 31, 32, 38, 49, and 50)

2. Sufficient investment capital for PEM fuel cell development and commercialization (drivers #4, 14, 46*, and 64)

3. Technological advancements in the components, sub-systems, products, and fuels for PEM fuel cells relative to technological advancements in fossil fuel technologies (#1*, 5, 11, 27*, 40*, 43, 44, 53, 54, 58, 59, and 60)

4. Environmental laws, regulations, standards, penalties, and taxes that in balance favor fuel cells over competitive fossil fuels (#10* and 18)

5. Federal, state, and local energy programs, policies, mandates, credits, incentives, and taxes that in balance favor fuel cells (#3, 18, 22, 23, 26*, 28, 35, 42, 52, 55, 61, and 63)

6. Hydrogen fuel processes and infrastructure to support PEM fuel cells (drivers #6* and 21)

7. Reliability and quality of grid electricity relative to the growth demand for it (drivers #15, 24*, 34, 62, and 63)

8. Performance quality of PEM fuel cells, including efficiency, reliability, safety, and service (drivers #2, 9, 13, 43, 57, and 65)

9. Successful early deployments and initial market penetrations of PEM fuel cells, both military and civilian, foreign and domestic, and transportation and stationary power generation applications (drivers #12, 14, 17, 20, 33, and 41)

10. Increasing consumer confidence and value through multiple and complementary applications of PEM fuel cells along with effective business models and financing mechanisms for consumers (drivers #19, 25, 29, 30, 37, 39, 45, 47, 48, and 56)

    * drivers that were ranked in the top ten by the voting procedure

APPENDIX B: DOCUMENTATION OF SECOND EXPERT FOCUS GROUP ON INPUTS TO THE PEM FUEL CELL SCENARIOS 2010

MAY 12, 2004

Documentation of
Expert Focus Group on Inputs to the
PEM Fuel Cell Scenarios 2010

Date:	Wednesday, May 12, 2004	
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	Jeff Kolde	Gore Fuel Cell Technologies
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	Mark Lillis	Proton Energy Systems
	Karlene McComb	3M
	Dan McMenamin	Verizon Wireless
	Philip Patterson	U.S. Department of Energy
	Michael Quah	NextEnergy
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	Kathya Mahadevan	Task I and Task II researcher
	Steve Millett	Task II leader
	Jill Engel-Cox	Task II researcher
Topic Question:	What are the most important additions, deletions, and further modifications to the current descriptors and other inputs to the futuring process [IFS cross-impact modeling and scenario generation]?	

Results: Modifications to the Inputs: Discussion in the Morning

1. Need to add a new descriptor on the Structure of the U.S. Electric Utility Industry.
2. Descriptor 1, Cost of PEM Fuel Cells, needs to be re-defined as retail price, or cost, of entire fuel cell system installed – including the stack, balance of plant, controls, and a reformer (if necessary) – this would also include a battery and any other ancillary equipment required for operation.
3. Descriptor 7, Fossil Fuel Technological Improvements, needs to include methane [and methanol?] in addition oil and coal.
4. Should there be an additional descriptor for nuclear power?
5. Descriptor 8, Energy Storage Technologies, needs to be redefined. It should include the reverse fuel cell and the dual-use membrane. This descriptor also needs to include various kinds of electrical and mechanic storage devices, not just batteries. Should this descriptor include hydrogen storage or should that be a separate descriptor or included in the definition of Descriptor 6, Hydrogen Availability? Descriptor 8 should be renamed "Electric Storage Devices."
6. Descriptor 9 should be just Environmental Regulations. Codes and Standards should be a separate descriptor.
7. Descriptor 13, Cogeneration, Backup, and DG Options, is confusing. It contains too many things. Cogeneration is not the same thing as backup or distributed generation. There is also a fundamental difference between base load and non-base load power. Leave Descriptor 13 as just Distributed Generation (or Distributed Resources) and put base load into a separate, new descriptor or incorporate it into another existing descriptor (such as Descriptor 12, Electrical Grid Sufficiency and Reliability, which is what we know today as base load power).
8. Descriptor 15, Prices of Fuels for PEM Fuel Cells, has alternative outcomes (states) expressed in dollars per gallon, such as gasoline. But this unit of measure does not capture other fuels, such as methane. Perhaps the units should be normalized to price per Btu or (better yet) kilowatt hour (kWh). Another, potentially better, approach is to redefine this descriptor as "Operating Costs of PEM Fuel Cells," which would include fuels but also maintenance, repair, and other operating costs and could also be expressed in price per kWh.
9. There may be a need for an additional descriptor on the price of oil as an indicator of fossil fuel prices. (This idea came up in the context of the discussion of Descriptor 15)
10. Descriptor 18, PEM Fuel Cells in Automotive Applications, should be discussed in global and not just American terms.
11. Descriptor 19, PEM Fuel Cell Applications and Markets, needs to be re-defined. We should think "last mile;" residential as well as commercial power; and places where there are no connections to the grid. Need to consider hybrids of the grid with fuel cells. Also, there is a question where to best include combined heat and power (CHP).
12. There should be another descriptor for competitive alternatives to PEM fuel cells, including solid oxide fuel cells (SOFC), other types of fuel cells, advanced internal combustion engines, and other types of power generation.
13. Stationary and automotive applications of fuel cells are very intertwined and need to be looked at simultaneously

14. Descriptor 14, Grid Electricity Prices, have states where the prices look too high. The ranges need to be lowered. Also, methane prices should be dealt with separately.

Results: Modification to the Inputs: Round-Robin Sharing of Ideas for Revisions to the Inputs in the Afternoon

1. Descriptor 15, Prices of Fuels for PEM Fuel Cells, needs to be straightened out and redefined. It should be just the cost of oil and there should be an additional descriptor for just fossil fuels.
2. Descriptor 2, Value of PEM Fuel Cell to Customers, should be made more quantitative [qualitative?]: there should be separate descriptors for benefits and costs – redefine Descriptor 2 very carefully, perhaps as payback, and also carefully redefine #1, Cost of PEM Fuel Cell. There may be a need for yet another descriptor on operational costs as opposed to retail, installation costs. Different markets have different value propositions. There is primary, backup, and CHP. There is also residential vs. other stationary power forms.
3. Add a new descriptor for operations and maintenance costs.
4. Other types of fuel cells and alternative technologies for power generation must be included in the model
5. Standardization of grid interconnects must be included in the model
6. A consideration of benefits should include many attributes, including durability, longevity, reliability, and performance, including efficiency.
7. Redefine Descriptor 1, Cost of PEM Fuel Cells, more carefully – Descriptor 5, PEM Fuel Cell Stack Technical Advances, too.
8. Descriptor 13, Cogeneration, Backup Power, and DG Options, needs to be disaggregated.
9. The issues of hydrogen storage and hydrogen fuel prices need to be explicitly in the model.
10. Power quality (six 9s, etc) needs to be explicitly in the model
11. Public perception of hydrogen is an issue that needs to be addressed
12. Competitive technologies to PEM fuel cells – how do they fit in? May need a separate Competitive Technologies descriptor.
13. There should be a consistent story for all the a priori probabilities
14. Reformer costs – there must be technological advances in reformers; issue of reformers vs. hydrogen storage
15. Descriptor 1, Cost of PEM Fuel Cells, needs to be expressed as the total installed system cost
16. Issues of bonding and grounding hydrogen storage and safety
17. Descriptor 9, Environmental Regulations and Standards, needs to be broken down into two different descriptors, one on environmental regulation and another on codes and standards, including safety codes and grid interconnection standards
18. Need to carefully redefine Descriptors 3, PEM Fuel Cell Investments; Descriptor 4, PEM Fuel Cell Manufacturing; and Descriptor 5, PEM Fuel Cell Stack Technical Advances. The principal challenge in manufacturing is the cost of labor. Descriptor 5 should include the architecture of the fuel cell system – the overall systems design. Also important is Descriptor 18, PEM Fuel Cells in Automotive Applications.

19. Capture an evolutionary dynamic – dynamic scenarios
20. Need to consider investments in Japan and Europe to support PEM fuel cells
21. Distributed asset management capacity [in connection to Descriptor 12, Electrical Grid Sufficiency and Reliability, or Descriptor 13, Cogeneration, Backup Power, and DG Options
22. For Descriptor 6, Hydrogen Availability, the state B (reformer for hydrogen at point of use) is the current state, not state C (special hydrogen source).
23. Clarify the definitions of the descriptors. Descriptor 13, Cogeneration, Backup Power, and DG Options, needs to include other technologies. Descriptor 18, PEM Fuel Cells in Automotive Applications, is very important. PEM fuel cells should be compared with other disruptive technologies.
24. Greater clarity is needed for Descriptor 1, Cost of PEM fuel cells – what does the definition include and exclude?
25. Descriptor 8, Energy Storage Technologies, should not include hydrogen – hydrogen storage should be a separate descriptor. Descriptor 6, Hydrogen Availability, needs to consider electricity, especially base load power vs. back up power. Also needing inclusion are renewable sources of energy, especially wind and solar. Include electrolysis as a way of producing electricity.
26. Remember that methanol comes primarily from methane
27. Descriptor 15, Prices of Fuels for PEM Fuel Cells, needs redefined, disaggregated, and more details. The price of fuel depends very much on applications and locales. There are highly niched markets with particular prices.
28. There are several PEM fuel cell applications, such as commercial vs. residential and prime vs. backup. There may be a need for separate descriptors for uses.
29. Need to include a consideration of warranty and parts for PEM fuel cells
30. There may be a need for a new descriptor on the Hydrogen Economy.
31. Since PEM fuel cells produce DC power, one might consider the future of the DC house and DC appliances.
32. Public education about fuel cells – not marketing hype, but reality
33. What are the primary barriers to PEM fuel cell commercialization?
    a. Costs – capital, operations, fuels, and life-cycle costs – not just absolute but relative to competitive alternatives
    b. Reliability and durability
    c. Hydrogen availability and storage
    d. Codes and standards
    e. Public education – what are fuel cells? True science and technology, not hype
34. There may be a need to split the scenario study into two separate models and two separate sets of scenarios by PEM fuel cell applications: one for primary power (base load, all-the-time power) and one for back up power (periodic use, efficiency, peak load management, emergency uses – where start up time is an issue). The state of the art of PEM fuel cells by 2010 may be substantially different in one application vs. the other.
35. Descriptor 8, Energy Storage Technologies, needs to have separated hydrogen and electric storage – need to redefine the descriptor and its states and to asses the advantages and disadvantages for PEM fuel cells
36. In Descriptor 1, Cost of PEM fuel cells, consider the cost vs. stack life – may want states expressed as cost per unit of life

37. Hydrogen purity required by the stack
38. CHP factored into the analysis
39. Renewable energy forms: life cycle cost of hydrogen, including all the costs of delivering hydrogen – including all the societal costs
40. Descriptor 18, PEM Fuel Cells in Automotive Applications, needs to be restructured to consider the roles of auxiliary and primary power for vehicles; need to consider three levels of commercialization: growing consumer market, fleets, and demonstration vehicles
41. Will PEM fuel cells meet consumer expectations?
42. PEM fuel cells are highly subsidized – should there be a separate descriptor for subsides?
43. Need a path from these general descriptors and scenarios to specific investment and commercialization opportunities. There is a need to specify PEM fuel cell applications, markets, and cost points. There is also a need to compare markets. There are at least four opportunities for investment: a) the 70 kW size for grocery and other types of stores, b) the 5 kW size for telecom, etc, c) the 200 kW size for hotels, hospitals, etc., and d) the 1-5 kW size for residential. What are the comparative benefits and costs?

APPENDIX C. DOCUMENTATION OF THIRD PEM FUEL CELL SCENARIOS 2015 WORKSHOP ON THE FURTURE OF STATIONARY PEM FUEL CELL

AUGUST 5, 2004

Battelle
The Business of Innovation

"The Future of Stationary PEM Fuel Cell Commercialization"
THIRD PEM FUEL CELL SCENARIOS 2015 WORKSHOP

Date: August 5, 2004, 8:30 am - 3:00 pm

Place: Battelle (Columbus, Ohio)

Agenda:

8:30 – 9:00 am	Welcome, Opening remarks, and Introductions
9:00 – 9:30 am	Briefing on the IFS method and Inputs to the Scenarios
9:30 - 10:30 am	Briefing on the PEM Fuel Cell Commercialization Scenarios 2015
10:30 – 10:45 am	Break and Networking
10:45 – 12:00 pm	Discussion of Stationary PEM Fuel Cell Commercialization Scenarios 2015
12:00- 12:45 pm	Lunch
12:45 – 2:00 pm	Implications of IFS Scenarios for Government and Industry
2:00 – 2:15 pm	Closing Remarks and Next Steps
2:15 – 3:00 pm	Tour of Battelle, including briefings on fuel cell R&D

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Recommended Revisions to Descriptors, States, and Probabilities

1. Descriptor 1, Retail Cost of PEM Fuel Cell System: The word "price" is better than "cost," as the meaning reflects what the customer has to pay for a PEM fuel cell. In addition, all dollar amounts throughout the descriptors should be constant 2004 dollars.

2. Descriptor 2, System Architecture of PEM Fuel Cell: There was disagreement on whether or not the PEM fuel cell of the future will or will not require a fuel processor or whether it will use a form of hydrogen or hydrogen-

rich fuel requiring no processor/reformer. There was further discussion about whether or not the customer will likely buy a fuel processor, if needed, that is already attached to or attachable with the PEM fuel cell stack (a separate, to-be-assembled item with the stack); there was a consensus that the * designating today's state should be "B. Stack with power electronics, but not processor" rather than "C. stack only."

3. Descriptor 3, Retail Cost of PEM Fuel Cell Processor: The cost (or price) ranges of the states need to be recalibrated and expressed as cost per kW capacity; the cost of the fuel processor is roughly one-third of the cost of the stack, so the states of Descriptor 3 should be aligned with (about one-third of) the states for Descriptor 1, Retail Cost of PEM Fuel Cell System (not including a fuel processor). It is recognized that the initial cost of the fuel processor may be based on kW capacity, but the cost will not likely rise linearly with increased kW capacity (in other words, a fuel processor for a 10 kW PEM fuel cell may cost less than ten times the cost of a fuel processor for a 1 kW PEM fuel cell).

4. Descriptor 5, Performance Benefits of PEM Fuel Cells to Customers: The definition of this descriptor might include cultural and social aspects of customers.

5. Descriptor 6, PEM Fuel Cell Investments in the U.S.: The current definition includes investments in both mobile and stationary power applications, so the descriptor title should also reflect both mobile and stationary applications; question whether the current ranges for the states are just for PEM fuel cells or for all types of fuel cells

6. Descriptor 8, PEM Fuel Cells Technical Advances: The argument was made that today's state is B. "advances in fuel handling, materials, and controls" rather than D. "show, incremental, piece-by-piece improvements." This is a matter of one's point of view and expectations.

7. Descriptor 9, Hydrogen Fuel Sources: definition should stress that this descriptor addresses the availability and source of hydrogen for a PEM fuel cell at the point of use; state C should be reworded to read "hydrogen produced locally," meaning "at point of use." There was also the suggestion that the probabilities should be changed, with the 0.35 for state B ("hydrogen from hydrocarbon fuels requiring processors") should be reduced. Another issue is how pure does the hydrogen have to be for the PEM fuel cells; or, in other words, how forgiving is the stack of impurities in the input hydrogen?

8. Descriptor 17, Role of Distributed Generation (DG): definition and states might include DG units selling electricity back to the grid; there might also be a grid parallel (fourth) state.

9. Descriptor 18, Grid Electricity Prices: the point of view of the Department of Energy is that the current prices ranges of the states are too high and need to be lowered; John Schneider of AEP volunteered to provide some alternative price rates.

10. Descriptor 19, PEM Fuel Cell Operating Costs: the definition should include fuels, maintenance, repair, insurance, etc., and it should exclude capital costs; current commercial market price of hydrogen is about $2.00 per kg.; price ranges of the states may have to be increased.

11. Descriptor 20, Price of Oil: this descriptor should be redefined as the price of natural gas (methane), which has more direct relevance for PEM fuel cells (although the price of natural gas tends to track with the price of oil).

12. Descriptor 22, Electric Utility Industry Structure: still unclear how this should be defined and what states it should have, or whether is should even be in the model. Descriptor might be redefined as Regulatory Policy. At stake are the various state-by-state regulations on utility ownership and operation of DG (which suggests that the point should be covered in Descriptor 17, Role of Distributed Generation (DG) as opposed to being a separate descriptor; several participants thoughts that this descriptor could be dropped.

13. Descriptor 24, PEM Fuel Cells in Automotive Applications: there was discussion and disagreement on how closely linked are the mobile and stationary applications, markets, and value propositions of PEM fuel cells.

14. Descriptor 25, Fuel Cell Markets: One point of view is that a PEM fuel cell could provide premium power both with the grid and off of the grid; likewise, auxiliary power might be generated both with the grid and off of the grid; the number of states need to be expanded, or they require tighter definitions to be mutually exclusive. In this context, there was also a discussion of whether combined heat and power (CHP) should be included in this descriptor or whether it should be a separate descriptor (an additional alternative would be to include in Descriptor 5, Performance Benefits of PEM Fuel Cells to Customers).

15. Descriptor 26, Most Successful PEM Fuel Cell Applications: there was a question what "successful" meant; suggestion to include military applications; there was also a discussion as to what sizes of PEM fuel cells could be reasonably inferred from the applications; this descriptor might be refined by PEM fuel cell size with the applications being inferred; alternatively, there might be an additional descriptor on fuel cells sizes with the alternative states being something like high (>150 kW), medium (50-150 kW), small (10-50 kW) and very small (1-10 kW).

16. Their may be a need to add a descriptor on "green" buying decisions and cultural and social factors [or, this may be included in the definition of Descriptor 5, Performance Benefits of PEM Fuel Cells to Customers]

17. The point was made that relatively inexpensive hydrogen would be very beneficial to internal combustion engines in competition with PEM fuel cells – that internal combustion engines can burn hydrogen, too.

Implications of the Scenarios for Strategy and Investments

Topic Question: "What are the most important implications of the scenarios for strategy and investments for the U.S. Department of Energy and for the private sector?"

Method: Modified Nominal Group Technique: three rounds of round-robin generation of ideas in response to the topic question and each of 18 participants voting on three choices from the master list as being "the most important"

Results:

1. Ways to subsidize the efforts of individual companies – the need for DOE support for private R&D in the face of declining venture capital investments in PEM fuel cell research [received four votes, ranked fifth in a tie]
2. Continued support to drive PEM fuel cell innovation and optimization [received one vote]
3. The Federal government needs to set the rule of the game for PEM fuel cells – national policy and regulations – sooner is better than later [received four votes, ranked fifth in a tie]
4. Inexpensive and widely available hydrogen will require a lot of new technologies in production, storage, and delivery [received seven votes, ranked first in a tie]
5. Need to drive down the operating costs (through efficiency, reliability, etc) of PEM fuel cells [received three votes, ranked eighth]
6. What do the PEM fuel cell end users want? Need more analysis of the markets for PEM fuel cells. What is a compelling value proposition for PEM fuel cell customers? The value proposition must be comprehensive and systemic. [received seven votes, ranked first in a tie]
7. There needs to be a standard PEM fuel cell platform based upon the key application and market, such as Federal government buildings. There should be a standard focused on the primary market opportunity. [received one vote]
8. Some one has to act as a catalyst for fuel cell intellectual property (IP) – to bring together the best of the best and provide synthesis and systems integration of IP [received one vote]
9. There needs to be more boldness in the commercialization of PEM fuel cells – the Federal government decides to use PEM fuel cells in all of its buildings – there is a need to stimulate business and create markets for PEM fuel cells [received one vote]
10. The Federal government needs to set national codes and standards for PEM fuel cells [received two votes]
11. There should be standard and uniform operating procedures for PEM fuel cell installations

12. Look at a long-term chain of commercialization steps – adopt a step-by-step climb toward a big market prize – the automotive market is probably the biggest prize – don't discourage growth
13. Education and PEM fuel cell demonstrations for consumers and for applications – demonstrate hydrogen safety [received one vote]
14. The commodity fuel is most likely to be natural gas converted at the building [point of use] to hydrogen – possibility of commodity methanol as well as natural gas (methane) [received five votes, ranked third in a tie]
15. Public sector support and subsidies for hydrogen technologies [received one vote]
16. Invest in the reduction of the first cost [retail price] through breakthroughs [received five votes, ranked third in a tie]
17. The Federal government should provide incentives for the use of advanced technologies by utilities – incentives such as tax credits, write-offs, rate cases, etc. – advanced technologies include various types of renewables as well as fuel cells [received two votes]
18. Strong trade associations, with a strong collective voice, for codes and standards for PEM fuel cells
19. Need for nationwide interconnect standards and more utility demonstrations of PEM fuel cells [received two votes]
20. Realistic expectations for PEM fuel cell performance
21 The back-up market for PEM fuel cells already exists and it is a $5 billion market – need to go beyond this market opportunity with other things that have to happen – need to combine and do ideas #4, 6, 13, and 16 above – need to work from today's value proposition for the customer [received two votes]
22. Position the PEM fuel cell industry correctly in the U.S., or the work will go offshore
23. Need for lots of data to support product claims, education, insurability, etc.
24. There must be a thermal value proposition in addition to electricity [receive two votes]
25. Design the PEM fuel cell for inexpensive mass manufacturing [received four votes, ranked fifth in a tie]
26. The Americans should work closely with the Canadians and with the EU on PEM fuel cells -- the market for PEM fuel cells is global
27. Safety must be proved – no PEM fuel cell accidents
28. The Federal government should provide incentives for the states to work together on PEM fuel cells – there must be multiple state cooperation on the development and commercialization of PEM fuel cells [received one vote]
29. There must be one consistent, uniform regulatory regime for distributed generation, not state-by-state regulations

APPENDIX D: DESCRIPTORS (FROM IFS)

Descriptors	States	A Priori Probabilities
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor)		
	A. *>3,000 per kW	0.15
	B. $2,000-$3,000 per kW	0.25
	C. $1,000-$2,000 per kW	0.35
	D. <$1,000 per kW	0.25

SOURCE: Group 1: driver #8, ranked first; Theme 1. Confirmed and redefined by Group 2. (Operational costs were separated into an additional Descriptor, #19). Further redefined as "price" rather than "cost" by Group 3.
DEFINITION: The first, or retail, system price to the end-use customer is viewed by many experts as the most important factor for PEM fuel cells to achieve commercial success. Based on currently available systems, the PEM fuel cell is defined to consist of the stack (including the electrodes and electrolytic materials, etc.), power electronics, and ancillary equipment and connections, but not the fuel processor (including a reformer). Some fuel cells may not require a fuel processor; in cases where the PEM fuel cell requires one, the fuel processor will be a separate piece of equipment at an additional cost. In other cases, such as the emerging direct methanol fuel cell, there may be no need for a fuel processor separate from the stack. The Department of Energy has identified general price point targets of $750 to $1,000 per kW capacity for an integrated PEM fuel cell system in the range of 3-250 kW capacity by the year 2010. Different applications and different customers will have varying price points. In the eyes of electric utilities, the retail cost must be no higher than about $1,500 per kW capacity. The preferred cost would be closer to $700 per kW. In the eyes of other customers, the acceptable price of the PEM fuel cell varies with circumstances, but in many cases, including commercial and residential buyers, the lower the retail cost the better. PEM fuel cell prices are declining, from as high as $7,000 per kW or higher to the present range of $3,000 to $4,000 per kW, without a fuel processor. Most potential buyers of PEM fuel cells see these prices as being too high and unacceptable except for the most extraordinary circumstances. Costs are expected to decline with technological innovations and with increased production volumes. Given current trends, the most likely outcome by 2015 is a retail cost in the range of $1,000 to $2,000 per kW. Dollar amounts are expressed in constant 2004 dollars (ignoring future inflation).

2. Prevailing System Architecture of PEM Fuel Cell		
	A. fully integrated fuel cell (inc. fuel handling)	0.30
	B. *stack with controls/power electronics and peripherals	0.45
	C. stack with controls, assembly required	0.25

SOURCE: The project team added this descriptor following the second workshop to add further detail and clarification to the analysis and more specificity to the subsequent

Descriptors	States	A Priori Probabilities

scenarios. It is a further disaggregation of PEM fuel cell costs. Group 3 confirmed the descriptor, but suggested a sharper redefinition of the states.
DEFINITION: Currently, the industry defines a PEM fuel cell as the stack, the power electronics (balance of plant), and ancillary equipment and connections. Some models require a fuel processor (including a fuel reformer), while others do not (such as those that consume pure hydrogen from canisters or tanks). The fully integrated system into one package, including whatever fuel handling devices are required, is still in development. Based on current trends, the most likely outcome by 2015 is a PEM fuel cell will consist of the stack and power electronics, but not a fuel processor. A highly desired outcome, although less likely to occur, would be a fully integrated PEM fuel cell system that includes the stack, power electronics, and fuel handling and processing constituents with no need for a separate fuel processor and reformer. State A is a fully integrated fuel cell containing within the stack fuel handling capabilities requiring no additional fuel processor/reformer. State B is a PEM fuel cell defined as a stack with power electronics (balance of plant), but not including a fuel processor, which is require but has to be purchased separately and attached to the stack. State C is a PEM fuel cell defined as only the stack, requiring other pieces to be purchased and assembled into a full system.

3. Retail Price of PEM Fuel Cell Processor

	A. high (>$1,500 per kW average)	0.20
	B. medium ($500 - $1,500 per kW average)	0.35
	C. low (<$500 per kW average.)	0.45

SOURCE: As a result of the second workshop, the project team decided to disaggregate PEM fuel cells costs to separate the processor from the fuel cell per se. The separation of costs is expected to provide more specificity and clarity to the scenarios. Group 3 confirmed the descriptor, with retail "cost" changed to retail "price" and respecified the states. The states should be expressed parallel to the states of Descriptor 1 -- on the basis of per kW capacity. In this case, the price of the fuel processor may go down on a kW basis as the capacity size increases, so the price is an average per kW range.
DEFINITION: The PEM fuel cell fuel processor, including the fuel reformer, extracts from a hydrocarbon source and purifies hydrogen of sufficient quality to generate electrons in the fuel cell stack without fouling its electrodes. Currently the processor/reformer is a considerable cost component for total PEM fuel cell systems. Its cost and size lend their use to larger fuel cells, the ones being used for large commercial, industrial, and utility applications for stationary power generation. With higher production volumes and technological improvements, the size and cost of reformers are expected to decline. Furthermore, with advances in stack technology it may be possible to operate a PEM fuel cell with no processor or reformer and with fuel processing integrated into the system.

4. PEM Fuel Cell System Installation

Descriptors	States	A Priori Probabilities
	A. difficult and expensive by professional installers	0.35
	B. mod expensive by local contractors	0.45
	C. easy and inexpensive: plug-n-play	0.20

SOURCE: This descriptor was added by the project team following the second workshop. It represents a further disaggregation of costs to provide more specificity to the cross-impact analysis and resulting scenarios. Group 3 validated its inclusion in the model.
DEFINITION: The ease, length of time, complexity, expense, and professionalism required to install a PEM fuel cell system are major factors for purchasers and end-users of them. Presently, professional engineering firms provide PEM fuel cell system integration and installation services for various applications. Installation is yet another cost that adds up to a total cost that may be unacceptable to buyers.

5. Consumer Market Image of PEM Fuel Cells

	A. high tech, high gloss, "best thing since sliced bread"	0.20
	B. effective electricity and heat appliance with green appeal	0.45
	C. an electric generator	0.35

SOURCE: Group 3 suggested a new descriptor that captured social, cultural, and environmental appeals beyond technical performance (Descriptor 6). To this should be added the psychological image, or sex appeal of a product.
DEFINITION: In the eyes of American consumers, price tracks with quality. Higher quality demands higher prices (and low prices are often associated with cheaply made goods). "Quality" is in the eye of the beholder -- the consumer has a mental image of a product. Products have brands and images that differentiate them from competitors in the subjective minds of consumers. This is the so-called "sex appeal" that so many successful consumer products enjoy. Appliances, for example, generally have low sex appeal and compete on standard features and at commodity prices. On the other hand, automobiles are highly differentiated and carry loads of "curb appeal" (which is another way of saying sex appeal).

6. Performance Benefits of PEM Fuel Cells to Customers

	A. exceed customers' expectations on several parameters	0.20
	B. consistently meet expectations	0.40
	C. usually meet expectations but w/exceptions	0.30
	D. * repeatedly fail to meet expectations s	0.10

Descriptors	States	A Priori Probabilities

SOURCE: Group 1, driver #8, ranked first; Themes 1 and 10 confirmed and redefined as just benefits, rather than value, by Group 2. Group 3 reaffirmed the importance of this descriptor, but redefined it to only customer expectations and not venders' claims. Performance benefits should include social and cultural and environmental benefits as well as the tangible benefits of reliability, durability, longevity, energy efficiency, low noise, safety, heat recovery (combined heat and power, CHP), and possible sell-back of electricity to the grid or to some other buyer.
DEFINITION: Benefits derived from the performance of PEM fuel cells exist in the eyes of customers for them. They include energy efficiency, reliability, durability, power quality (six 9s), low maintenance, low operating costs, and environmental friendliness. For some customers (especially industrial and commercial), a major benefit might be quantitative, such as a quick time to pay-back. For other customers (especially residential), benefits may be highly qualitative. The important point is that to be commercially successful, PEM fuel cells must meet or exceed customer expectations, whatever they may be. Of course, to make customers happy, the claims made for PEM fuel cell performance will have to align with expectations and with demonstrated performance. Benefits will likely include warranties and guarantees made by manufacturers and distributors to back up performance claims.

7. Stationary and Mobile Fuel Cell Investments in the U.S.

	A. >$2.0 billion average annual (>2X base 2004)	0.25
	B. $1.0-$2.0 billion average annual (1-2X base 2004)	0.45
	C. *<$1.0 billion (base 2004 or less)	0.30

SOURCE: Group 1, driver #46, ranked third; Theme 2. Confirmed by Group 2 with changes in the ranges of the descriptor states. Group 3 reconfirmed the importance of this descriptor, but broadened its meaning to include all types of fuel cells as well as both stationary and mobile fuel cells. There was also the suggestion to broaden the middle range and reduce the size of the third state's range.
DEFINITION: Investments include resources in support of R&D, advanced manufacturing equipments, and commercialization in the U.S. for all types of fuel cells in both stationary and mobile applications by industry, private investors, venture capitalists, and the Federal and state governments. In the U.S., the annual investment in fuel cell R&D and commercialization has been about $1 billion, and may be rising. Investments are expected to increase as sales increase. In addition, state and Federal government support for R&D and commercialization could increase.

8. PEM Fuel Cell Manufacturing

	A. mass produced, quality controlled	0.30
	B. semi-automated assembly	0.45
	C. *extensive handling of materials	0.25

Descriptors	States	A Priori Probabilities

SOURCE: Group 1, driver #7, ranked second; Theme 3; confirmed by Group 2 and reconfirmed by Group 3.
DEFINITION: Currently laboratory models of PEM fuel cells are being crafted by hand, much the way that cobblers made shoes. Fuel cells are expensive to produce due to costly materials and high labor costs. Successful fuel cells will have to be mass produced with strictly controlled quality to achieve competitive prices. The question is the rate of progress that manufacturing of PEM fuel cells will likely achieve over the next 10 years.

9. PEM Fuel Cell Technical Advances		
	A. system-wide innovations and optimization	0.15
	B. advances in stack fuel handling, materials, and controls	0.35
	C. *advances primarily in materials and controls	0.40
	D. *slow, incremental, piece-by-piece improvements	0.10

SOURCE: Group 1, driver #40, ranked fourth; Theme 3. Confirmed and redefined to include the entire PEM fuel cell, not just the stack, by Group 2.
DEFINITION: PEM fuel cells will work and they can be made. The proof of concept has long since been established. However, in order to become commercially successful and cost competitive, many technical advances are required to improve performance and to lower costs. For example, the principal polymer membrane, Nafion, has been quoted as high as $800 per square foot, although in large quantities from the manufacturer it might be available for as low as $100 per meter -- many people believe that it may be even less expensive in the not to distant future; to be commercially successful, however, the membrane should cost closer to $8 per square foot. As another example, the catalyst is platinum. The balance of plant is a major challenge for long-term durability, reliability, and system optimization. Unless pure hydrogen becomes available or there is an innovation in the stack that allows for the use of a range of fuel impurities, there will also have to be technical innovations in fuel processors, including fuel reformers.

10. Hydrogen Fuel for PEM Fuel Cells		
	A. hydrogen or hydrogen-rich fuels as commodities	0.10
	B. hydrogen from hydrocarbon fuels requiring fuel processors	0.45
	C. hydrogen produced at or near point of PEM fuel cell use	0.30
	D. *compressed, tanks and canisters	0.15

SOURCE: Group 1, driver #6, ranked 9th; Theme 6. Confirmed and redefined by Group

Descriptors	States	A Priori Probabilities

2. Reconfirmed by Group 3. The descriptor is defined for the prevailing availability of hydrogen, recognizing that different applications will likely use different sources of hydrogen

DEFINITION: As internal combustion engines require gasoline or diesel fuels, PEM fuel cells require hydrogen. One concept is that the PEM fuel cell will operate on a commodity-like hydrogen fuel, which will be commonly available and commodity priced like gasoline and diesel fuels are today. It is most likely that the form of commodity hydrogen would be a liquid or a hydride. There is also the option of using methanol directly into the stack with little or no fuel processing separate from the stack. PEM fuel cells require a very pure form of hydrogen -- pure enough that it would not cause fouling of the electrodes or damage to the electrolytic membranes. The purer the source of hydrogen, the better for current PEM fuel cells, especially at relatively low operating temperatures. Will there be sufficient quantities with sufficient availability of pure-enough hydrogen to support the successful commercialization of PEM fuel cells? The answer depends upon the further development of several technologies to improve the volume and reduce the costs of producing hydrogen, including large scale electrolysis; technologies to improve hydrogen transport and storage; and technologies to improve hydrogen distribution mechanisms. The assumption is that if hydrogen were to be widely available as a fuel commodity, it will be competitively priced. Alternatively, there may be developed fuel processors/reformers that will extract hydrogen from hydrocarbons (methane, methanol, and oil products), most likely at the point of use. An effective processor would permit the use of the already extensive fuel infrastructure; natural gas and methanol -- perhaps even gasoline and diesel fuels, could be produced, transported, stored, and distributed much like gasoline is today. Another option is that hydrogen will be produced by electrolysis at or near the point of use of a fuel cell. This hydrogen might be produced by electrolysis of water, a process that requires a lot of electricity (such as that produced by a power plant at night). Another option is that there will have to be special hydrogen sources, including compressed hydrogen in specially designed tanks and canisters. In all cases, there are regulatory, safety, and public perceptions issues. The availability of hydrogen is one of the most important infrastructure issues for fuel cells.

11. Fossil Fuel and Engine/Turbine Technical Advances		
	A. virtually clean, highly efficient fuels and engines	0.15
	B. virtually clean, more efficient fuels and engines	0.30
	C. improved gasoline and diesel efficiency/emissions	0.35
	D. *little change from 2003	0.20

SOURCE: Group 1, driver #1, ranked eighth; Theme 3. Confirmed and redefined to include engines by Group 2. Reconfirmed by Group 3.

DEFINITION: Technology advances are being made to conventional fossil fuels and

Descriptors	States	A Priori Probabilities

engines that combust them while technology advances are also being made in PEM fuel cells. New blends of gasoline and diesel fuels are more efficient and less polluting; advances in the design and operation of the internal combustion engine and turbines are also producing more efficient and cleaner ways of burning fossil fuels. A major breakthrough, for example, in a low-pollution diesel engine could be a viable competitive option besides fuel cells. The gasification of coal would be another huge technical advance for fossil fuels. Methane is also a relatively clean fuel, but leaks of methane, a greenhouse gas, into the atmosphere may contribute to global warming. Advances are also possible in the use and storage of methane.

12. Electric Storage Technologies

	A. greatly improved capabilities	0.20
	B. moderately improved capabilities	0.45
	C. *marginally improved capabilities	0.35

SOURCE: Group 1, driver #27, ranked fifth; Theme 3. Confirmed and redefined to include just electric power storage by Group 2. Reconfirmed by Group 3.
DEFINITION: Advanced electrical storage technologies benefit both existing generation capacity and PEM fuel cells. Electricity storage on a large scale has been a major challenge for electric utilities; they could save much money by storing large amounts of electricity at night to be used for peak load management. Advanced storage would benefit distributed generation, including fuel cells, by providing quick start-up and load smoothing. Examples of advance storage include the lithium ion and the sodium sulfur batteries; ancillary storage devices; electro-mechanical devices; super capacitors; and electro-materials, including nano carbon fibers.

13. Environmental Regulations

	A. virtually zero emissions with mandated carbon management	0.15
	B. lower emissions with voluntary carbon management	0.45
	C. *little change from 2003	0.40

SOURCE: Group 1, driver #10, ranked sixth; Theme 4. Confirmed and redefined to include just environmental regulations, with codes and standards as a separate descriptor, by Group 2. Reconfirmed by Group 3.
DEFINITION: There is a strong relationship between energy use and environmental quality. Any form of combustion produces waste products that may impact environmental quality. For example, coal-burning plants today produce NOx, SOx, and carbon dioxide. Gasoline and diesel produce particulates and ozone as waste products of carbon combustion. In addition, leaks of fuels before combustion may also damage the environment; methane, the principal constituent of natural gas, is a greenhouse gas and if leaked by pipes or wells into the atmosphere may contribute to global warming. The state of the art in environmental sciences and the level of regulatory standards have huge

Descriptors	States	A Priori Probabilities

impacts on the use of fossil fuels and on fuel cells. Generally, PEM fuel cells are considered to be environmentally friendly -- more severe environmental regulations and standards placed on the use of fossil fuels will encourage the alternative use of fuel cells.

14. Codes and Standards for PEM Fuel Cells

	A. comprehensive and aligned with products/technologies	0.30
	B. *less than comprehensive and somewhat aligned	0.50
	C. major gaps and not aligned	0.20

SOURCE: Group 1, driver #10, ranked sixth; Theme 4. Confirmed and redefined as a new descriptor addressing only codes and standards separately from environmental regulations. Reconfirmed by Group 3.
DEFINITION: An important infrastructure requirement for PEM fuel cells is that they meet various safety and interconnect codes and standards. The IEEE has been writing standards for the interconnections between distributed generators and the grid and more recently the interconnection standards (IEEE 1547) for PEM fuel cells. There are also safety codes, as well as many standards for the parts and systems integration of fuel cells. The issue is to what extent the codes and standards will align with fuel cells during the commercialization process.

15. Public Policy Support for PEM Fuel Cells

	A. Federal and state governments as customers and lead users	0.10
	B. subsidies, credits, tax breaks, and other incentives	0.40
	C. tax breaks for PEM fuel cell purchases	0.30
	D. *just support of PEM fuel cell R&D	0.20

SOURCE: Group 1, driver #26, ranked seventh; Theme 5. Confirmed by Group 2. Reconfirmed by Group 3.
DEFINITION: Public policy includes actions taken by both the Federal and the state governments to provide financial support to the development, manufacturing, commercialization, and use of PEM fuel cells. Various forms of subsidies and credits discount the costs of fuel cells. Public policy has encouraged the growing use of renewable energy forms, such as wind power. Public policies could include taxes and penalties for certain types of energy use and could provide incentives for desired energy use. Public policy support for PEM fuel cells is considered to be a very important element in the early commercialization of PEM fuel cells. The Federal and state governments could support PEM fuel cells by buying and using them for their own electricity needs.

Descriptors	States	A Priori Probabilities
16. National Energy Policy and Security		
	A. policies driven by goals of sufficiency and security	0.25
	B. policies driven largely by security concerns	0.35
	C. *passive to free market and deregulation	0.40

SOURCE: Group 1, driver #26, ranked seventh; idea #3 Theme 5. Confirmed by Group 2. Reconfirmed by Group 3.
DEFINITION: National energy policy and security deals with such issues as national energy sufficiency, including decreasing U.S. dependence upon foreign oil sources. The Federal government might support fuel cells and hydrogen as alternative energy sources to foreign oil. Another national energy policy issue is energy security in the context of Homeland Security and counter-terrorism. Today the primary Federal policy seems to favor free market forces and deregulation, with more emphasis on economic growth and industry prosperity than national energy sufficiency and security.

17. Electrical Grid Reliability and Quality		
	A. high reliability and quality for base and peak loads	0.35
	B. *high reliability and quality w/exceptions (peak loads)	0.45
	C. inconsistent for base as well as peak loads	0.20

SOURCE: Group 1, driver #24, ranked tenth; Theme 7. Confirmed and redefined by Group 2. Reconfirmed with the suggestion of adding sufficient electric quality by Group 3.
DEFINITION: A major challenge for the U.S. in the future will be the adequacy of the electric power grid. There is the expectation of continued strong growth in electric demand, but new generation may not be adequate to keep up with growing demand. The commercial viability of both distributed generation and PEM fuel cells depend upon the sufficiency and reliability of the electric grid. If the grid continues to meet rising demand with sufficient quantities and quality of electricity and if the grid remains highly reliable with rare and inconsequential blackouts, then there will be little need for distributed generation and stationary PEM fuel cells. One must consider all sources of electric grid power generation, especially coal-burning and nuclear plants. On the other hand, insufficient quantity and quality of power from the grid will encourage all forms of distributed generation, including PEM fuel cells. One likely outcome is that the grid will continue to be highly reliable for both increasing base and peak loads. A second and more likely outcome is that the grid will be highly reliable in meeting base load growth but will experience exceptions with occasional black outs, especially during times of peak loads. A third but not likely outcome is that grid reliability will be generally

Descriptors	States	A Priori Probabilities

inconsistent for both base and peak loads, meaning that the grid will increasingly fail to keep up with growing power demand.

18. Role of Distributed Generation (DG)

	A. DG integrated with grid in an extended power network	0.20
	B. DG combination of customer and utility	0.50
	C. *DG primarily customer driven	0.30

SOURCE: Group 1, driver #24, ranked tenth; Theme 7. Confirmed but re-defined by Group 2. Reconfirmed by Group 3.
DEFINITION: Distributed generation addresses the issue of decentralization of the highly centralized electric power grid and utility business model. For over 100 years, the model has been large scale power generation at huge plants (much like earlier models of River Rouge manufacturing centers) with transmission lines and distribution networks to widely distributed customers. Will power generation decentralize like manufacturing plants have and move closer to the customers? Will there emerge flexible power generation like flexible manufacturing? Technologies, business economics, and regulations have favored central power generation. New technologies may favor distributed generation, depending upon many factors, such as customer value, pricing, environmental regulations, and codes and standards. One likely possibility is that the utilities will take the lead in DG, champion it, and integrate it with the grid in an extended power network. Consumer purchased back up generation will become part of the decentralized grid network. A second possibility is that DG will occur with customers having their own back-up, power load management, and cogeneration and they will seek to coordinate, if not fully integrate, DG with the utility's grid. This outcome may contain the option of customer back up generators selling electricity back to the utility. The third possibility, which reflects little change from the past, is that DG will be primarily customer driven and will remain "off line" relative to the grid. Many electric utilities today view customer back up and cogeneration as independent customer assets that are neither DG nor relevant to the operation of the grid.

19. Grid Electricity Prices

	A. very high (>15 cents kWh)	0.15
	B. high (11-15 cents kWh)	0.30
	C. medium (7-10 cents kWh)	0.35
	D. *low (<7 cents kWh)	0.20

SOURCE: Group 1, #8 ranked first; Theme 1. Confirmed by Group 2 and reconfirmed, but with respecified states, by Group 3. Prices are based on constant 2004 dollars.
DEFINITION: The competitive cost of electricity from the grid may make PEM fuel cells look too expensive from the point of view of a kilowatt hour (kWh). This has to do with operating costs beyond the first (retail) costs of the PEM fuel cell. High grid kWh

Descriptors	States	A Priori Probabilities

prices will make PEM fuel cells more attractive, and low grid kWh prices will make PEM fuel cells look less attractive.

20. Integrated PEM Fuel Cell Operating Costs

A. high (>20 cents/kWh)	0.35
B. *medium (10-20 cents/kWh)	0.40
C. low (<10 cents/kWh)	0.25

SOURCES: Defined as prices of fuels for PEM fuel cells by Group 1, driver #8, ranked first; Theme 1; re-defined as PEM fuel cell operating costs, including fuels, by Group 2. Confirmed but respecified by Group 3. This descriptor covers all variable (operating) costs of the entire, integrated PEM fuel cell system, such as the cost of fuel, maintenance and repair, insurance, etc. The presumption is that the user of the PEM fuel cell will also be the owner (with the fixed costs captured in Descriptor 1).
DEFINITION: PEM fuel cell operating costs include fuels, maintenance and repair, insurance, taxes (if any), finance charges (if any), and incidental costs. Fuel will likely be the principal operating cost. A major unknown is whether hydrogen will be available commercially (and competitively) in a purified form or through a hydrocarbon from which the hydrogen will be extracted by processors and reformers. Hydrocarbon fuels that may be used for hydrogen extraction for PEM fuel cells include methane, methanol, gasoline, and diesel. Maintenance and repair have been major costs for other types of fuel cells (especially molten carbonate); how much maintenance and repair that will be required for PEM fuel cells is still highly uncertain. Perhaps the best way to measure the operating costs for PEM fuel cells would be a calculation of cents per kilowatt hour (kWh) of power generated by the PEM fuel cell.

21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas)

A. high (>2X base 2004 prices)	0.25
B. *medium (1-2X base 2004 prices)	0.60
C. low (< base 2004 prices)	0.15

SOURCE: Descriptor recommended for inclusion by Group 2 as a leading indicator for prices of fossil fuels in general. Reconfirmed but redefined by Group 3.
DEFINITION: The price of hydrocarbon fuels is a factor in the potential success of PEM fuel cells. Low hydrocarbon fuel prices might discourage the commercialization of all forms of renewable energy, including fuel cells. To the extent that hydrogen for PEM fuel cells may be extracted from hydrocarbon fuels, especially natural gas (methane), lower prices might reduce fuel cell operating costs. The leading forms of hydrocarbon fuels in the U.S. are oil (and its derivatives, like gasoline) and natural gas (methane). The price of oil tends to set market conditions for many types of energy. As the price of oil goes up, so, too, do the prices of many liquid fuels. Also, as the price of oil and other fuels go up, alternative energy prices become more competitive by comparison.

Descriptors	States	A Priori Probabilities
22. PEM Fuel Cell Stationary Power Units Abroad		
	A. significant impact on the U.S.	0.20
	B. moderate impact on the U.S.	0.50
	C. *marginal impact on the U.S.	0.30

SOURCE: Group 1, idea #33, Theme 9. Reconfirmed as re-defined and with new alternative states by Group 2.
DEFINITION: Japan appears to be the market leader for PEM fuel cells. The Japanese government has a vigorous PEM fuel cell program and it is receiving the cooperation of automotive companies and utilities. Japan will likely be the first successful market for PEM fuel cells. Other countries that may emerge as early fuel cell markets include China, Germany, and Canada. Market successes in Japan and other countries will likely have a positive impact on the development of the U.S. market for PEM fuel cells.

23. Electric Utility Industry Structure		
	A. less regulated, less vertical, more enterprising than today	0.30
	B. about the same as today	0.50
	C. more regulated, more vertical, less enterprising than today	0.20

SOURCE: Suggested by Group 2, especially one vocal participant. Group 3 was divided in its views on the virtues of this descriptor.
DEFINITION: The structure of the electric utility industry, especially the nature and extent of regulations by the Federal Energy Regulatory Commission (FERC) and the public utility commissions of the states, will likely have a major impact on the extent to electric utilities will pursue distributed resources and innovative, but potentially expensive, new technologies, including PEM fuel cells. Beginning in 1935, utilities were highly regulated. They were also highly vertically integrated, tightly binding generation, transmission, and distribution within a defined territory. Utilities were local monopolies with no direct competitor, and they tended to be highly regimented with little enterprising risk-taking. The current regime is a combination of regulation and deregulation that varies from state to state. For example, in Ohio generation has been deregulated and utilities are free to invest in distributed generation if they wish to do so; in Texas, however, utilities may not own distributed generation assets.

24. Competition to PEM Fuel Cells		
	A. the grid is the primary competition to PEM fuel cells	0.35
	B. advanced IC engines and renewable	0.40
	C. other types of fuel cells	0.25

SOURCE: Recommended by participants in the second workshop (Group 2).

Descriptors	States	A Priori Probabilities

Reconfirmed by Group 3.
DEFINITION: The desirability of PEM fuel cells in the eyes of buyers and users will not be determined only by their price and performance; desirability will always be relative to competitive alternatives.

25. PEM Fuel Cells in Automotive Applications

	A. mass consumer appeal (auto, motorcycle, or scooter)	0.20
	B. delivery fleets	0.35
	C. *special vehicles (military, off road, carts, etc.)	0.45

SOURCE: Group 1, Idea #12; Theme #9. Re-confirmed by Group 2, but with alternative states. Reconfirmed by Group 3, with the recommendation that both auxiliary power units (APUs) be considered as well as primary power source.
DEFINITION: Successes of PEM fuel cells in automotive applications will contribute to the successes of PEM fuel cells in stationary power generation applications, and vice versa. Initially, automotive applications will likely be APUs for heavy vehicles. An intermediate stage is the use of fuel cells in conjunction with batteries and with small internal combustion engines in hybrid fuel vehicles. Eventually, there will be all-electric vehicles with fuel cells and batteries. "Special applications" include specialty vehicles and trucks, including military vehicles. One likely possibility by 2015 is that PEM fuel cells will become so well developed and affordable that they will appeal to a mass consumer markets. Another possibility is that PEM fuel cells will be developed primarily for delivery fleets and short-range transportation (including motorcycles and scooters as well as delivery trucks and taxis). The most likely outcome is that PEM fuel cells will be used primarily on special vehicles, such as heavy trucks, off the road vehicles, and military vehicles.

26. Prevailing PEM Fuel Cell Application

	A. grid parallel (any time and CHP with the grid)	0.10
	B. back up and added CHP	0.40
	C. primarily backup	0.30
	D. *isolated, high value power	0.20

SOURCE: Added by the project team following Group 1. Re-confirmed by Group 2 and Group 3. Group 3 suggested changing the title from "PEM Fuel Cell Markets" to "PEM Fuel Cell Applications" with the understanding of "prevailing" applications rather than exclusive applications. Group 3 also suggested respecifications of the descriptor states.
DEFINITION: This is a descriptor that directly addresses the topic question. PEM fuel cell applications and markets in this study focuses on stationary power generation, either in conjunction with central power generation or with distributed generation. Possibilities include premium power generation for both base and peak loads; auxiliary power

Descriptors	States	A Priori Probabilities

coordinated with or not with the grid; and only very special situations (such as where the grid is not available and where areas of environmental non-attainment preclude conventional generation options.

27. Prevailing PEM Fuel Cell Customers

	A. institutional/heavy commercial (>200 kW)	0.35
	B. commercial and light industrial (50-200 kW)	0.45
	C. residential and light commercial (<50 kW)	0.20

SOURCE: Requested by the client following Group 2. Reconfirmed and respecified by Group 3.

28. PEM Fuel Cell Market Size

	A. high (>$8 billion)	0.25
	B. medium ($5-8 billion)	0.45
	C. low (<$5 billion)	0.30

This is the second descriptor that directly addresses the topic question. This descriptor addresses the total annual market for PEM fuel cells used in stationary power generation applications and is the surrogate for Economic Impact.

APPENDIX E: CROSS-IMPACT GUIDES

Descriptor: 1. Retail Price of PEM Fuel Cell (w/o Fuel Processor)

How would the "high" state (*>3,000 per kW) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (including fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Weak
High prices are often associated with high quality and high gloss products.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
No net effect.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Negative, Weak
High cost of PEM fuel cells discourages investors seeking successful commercial products.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
High cost will encourage researchers to find technical solutions that will lower costs.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None

Descriptors	Direct Impact
13. Environmental Regulations (virtually zero emissions with mandated carbon mgt.)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Negative, Moderate
Higher costs decrease government purchases.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Negative, Weak
Higher costs weaken the arguments for fuel cells based on national energy sufficiency and security.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Strong
Higher costs are less competitive, while lower costs are more competitive relative to the alternatives for buyers.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Negative, Moderate

Descriptors	Direct Impact
Expensive fuel cells will have limited applications in automotive.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Negative, Strong
Higher costs limit the opportunities for applications and markets.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Moderate
Higher costs will favor larger units over smaller units because of larger economies of scale.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Moderate
High retail prices will discourage sales.	

Descriptor: 2. Prevailing System Architecture of PEM Fuel Cell

How would the "high" state (fully integrated fuel cell (inc. fuel handling)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Weak
Generally, the more the system is integrated and holistic, the lower the (apparent) price for the fuel cell.	
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Strong
The more integrated the fuel cell architecture is, the more likely that it will be easier and less inexpensive to install.	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Weak
The fully integrated product will have stronger market appeal than the kit that has to be assembled.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Moderate
Integrated systems are more likely to achieve satisfactory and optimized performance.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Weak
An integrated architecture will improve the capabilities of doing mass production with quality controls.	
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Moderate

Descriptors	Direct Impact
An integrated architecture will improve systems innovation and optimization.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
A fully integrated system that includes the fuel handling could increase the possibility of using commodity fuels.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Moderate
An integrated architecture simplifies the specification of codes and standards and improves alignment of codes and standards with fuel cell products and technologies.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Weak
An integrated architecture may improve the economies of operations.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
Indirect relationship.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
Indirect relationship through costs and performance.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 3. Retail Price of PEM Fuel Cell Processor

How would the "high" state (high (>$1,500 per kW average)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	Positive, Weak
An expensive reformer would encourage the stack developers to include fuel handling into the fuel cell product.	
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Negative, Weak
An additional part, like a processor, would turn some consumers off.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Weak
Expensive fuel reformers will encourage people to seek other ways to supply hydrogen to fuel cells.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved	None

Descriptors	Direct Impact
capabilities)	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Weak
Expensive reformers, when used, will increase operating costs directly and indirectly.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None

Descriptors	Direct Impact
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Weak

High fuel processor prices, if processors are needed, will discourage sales.

Descriptor: 4. PEM Fuel Cell System Installation

How would the "high" state (difficult and expensive by professional installers) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
No clear net affect.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
High installation costs would encourage systemic improvements in PEM fuel cells, especially systems integration and turn-key operation.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions	None

Descriptors	Direct Impact
with mandated carbon management)	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Negative, Weak
Complicated installations will make codes and standards more difficult to make and to enforce.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Negative, Weak
Governments will not likely buy fuel cells if they are complicated and inexpensive to install.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Moderate
Difficult and expensive installation will discourage customers and they will rely more on the grid for cheap power	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None

Descriptors	Direct Impact
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Moderate

Complicated and expensive installation will encourage only the use of large units and will discourage proliferation of units as distributed power generation.

28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Weak

High costs will discourage sales.

Descriptor: 5. Consumer Market Image of PEM Fuel Cells

How would the "high" state (high tech, high gloss, "best thing since sliced bread") of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Moderate
High gloss image works in favor of higher, not lower commodity, prices.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Negative, Weak
A high gloss image will raise expectations, so some consumers may be set up for a disappointment if performance does not live up to image.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None

Descriptors	Direct Impact
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Negative, Moderate
The high gloss image establishes product differentiation and fights competitors.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Weak
The high gloss image (a new, sexy feature) will attract some automotive customers	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Weak

Descriptors	Direct Impact
High sex appeal moves in the direction of premium power.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Negative, Strong
High gloss image appeals most to residential customers and then light commercial.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Strong
Strong market appeal will drive sales.	

Descriptor: 6. Performance Benefits of PEM Fuel Cells to Customers

How would the "high" state (exceed customers' expectations on several parameters) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Weak
When consumers are delighted with the quality of performance of a product, they will be more willing to pay more for it.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Strong
Performance benefits beyond standard expectations contribute greatly to market image.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
More benefits that please consumers will attract more investment.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None

Descriptors	Direct Impact
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Moderate
If PEM fuel cells offered superior value, then the government would become a lead user.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Moderate
The Federal government would advance the causes of national energy sufficiency and security if PEM fuel cells offered superior value.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
Indirect relationship.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
Not a direct relationship.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	Positive, Weak
PEM fuel cell advantages in U.S. would be exported abroad.	
23. Electric Utility Industry Structure (less regulated, less	None

Descriptors	Direct Impact
vertical, more enterprising than today)	
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Negative, Moderate
If customers are happy with PEM fuel cells, they will not be attracted to the alternatives; superior performance is a competitive advantage.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate
Benefits and lower prices will make PEM fuel cells attractive for automotive applications.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Strong
Superior benefits would attract more users for primary power requirements, and hence capture larger market share, if the prices were indeed competitive with electricity from the grid.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Moderate
Performance benefits will please buyers and encourage sales generally.	

Descriptor: 7. Stationary and Mobile Fuel Cell Investments in the U.S.

How would the "high" state (>$2.0 billion average annual (>2X base 2004)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
Indirect relationship.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	Positive, Weak
More investment would mean more R&D into systems integration and optimization.	
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Weak
More investment would assist plug-n-play	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Weak
There is a direct effect only to the extent that investments go to packaging and marketing as well as technical performance.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
Indirect, not direct, impact through technical performance.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Moderate
Investments in the production technologies and product unit simplification would improve manufacturing capabilities.	
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Moderate

Descriptors	Direct Impact
High levels of investment will stimulate technological developments through more intensive R&D, although some failures will occur no matter how much money is invested in R&D.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
High levels of investment would also go into hydrogen production, storage, and distribution.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
No net effect.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
Not a direct relationship	
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate

Investments in commercialization will impact market penetration.

27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 8. PEM Fuel Cell Manufacturing

How would the "high" state (mass produced, quality controlled) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Strong
Mass produced PEM fuel cells will lower unit costs.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	Positive, Weak
Mass production means will encourage a more fully integrated product design.	
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Moderate
Mass produced fuel cells are likely to evolve to commonly used, commonly installed units.	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Moderate
Mass produced PEM fuel cells with quality control will make them more consistently right with fewer defects and problems.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Manufacturing breakthroughs would attract more investment capital.	
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None

Descriptors	Direct Impact
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak

Mass production of PEM fuel cells will lead to standardization and help in establishing standards.

15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None

Not a direct impact.

23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None

Descriptors	Direct Impact
Indirect relationship.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
Indirect through prices.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Negative, Weak
Advanced manufacturing will slightly favor medium to small units.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 9. PEM Fuel Cell Technical Advances

How would the "high" state (system-wide innovations and optimization) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Moderate
Technical advances will lead to lower costs in general.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	Positive, Strong
Technical advances will likely simplify the system, making systems integration easier to do.	
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Moderate
Technical advances in system innovation and optimization will help plug-n-play.	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Strong
Technical breakthroughs greatly contribute to the market image and sex appeal of PEM fuel cells.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Strong
Technological breakthroughs and systems optimization would significantly improve performance and benefits.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Strong
Technological advancements will attract more investment as PEM fuel cells represent less risk heading toward commercialization. This is especially true of private investment.	
8. PEM Fuel Cell Manufacturing (mass produced, quality	Positive, Weak

Descriptors	Direct Impact
controlled)	
Improved stack technologies will likely lead to simpler and better manufacturing methods.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak
Technology improvements would impact codes and standards with more uniformity.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak
Public support, especially financial incentives, will likely rise as PEM fuel cell technological advances show increasing commercial viability of fuel cells.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
Indirect relationship.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
Indirect.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Weak
Successful PEM fuel cells offer more DG options.	
19. Grid Electricity Prices (very high (>15 cents kWh))	None

Descriptors	Direct Impact
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Negative, Moderate

Technological breakthroughs would lower both retail and operating costs. New technologies will likely reduce maintenance and repair and may require less expensive fuels.

21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	Positive, Weak

Technical advances, whether in U.S. or abroad, will be rapidly transferred to non-U.S. applications and markets.

23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Negative, Weak

Better PEM fuel cells will make them more competitive.

25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Weak

Technological advances will make PEM fuel cells more attractive for automotive applications, although costs will remain the paramount concern.

26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate

Improved performance will impact market appeal and have more applications (along with lower prices).

27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Negative, Moderate

In general, technology innovations favor small PEM fuel cells where the economies of scale are so important.

Descriptors	Direct Impact
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Indirect effect through performance benefits and prices.

Descriptor: 10. Hydrogen Fuel for PEM Fuel Cells

How would the "high" state (hydrogen or hydrogen-rich fuels as commodities) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Weak

A simple fuel source will make installation quicker and easier.

5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate

Commodity fuels will add greatly to the popular image of PEM fuel cells.

6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak

Hydrogen as a commodity fuel would improve the overall benefits and value of PEM fuel cells.

7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Moderate

Hydrogen fuels would encourage more investment in PEM fuel cells.

8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None

Descriptors	Direct Impact
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak

Hydrogen fuels as commodity fuels would simplify codes and standards.

15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Moderate

Hydrogen fuels as commodities would encourage all kinds of buyers, especially the government, of PEM fuel cells.

16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Moderate

Commodity hydrogen fuels would further encourage the Federal government to drive for national energy self-sufficiency.

17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Weak

Commodity hydrogen fuels might supplement coal and thereby generally reduce the costs of electric generation and reduce electricity prices.

20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Negative, Strong

Commodity hydrogen fuels are expected to result in lower fuel costs and therefore lower operating costs of PEM fuel cells.

21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Positive, Moderate

Commodity hydrogen would compete with commodity gasoline, thereby lowering the prices of oil at each level.

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None

No net effect.

25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate

Commodity hydrogen fuels would greatly increase the mass appeal for automotive fuel cells.

26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate

Commodity hydrogen would encourage continuous operation of fuel cells, both base and peak and emergency load.

27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Negative, Moderate

Commodity hydrogen would encourage a proliferation of PEM fuel cells, especially in the mid- and lower-kW ranges.

28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Indirect impact through operating costs.

Descriptor: 11. Fossil Fuel and Engine/Turbine Technical Advances

How would the "high" state (virtually clean, highly efficient fuels and engines) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Negative, Moderate

New life in fossil fuels would discourage private investment in PEM fuel cells.

8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Positive, Weak

New technologies for fossil fuels, as well as for PEM fuel cells, will further

Descriptors	Direct Impact
encourage environmental regulation because newer and higher standards could be achieved and enforced.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Negative, Moderate
Clean fossil fuels might somewhat dampen public policy enthusiasm for fuel cells.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Weak
Highly efficient and clean coal would significantly advance national energy sufficiency, although clean gasoline and diesel make work in the opposite direction.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Positive, Moderate
New technologies for fossil fuels, especially those used to generate central station generation (most especially clean coal) would further improve the ability to meet future rising demand and achieve reliability (although there remains the potential problems of transmission).	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate
Cleaner fossil fuels will stimulate various forms of DG.	
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Moderate
Clean and highly efficient fossil fuels would give new life to both central station power generation and DG and would help to keep grid costs and prices down.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
No clear net effect.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Positive, Moderate
Advances in clean fossil fuels and internal combustion engines will further	

Descriptors	Direct Impact
increase the demand for and the prices of oil.	
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Strong
Clean fossil fuels and cleaner engines and turbines would be strong competitors with all types of fuel cells.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Negative, Moderate
Improvements in fossil fuels would continue the use of gasoline and diesel to the detriment of PEM fuel cells.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Negative, Moderate
Clean and high efficient fossil fuels will look more attractive for power generation than fuel cells.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Weak
With competition with fossil fuels, the larger PEM fuel cells will likely look more attractive than the smaller units, which will get intense competition from cleaner internal combustion engines.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Strong
Advanced turbines will strongly complete with fuel cells.	

Descriptor: 12. Electric Storage Technologies

How would the "high" state (greatly improved capabilities) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Improved power storage would increase the benefits of PEM fuel cells by better management of generation.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
Advances in energy storage technologies will help move forward PEM fuel cell technologies through better balance of plant.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None

Descriptors	Direct Impact
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Positive, Moderate
Electric storage would greatly help utilities better manage generation to match fluctuating demand.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate
Advance storage technologies increase the attractiveness and options of DG.	
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Moderate
Advanced storage devices might capture and hold electricity generated at night for use at peak load times of day, thereby lowering costs and prices.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Negative, Weak
Advanced batteries will likely improve systems optimization, and thereby help contain operating costs of PEM fuel cells.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Moderate

Descriptors	Direct Impact
Electric storage technologies would strengthen the position of the grid.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate
Improved batteries will complement the use of PEM fuel cells on vehicles.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Weak
Advanced storage would be used with PEM fuel cells for both base and backup power.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 13. Environmental Regulations

How would the "high" state (virtually zero emissions with mandated carbon management) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Weak
Environmental controls and carbon capture will add some costs.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	Positive, Weak
They will add some additional costs for compliance and carbon capture.	
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
More stringent environmental regulations will add to the green image of PEM fuel cells.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Moderate
More stringent regulations might put further burdens on fossil fuels and thereby more fuel cells look more competitive by comparison.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
More stringent environmental regulations will stimulate investments in technology solutions, including PEM fuel cells.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide	None

Descriptors	Direct Impact
innovations and optimization)	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	Positive, Moderate
More stringent environmental regulations will force the fossil fuel industry to improve emissions and look for ways to manage carbon (if they can be done).	
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Weak
More stringent regulations may work in favor of advanced electric storage devices as "clean" technologies.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Moderate
More stringent environmental regulations will encourage governments to support technology solutions, including PEM fuel cells.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Negative, Weak
Environmental policies may make national energy sufficiency and security goals more difficult to achieve.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Negative, Moderate
More stringent environmental regulations place additional cost and performance pressures on the grid that make meeting rising demand more, not less, difficult and costly.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Negative, Moderate
More stringent environmental regulations work against DG (especially traditional back up power) unless DG becomes cleaner.	

Descriptors	Direct Impact
19. Grid Electricity Prices (very high (>15 cents kWh))	Positive, Moderate

New and more stringent regulations, unless matched with new technologies, will drive grid prices up.

20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Weak

They could increase operating costs by having more stringent controls on hydrogen leaks and require more maintenance and repair to prevent undesirable emissions.

21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Positive, Weak

Environmental restricts are expected to drive up the cost of all fossil fuels, especially oil.

22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	Negative, Moderate

Environmental regulation has a small influence on total utility regulations.

24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Negative, Weak

More stringent environmental regulations and carbon capture will have a net affect that is positive for PEM fuel cells.

25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Weak

More stringent regulations might give more emphasis to the development of hybrid vehicles and to all electric vehicles as alternatives to all gasoline and diesel fuels and engines.

26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Weak

More stringent environmental regulations will provide opportunities for PEM fuel cells to penetrate markets, especially in non-attainment areas.

Descriptors	Direct Impact
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Moderate

Stronger regulations will stimulate sales of cleaner fuel cells.

Descriptor: 14. Codes and Standards for PEM Fuel Cells

How would the "high" state (comprehensive and aligned with products/technologies) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
No apparent net effect.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Negative, Weak
Codes and standards could make installation less complicated and costly.	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Weak
Codes and standards will provide part of the infrastructure required to make PEM fuel cells popular.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Codes and standards will generally promote more uniform and consistent benefits.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Codes and standards, reducing complexity and risk, will generally encourage further investments in PEM fuel cells.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Weak
They could improve the quality control of manufacturing.	

Descriptors	Direct Impact
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Weak

Uniform codes and standards would help the commoditization of hydrogen fuel.

11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak

Codes and standards would encourage the government to be a lead user.

16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate

They would greatly help the integration of PEM fuel cells with the grid.

19. Grid Electricity Prices (very high (>15 cents kWh))	None

No apparent net effect.

20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None

Descriptors	Direct Impact
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Weak

They would further encourage the use of PEM fuel cells in vehicles.

26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Weak

They would help commercialization.

27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Moderate

The infrastructure of codes and standards will help fuel cell sales.

Descriptor: 15. Public Policy Support for PEM Fuel Cells

How would the "high" state (Fed and state governments as customers and lead users) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Moderate
Public policy, especially purchases and subsidies, will drive down the costs of PEM fuel cells to all consumers.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
Government leadership in buying and using PEM fuel cells would add greatly to their positive market appeal ("If it's good enough for your Uncle Sam, it's good enough for you!")	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
Not a direct effect.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Public support and encouragement will help private sector investments.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Weak
Public policy could support advanced manufacturing as well as fuel cell development.	

Descriptors	Direct Impact
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Moderate
Public support, especially in R&D, will stimulate further technological advancements in PEM fuel cells.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
Government support would help the commoditization of hydrogen fuel.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Moderate
The government could insist upon codes and standards for every one.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
Indirect.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
Indirect.	
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Weak
Government support would be a competitive advantage.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Weak
Public policy could support transportation, especially fleets, as well as stationary applications.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Weak
Public policy support for PEM fuel cells will help their market penetration (especially if governments buy them).	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Weak
The government would generally buy PEM fuel cells for offices and facilities and these would be in the medium to small sizes.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Strong
Strong Federal leadership would greatly help fuel cell sales.	

Descriptor: 16. National Energy Policy and Security

How would the "high" state (policies driven by goals of sufficiency and security) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
The patriotism of energy sufficiency and security would add to the luster of PEM fuel cells.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Policy might encourage more investments.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
Policy will support further R&D in PEM fuel cells.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
A strong policy of energy security and national self-sufficiency would encourage	

Descriptors	Direct Impact
much more work in hydrogen fuels.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	Positive, Moderate
National government policy could significantly impact fossil fuel and engine efficiency. Efficiency is a major government policy today to relieve in part the dependence on foreign oil.	
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Weak
Policy would favor advanced power storage technologies.	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Negative, Weak
National energy sufficiency and security policy might work against environmental regulations (through lower limits and exceptions).	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Moderate
Federal government might insist upon industry-wide codes and standards for PEM fuel cells, especially as DG options interconnected with the grid.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Strong
A vigorous national energy sufficiency and security policy would greatly stimulate a public policy favoring fuel cells.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
No apparent net effect.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate
National energy security favors the redundancies and backup features of DG.	
19. Grid Electricity Prices (very high (>15 cents kWh))	Positive, Weak
Additional security measures will likely increase system costs.	

Descriptors	Direct Impact
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Negative, Weak
Government will likely take a more active leadership role in containing the cost of oil (in part through the national oil reserves).	
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	Negative, Moderate
The government would increase regulation of the electric utility industry.	
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate
Government policy could force the use of more fuel cells as part of the campaign against dependence on foreign oil.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate
Policy would drive more applications and open more markets for PEM fuel cells.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Weak
Federal policies and support would help fuel cell sales.	

Descriptor: 17. Electrical Grid Reliability and Quality

How would the "high" state (high reliability and quality for base and peak loads) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
Indirect relationship through other descriptors.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Negative, Weak
Sufficient and reliable electricity from the grid takes off the edge for hydrogen fuels, especially for any DG applications.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None

Descriptors	Direct Impact
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Negative, Weak

A strong grid would likely dampen public policy enthusiasm for PEM fuel cells.

16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Negative, Strong

Highly reliable and growing grid does not present opportunities for DG.

19. Grid Electricity Prices (very high (>15 cents kWh))	Positive, Moderate

For the grid to expand to meet growing demand, the electric utilities will have to make more investments that will drive up costs and prices.

20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	Positive, Moderate

A strong grid system would likely loosen the grip of regulations and lead to more free enterprise.

24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Strong

Descriptors	Direct Impact
A strong grid would provide very strong competition to PEM fuel cells.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Negative, Moderate
A strong grid will block widespread deployment of PEM fuel cells as DG.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 18. Role of Distributed Generation (DG)

How would the "high" state (DG integrated with grid in an extended power network) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	Positive, Moderate
Grid integration will require more careful installation of fuel cells.	
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
A "grid friendly" fuel cell adds to the image and popular appeal of PEM fuel cells.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Stationary power PEM fuel cells deployed as DG would have more benefits if connected with the grid.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances	Positive, Weak

Descriptors	Direct Impact
(virtually clean, highly efficient fuels and engines)	
The growth of DG will increase the demand and desirability for cleaner fossil fuels for engines and turbines.	
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Moderate
DG requires more power storage and better technologies.	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Moderate
DG will necessitate codes and standards.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Moderate
An integrated system of the grid with DG would encourage government purchases and use of PEM fuel cells.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Positive, Strong
DG connected with the grid provides more redundancy and generation options that make the grid more reliable as a whole (with less dependence upon power stations and transmission).	
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Weak
Backup and DG options will generally help to keep prices down.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Moderate
Greater DG demands for fuels will likely result in higher fuel costs.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	Negative, Weak
Integration with the grid will likely lead to more regulations of and for the grid.	
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Weak
Strong DG with the grid increases the strength of the grid.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate
More DG options opens up applications for PEM fuel cells.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Moderate
An expanded network of DG could stimulate the market for fuel cells for stationary power applications.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Weak
DG network would supply an infrastructure for fuel cells.	

Descriptor: 19. Grid Electricity Prices

How would the "high" state (very high (>15 cents kWh)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
Not a direct relationship.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
Higher grid electricity prices make the PEM fuel cell look like a more attractive option than when grid prices are low.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
High grid prices will encourage investors to invest in alternative generation options.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Weak
High grid electricity prices will make hydrogen look more attractive and move to make hydrogen fuels more competitive.	

Descriptors	Direct Impact
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Moderate
Higher electricity prices will likely encourage more interest in better power storage technologies that help modulate electric prices.	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Negative, Weak
High grid prices will discourage more regulation that might drive prices yet higher.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Moderate
The public policy would seek alternatives to the grid as a form of relief to electric consumers.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Positive, Moderate
Higher prices would generate more revenues for utility re-investment in the grid.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Strong
High grid prices will stimulate the market for backup and DG options, especially for peak shaving.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad	None

Descriptors	Direct Impact
(significant impact on the U.S.)	
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	Positive, Moderate
Higher grid prices will attract more regulation of the electric utility industry.	
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Negative, Strong
The grid must supply power at low prices to be competitive.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
Indirect relationship.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 20. Integrated PEM Fuel Cell Operating Costs

How would the "high" state (high (>20 cents/kWh)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Negative, Moderate
High operating costs are not "sexy" and they will be a turn-off for consumers who think about having a PEM fuel cell.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Negative, Weak
High operating costs will discourage heavy investment in PEM fuel cell development.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
High operating costs will stimulate further R&D to improve PEM fuel cell operations.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Weak

Descriptors	Direct Impact
High operating costs will create an opportunity and a demand for commodity hydrogen fuels.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Negative, Moderate
High operating costs will discourage strong government role in PEM fuel cell commercialization.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Moderate
High operating costs will make PEM fuel cells less attractive and less competitive.	

Descriptors	Direct Impact
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Negative, Moderate
High operating costs, especially maintenance and repair, would discourage PEM fuel cell commercialization for auto applications.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Negative, Moderate
High fuel prices and maintenance and repair will discourage the broad applications of PEM fuel cells.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Moderate
Higher operating costs would favor large PEM fuel cells over small ones.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Moderate
High operating costs will discourage sales.	

Descriptor: 21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas)

How would the "high" state (high (>2X base 2004 prices)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
Higher hydrocarbon fuel prices make PEM fuel cells look like an attractive high tech option.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Higher oil prices will encourage investments in alternative energy forms, including PEM fuel cells.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
High oil prices will create more competitive opportunities for hydrogen as an alternative to oil.	

Descriptors	Direct Impact
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	Positive, Moderate
Higher oil prices will stimulate further work and development of cleaner and more efficient engines and fossil fuels.	
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Negative, Moderate
High oil prices discourage environmental regulations and enforcement that add further costs to oil products.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak
Federal government would seriously look at PEM fuel cells to set the example for the rest of the country to relieve demand for oil.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Moderate
Strong government leadership will influence the policies of energy sufficiency and security that generally favor PEM fuel cells.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	Positive, Weak
Higher oil prices will drive natural gas prices higher and may have some impact on coal prices.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Moderate
Higher oil prices will drive higher prices for methane and methanol.	

Descriptors	Direct Impact
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate

Higher oil (gasoline and diesel) prices will stimulate more interest in PEM fuel cells, especially to the extent that they can improve efficiency (such as through auxiliary power generation for on-board electronics).

26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate

High oil (fossil fuel) prices will make PEM fuel cells generally look more attractive.

27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 22. PEM Fuel Cell Stationary Power Units Abroad

How would the "high" state (significant impact on the U.S.) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Weak
PEM fuel cell successes abroad and strong impact on U.S. market would drive PEM fuel cells costs down.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Weak
Successful PEM fuel cells in Europe and Japan will have some appeal to American consumers.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Successful units from Japan or Europe would likely deliver better performance and benefits.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Japanese and European successes will likely encourage further PEM fuel cell investments in the U.S.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Weak
Japanese and European successes in PEM fuel cell production would likely find applications in the U.S.	

Descriptors	Direct Impact
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
Foreign PEM fuel cells will speed up technical advances in the U.S.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Weak
Hydrogen solutions abroad may be attractive for and imported into the U.S.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Weak
PEM fuel cell successes in Japan and Europe will likely include advanced batteries that would eventually come to the U.S. market.	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak
Foreign codes and standards would likely influence American.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Weak
Japanese and European PEM fuel cells will be used for DG options and will show how those options could work in the U.S.	
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20	Negative, Weak

Descriptors	Direct Impact
cents/kWh))	
Successes abroad would show ways of reducing operating costs in the U.S.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Negative, Weak
PEM fuel cell successes around the world would give oil more competition and slightly pressure oil prices down.	
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Positive, Moderate
Japanese and European successes in PEM fuel cells will find automotive applications, especially through successful companies in the U.S. (Toyota, Honda, DaimlerChrysler, etc.)	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Positive, Moderate
Foreign fuel cell successes could be transferred to the U.S.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Positive, Moderate
Japanese and European PEM fuel cells will likely be in medium to small sizes.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 23. Electric Utility Industry Structure

How would the "high" state (less regulated, less vertical, more enterprising than today) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
With fewer restrictions, the utilities might be freer to pursue more risky investments, including fuel cells.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None

Descriptors	Direct Impact
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	Negative, Weak
More liberal regulation of utilities might lead to a relaxation that would be bad for the long-term reliability of the grid.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Weak
Less regulation might result in more interest in DG. In Texas, for example, by regulation an electric utility may not own DG.	
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Weak
Less regulation would likely lead to more competition with lower rates.	
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
Could go either way.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None

Descriptors	Direct Impact
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	None

Descriptor: 24. Competition to PEM Fuel Cells

How would the "high" state (the grid is the primary competition to PEM fuel cells) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Weak
More competition would force prices down to be more competitive.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
No apparent net effect.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
More competition would require better performance to be competitive.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
indirect	
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None

Descriptors	Direct Impact
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
no apparent net effect	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak
There would be more options for the government.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Negative, Weak
Operating costs would have to come down to keep competitive with the alternatives.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None

Descriptors	Direct Impact
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	Negative, Moderate
Too much competition.	
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Strong
It would be very difficult for fuel cells to compete with the grid.	

Descriptor: 25. PEM Fuel Cells in Automotive Applications

How would the "high" state (mass consumer appeal (auto, motorcycle, or scooter)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Positive, Moderate
Successes in automotive applications will likely increase production and lower prices for all types of PEM fuel cell uses.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
Mass appeal in automotive applications will have a positive impact on the appeal of PEM fuel cells in stationary applications.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Automotive uses would provide new benefits and value equation for PEM fuel cells.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
Automotive successes would stimulate more investment in general in PEM fuel cells (the bandwagon effect of a winner).	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	Positive, Weak
Mass appeal and higher volumes will lead to better manufacturing methods and quality control.	

Descriptors	Direct Impact
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate
Strong appeal of PEM fuel cells would encourage commodity hydrogen.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak
There would be more urgency for PEM fuel cell codes and standards.	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak
Success in the automotive arena would encourage more public support for stationary power generation.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Weak
Increased use of PEM fuel cells in automotive applications would be a first but important step toward substantial dependence on foreign oil.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Negative, Weak
Automotive PEM fuel cells might even become DR options in competition with the grid.	
19. Grid Electricity Prices (very high (>15 cents kWh))	None

Descriptors	Direct Impact
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Weak
Automotive uses of PEM fuel cells will increase the demand and the prices for fuels for fuel cells.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	Negative, Moderate
Increased use of PEM fuel cells would provide competition to oil and help lower oil prices.	
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	Positive, Weak
Foreign auto development and use of PEM fuel cells will impact both transportation and stationary uses of PEM fuel cells in the U.S.	
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	Negative, Moderate
Automotive PEM fuel cell success will stimulate demand for medium to small fuel cells.	
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Weak
There would be some carry over from automotive sales to stationary power sales.	

Descriptor: 26. Prevailing PEM Fuel Cell Application

How would the "high" state (grid parallel (any time and CHP with the grid)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Strong
Strong markets will increase sales volumes and reduce unit prices.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	None
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	Positive, Weak
Increased markets will lead to increased customer satisfaction.	
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Weak
More market growth stimulates more investments to capture sales.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	Positive, Weak
The premium power market will encourage further advances in the technological performance of PEM fuel cells.	
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	Positive, Moderate

Descriptors	Direct Impact
Strong use of PEM fuel cells would encourage commodity hydrogen.	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None
12. Electric Storage Technologies (greatly improved capabilities)	Positive, Weak
More PEM fuel cells will mean more storage needs.	
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Positive, Weak
Successful PEM fuel cells will encourage further regulations of environmental polluting equipment and fuels.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	Positive, Weak
Government would likely increase its purchases of PEM fuel cells.	
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Weak
The spread of PEM fuel cells would slightly encourage policies of energy sufficiency and security.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
Not a direct effect (indirect through DG).	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate
Strong PEM fuel cell sales would go into DG market.	
19. Grid Electricity Prices (very high (>15 cents kWh))	Negative, Weak
PEM fuel cell options for both base and peak loads would help control rising grid prices.	

Descriptors	Direct Impact
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	Positive, Weak
More applications and markets and more units sold will increase demand and prices for fuels and might increase maintenance and repair costs.	
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	Positive, Strong
If PEM fuel cells were sold for both base and peak loads, then they would be in competition with the grid	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Positive, Moderate
PEM fuel cells would be an attractive option.	

Descriptor: 27. Prevailing PEM Fuel Cell Customers

How would the "high" state (institutional/heavy commercial (>200 kW)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	None
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	None
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Negative, Moderate
If utilities are the use leaders, it will hurt the image of PEM fuel cells as a consumer product.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	None
Indirect through sales.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
no apparent net effect	
11. Fossil Fuel and Engine/Turbine Technical Advances (virtually clean, highly efficient fuels and engines)	None

Descriptors	Direct Impact
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	Positive, Weak
The larger units might have more appeal, especially for carbon management.	
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	None
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	None
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
Indirect through DG.	
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	Positive, Moderate
The larger units would be easier to integrate with the grid than many small units.	
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None

Descriptors	Direct Impact
No apparent net effect.	
25. PEM Fuel Cells in Automotive Applications (mass consumer appeal (auto, motorcycle, or scooter))	Negative, Moderate
Larger units would have few applications for automotive, but the small ones would.	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
28. PEM Fuel Cell Market Size (high (>$8 billion))	Negative, Moderate
The big markets would be residential and light commercial.	

Descriptor: 28. PEM Fuel Cell Market Size

How would the "high" state (high (>$8 billion)) of this descriptor directly impact the probability of occurrence of the "high" state of each of the other descriptors?

Descriptors	Direct Impact
1. Retail Price of PEM Fuel Cell (w/o Fuel Processor) (*>3,000 per kW)	Negative, Moderate
More sales would reduce prices.	
2. Prevailing System Architecture of PEM Fuel Cell (fully integrated fuel cell (inc. fuel handling))	None
3. Retail Price of PEM Fuel Cell Processor (high (>$1,500 per kW average))	Positive, Weak
Same as for Des 1, but less so.	
4. PEM Fuel Cell System Installation (difficult and expensive by professional installers)	None
5. Consumer Market Image of PEM Fuel Cells (high tech, high gloss, "best thing since sliced bread")	Positive, Moderate
More sales add to the product luster.	
6. Performance Benefits of PEM Fuel Cells to Customers (exceed customers' expectations on several parameters)	None
7. Stationary and Mobile Fuel Cell Investments in the U.S. (>$2.0 billion average annual (>2X base 2004))	Positive, Moderate
More sales stimulates more investment.	
8. PEM Fuel Cell Manufacturing (mass produced, quality controlled)	None
9. PEM Fuel Cell Technical Advances (system-wide innovations and optimization)	None
10. Hydrogen Fuel for PEM Fuel Cells (hydrogen or hydrogen-rich fuels as commodities)	None
11. Fossil Fuel and Engine/Turbine Technical Advances	None

Descriptors	Direct Impact
(virtually clean, highly efficient fuels and engines)	
12. Electric Storage Technologies (greatly improved capabilities)	None
13. Environmental Regulations (virtually zero emissions with mandated carbon management)	None
14. Codes and Standards for PEM Fuel Cells (comprehensive and aligned with products/technologies)	Positive, Weak
More sales might stimulate more standards (and uniformity).	
15. Public Policy Support for PEM Fuel Cells (Fed and state governments as customers and lead users)	None
16. National Energy Policy and Security (policies driven by goals of sufficiency and security)	Positive, Weak
More sales makes national policy of security and sufficiency easier to implement.	
17. Electrical Grid Reliability and Quality (high reliability and quality for base and peak loads)	None
18. Role of Distributed Generation (DG) (DG integrated with grid in an extended power network)	None
19. Grid Electricity Prices (very high (>15 cents kWh))	None
20. Integrated PEM Fuel Cell Operating Costs (high (>20 cents/kWh))	None
21. Price of Hydrocarbon Fuels (Primarily Oil and Natural Gas) (high (>2X base 2004 prices))	None
22. PEM Fuel Cell Stationary Power Units Abroad (significant impact on the U.S.)	None
23. Electric Utility Industry Structure (less regulated, less vertical, more enterprising than today)	None
24. Competition to PEM Fuel Cells (the grid is the primary competition to PEM fuel cells)	None
25. PEM Fuel Cells in Automotive Applications (mass	None

Descriptors	Direct Impact
consumer appeal (auto, motorcycle, or scooter))	
26. Prevailing PEM Fuel Cell Application (grid parallel (any time and CHP with the grid))	None
27. Prevailing PEM Fuel Cell Customers (institutional/heavy commercial (>200 kW))	None

APPENDIX F: CROSS-IMPACT MATRIX (FROM IFS)

Occurrence	1. Retail Price of	0.15 A. *>3,000 pe	0.25 B. $2,000-$3,	0.35 C. $1,000-$2,	0.25 D. <$1,000 pe	2. Prevailing Syst	0.30 A. fully inte	0.45 B. *stack wit	0.25 C. stack with	3. Retail Price of	0.20 A. high (>$1,	0.35 B. medium ($5	0.45 C. low (<$500	4. PEM Fuel Cell S	0.35 A. difficult	0.45 B. mod expens	0.20 C. easy and i	5. Consumer Market	0.20 A. high tech,	0.45 B. effective	0.35 C. an electri	6. Performance Ben	0.20 A. exceed cus	0.40 B. consistent	0.30 C. usually me	0.10 D. * repeated	7. Stationary and	0.25 A. >$2.0 bill	0.45 B. $1.0-$2.0	0.30 C. *<$1.0 bil
1. Retail Price of																														
0.15 A. *>3,000 pe		*	*	*	*		-1	0	1		0	0	0		0	0	0		2	0	-2		1	0	0	-1		0	0	0
0.25 B. $2,000-$3,		*	*	*	*		0	0	0		0	0	0		0	0	0		1	1	-1		0	1	0	0		0	0	0
0.35 C. $1,000-$2,		*	*	*	*		0	1	0		0	0	0		0	0	0		-1	0	1		0	0	1	0		0	0	0
0.25 D. <$1,000 pe		*	*	*	*		1	0	-1		0	0	0		0	0	0		-2	0	2		-1	0	0	1		0	0	0
2. Prevailing Syst																														
0.30 A. fully inte		0	0	0	0		*	*	*		1	0	-1		0	0	0		0	0	0		0	0	0	0		1	0	-1
0.45 B. *stack wit		0	0	0	0		*	*	*		0	0	0		0	0	0		0	0	0		0	0	0	0		0	1	0
0.25 C. stack with		0	0	0	0		*	*	*		-1	0	1		0	0	0		0	0	0		0	0	0	0		-1	0	1
3. Retail Price of																														
0.20 A. high (>$1,		0	0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 B. medium ($5		0	0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 C. low (<$500		0	0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
4. PEM Fuel Cell S																														
0.35 A. difficult		0	0	0	0		-3	-1	3		0	0	0		*	*	*		0	0	0		0	0	0	0		-1	0	1
0.45 B. mod expens		0	0	0	0		-1	1	1		0	0	0		*	*	*		0	0	0		0	0	0	0		0	0	0
0.20 C. easy and i		0	0	0	0		3	1	-3		0	0	0		*	*	*		0	0	0		0	0	0	0		1	0	-1
5. Consumer Market																														
0.20 A. high tech,		1	0	0	-1		1	0	-1		-1	0	1		0	0	0		*	*	*		3	1	-1	-3		1	0	-1
0.45 B. effective		0	1	1	0		0	1	0		0	1	0		0	0	0		*	*	*		1	1	-1	-1		0	1	0
0.35 C. an electri		-1	0	0	1		-1	0	1		1	0	-1		0	0	0		*	*	*		-3	-1	1	3		-1	0	1
6. Performance Ben																														
0.20 A. exceed cus		0	0	0	0		2	0	-2		0	0	0		0	0	0		-1	0	1		*	*	*	*		0	0	0
0.40 B. consistent		0	0	0	0		1	1	-1		0	0	0		0	0	0		0	1	0		*	*	*	*		0	0	0
0.30 C. usually me		0	0	0	0		-1	-1	1		0	0	0		0	0	0		0	1	0		*	*	*	*		0	0	0
0.10 D. * repeated		0	0	0	0		-2	0	2		0	0	0		0	0	0		1	0	-1		*	*	*	*		0	0	0
7. Stationary and																														
0.25 A. >$2.0 bill		-1	0	0	1		0	0	0		0	0	0		0	0	0		0	0	0		1	0	0	-1		*	*	*
0.45 B. $1.0-$2.0		0	1	1	0		0	0	0		0	0	0		0	0	0		0	0	0		0	1	1	0		*	*	*
0.30 C. *<$1.0 bil		1	0	0	-1		0	0	0		0	0	0		0	0	0		0	0	0		-1	0	0	1		*	*	*
8. PEM Fuel Cell M																														
0.30 A. mass produ		0	0	0	0		1	0	-1		0	0	0		0	0	0		0	0	0		0	0	0	0		2	0	-2
0.45 B. semi-autom		0	0	0	0		0	1	0		0	0	0		0	0	0		0	0	0		0	0	0	0		1	1	-1
0.25 C. *extensive		0	0	0	0		-1	0	1		0	0	0		0	0	0		0	0	0		0	0	0	0		-2	0	2
9. PEM Fuel Cell T																														
0.15 A. system-wid		1	0	0	-1		2	0	-2		0	0	0		1	0	-1		0	0	0		0	0	0	0		2	1	-2
0.35 B. advances i		0	1	0	0		1	1	-1		0	0	0		0	1	0		0	0	0		0	0	0	0		1	2	-1

Occurrence	1. Retail Price of	0.15 A. *>3,000 pe	0.25 B. $2,000-$3,	0.35 C. $1,000-$2,	0.25 D. <$1,000 pe	2. Prevailing Syst	0.30 A. fully inte	0.45 B. *stack wit	0.25 C. stack with	3. Retail Price of	0.20 A. high (>$1,	0.35 B. medium ($5	0.45 C. low (<$500	4. PEM Fuel Cell S	0.35 A. difficult	0.45 B. mod expens	0.20 C. easy and i	5. Consumer Market	0.20 A. high tech,	0.45 B. effective	0.35 C. an electri	6. Performance Ben	0.20 A. exceed cus	0.40 B. consistent	0.30 C. usually me	0.10 D. * repeated	7. Stationary and	0.25 A. >$2.0 bill	0.45 B. $1.0-$2.0	0.30 C. *<$1.0 bil
0.40 C. *advances		0	0	1	0		-1	1	1		0	0	0		0	1	0		0	0	0		0	0	0	0		-1	-1	1
0.10 D. *slow, inc		-1	0	0	1		-2	0	2		0	0	0		-1	0	1		0	0	0		0	0	0	0		-2	-1	2
10. Hydrogen Fuel																														
0.10 A. hydrogen o		0	0	0	0		2	0	-2		1	0	-1		0	0	0		0	0	0		0	0	0	0		2	0	-2
0.45 B. hydrogen f		0	0	0	0		1	2	-1		1	1	0		0	0	0		0	0	0		0	0	0	0		1	2	-1
0.30 C. hydrogen p		0	0	0	0		-1	1	1		0	1	0		0	0	0		0	0	0		0	0	0	0		-1	1	1
0.15 D. *compresse		0	0	0	0		-2	0	2		-1	0	1		0	0	0		0	0	0		0	0	0	0		-2	0	2
11. Fossil Fuel an																														
0.15 A. virtually		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.30 B. virtually		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 C. improved g		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 D. *little ch		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
12. Electric Stora																														
0.20 A. greatly im		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. moderately		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 C. *marginall		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
13. Environmental																														
0.15 A. virtually		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. lower emis		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.40 C. *little ch		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
14. Codes and Stan																														
0.30 A. comprehens		0	0	0	0		2	0	-2		0	0	0		-1	0	1		0	0	0		0	0	0	0		0	0	0
0.50 B. *less than		0	0	0	0		1	1	-1		0	0	0		0	1	0		0	0	0		0	0	0	0		0	0	0
0.20 C. major gaps		0	0	0	0		-2	0	2		0	0	0		1	0	-1		0	0	0		0	0	0	0		0	0	0
15. Public Policy																														
0.10 A. Fed and st		-2	0	0	2		0	0	0		0	0	0		-1	0	1		0	0	0		2	-1	-1	-2		0	0	0
0.40 B. subsidies,		-1	0	0	1		0	0	0		0	0	0		0	1	0		0	0	0		1	1	-1	-1		0	0	0
0.30 C. tax breaks		1	0	1	-1		0	0	0		0	0	0		0	0	0		0	0	0		-1	-1	1	1		0	0	0
0.20 D. *just supp		2	0	0	-2		0	0	0		0	0	0		1	0	-1		0	0	0		-2	1	1	2		0	0	0
16. National Energ																														
0.25 A. policies d		-1	0	0	1		0	0	0		0	0	0		0	0	0		0	0	0		2	0	0	-2		0	0	0
0.35 B. policies d		0	1	1	0		0	0	0		0	0	0		0	0	0		0	0	0		1	1	0	-1		0	0	0
0.40 C. *passive t		1	0	0	-1		0	0	0		0	0	0		0	0	0		0	0	0		-2	0	1	2		0	0	0
17. Electrical Gri																														
0.35 A. high relia		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. *high reli		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 C. inconsiste		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0

Occurrence	1. Retail Price of	0.15 A. *>3,000 pe	0.25 B. $2,000-$3,	0.35 C. $1,000-$2,	0.25 D. <$1,000 pe	2. Prevailing Syst	0.30 A. fully inte	0.45 B. *stack wit	0.25 C. stack with	3. Retail Price of	0.20 A. high (>$1,	0.35 B. medium ($5	0.45 C. low (<$500	4. PEM Fuel Cell S	0.35 A. difficult	0.45 B. mod expens	0.20 C. easy and i	5. Consumer Market	0.20 A. high tech,	0.45 B. effective	0.35 C. an electri	6. Performance Ben	0.20 A. exceed cus	0.40 B. consistent	0.30 C. usually me	0.10 D. * repeated	7. Stationary and	0.25 A. >$2.0 bill	0.45 B. $1.0-$2.0	0.30 C. *<$1.0 bil
18. Role of Distri																														
0.20 A. DG integra		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.50 B. DG combina		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.30 C. *DG primar		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
19. Grid Electrici																														
0.15 A. very high		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.30 B. high (11-1		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 C. medium (7-		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 D. *low (<7 c		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
20. Integrated PEM																														
0.35 A. high (>20		0	0	0	0		1	0	-1		1	0	-1		0	0	0		0	0	0		0	0	0	0		0	0	0
0.40 B. *medium (1		0	0	0	0		0	1	0		0	1	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 C. low (<10 c		0	0	0	0		-1	0	1		-1	0	1		0	0	0		0	0	0		0	0	0	0		0	0	0
21. Price of Hydro																														
0.25 A. high (>2X		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.60 B. *medium (1		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.15 C. low (< bas		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
22. PEM Fuel Cell																														
0.20 A. significan		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		1	0	0	-1		0	0	0
0.50 B. moderate i		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	1	1	0		0	0	0
0.30 C. *marginal		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		-1	0	0	1		0	0	0
23. Electric Utili																														
0.30 A. less regul		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.50 B. about the		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 C. more regul		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
24. Competition to																														
0.35 A. the grid i		3	1	-1	-3		0	0	0		0	0	0		2	0	-2		-2	0	2		-2	0	0	2		0	0	0
0.40 B. advanced I		1	1	-1	-1		0	0	0		0	0	0		1	1	-1		-1	1	1		-1	1	0	1		0	0	0
0.25 C. other type		-3	-1	1	3		0	0	0		0	0	0		-2	0	2		2	0	-2		2	0	0	-2		0	0	0
25. PEM Fuel Cells																														
0.20 A. mass consu		-2	-1	-1	2		0	0	0		0	0	0		0	0	0		1	0	-1		2	-1	-1	-2		0	0	0
0.35 B. delivery f		-1	-1	1	1		0	0	0		0	0	0		0	0	0		0	1	0		1	2	-1	-1		0	0	0
0.45 C. *special v		2	1	1	-2		0	0	0		0	0	0		0	0	0		-1	0	1		-2	1	1	2		0	0	0
26. Prevailing PEM																														
0.10 A. grid paral		-3	-1	1	3		0	0	0		0	0	0		0	0	0		1	0	-1		3	1	-1	-3		2	-1	-2
0.40 B. back up an		-1	-1	1	1		0	0	0		0	0	0		0	0	0		0	1	0		1	1	-1	-1		1	1	-1
0.30 C. primarily		1	2	-1	-1		0	0	0		0	0	0		0	0	0		0	1	0		-1	-1	2	1		-1	1	1

Occurrence	1. Retail Price of	0.15 A. *>3,000 pe	0.25 B. $2,000-$3,	0.35 C. $1,000-$2,	0.25 D. <$1,000 pe	2. Prevailing Syst	0.30 A. fully inte	0.45 B. *stack wit	0.25 C. stack with	3. Retail Price of	0.20 A. high (>$1,	0.35 B. medium ($5	0.45 C. low (<$500	4. PEM Fuel Cell S	0.35 A. difficult	0.45 B. mod expens	0.20 C. easy and i	5. Consumer Market	0.20 A. high tech,	0.45 B. effective	0.35 C. an electri	6. Performance Ben	0.20 A. exceed cus	0.40 B. consistent	0.30 C. usually me	0.10 D. * repeated	7. Stationary and	0.25 A. >$2.0 bill	0.45 B. $1.0-$2.0	0.30 C. *<$1.0 bil
0.20 D. *isolated,		3	1	-1	-3		0	0	0		0	0	0		0	0	0		-1	0	1		-3	-1	1	3		-2	0	2
27. Prevailing PEM																														
0.35 A. institutio		2	1	-1	-2		0	0	0		0	0	0		2	0	-2		-3	-1	3		0	0	0	0		0	0	0
0.45 B. commercial		1	1	1	-1		0	0	0		0	0	0		1	1	-1		-1	1	1		0	0	0	0		0	0	0
0.20 C. residentia		-2	-1	1	2		0	0	0		0	0	0		-2	0	2		3	1	-3		0	0	0	0		0	0	0
28. PEM Fuel Cell																														
0.25 A. high (>$8		-2	1	0	2		0	0	0		-1	0	1		-1	0	1		3	1	-3		2	0	0	-2		0	0	0
0.45 B. medium ($5		-1	1	1	1		0	0	0		0	1	0		0	1	0		1	1	-1		1	1	0	-1		0	0	0
0.30 C. low (<$5 b		2	0	0	-2		0	0	0		1	0	-1		1	0	-1		-3	-1	3		-2	0	0	2		0	0	0
Sum of Values		0	8	7	0		0	11	0		1	5	0		2	7	-2		-1	9	1		3	9	3	-3		1	8	-1
Non-Zero Entries		28	19	19	28		26	14	26		11	5	10		14	7	14		19	13	19		29	20	18	29		21	12	21

Occurrence	8. PEM Fuel Cell M	0.30 A. mass produ	0.45 B. semi-autom	0.25 C. *extensive	9. PEM Fuel Cell T	0.15 A. system-wid	0.35 B. advances i	0.40 C. *advances	0.10 D. *slow, inc	10. Hydrogen Fuel	0.10 A. hydrogen o	0.45 B. hydrogen f	0.30 C. hydrogen p	0.15 D. *compresse	11. Fossil Fuel an	0.15 A. virtually	0.30 B. virtually	0.35 C. improved g	0.20 D. *little ch	12. Electric Stora	0.20 A. greatly im	0.45 B. moderately	0.35 C. *marginall	13. Environmental	0.15 A. virtually	0.45 B. lower emis	0.40 C. *little ch
1. Retail Price of																											
0.15 A. *>3,000 pe		-3	-1	3		-2	0	0	2		0	0	0	0		0	0	0	0		0	0	0		1	0	-1
0.25 B. $2,000-$3,		-1	-1	1		-1	-1	0	1		0	0	0	0		0	0	0	0		0	0	0		0	1	0
0.35 C. $1,000-$2,		1	1	-1		1	0	1	-1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.25 D. <$1,000 pe		3	1	-3		2	0	0	-2		0	0	0	0		0	0	0	0		0	0	0		-1	0	1
2. Prevailing Syst																											
0.30 A. fully inte		1	0	-1		3	1	-1	-3		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.45 B. *stack wit		0	1	0		1	1	-1	-1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.25 C. stack with		-1	0	1		-3	-1	1	3		0	0	0	0		0	0	0	0		0	0	0		0	0	0
3. Retail Price of																											
0.20 A. high (>$1,		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		1	0	-1
0.35 B. medium ($5		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		0	1	0
0.45 C. low (<$500		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		-1	0	1
4. PEM Fuel Cell S																											
0.35 A. difficult		-2	0	2		-2	0	0	2		-1	0	0	1		0	0	0	0		0	0	0		0	0	0
0.45 B. mod expens		-1	1	1		-1	0	0	1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.20 C. easy and i		2	0	-2		2	0	0	-2		1	0	0	-1		0	0	0	0		0	0	0		0	0	0
5. Consumer Market																											
0.20 A. high tech,		0	0	0		3	1	-1	-3		2	0	0	-2		0	0	0	0		0	0	0		2	0	-2
0.45 B. effective		0	0	0		1	1	-1	-1		1	1	0	-1		0	0	0	0		0	0	0		1	1	-1
0.35 C. an electri		0	0	0		-3	-1	1	3		-2	0	0	2		0	0	0	0		0	0	0		-2	0	2
6. Performance Ben																											
0.20 A. exceed cus		2	0	-2		3	1	-1	-3		1	0	0	-1		0	0	0	0		1	0	-1		2	0	-2
0.40 B. consistent		1	1	-1		1	1	-1	-1		0	1	0	0		0	0	0	0		0	1	0		1	1	-1
0.30 C. usually me		-1	1	1		-1	-1	1	1		0	0	1	0		0	0	0	0		0	1	0		-1	1	1
0.10 D. * repeated		-2	0	2		-3	-1	1	3		-1	0	0	1		0	0	0	0		-1	0	1		-2	0	2
7. Stationary and																											
0.25 A. >$2.0 bill		1	0	-1		3	1	-1	-3		2	0	0	-2		-2	-1	-1	2		0	0	0		1	0	-1
0.45 B. $1.0-$2.0		0	1	0		1	2	-1	-1		1	1	0	-1		-1	1	-1	1		0	0	0		0	1	0
0.30 C. *<$1.0 bil		-1	0	1		-3	-1	1	3		-2	0	0	2		2	1	1	-2		0	0	0		-1	0	1
8. PEM Fuel Cell M																											
0.30 A. mass produ		*	*	*		1	0	0	-1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.45 B. semi-autom		*	*	*		0	1	1	0		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.25 C. *extensive		*	*	*		-1	0	0	1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
9. PEM Fuel Cell T																											
0.15 A. system-wid		0	0	0		*	*	*	*		0	0	0	0		0	0	0	0		1	0	-1		0	0	0

Occurrence	8. PEM Fuel Cell M	0.30 A. mass produ	0.45 B. semi-autom	0.25 C. *extensive	9. PEM Fuel Cell T	0.15 A. system-wid	0.35 B. advances i	0.40 C. *advances	0.10 D. *slow, inc	10. Hydrogen Fuel	0.10 A. hydrogen o	0.45 B. hydrogen f	0.30 C. hydrogen p	0.15 D. *compresse	11. Fossil Fuel an	0.15 A. virtually	0.30 B. virtually	0.35 C. improved g	0.20 D. *little ch	12. Electric Stora	0.20 A. greatly im	0.45 B. moderately	0.35 C. *marginall	13. Environmental	0.15 A. virtually	0.45 B. lower emis	0.40 C. *little ch
0.35 B. advances i		0	0	0		*	*	*	*		0	0	0	0		0	0	0	0		0	1	0		0	0	0
0.40 C. *advances		0	0	0		*	*	*	*		0	0	0	0		0	0	0	0		0	1	0		0	0	0
0.10 D. *slow, inc		0	0	0		*	*	*	*		0	0	0	0		0	0	0	0		-1	0	1		0	0	0
10. Hydrogen Fuel																											
0.10 A. hydrogen o		0	0	0		0	0	0	0		*	*	*	*		0	0	0	0		0	0	0		0	0	0
0.45 B. hydrogen f		0	0	0		0	0	0	0		*	*	*	*		0	0	0	0		0	0	0		0	0	0
0.30 C. hydrogen p		0	0	0		0	0	0	0		*	*	*	*		0	0	0	0		0	0	0		0	0	0
0.15 D. *compresse		0	0	0		0	0	0	0		*	*	*	*		0	0	0	0		0	0	0		0	0	0
11. Fossil Fuel an																											
0.15 A. virtually		0	0	0		0	0	0	0		0	0	0	0		*	*	*	*		0	0	0		2	0	-2
0.30 B. virtually		0	0	0		0	0	0	0		0	0	0	0		*	*	*	*		0	0	0		1	1	-1
0.35 C. improved g		0	0	0		0	0	0	0		0	0	0	0		*	*	*	*		0	0	0		-1	0	1
0.20 D. *little ch		0	0	0		0	0	0	0		0	0	0	0		*	*	*	*		0	0	0		-2	0	2
12. Electric Stora																											
0.20 A. greatly im		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		*	*	*		1	0	-1
0.45 B. moderately		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		*	*	*		0	1	0
0.35 C. *marginall		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		*	*	*		-1	0	1
13. Environmental																											
0.15 A. virtually		0	0	0		0	0	0	0		0	0	0	0		1	0	0	-1		0	0	0		*	*	*
0.45 B. lower emis		0	0	0		0	0	0	0		0	0	0	0		0	1	0	0		0	0	0		*	*	*
0.40 C. *little ch		0	0	0		0	0	0	0		0	0	0	0		-1	0	1	1		0	0	0		*	*	*
14. Codes and Stan																											
0.30 A. comprehens		1	0	-1		1	0	0	-1		1	0	0	-1		0	0	0	0		0	0	0		0	0	0
0.50 B. *less than		0	1	0		0	1	1	0		0	1	0	0		0	0	0	0		0	0	0		0	0	0
0.20 C. major gaps		-1	0	1		-1	0	0	1		-1	0	0	1		0	0	0	0		0	0	0		0	0	0
15. Public Policy																											
0.10 A. Fed and st		0	0	0		1	0	0	-1		2	0	0	-2		-2	0	0	2		0	0	0		2	0	-2
0.40 B. subsidies,		0	0	0		0	1	0	0		1	1	0	-1		-1	1	0	1		0	0	0		1	1	-1
0.30 C. tax breaks		0	0	0		0	0	1	0		-1	0	1	1		1	0	1	-1		0	0	0		-1	1	1
0.20 D. *just supp		0	0	0		-1	0	0	1		-2	0	0	2		2	0	0	-2		0	0	0		-2	0	2
16. National Energ																											
0.25 A. policies d		0	0	0		0	0	0	0		2	0	0	-2		1	0	0	-1		0	0	0		-1	0	1
0.35 B. policies d		0	0	0		0	0	0	0		1	1	0	-1		0	1	1	0		0	0	0		0	1	0
0.40 C. *passive t		0	0	0		0	0	0	0		-2	0	0	2		-1	0	0	1		0	0	0		1	0	-1
17. Electrical Gri																											
0.35 A. high relia		0	0	0		0	0	0	0		0	0	0	0		2	1	-1	-2		2	0	-2		-2	0	2
0.45 B. *high reli		0	0	0		0	0	0	0		0	0	0	0		1	1	1	-1		1	1	-1		-1	1	1

Occurrence	8. PEM Fuel Cell M	0.30 A. mass produ	0.45 B. semi-autom	0.25 C. *extensive	9. PEM Fuel Cell T	0.15 A. system-wid	0.35 B. advances i	0.40 C. *advances	0.10 D. *slow, inc	10. Hydrogen Fuel	0.10 A. hydrogen o	0.45 B. hydrogen f	0.30 C. hydrogen p	0.15 D. *compresse	11. Fossil Fuel an	0.15 A. virtually	0.30 B. virtually	0.35 C. improved g	0.20 D. *little ch	12. Electric Stora	0.20 A. greatly im	0.45 B. moderately	0.35 C. *marginall	13. Environmental	0.15 A. virtually	0.45 B. lower emis	0.40 C. *little ch
0.20 C. inconsiste		0	0	0		0	0	0	0		0	0	0	0		-2	-1	0	2		-2	0	2		2	0	-2
18. Role of Distri																											
0.20 A. DG integra		0	0	0		1	0	0	-1		0	0	0	0		2	0	0	-2		2	1	-2		-2	0	2
0.50 B. DG combina		0	0	0		0	1	1	0		0	0	0	0		1	1	0	-1		1	1	-1		-1	1	1
0.30 C. *DG primar		0	0	0		-1	0	0	1		0	0	0	0		-2	0	0	2		-2	-1	2		2	0	-2
19. Grid Electrici																											
0.15 A. very high		0	0	0		0	0	0	0		-1	0	0	1		-2	0	0	2		-2	0	2		2	1	-2
0.30 B. high (11-1		0	0	0		0	0	0	0		0	1	0	0		-1	1	0	1		-1	-1	1		1	2	-1
0.35 C. medium (7-		0	0	0		0	0	0	0		0	0	0	0		1	0	1	-1		1	1	-1		-1	-1	1
0.20 D. *low (<7 c		0	0	0		0	0	0	0		1	0	0	-1		2	0	0	-2		2	0	-2		-2	-1	2
20. Integrated PEM																											
0.35 A. high (>20		0	0	0		-2	0	0	2		-3	-1	1	3		0	0	0	0		-1	0	1		1	0	-1
0.40 B. *medium (1		0	0	0		-1	-1	1	1		-1	-1	1	1		0	0	0	0		0	1	0		0	1	0
0.25 C. low (<10 c		0	0	0		2	0	1	-2		3	1	-1	-3		0	0	0	0		1	0	-1		-1	0	1
21. Price of Hydro																											
0.25 A. high (>2X		0	0	0		0	0	0	0		2	0	0	-2		2	0	0	-2		0	0	0		1	0	-1
0.60 B. *medium (1		0	0	0		0	0	0	0		1	1	0	-1		1	1	1	-1		0	0	0		0	1	0
0.15 C. low (< bas		0	0	0		0	0	0	0		-2	0	0	2		-2	0	0	2		0	0	0		-1	0	1
22. PEM Fuel Cell																											
0.20 A. significan		0	0	0		1	0	0	-1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.50 B. moderate i		0	0	0		0	1	0	0		0	0	0	0		0	0	0	0		0	0	0		0	0	0
0.30 C. *marginal		0	0	0		-1	0	0	1		0	0	0	0		0	0	0	0		0	0	0		0	0	0
23. Electric Utili																											
0.30 A. less regul		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		-2	0	2
0.50 B. about the		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		-1	1	1
0.20 C. more regul		0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0		2	0	-2
24. Competition to																											
0.35 A. the grid i		0	0	0		-1	0	0	1		0	0	0	0		3	1	-1	-3		2	0	-2		-1	0	1
0.40 B. advanced I		0	0	0		0	0	0	0		0	0	0	0		1	1	-1	-1		1	1	-1		0	0	0
0.25 C. other type		0	0	0		1	0	0	-1		0	0	0	0		-3	-1	1	3		-2	0	2		1	0	-1
25. PEM Fuel Cells																											
0.20 A. mass consu		0	0	0		1	0	0	-1		2	0	0	-2		-2	0	0	2		2	0	-2		1	0	-1
0.35 B. delivery f		0	0	0		0	1	1	0		1	1	0	-1		-1	1	0	1		1	1	-1		0	1	0
0.45 C. *special v		0	0	0		-1	0	0	1		-2	0	0	2		2	0	0	-2		-2	0	2		-1	0	1
26. Prevailing PEM																											
0.10 A. grid paral		0	0	0		2	-1	-1	-2		2	0	0	-2		-2	-1	1	2		1	0	-1		1	0	-1
0.40 B. back up an		0	0	0		1	2	1	-1		1	1	0	-1		-1	1	1	1		0	1	0		0	1	0

Occurrence	8. PEM Fuel Cell M	0.30 A. mass produ	0.45 B. semi-autom	0.25 C. *extensive	9. PEM Fuel Cell T	0.15 A. system-wid	0.35 B. advances i	0.40 C. *advances	0.10 D. *slow, inc	10. Hydrogen Fuel	0.10 A. hydrogen o	0.45 B. hydrogen f	0.30 C. hydrogen p	0.15 D. *compresse	11. Fossil Fuel an	0.15 A. virtually	0.30 B. virtually	0.35 C. improved g	0.20 D. *little ch	12. Electric Stora	0.20 A. greatly im	0.45 B. moderately	0.35 C. *marginall	13. Environmental	0.15 A. virtually	0.45 B. lower emis	0.40 C. *little ch
0.30 C. primarily		0	0	0		-1	-1	1	1		-1	0	1	1		1	1	2	-1		0	1	0		0	1	1
0.20 D. *isolated,		0	0	0		-2	1	1	2		-2	0	0	2		2	1	-1	-2		-1	0	1		-1	0	1
27. Prevailing PEM																											
0.35 A. institutio		-1	0	1		-2	0	0	2		-2	0	0	2		1	0	0	-1		0	0	0		0	0	0
0.45 B. commercial		0	1	0		-1	1	1	1		-1	1	0	1		0	1	1	0		0	0	0		0	0	0
0.20 C. residentia		1	0	-1		2	0	0	-2		2	0	0	-2		-1	0	0	1		0	0	0		0	0	0
28. PEM Fuel Cell																											
0.25 A. high (>$8		0	0	0		0	0	0	0		0	0	0	0		-3	-1	1	3		0	0	0		2	0	-2
0.45 B. medium ($5		0	0	0		0	0	0	0		0	0	0	0		-1	-1	1	1		0	0	0		1	1	-1
0.30 C. low (<$5 b		0	0	0		0	0	0	0		0	0	0	0		3	1	-1	-3		0	0	0		-2	0	2
Sum of Values		-1	7	1		0	10	8	0		3	10	4	-3		1	12	8	-1		4	11	-4		-1	21	2
Non-Zero Entries		19	11	19		44	26	26	44		37	14	6	37		39	24	21	39		24	15	24		51	24	52

Occurrence	14. Codes and Stan	0.30 A. comprehens	0.50 B. *less than	0.20 C. major gaps	15. Public Policy	0.10 A. Fed and st	0.40 B. subsidies,	0.30 C. tax breaks	0.20 D. *just supp	16. National Energ	0.25 A. policies d	0.35 B. policies d	0.40 C. *passive t	17. Electrical Gri	0.35 A. high relia	0.45 B. *high reli	0.20 C. inconsiste	18. Role of Distri	0.20 A. DG integra	0.50 B. DG combina	0.30 C. *DG primar	19. Grid Electrici	0.15 A. very high	0.30 B. high (11-1	0.35 C. medium (7-	0.20 D. *low (<7 c	20. Integrated PEM	0.35 A. high (>20	0.40 B. *medium (1	0.25 C. low (<10 c
1. Retail Price of																														
0.15 A. *>3,000 pe		0	0	0		2	-1	-1	-2		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 B. $2,000-$3,		0	0	0		1	2	1	-1		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 C. $1,000-$2,		0	0	0		-1	1	1	1		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 D. <$1,000 pe		0	0	0		-2	1	1	2		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
2. Prevailing Syst																														
0.30 A. fully inte		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. *stack wit		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 C. stack with		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
3. Retail Price of																														
0.20 A. high (>$1,		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 B. medium ($5		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 C. low (<$500		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
4. PEM Fuel Cell S																														
0.35 A. difficult		-1	0	1		0	0	0	0		0	0	0		0	0	0		2	0	-2		0	0	0	0		0	0	0
0.45 B. mod expens		0	0	0		0	0	0	0		0	0	0		0	0	0		1	1	-1		0	0	0	0		0	0	0
0.20 C. easy and i		1	0	-1		0	0	0	0		0	0	0		0	0	0		-2	0	2		0	0	0	0		0	0	0
5. Consumer Market																														
0.20 A. high tech,		1	0	-1		2	0	0	-2		2	0	-2		0	0	0		2	0	-2		2	0	0	-2		-2	0	2
0.45 B. effective		0	1	0		1	1	1	-1		1	1	-1		0	0	0		1	1	-1		1	1	0	-1		-1	1	1
0.35 C. an electri		-1	0	1		-2	0	0	2		-2	0	2		0	0	0		-2	0	2		-2	0	0	2		2	0	-2
6. Performance Ben																														
0.20 A. exceed cus		1	0	-1		0	0	0	0		0	0	0		0	0	0		1	0	-1		0	0	0	0		0	0	0
0.40 B. consistent		0	1	0		0	0	0	0		0	0	0		0	0	0		0	1	0		0	0	0	0		0	0	0
0.30 C. usually me		0	1	0		0	0	0	0		0	0	0		0	0	0		0	1	0		0	0	0	0		0	0	0
0.10 D. * repeated		-1	0	1		0	0	0	0		0	0	0		0	0	0		-1	0	1		0	0	0	0		0	0	0
7. Stationary and																														
0.25 A. >$2.0 bill		1	0	-1		1	0	0	-1		1	0	-1		0	0	0		0	0	0		1	0	0	-1		-1	0	1
0.45 B. $1.0-$2.0		0	1	0		0	1	1	0		0	1	0		0	0	0		0	0	0		0	1	1	0		0	1	0
0.30 C. *<$1.0 bil		-1	0	1		-1	0	0	1		-1	0	1		0	0	0		0	0	0		-1	0	0	1		1	0	-1
8. PEM Fuel Cell M																														
0.30 A. mass produ		1	0	-1		1	0	0	-1		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. semi-autom		0	1	0		0	1	1	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 C. *extensive		-1	0	1		-1	0	0	1		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
9. PEM Fuel Cell T																														
0.15 A. system-wid		0	0	0		2	1	1	-2		1	0	-1		0	0	0		0	0	0		0	0	0	0		1	0	-1

Occurrence	14. Codes and Stan	0.30 A. comprehens	0.50 B. *less than	0.20 C. major gaps	15. Public Policy	0.10 A. Fed and st	0.40 B. subsidies,	0.30 C. tax breaks	0.20 D. *just supp	16. National Energ	0.25 A. policies d	0.35 B. policies d	0.40 C. *passive t	17. Electrical Gri	0.35 A. high relia	0.45 B. *high reli	0.20 C. inconsiste	18. Role of Distri	0.20 A. DG integra	0.50 B. DG combina	0.30 C. *DG primar	19. Grid Electrici	0.15 A. very high	0.30 B. high (11-1	0.35 C. medium (7-	0.20 D. *low (<7 c	20. Integrated PEM	0.35 A. high (>20	0.40 B. *medium (1	0.25 C. low (<10 c
0.35 B. advances i		0	0	0		1	1	1	-1		0	1	0		0	0	0		0	0	0		0	0	0	0		0	1	0
0.40 C. *advances		0	0	0		-1	-1	2	1		0	1	0		0	0	0		0	0	0		0	0	0	0		0	1	0
0.10 D. *slow, inc		0	0	0		-2	-1	-1	2		-1	0	1		0	0	0		0	0	0		0	0	0	0		-1	0	1
10. Hydrogen Fuel																														
0.10 A. hydrogen o		1	0	-1		2	0	0	-2		2	0	-2		-1	0	1		0	0	0		1	0	0	-1		1	0	-1
0.45 B. hydrogen f		1	1	0		1	2	0	-1		1	2	-1		0	1	0		0	0	0		0	1	0	0		0	1	0
0.30 C. hydrogen p		0	1	0		-1	0	1	1		-1	1	1		0	1	0		0	0	0		0	1	1	0		0	1	0
0.15 D. *compresse		-1	0	1		-2	0	0	2		-2	0	2		1	0	-1		0	0	0		-1	0	0	1		-1	0	1
11. Fossil Fuel an																														
0.15 A. virtually		0	0	0		0	0	0	0		2	0	-2		0	0	0		1	0	-1		0	0	0	0		0	0	0
0.30 B. virtually		0	0	0		0	0	0	0		1	1	-1		0	0	0		0	1	0		0	0	0	0		0	0	0
0.35 C. improved g		0	0	0		0	0	0	0		-1	0	1		0	0	0		0	1	0		0	0	0	0		0	0	0
0.20 D. *little ch		0	0	0		0	0	0	0		-2	0	2		0	0	0		-1	0	1		0	0	0	0		0	0	0
12. Electric Stora																														
0.20 A. greatly im		0	0	0		0	0	0	0		1	0	-1		0	0	0		2	1	-2		2	1	-1	-2		0	0	0
0.45 B. moderately		0	0	0		0	0	0	0		0	1	0		0	0	0		1	1	-1		1	1	-1	-1		0	0	0
0.35 C. *marginall		0	0	0		0	0	0	0		-1	0	1		0	0	0		-2	-1	2		-2	1	1	2		0	0	0
13. Environmental																														
0.15 A. virtually		0	0	0		0	0	0	0		-1	0	1		0	0	0		0	0	0		-1	0	0	1		0	0	0
0.45 B. lower emis		0	0	0		0	0	0	0		0	1	0		0	0	0		0	0	0		0	1	1	0		0	0	0
0.40 C. *little ch		0	0	0		0	0	0	0		1	1	-1		0	0	0		0	0	0		1	0	1	-1		0	0	0
14. Codes and Stan																														
0.30 A. comprehens		*	*	*		2	0	0	-2		2	0	-2		0	0	0		2	0	-2		0	0	0	0		0	0	0
0.50 B. *less than		*	*	*		1	1	0	-1		1	1	-1		0	0	0		1	1	-1		0	0	0	0		0	0	0
0.20 C. major gaps		*	*	*		-2	0	0	2		-2	0	2		0	0	0		-2	0	2		0	0	0	0		0	0	0
15. Public Policy																														
0.10 A. Fed and st		1	0	-1		*	*	*	*		3	1	-3		-1	0	1		2	0	-2		2	1	-1	-2		-2	0	2
0.40 B. subsidies,		0	1	0		*	*	*	*		1	1	-1		0	1	0		1	1	-1		1	1	0	-1		-1	1	1
0.30 C. tax breaks		0	1	0		*	*	*	*		-1	-1	1		0	1	0		-1	1	1		-1	1	1	1		1	1	-1
0.20 D. *just supp		-1	0	1		*	*	*	*		-3	-1	3		1	0	-1		-2	0	2		-2	-1	-1	2		2	0	-2
16. National Energ																														
0.25 A. policies d		0	0	0		0	0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 B. policies d		0	0	0		0	0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.40 C. *passive t		0	0	0		0	0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
17. Electrical Gri																														
0.35 A. high relia		0	0	0		0	0	0	0		0	0	0		*	*	*		3	1	-3		2	1	-1	-2		0	0	0
0.45 B. *high reli		0	0	0		0	0	0	0		0	0	0		*	*	*		1	1	-1		1	1	-1	-1		0	0	0

Occurrence	14. Codes and Stan	0.30 A. comprehens	0.50 B. *less than	0.20 C. major gaps	15. Public Policy	0.10 A. Fed and st	0.40 B. subsidies,	0.30 C. tax breaks	0.20 D. *just supp	16. National Energ	0.25 A. policies d	0.35 B. policies d	0.40 C. *passive t	17. Electrical Gri	0.35 A. high relia	0.45 B. *high reli	0.20 C. inconsiste	18. Role of Distri	0.20 A. DG integra	0.50 B. DG combina	0.30 C. *DG primar	19. Grid Electrici	0.15 A. very high	0.30 B. high (11-1	0.35 C. medium (7-	0.20 D. *low (<7 c	20. Integrated PEM	0.35 A. high (>20	0.40 B. *medium (1	0.25 C. low (<10 c
0.20 C. inconsiste		0	0	0		0	0	0	0		0	0	0		*	*	*		-3	-1	3		-2	-1	1	2		0	0	0
18. Role of Distri																														
0.20 A. DG integra		2	0	-2		0	0	0	0		2	0	-2		-3	-1	3		*	*	*		3	1	-1	-3		0	0	0
0.50 B. DG combina		1	1	-1		0	0	0	0		1	1	-1		-1	2	1		*	*	*		1	1	-1	-1		0	0	0
0.30 C. *DG primar		-2	0	2		0	0	0	0		-2	0	2		3	1	-3		*	*	*		-3	-1	1	3		0	0	0
19. Grid Electrici																														
0.15 A. very high		0	0	0		0	0	0	0		1	0	-1		2	1	-2		-1	0	1		*	*	*	*		0	0	0
0.30 B. high (11-1		0	0	0		0	0	0	0		0	1	0		1	1	-1		0	1	0		*	*	*	*		0	0	0
0.35 C. medium (7-		0	0	0		0	0	0	0		0	1	0		-1	1	1		0	1	0		*	*	*	*		0	0	0
0.20 D. *low (<7 c		0	0	0		0	0	0	0		-1	0	1		-2	-1	2		1	0	-1		*	*	*	*		0	0	0
20. Integrated PEM																														
0.35 A. high (>20		0	0	0		0	0	0	0		0	0	0		0	0	0		2	1	-2		0	0	0	0		*	*	*
0.40 B. *medium (1		0	0	0		0	0	0	0		0	0	0		0	0	0		1	1	-1		0	0	0	0		*	*	*
0.25 C. low (<10 c		0	0	0		0	0	0	0		0	0	0		0	0	0		-2	-1	2		0	0	0	0		*	*	*
21. Price of Hydro																														
0.25 A. high (>2X		0	0	0		0	0	0	0		-1	0	1		0	0	0		0	0	0		0	0	0	0		0	0	0
0.60 B. *medium (1		0	0	0		0	0	0	0		0	1	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.15 C. low (< bas		0	0	0		0	0	0	0		1	0	-1		0	0	0		0	0	0		0	0	0	0		0	0	0
22. PEM Fuel Cell																														
0.20 A. significan		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.50 B. moderate i		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.30 C. *marginal		0	0	0		0	0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
23. Electric Utili																														
0.30 A. less regul		0	0	0		0	0	0	0		-2	0	2		2	0	-2		-1	0	1		2	0	0	-2		0	0	0
0.50 B. about the		0	0	0		0	0	0	0		-1	1	1		1	1	-1		0	1	0		1	1	1	-1		0	0	0
0.20 C. more regul		0	0	0		0	0	0	0		2	0	-2		-2	0	2		1	0	-1		-2	0	0	2		0	0	0
24. Competition to																														
0.35 A. the grid i		0	0	0		1	0	0	-1		0	0	0		3	1	-3		1	0	-1		-3	-1	1	3		2	0	-2
0.40 B. advanced I		0	0	0		0	1	0	0		0	0	0		1	1	-1		0	0	0		-1	-1	1	1		1	1	-1
0.25 C. other type		0	0	0		-1	0	0	1		0	0	0		-3	-1	3		-1	0	1		3	1	-1	-3		-2	0	2
25. PEM Fuel Cells																														
0.20 A. mass consu		1	0	-1		1	0	0	-1		2	1	-2		0	0	0		0	0	0		0	0	0	0		-2	0	2
0.35 B. delivery f		0	1	0		0	1	1	0		1	1	-1		0	0	0		0	0	0		0	0	0	0		-1	1	1
0.45 C. *special v		-1	0	1		-1	0	0	1		-2	-1	2		0	0	0		0	0	0		0	0	0	0		2	0	-2
26. Prevailing PEM																														
0.10 A. grid paral		1	0	-1		1	0	0	-1		2	1	-2		-2	0	2		2	-1	-2		0	0	0	0		-2	0	2
0.40 B. back up an		0	1	0		0	1	0	0		1	2	-1		-1	1	1		1	2	-1		0	0	0	0		-1	2	1

Occurrence	14. Codes and Stan	0.30 A. comprehens	0.50 B. *less than	0.20 C. major gaps	15. Public Policy	0.10 A. Fed and st	0.40 B. subsidies,	0.30 C. tax breaks	0.20 D. *just supp	16. National Energ	0.25 A. policies d	0.35 B. policies d	0.40 C. *passive t	17. Electrical Gri	0.35 A. high relia	0.45 B. *high reli	0.20 C. inconsiste	18. Role of Distri	0.20 A. DG integra	0.50 B. DG combina	0.30 C. *DG primar	19. Grid Electrici	0.15 A. very high	0.30 B. high (11-1	0.35 C. medium (7-	0.20 D. *low (<7 c	20. Integrated PEM	0.35 A. high (>20	0.40 B. *medium (1	0.25 C. low (<10 c
0.30 C. primarily		0	1	0		0	0	1	0		-1	-1	1		1	1	-1		-1	1	1		0	0	0	0		1	1	-1
0.20 D. *isolated,		-1	0	1		-1	0	0	1		-2	-1	2		2	0	-2		-2	1	2		0	0	0	0		2	0	-2
27. Prevailing PEM																														
0.35 A. institutio		0	0	0		1	0	0	-1		0	0	0		0	0	0		2	0	-2		0	0	0	0		2	0	-2
0.45 B. commercial		0	0	0		0	1	1	0		0	0	0		0	0	0		1	1	-1		0	0	0	0		1	1	-1
0.20 C. residentia		0	0	0		-1	0	0	1		0	0	0		0	0	0		-2	0	2		0	0	0	0		-2	0	2
28. PEM Fuel Cell																														
0.25 A. high (>$8		2	0	-2		3	1	-1	-3		1	0	-1		0	0	0		1	0	-1		0	0	0	0		-2	1	2
0.45 B. medium ($5		1	1	-1		1	1	-1	-1		0	1	0		0	0	0		0	1	0		0	0	0	0		-1	1	1
0.30 C. low (<$5 b		-2	0	2		-3	-1	1	3		-1	0	1		0	0	0		-1	0	1		0	0	0	0		2	0	-2
Sum of Values		3	14	-2		3	14	11	-3		3	20	-3		1	12	-1		7	20	-7		4	12	2	-4		-1	16	1
Non-Zero Entries		25	14	24		33	20	18	33		45	28	45		21	17	21		41	27	41		28	22	20	28		29	15	29

Occurrence	21. Price of Hydro	0.25 A. high (>2X	0.60 B. *medium (1	0.15 C. low (< bas	22. PEM Fuel Cell	0.20 A. significan	0.50 B. moderate i	0.30 C. *marginal	23. Electric Utili	0.30 A. less regul	0.50 B. about the	0.20 C. more regul	24. Competition to	0.35 A. the grid i	0.40 B. advanced I	0.25 C. other type	25. PEM Fuel Cells	0.20 A. mass consu	0.35 B. delivery f	0.45 C. *special v	26. Prevailing PEM	0.10 A. grid paral	0.40 B. back up an	0.30 C. primarily	0.20 D. *isolated,	27. Prevailing PEM	0.35 A. institutio	0.45 B. commercial	0.20 C. residentia
1. Retail Price of																													
0.15 A. *>3,000 pe		0	0	0		1	0	-1		0	0	0		-1	0	1		2	-1	-2		-3	-1	1	3		0	0	0
0.25 B. $2,000-$3,		0	0	0		0	1	0		0	0	0		0	1	0		1	-1	-1		-1	-1	1	1		0	0	0
0.35 C. $1,000-$2,		0	0	0		0	0	0		0	0	0		0	0	0		-1	1	1		1	2	-1	-1		0	0	0
0.25 D. <$1,000 pe		0	0	0		-1	0	1		0	0	0		1	0	-1		-2	1	2		3	1	-1	-3		0	0	0
2. Prevailing Syst																													
0.30 A. fully inte		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. *stack wit		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.25 C. stack with		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
3. Retail Price of																													
0.20 A. high (>$1,		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 B. medium ($5		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 C. low (<$500		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
4. PEM Fuel Cell S																													
0.35 A. difficult		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. mod expens		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 C. easy and i		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
5. Consumer Market																													
0.20 A. high tech,		2	0	-2		1	0	-1		0	0	0		0	0	0		2	0	-2		0	0	0	0		-2	0	2
0.45 B. effective		1	1	-1		0	1	0		0	0	0		0	0	0		1	1	-1		0	0	0	0		-1	1	1
0.35 C. an electri		-2	0	2		-1	0	1		0	0	0		0	0	0		-2	0	2		0	0	0	0		2	0	-2
6. Performance Ben																													
0.20 A. exceed cus		0	0	0		1	0	-1		0	0	0		1	0	-1		1	0	-1		1	0	0	-1		0	0	0
0.40 B. consistent		0	0	0		0	1	0		0	0	0		0	1	0		0	1	0		0	1	0	0		0	0	0
0.30 C. usually me		0	0	0		0	1	0		0	0	0		0	1	0		0	1	0		0	0	1	0		0	0	0
0.10 D. * repeated		0	0	0		-1	0	1		0	0	0		-1	0	1		-1	0	1		-1	0	0	1		0	0	0
7. Stationary and																													
0.25 A. >$2.0 bill		1	0	-1		1	0	-1		1	0	-1		0	0	0		1	0	-1		1	0	0	-1		0	0	0
0.45 B. $1.0-$2.0		0	1	0		0	1	0		0	1	0		0	0	0		0	1	0		0	1	1	0		0	0	0
0.30 C. *<$1.0 bil		-1	0	1		-1	0	1		-1	0	1		0	0	0		-1	0	1		-1	0	0	1		0	0	0
8. PEM Fuel Cell M																													
0.30 A. mass produ		0	0	0		1	0	-1		0	0	0		0	0	0		1	0	-1		0	0	0	0		0	0	0
0.45 B. semi-autom		0	0	0		0	1	0		0	0	0		0	0	0		0	1	0		0	0	0	0		0	0	0
0.25 C. *extensive		0	0	0		-1	0	1		0	0	0		0	0	0		-1	0	1		0	0	0	0		0	0	0
9. PEM Fuel Cell T																													
0.15 A. system-wid		0	0	0		1	0	-1		0	0	0		0	0	0		0	0	0		1	0	0	-1		0	0	0

Occurrence	21. Price of Hydro	0.25 A. high (>2X	0.60 B. *medium (1	0.15 C. low (< bas	22. PEM Fuel Cell	0.20 A. significan	0.50 B. moderate i	0.30 C. *marginal	23. Electric Utili	0.30 A. less regul	0.50 B. about the	0.20 C. more regul	24. Competition to	0.35 A. the grid i	0.40 B. advanced I	0.25 C. other type	25. PEM Fuel Cells	0.20 A. mass consu	0.35 B. delivery f	0.45 C. *special v	26. Prevailing PEM	0.10 A. grid paral	0.40 B. back up an	0.30 C. primarily	0.20 D. *isolated,	27. Prevailing PEM	0.35 A. institutio	0.45 B. commercial	0.20 C. residentia
0.35 B. advances i		0	0	0		0	1	0		0	0	0		0	0	0		0	0	0		0	1	0	0		0	0	0
0.40 C. *advances		0	0	0		0	1	0		0	0	0		0	0	0		0	0	0		0	0	1	0		0	0	0
0.10 D. *slow, inc		0	0	0		-1	0	1		0	0	0		0	0	0		0	0	0		-1	0	0	1		0	0	0
10. Hydrogen Fuel																													
0.10 A. hydrogen o		2	0	-2		1	0	-1		0	0	0		0	0	0		2	0	-2		2	0	0	-2		0	0	0
0.45 B. hydrogen f		1	2	-1		0	1	0		0	0	0		0	0	0		1	2	-1		1	2	0	-1		0	0	0
0.30 C. hydrogen p		-1	1	1		0	1	0		0	0	0		0	0	0		-1	1	1		-1	0	1	1		0	0	0
0.15 D. *compresse		-2	0	2		-1	0	1		0	0	0		0	0	0		-2	0	2		-2	0	0	2		0	0	0
11. Fossil Fuel an																													
0.15 A. virtually		2	0	-2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.30 B. virtually		1	1	-1		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.35 C. improved g		-1	1	1		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 D. *little ch		-2	0	2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0	0		0	0	0
12. Electric Stora																													
0.20 A. greatly im		0	0	0		1	0	-1		0	0	0		0	0	0		0	0	0		1	0	0	-1		0	0	0
0.45 B. moderately		0	0	0		0	1	0		0	0	0		0	0	0		0	0	0		0	1	1	0		0	0	0
0.35 C. *marginall		0	0	0		-1	0	1		0	0	0		0	0	0		0	0	0		-1	0	0	1		0	0	0
13. Environmental																													
0.15 A. virtually		-2	0	2		0	0	0		0	0	0		0	0	0		0	0	0		1	0	0	-1		1	0	-1
0.45 B. lower emis		-1	1	1		0	0	0		0	0	0		0	0	0		0	0	0		0	1	1	0		0	1	0
0.40 C. *little ch		2	1	-2		0	0	0		0	0	0		0	0	0		0	0	0		-1	0	1	1		-1	0	1
14. Codes and Stan																													
0.30 A. comprehens		0	0	0		1	0	-1		0	0	0		0	0	0		1	0	-1		0	0	0	0		0	0	0
0.50 B. *less than		0	0	0		0	1	0		0	0	0		0	0	0		0	1	0		0	0	0	0		0	0	0
0.20 C. major gaps		0	0	0		-1	0	1		0	0	0		0	0	0		-1	0	1		0	0	0	0		0	0	0
15. Public Policy																													
0.10 A. Fed and st		1	0	-1		0	0	0		0	0	0		1	0	-1		1	0	-1		1	0	0	-1		0	0	0
0.40 B. subsidies,		0	1	0		0	0	0		0	0	0		0	0	0		0	1	0		0	1	0	0		0	0	0
0.30 C. tax breaks		0	1	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	1	0		0	0	0
0.20 D. *just supp		-1	0	1		0	0	0		0	0	0		-1	0	1		-1	0	1		-1	0	0	1		0	0	0
16. National Energ																													
0.25 A. policies d		2	0	-2		0	0	0		0	0	0		0	0	0		1	0	-1		1	0	0	-1		0	0	0
0.35 B. policies d		1	1	-1		0	0	0		0	0	0		0	0	0		0	1	0		0	1	0	0		0	0	0
0.40 C. *passive t		-2	0	2		0	0	0		0	0	0		0	0	0		-1	0	1		-1	0	0	1		0	0	0
17. Electrical Gri																													
0.35 A. high relia		0	0	0		0	0	0		-1	0	1		0	0	0		0	0	0		0	0	0	0		0	0	0
0.45 B. *high reli		0	0	0		0	0	0		0	1	0		0	0	0		0	0	0		0	0	0	0		0	0	0

Occurrence	21. Price of Hydro	0.25 A. high (>2X	0.60 B. *medium (1	0.15 C. low (< bas	22. PEM Fuel Cell	0.20 A. significan	0.50 B. moderate i	0.30 C. *marginal	23. Electric Utili	0.30 A. less regul	0.50 B. about the	0.20 C. more regul	24. Competition to	0.35 A. the grid i	0.40 B. advanced I	0.25 C. other type	25. PEM Fuel Cells	0.20 A. mass consu	0.35 B. delivery f	0.45 C. *special v	26. Prevailing PEM	0.10 A. grid paral	0.40 B. back up an	0.30 C. primarily	0.20 D. *isolated,	27. Prevailing PEM	0.35 A. institutio	0.45 B. commercial	0.20 C. residentia
0.20 C. inconsiste		0	0	0		0	0	0		1	0	-1		0	0	0		0	0	0		0	0	0	0		0	0	0
18. Role of Distri																													
0.20 A. DG integra		0	0	0		1	0	-1		1	0	-1		0	0	0		-1	0	1		2	0	0	-2		2	0	-2
0.50 B. DG combina		0	0	0		0	1	0		0	1	0		0	0	0		0	1	0		1	1	0	-1		1	1	-1
0.30 C. *DG primar		0	0	0		-1	0	1		-1	0	1		0	0	0		1	0	-1		-2	0	0	2		-2	0	2
19. Grid Electrici																													
0.15 A. very high		1	0	-1		0	0	0		-1	0	1		0	0	0		0	0	0		-1	0	0	1		0	0	0
0.30 B. high (11-1		0	1	0		0	0	0		0	1	0		0	0	0		0	0	0		0	1	0	0		0	0	0
0.35 C. medium (7-		0	1	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	1	0		0	0	0
0.20 D. *low (<7 c		-1	0	1		0	0	0		1	0	-1		0	0	0		0	0	0		1	0	0	-1		0	0	0
20. Integrated PEM																													
0.35 A. high (>20		2	0	-2		-1	0	1		0	0	0		-1	0	1		1	0	-1		1	0	0	-1		0	0	0
0.40 B. *medium (1		1	1	-1		0	1	0		0	0	0		0	1	0		0	1	0		0	1	1	0		0	0	0
0.25 C. low (<10 c		-2	0	2		1	0	-1		0	0	0		1	0	-1		-1	0	1		-1	0	0	1		0	0	0
21. Price of Hydro																													
0.25 A. high (>2X		*	*	*		-1	0	1		0	0	0		0	0	0		-2	0	2		0	0	0	0		0	0	0
0.60 B. *medium (1		*	*	*		0	1	0		0	0	0		0	0	0		-1	1	1		0	0	0	0		0	0	0
0.15 C. low (< bas		*	*	*		1	0	-1		0	0	0		0	0	0		2	0	-2		0	0	0	0		0	0	0
22. PEM Fuel Cell																													
0.20 A. significan		0	0	0		*	*	*		0	0	0		0	0	0		1	0	-1		0	0	0	0		0	0	0
0.50 B. moderate i		0	0	0		*	*	*		0	0	0		0	0	0		0	1	0		0	0	0	0		0	0	0
0.30 C. *marginal		0	0	0		*	*	*		0	0	0		0	0	0		-1	0	1		0	0	0	0		0	0	0
23. Electric Utili																													
0.30 A. less regul		0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.50 B. about the		0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
0.20 C. more regul		0	0	0		0	0	0		*	*	*		0	0	0		0	0	0		0	0	0	0		0	0	0
24. Competition to																													
0.35 A. the grid i		0	0	0		0	0	0		0	0	0		*	*	*		0	0	0		3	1	-1	-3		0	0	0
0.40 B. advanced I		0	0	0		0	0	0		0	0	0		*	*	*		0	0	0		1	1	-1	-1		0	0	0
0.25 C. other type		0	0	0		0	0	0		0	0	0		*	*	*		0	0	0		-3	-1	1	3		0	0	0
25. PEM Fuel Cells																													
0.20 A. mass consu		2	0	-2		2	0	-2		0	0	0		0	0	0		*	*	*		0	0	0	0		-2	0	2
0.35 B. delivery f		1	1	-1		1	1	-1		0	0	0		0	0	0		*	*	*		0	0	0	0		-1	1	1
0.45 C. *special v		-2	0	2		-2	0	2		0	0	0		0	0	0		*	*	*		0	0	0	0		2	0	-2
26. Prevailing PEM																													
0.10 A. grid paral		2	0	-2		2	-1	-2		0	0	0		-2	0	2		0	0	0		*	*	*	*		0	0	0
0.40 B. back up an		1	2	-1		1	-1	-1		0	0	0		-1	1	1		0	0	0		*	*	*	*		0	0	0

Occurrence	21. Price of Hydro	0.25 A. high (>2X	0.60 B. *medium (1	0.15 C. low (< bas	22. PEM Fuel Cell	0.20 A. significan	0.50 B. moderate i	0.30 C. *marginal	23. Electric Utili	0.30 A. less regul	0.50 B. about the	0.20 C. more regul	24. Competition to	0.35 A. the grid i	0.40 B. advanced I	0.25 C. other type	25. PEM Fuel Cells	0.20 A. mass consu	0.35 B. delivery f	0.45 C. *special v	26. Prevailing PEM	0.10 A. grid paral	0.40 B. back up an	0.30 C. primarily	0.20 D. *isolated,	27. Prevailing PEM	0.35 A. institutio	0.45 B. commercial	0.20 C. residentia
0.30 C. primarily		-1	1	1		-1	1	1		0	0	0		1	1	-1		0	0	0		*	*	*	*		0	0	0
0.20 D. *isolated,		-2	0	2		-2	1	2		0	0	0		2	0	-2		0	0	0		*	*	*	*		0	0	0
27. Prevailing PEM																													
0.35 A. institution		0	0	0		2	-1	-2		0	0	0		0	0	0		-2	0	2		0	0	0	0		*	*	*
0.45 B. commercial		0	0	0		1	1	-1		0	0	0		0	0	0		-1	1	1		0	0	0	0		*	*	*
0.20 C. residential		0	0	0		-2	0	2		0	0	0		0	0	0		2	0	-2		0	0	0	0		*	*	*
28. PEM Fuel Cell																													
0.25 A. high (>$8		0	0	0		0	0	0		0	0	0		-3	-1	3		1	0	-1		2	0	0	-2		-2	0	2
0.45 B. medium ($5		0	0	0		0	0	0		0	0	0		-1	1	1		0	1	0		1	1	1	-1		-1	1	1
0.30 C. low (<$5 b		0	0	0		0	0	0		0	0	0		3	1	-3		-1	0	1		-2	0	0	2		2	0	-2
Sum of Values		3	19	-3		2	16	-2		0	4	0		-1	7	1		-1	17	1		3	15	10	-3		-2	5	2
Non-Zero Entries		33	17	33		34	22	34		8	4	8		15	9	15		37	20	37		35	19	18	35		14	5	14

Occurrence	28. PEM Fuel Cell	0.25 A. high (>$8	0.45 B. medium ($5	0.30 C. low (<$5 b	Sum of Values	Non-Zero Entries
1. Retail Price of						
0.15 A. *>3,000 pe		-2	0	2	-4	30
0.25 B. $2,000-$3,		-1	1	1	6	27
0.35 C. $1,000-$2,		1	0	-1	8	23
0.25 D. <$1,000 pe		2	0	-2	4	30
2. Prevailing Syst						
0.30 A. fully inte		0	0	0	0	10
0.45 B. *stack wit		0	0	0	2	6
0.25 C. stack with		0	0	0	0	10
3. Retail Price of						
0.20 A. high (>$1,		1	0	-1	0	4
0.35 B. medium ($5		0	1	0	2	2
0.45 C. low (<$500		-1	0	1	0	4
4. PEM Fuel Cell S						
0.35 A. difficult		0	0	0	-1	15
0.45 B. mod expens		0	0	0	3	11
0.20 C. easy and i		0	0	0	1	15
5. Consumer Market						
0.20 A. high tech,		2	0	-2	0	42
0.45 B. effective		1	1	-1	19	49
0.35 C. an electri		-2	0	2	0	42
6. Performance Ben						
0.20 A. exceed cus		0	0	0	0	28
0.40 B. consistent		0	0	0	12	22
0.30 C. usually me		0	0	0	10	22
0.10 D. * repeated		0	0	0	0	28
7. Stationary and						
0.25 A. >$2.0 bill		2	0	-2	-2	40
0.45 B. $1.0-$2.0		1	1	-1	22	33
0.30 C. *<$1.0 bil		-2	0	2	2	40
8. PEM Fuel Cell M						
0.30 A. mass produ		0	0	0	0	14
0.45 B. semi-autom		0	0	0	9	11
0.25 C. *extensive		0	0	0	0	14
9. PEM Fuel Cell T						
0.15 A. system-wid		0	0	0	3	23
0.35 B. advances i		0	0	0	12	17
0.40 C. *advances		0	0	0	8	17
0.10 D. *slow, inc		0	0	0	-3	23
10. Hydrogen Fuel						
0.10 A. hydrogen o		0	0	0	0	26
0.45 B. hydrogen f		0	0	0	22	29
0.30 C. hydrogen p		0	0	0	14	28
0.15 D. *compresse		0	0	0	0	26
11. Fossil Fuel an						
0.15 A. virtually		0	0	0	0	8
0.30 B. virtually		0	0	0	4	10
0.35 C. improved g		0	0	0	2	8
0.20 D. *little ch		0	0	0	0	8
12. Electric Stora						
0.20 A. greatly im		0	0	0	1	15
0.45 B. moderately		0	0	0	6	12
0.35 C. *marginall		0	0	0	1	15
13. Environmental						
0.15 A. virtually		0	0	0	0	12
0.45 B. lower emis		0	0	0	8	10
0.40 C. *little ch		0	0	0	5	17
14. Codes and Stan						
0.30 A. comprehens		1	0	-1	0	22

Occurrence	28. PEM Fuel Cell	0.25 A. high (>$8	0.45 B. medium ($5	0.30 C. low (<$5 b	Sum of Values	Non-Zero Entries
0.50 B. *less than		0	1	0	12	20
0.20 C. major gaps		-1	0	1	0	22
15. Public Policy						
0.10 A. Fed and st		0	0	0	-1	39
0.40 B. subsidies,		0	0	0	14	34
0.30 C. tax breaks		0	0	0	12	34
0.20 D. *just supp		0	0	0	-1	39
16. National Energ						
0.25 A. policies d		1	0	-1	0	18
0.35 B. policies d		0	1	0	11	17
0.40 C. *passive t		-1	0	1	1	19
17. Electrical Gri						
0.35 A. high relia		0	0	0	1	17
0.45 B. *high reli		0	0	0	6	18
0.20 C. inconsiste		0	0	0	-2	16
18. Role of Distri						
0.20 A. DG integra		0	0	0	0	30
0.50 B. DG combina		0	0	0	14	33
0.30 C. *DG primar		0	0	0	0	30
19. Grid Electrici						
0.15 A. very high		0	0	0	2	22
0.30 B. high (11-1		0	0	0	9	18
0.35 C. medium (7-		0	0	0	6	16
0.20 D. *low (<7 c		0	0	0	-2	22
20. Integrated PEM						
0.35 A. high (>20		0	0	0	1	27
0.40 B. *medium (1		0	0	0	11	23
0.25 C. low (<10 c		0	0	0	0	28
21. Price of Hydro						
0.25 A. high (>2X		0	0	0	0	12
0.60 B. *medium (1		0	0	0	7	13
0.15 C. low (< bas		0	0	0	0	12
22. PEM Fuel Cell						
0.20 A. significan		0	0	0	0	6
0.50 B. moderate i		0	0	0	4	4
0.30 C. *marginal		0	0	0	0	6
23. Electric Utili						
0.30 A. less regul		0	0	0	0	10
0.50 B. about the		0	0	0	6	14
0.20 C. more regul		0	0	0	0	10
24. Competition to						
0.35 A. the grid i		0	0	0	1	37
0.40 B. advanced I		0	0	0	7	35
0.25 C. other type		0	0	0	-1	37
25. PEM Fuel Cells						
0.20 A. mass consu		0	0	0	-3	35
0.35 B. delivery f		0	0	0	16	39
0.45 C. *special v		0	0	0	3	35
26. Prevailing PEM						
0.10 A. grid paral		0	0	0	-4	48
0.40 B. back up an		0	0	0	21	48
0.30 C. primarily		0	0	0	18	49
0.20 D. *isolated,		0	0	0	3	47
27. Prevailing PEM						
0.35 A. institutio		0	0	0	-2	28
0.45 B. commercial		0	0	0	16	34
0.20 C. residentia		0	0	0	1	27
28. PEM Fuel Cell						
0.25 A. high (>$8		*	*	*	2	40
0.45 B. medium ($5		*	*	*	16	42

Occurrence	28. PEM Fuel Cell	0.25 A. high (>$8	0.45 B. medium ($5	0.30 C. low (<$5 b	Sum of Values	Non-Zero Entries
0.30 C. low (<$5 b		*	*	*	0	38
Sum of Values		2	6	-2		
Non-Zero Entries		16	6	16		

APPENDIX G: SCENARIO RESULTS (FROM IFS)

Multiple Scenario Results (Original Algorithm)

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
1. Retail Price of PEM F																			
A. *>3,000 per kW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	3	0.02
B. $2,000-$3,000 per kW	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0.25	84	0.46
C. $1,000-$2,000 per kW	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0.35	79	0.43
D. <$1,000 per kW	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.25	18	0.10
2. Prevailing System Arc																			
A. fully integrated fuel cell (inc. fuel handling)	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.30	35	0.19
B. *stack with controls/power electronics and peripherals	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.45	74	0.40
C. stack with controls, assembly required	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.25	75	0.41
3. Retail Price of PEM F																			
A. high (>$1,500 per kW average)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	1	0.01
B. medium ($500 - $1,500 per kW average)	0	1	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.35	94	0.51
C. low (<$500 per kW average.)	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.45	89	0.48
4. PEM Fuel Cell System																			
A. difficult and expensive by professional installers	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.35	75	0.41
B. mod expensive by local contractors	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0.45	39	0.21
C. easy and inexpensive: plug-n-play	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0.20	70	0.38
5. Consumer Market																			

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
Image																			
A. high tech, high gloss, "best thing since sliced bread"	0	1	1	0	0	0	0	1	1	0	0	0	1	0	0	1	0.20	70	0.38
B. effective electricity and heat appliance with green appeal	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0.45	40	0.22
C. an electric generator	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.35	74	0.40
6. Performance Benefits																			
A. exceed customers' expectations on several parameters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	8	0.04
B. consistently meet expectations	0	1	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.40	99	0.54
C. usually meet expectations but w/exceptions	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0.30	22	0.12
D. * repeatedly fail to meet expectations s	1	0	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0.10	55	0.30
7. Stationary and Mobile																			
A. >$2.0 billion average annual (>2X base 2004)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	27	0.15
B. $1.0-$2.0 billion average annual (1-2X base 2004)	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.45	81	0.44
C. *<$1.0 billion (base 2004 or less)	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.30	76	0.41
8. PEM Fuel Cell Manufac																			
A. mass produced, quality controlled	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.30	34	0.18
B. semi-automated assembly	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.45	74	0.40

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
C. *extensive handling of materials	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.25	76	0.41
9. PEM Fuel Cell Technic																			
A. system-wide innovations and optimization	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0.15	60	0.33
B. advances in stack fuel handling, materials, and controls	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0.35	28	0.15
C. *advances primarily in materials and controls	1	0	0	1	0	1	0	0	1	1	0	0	0	0	1	0	0.40	68	0.37
D. *slow, incremental, piece-by-piece improvements	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0.10	28	0.15
10. Hydrogen Fuel for PE																			
A. hydrogen or hydrogen-rich fuels as commodities	0	1	1	0	0	0	0	0	1	0	1	0	1	0	0	1	0.10	60	0.33
B. hydrogen from hydrocarbon fuels requiring fuel processors	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0.45	46	0.25
C. hydrogen produced at or near point of PEM fuel cell use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.30	4	0.02
D. *compressed, tanks and canisters	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.15	74	0.40
11. Fossil Fuel and Engi																			
A. virtually clean, highly efficient fuels and engines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	3	0.02
B. virtually clean, more efficient fuels and engines	0	1	1	0	0	0	0	1	1	0	1	1	1	0	0	1	0.30	93	0.51
C. improved gasoline and diesel	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0.35	24	0.13

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
efficiency/emissions																			
D. *little change from 2003	1	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0.20	64	0.35
12. Electric Storage Tec																			
A. greatly improved capabilities	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	15	0.08
B. moderately improved capabilities	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.45	96	0.52
C. *marginally improved capabilities	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.35	73	0.40
13. Environmental Regula																			
A. virtually zero emissions with mandated carbon mag't	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	1	0.01
B. lower emissions with voluntary carbon mag't	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.45	168	0.91
C. *little change from 2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.40	15	0.08
14. Codes and Standards																			
A. comprehensive and aligned with products/technologies	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.30	54	0.29
B. *less than comprehensive and somewhat aligned	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.50	55	0.30
C. major gaps and not aligned	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.20	75	0.41
15. Public Policy Suppor																			
A. Fed and state gov'ts as customers and lead users	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.10	37	0.20
B. subsidies, credits,	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.40	68	0.37

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
tax breaks, and other incentives																			
C. tax breaks for PEM fuel cell purchases	1	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	0.30	54	0.29
D. *just support of PEM fuel cell R&D	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0.20	25	0.14
16. National Energy Poli																			
A. policies driven by goals of sufficiency and security	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0.25	40	0.22
B. policies driven largely by security concerns	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0.35	67	0.36
C. *passive to free market and deregulation	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.40	77	0.42
17. Electrical Grid Reli																			
A. high reliability and quality for base and peak loads	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	24	0.13
B. *high reliability and quality w/exceptions (peak loads)	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.45	92	0.50
C. inconsistent for base as well as peak loads	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.20	68	0.37
18. Role of Distributed																			
A. DG integrated with grid in an extended power network	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	3	0.02
B. DG combination of customer and utility	0	1	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0.50	107	0.58
C. *DG primarily customer driven	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.30	74	0.40
19. Grid Electricity Pri																			

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
A. very high (>15 cents kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	3	0.02
B. high (11-15 cents kWh)	1	1	0	1	1	1	1	1	0	1	1	1	0	1	0	1	0.30	121	0.66
C. medium (7-10 cents kWh)	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0	0.35	59	0.32
D. *low (<7 cents kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	1	0.01
20. Integrated PEM Fuel																			
A. high (>20 cents/kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	1	0.01
B. *medium (10-20 cents/kWh)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.40	177	0.96
C. low (<10 cents/kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	6	0.03
21. Price of Hydrocarbon																			
A. high (>2X base 2004 prices)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	3	0.02
B. *medium (1-2X base 2004 prices)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.60	179	0.97
C. low (< base 2004 prices)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	2	0.01
22. PEM Fuel Cell Statio																			
A. significant impact on the U.S.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	4	0.02
B. moderate impact on the U.S.	0	1	1	0	0	1	0	1	1	1	1	1	1	1	0	1	0.50	126	0.68
C. *marginal impact on the U.S.	1	0	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0.30	54	0.29
23. Electric Utility Ind																			
A. less regulated, less vertical, more enterprising than today	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.30	11	0.06

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
B. about the same as today	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.50	170	0.92
C. more regulated, more vertical, less enterprising than today	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	3	0.02
24. Competition to PEM F																			
A. the grid is the primary competition to PEM fuel cells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	2	0.01
B. advanced IC engines and renewable	1	1	1	0	1	1	0	1	1	0	1	1	0	0	1	1	0.40	138	0.75
C. other types of fuel cells	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0.25	44	0.24
25. PEM Fuel Cells in Au																			
A. mass consumer appeal (auto, motorcycle, or scooter)	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.20	37	0.20
B. delivery fleets	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.35	68	0.37
C. *special vehciles (military, off road, carts, etc.)	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.45	79	0.43
26. Prevailing PEM Fuel																			
A. grid parallel (any time and CHP with the grid)	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0.10	51	0.28
B. back up and added CHP	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0.40	55	0.30
C. primarily backup	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0.30	15	0.08
D. *isolated, high value power	1	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0.20	63	0.34
27. Prevailing PEM Fuel																			
A. institutional/heavy commercial (>200 kW)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	1	0.01

Scenario Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A Priori	Total	Posterior
Frequency	10	7	6	4	3	3	3	3	3	2	2	2	2	2	2	2	Prob	Occurs	Prob
B. commercial and light industrial (50-200 kW)	1	0	0	1	1	1	1	0	0	1	0	1	0	0	1	0	0.45	89	0.48
C. residential and light commercial (<50 kW)	0	1	1	0	0	0	0	1	1	0	1	0	1	1	0	1	0.20	94	0.51
28. PEM Fuel Cell Market																			
A. high (>$8 billion)	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.25	37	0.20
B. medium ($5-8 billion)	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0.45	73	0.40
C. low (<$5 billion)	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0.30	74	0.40

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
1. Retail Price of PEM F				
A. *>3,000 per kW	0	0.15	3	0.02
B. $2,000-$3,000 per kW	1	0.25	84	0.46
C. $1,000-$2,000 per kW	0	0.35	79	0.43
D. <$1,000 per kW	0	0.25	18	0.10
2. Prevailing System Arc				
A. fully integrated fuel cell (inc. fuel handling)	1	0.30	35	0.19
B. *stack with controls/power electronics and peripherals	0	0.45	74	0.40
C. stack with controls, assembly required	0	0.25	75	0.41
3. Retail Price of PEM F				
A. high (>$1,500 per kW average)	0	0.20	1	0.01
B. medium ($500 - $1,500 per kW average)	1	0.35	94	0.51
C. low (<$500 per kW average.)	0	0.45	89	0.48
4. PEM Fuel Cell System				
A. difficult and expensive by professional installers	0	0.35	75	0.41
B. mod expensive by local contractors	0	0.45	39	0.21
C. easy and inexpensive: plug-n-play	1	0.20	70	0.38
5. Consumer Market Image				
A. high tech, high gloss, "best thing since sliced bread"	1	0.20	70	0.38
B. effective electricity and heat appliance with green appeal	0	0.45	40	0.22
C. an electric generator	0	0.35	74	0.40
6. Performance Benefits				
A. exceed customers' expectations on several parameters	0	0.20	8	0.04
B. consistently meet expectations	1	0.40	99	0.54
C. usually meet expectations but	0	0.30	22	0.12

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
w/exceptions				
D. * repeatedly fail to meet expectations s	0	0.10	55	0.30
7. Stationary and Mobile				
A. >$2.0 billion average annual (>2X base 2004)	1	0.25	27	0.15
B. $1.0-$2.0 billion average annual (1-2X base 2004)	0	0.45	81	0.44
C. *<$1.0 billion (base 2004 or less)	0	0.30	76	0.41
8. PEM Fuel Cell Manufac				
A. mass produced, quality controlled	1	0.30	34	0.18
B. semi-automated assembly	0	0.45	74	0.40
C. *extensive handling of materials	0	0.25	76	0.41
9. PEM Fuel Cell Technic				
A. system-wide innovations and optimization	1	0.15	60	0.33
B. advances in stack fuel handling, materials, and controls	0	0.35	28	0.15
C. *advances primarily in materials and controls	0	0.40	68	0.37
D. *slow, incremental, piece-by-piece improvements	0	0.10	28	0.15
10. Hydrogen Fuel for PE				
A. hydrogen or hydrogen-rich fuels as commodities	1	0.10	60	0.33
B. hydrogen from hydrocarbon fuels requiring fuel processors	0	0.45	46	0.25
C. hydrogen produced at or near point of PEM fuel cell use	0	0.30	4	0.02
D. *compressed, tanks and canisters	0	0.15	74	0.40
11. Fossil Fuel and Engi				
A. virtually clean, highly efficient fuels and engines	0	0.15	3	0.02

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
B. virtually clean, more efficient fuels and engines	1	0.30	93	0.51
C. improved gasoline and diesel efficiency/emissions	0	0.35	24	0.13
D. *little change from 2003	0	0.20	64	0.35
12. Electric Storage Tec				
A. greatly improved capabilities	0	0.20	15	0.08
B. moderately improved capabilities	1	0.45	96	0.52
C. *marginally improved capabilities	0	0.35	73	0.40
13. Environmental Regula				
A. virtually zero emissions with mandated carbon mag't	0	0.15	1	0.01
B. lower emissions with voluntary carbon mag't	1	0.45	168	0.91
C. *little change from 2003	0	0.40	15	0.08
14. Codes and Standards				
A. comprehensive and aligned with products/technologies	1	0.30	54	0.29
B. *less than comprehensive and somewhat aligned	0	0.50	55	0.30
C. major gaps and not aligned	0	0.20	75	0.41
15. Public Policy Suppor				
A. Fed and state gov'ts as customers and lead users	1	0.10	37	0.20
B. subsidies, credits, tax breaks, and other incentives	0	0.40	68	0.37
C. tax breaks for PEM fuel cell purchases	0	0.30	54	0.29
D. *just support of PEM fuel cell R&D	0	0.20	25	0.14
16. National Energy Poli				
A. policies driven by goals of sufficiency and security	0	0.25	40	0.22
B. policies driven	1	0.35	67	0.36

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
largely by security concerns				
C. *passive to free market and deregulation	0	0.40	77	0.42
17. Electrical Grid Reli				
A. high reliability and quality for base and peak loads	1	0.35	24	0.13
B. *high reliability and quality w/exceptions (peak loads)	0	0.45	92	0.50
C. inconsistent for base as well as peak loads	0	0.20	68	0.37
18. Role of Distributed				
A. DG integrated with grid in an extended power network	0	0.20	3	0.02
B. DG combination of customer and utility	1	0.50	107	0.58
C. *DG primarily customer driven	0	0.30	74	0.40
19. Grid Electricity Pri				
A. very high (>15 cents kWh)	0	0.15	3	0.02
B. high (11-15 cents kWh)	1	0.30	121	0.66
C. medium (7-10 cents kWh)	0	0.35	59	0.32
D. *low (<7 cents kWh)	0	0.20	1	0.01
20. Integrated PEM Fuel				
A. high (>20 cents/kWh)	0	0.35	1	0.01
B. *medium (10-20 cents/kWh)	1	0.40	177	0.96
C. low (<10 cents/kWh)	0	0.25	6	0.03
21. Price of Hydrocarbon				
A. high (>2X base 2004 prices)	0	0.25	3	0.02
B. *medium (1-2X base 2004 prices)	1	0.60	179	0.97
C. low (< base 2004 prices)	0	0.15	2	0.01
22. PEM Fuel Cell Statio				
A. significant impact on the U.S.	0	0.20	4	0.02

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
B. moderate impact on the U.S.	1	0.50	126	0.68
C. *marginal impact on the U.S.	0	0.30	54	0.29
23. Electric Utility Ind				
A. less regulated, less vertical, more enterprising than today	0	0.30	11	0.06
B. about the same as today	1	0.50	170	0.92
C. more regulated, more vertical, less enterprising than today	0	0.20	3	0.02
24. Competition to PEM F				
A. the grid is the primary competition to PEM fuel cells	0	0.35	2	0.01
B. advanced IC engines and renewable	1	0.40	138	0.75
C. other types of fuel cells	0	0.25	44	0.24
25. PEM Fuel Cells in Au				
A. mass consumer appeal (auto, motorcycle, or scooter)	1	0.20	37	0.20
B. delivery fleets	0	0.35	68	0.37
C. *special vehciles (military, off road, carts, etc.)	0	0.45	79	0.43
26. Prevailing PEM Fuel				
A. grid parallel (any time and CHP with the grid)	1	0.10	51	0.28
B. back up and added CHP	0	0.40	55	0.30
C. primarily backup	0	0.30	15	0.08
D. *isolated, high value power	0	0.20	63	0.34
27. Prevailing PEM Fuel				
A. institutional/heavy commercial (>200 kW)	0	0.35	1	0.01
B. commercial and light industrial (50-200 kW)	0	0.45	89	0.48
C. residential and light commercial (<50 kW)	1	0.20	94	0.51
28. PEM Fuel Cell Market				

Scenario Type Frequency	17 2	A Priori Prob	Total Occurs	Posterior Prob
A. high (>$8 billion)	0	0.25	37	0.20
B. medium ($5-8 billion)	1	0.45	73	0.40
C. low (<$5 billion)	0	0.30	74	0.40

APPENDIX H : THE CALCULATION OF IFS SCENARIO PROBABILITIES FOR DESCRIPTOR STATES AND SCENARIOS

THE CALCULATION OF IFS SCENARIO PROBABILITIES FOR DESCRIPTOR STATES AND SCENARIOS

This report presents five principal scenarios, which are as follows:

Scenario A: Slow Market Development
Scenario B: Qualified Success in Residential and Light Commercial Applications
Scenario C: Roaring Success
Scenario D: Success with a Hydrocarbon Infrastructure
Scenario E: Qualified Success in Commercial and Light Industrial Applications

The probabilities assigned to these five scenarios are Bayesian *a posteriori* probabilities resulting from Battelle's scenario analytical method and supporting software program, which is called Interactive Future Simulations (IFS). More specifically, the *a posteriori* probabilities are derived from the *a priori* probabilities assigned by expert judgment to the alternative outcomes (states) of the descriptors and the index values of the cross-impact analysis.

In the current IFS model, there are a total of 28 descriptors, each of which has three or four alternative outcomes (states) by 2015. Each state is assigned an *a priori* probability of occurrence, with the probabilities of the states summing to 1.0 for each descriptor. There were a total of 92 descriptor states. For example, Descriptor 1, Retail Price of PEM Fuel Cell (without Fuel Processor) has four alternative states by 2015:

>$3,000 per kW	0.15 (or 15%)
$2,000-$3,000 per kW	0.25 (or 25%)
$1,000-$2,000 per kW	0.35 (or 35%)
<$1,000 per kW	0.25 (or 25%)

Ideally, the descriptor states are mutually exclusive and exhaustive of all reasonable possibilities by the target year. They are typically expressed as ranges rather than points to bound uncertainty.

These probabilities, in Bayesian terms, are *a priori* in both the sense that they are judgment probabilities (incorporating expert judgment about past trends and future expectations) and that they are initial, intuitive, and unrefined (prior) probabilities subject to further information and analysis. Whether or not the *a priori* probabilities have any absolute meaning can be argued (and they may not be linear projections of historical data), but they do have relative meaning. Using the above example, in the view of the experts the most likely outcome is that by 2015 the retail price will be in the range of $1,000 to $2,000 per kW (in constant 2004 dollars), and that the price ranges of $2,000 to $3,000 per kW and the range of less than $1,000 per kW are equally likely with each other but less likely than the range of $1,000 to $2,000 per kW. The least likely outcome is that the price will remain at today's "high" range of more than $3,000 per kW. These judgments incorporate the fact that prices are falling and not likely to remain as high as they have been in the past. There is a strong trend toward lower costs. The judgments, however, also reflect skepticism that prices will go so low as to be less than $1,000 per kW by 2015.

The selection of descriptors, states, and the *a priori* probabilities of occurrence in this model were judgments made by the Battelle scenario team in conjunction with three workshops of industrial, government, and academic experts in fuel cell technologies or economics.

In the IFS method, a cross-impact matrix is created with the help of the IFS software program. All descriptors and their states are arrayed on both the *x* and *y* axes of the matrix. Moving down the columns (across the rows) from left to right, judgments are made as to how the hypothetical occurrence of each descriptor state would adjust up (more likely) or down (less likely) the *a priori* probabilities of all other descriptor states. The method uses index values ranging from +3 (meaning, much more likely to occur) to -3 (meaning, much less likely to occur). In the language of statistics, the *a priori* probabilities are marginal probabilities and the index values in the cross-impact matrix represent conditional probabilities.

When assigning cross-impact values in the matrix, the experts ask the questions: is there a direct cause-and effect relationship of one descriptor state upon other descriptors' states (yes means to continue the process; no means a value in the matrix of 0); is the relationship positive (makes more likely) or negative (makes less likely), and is the relationship strong (3), medium (2), or weak (1) in strength?

For example, does Descriptor 1, the Retail Price of the PEM Fuel Cell (without a Fuel Processor) have a direct impact on Descriptor 2, the Retail Price of PEM Fuel Cell Processor. Or, to say it more precisely, if the Retail Price of the PEM Fuel Cell were to be high (>$3,000 per kW), would it have any direct impact on the probability that the Retail Price of PEM Fuel Cell Processor would also be high (>$1,500). The judgment was "no" – there is no direct cause and effect relationship. The values in the matrix for all of the states of Descriptor 1 impacting all of the states of Descriptor 2 are 0.

If the Retail Price of PEM Fuel Cell (Descriptor 1) were to be >$3,000 per kW, would it impact the probability that Descriptor 5, Consumer Market Image of PEM Fuel Cells, being "high tech, high gloss, best thing since sliced bread," would occur? The judgments were that "yes," there is a direct impact, which is positive and weak based on the fact that consumers often associate high prices with high quality (and conversely associate low prices with undifferentiated, commodity products).

The goal of the cross-impact analysis is to inter-relate all the descriptors and their states. So often one says in conversation, "All other things being equal, then…," which is a phrase that captures very simple cross-impact analysis. The values in the cross-impact analysis are viewed as first order (direct) cause-and-effect relationships and not correlations and not second or third (indirect and very indirect) order derivatives. It would be impossible to calculate the interactions among 28 descriptors and 92 descriptor states in one's head and very tedious to do on paper, so the IFS program provides a very easy to use tool for cross-impact analysis or large models.

Cross-impact analysis is the method used to integrate all of the descriptors and to generate the sets of occurring conditions that are called "scenarios." Scenarios are the clustering of occurring and non-occurring descriptor states. Each scenario is internally consistent (because of the rigor

and explicability of the method and its mathematics) and different in some way (at least one occurring descriptor state) from each other.

The IFS algorithm calculates the resulting scenarios from starting points, cross-impact values, and descriptor states *a priori* probabilities. The algorithm starts a single scenario calculation with each (and every) descriptor state set to 1.0 (occurs) and to 0 (does not occur). Therefore, the total number of single scenarios equals to total number of descriptor states times two (1.0 and 0). In this model, there were 92 descriptor states, so there were 184 single scenarios.

In a single scenario, the algorithm adjusts the *a priori* probabilities of descriptor states up or down according to the values in the cross-impact matrix cells and a formula that determines how much adjustment is made according to the strengths of the cross-impact values (ranging from +3 to -3, as mentioned above). When a single scenario has adjusted all descriptor states to either 1.0 or 0, it completes the single scenario and goes on to calculate a new single scenario based on a new starting point.

The IFS algorithm is deterministic in the sense that the formula always adjusts the probabilities according to the cross-impact values in the same way. It is replicable. There is no random number generation (except to break "ties" in the calculations) and no Monte Carlo. The deterministic formula gives one the confidence that simulations are reliable – that changes in results are due directly to changes in inputs without changes in the mathematical routines.

After completing all single scenarios (in this model, 184), the algorithm organizes the single scenarios into scenario types, which are clusters of single scenarios with exactly the same results of descriptor state *a posteriori* probabilities of 1.0 or 0). One cluster may differ from another cluster by the occurrence or non-occurrence of just one descriptor state. The largest cluster was called Scenario Type 1 and it had a frequency of 10, meaning that there were 10 single scenarios that were exactly alike. The second largest cluster was Scenario Type 2, with a frequency of seven (meaning a cluster of seven single scenarios that were exactly the same in occurring and non-occurring descriptor states). It is assumed that the size of the cluster relative to the sizes of other clusters reflects a probability of occurrence in the future; that is, that a cluster of 10 single scenarios is more likely to occur than a cluster of seven.

The scenario types and their frequencies were as follows:

Scenario Type 1	10
Scenario Type 2	7
Scenario Type 3	6
Scenario Type 4	4
Scenario Type 5	3
Scenario Type 6	3
Scenario Type 7	3
Scenario Type 8	3
Scenario Type 9	3

In addition, Type 10 through Type 17 each had a frequency of two.

Therefore, there were nine scenario types that captured 42 single scenarios out of a total of 184 single scenarios. There were 17 scenario types that captured 58 single scenarios; these 17 scenarios were all of the Scenario Types with a frequency of two or more. The rest of the single scenarios, or 126, were literally single scenarios.

For purposes of further analysis, the Battelle team considered five primary scenarios based upon the first 17 scenario types with frequencies of two or more. The 17 scenario types in the final analysis were studied with an eye for major similarities and differences. The most important similarities were in the results for applications, customers, and market size, with as few as possible differences in the results of other descriptors. The final five principal scenarios, along with there final probabilities, were as follows:

Scenario A: Slow Market Development

Scenario Type 1	10
Scenario Type 4	4
Scenario Type 5	3
Scenario Type 6	3
Scenario Type 7	3
Scenario Type 10	2
Scenario Type 15	2
Total	27

Scenario B: Qualified Success in Residential and Light Commercial Applications

Scenario Type 3	6
Scenario Type 9	3
Scenario Type 11	2
Scenario Type 13	2
Scenario Type 14	2
Scenario Type 16	2
Scenario Type 17	2
Total	19

Scenario C: Roaring Success

Scenario Type 2	7

Scenario D: Success with a Hydrocarbon Infrastructure

Scenario Type 8	3

Scenario E: Qualified Success in Commercial and Light Industrial Applications

Scenario Type 12	2

The *a posteriori* probabilities can be calculated from either the whole set of 184 single scenarios or from the truncated set of 17 scenarios with a frequency of two or more, which represents a frequency subset of 58. It might be argued that the single scenarios with a frequency of only one

are statistical outliers and the predetermined starting points of the algorithm. The *a posteriori* probabilities are as follows"

Scenario	*A Posteriori Probability based on 184*	*A Posteriori Probability based on 58*
A.	15%	47%
B.	10%	33%
C.	4%	12%
D.	2%	5%
E.	1%	3%

These five scenarios are baseline scenarios because they reflect likely alternative futures based on what is known today and with known descriptors playing out as expected. These scenarios do not reflect alternative futures caused by high consequence, low probability events (what is commonly called disruptive events, wild cards, or "black swans."). In continued work with the IFS model, new information and events should be incorporated into the model and new scenarios should be run. Also, disruptive events should be simulated to see how they change the baseline scenarios. The disruptive events might be either hypothetical, imaginary events or they might be proactive strategies. IFS allows for extensive sensitivity analysis and simulations (virtual experiments on the future). Scenario analysis is a dynamic and learning process addressing the uncertainties of the dynamic future.

Appendix B: Analysis of Stakeholder Feedback on Polymer Electrolyte Membrane Fuel Cells for Stationary Applications

Economic Analysis of Polymer Electrolyte Membrane Fuel Cells

Interim Report: Analysis of Stakeholder Feedback on Polymer Electrolyte Membrane Fuel Cells for Stationary Applications

for

The Department of Energy, Office of Energy Efficiency and Renewable Energy

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Executive Summary

Battelle's efforts to understand the economic, technology, and marketplace drivers needed for commercialization of stationary polymer electrolyte membrane fuel cell (PEMFC) systems are largely dependent on input from key stakeholders. This study explores the points of view of various stakeholders in PEMFC commercialization, including current and candidate users, key influencers, and industry members. It examines the general perspectives of these stakeholder groups on the timing and likelihood of PEMFC adoption in different applications, as well as the critical decision factors driving fuel cell investment decisions and the factors considered most important to achieving widespread commercialization. While the focus of this study is on PEMFC, information was also collected on the market and user requirements for stationary fuel cell applications in general, as this is the market space in which PEM will be competing. It was also considered important to learn from phosphoric acid fuel cell (PAFC) and molten carbonate fuel cell (MCFC) users, as those technologies have a longer track record of use in larger applications.

Nearly all of the stakeholders interviewed believe that fuel cells will be adopted for some stationary applications. Most think the technology for PEM fuel cells will take another 5 to 10 years to develop, and up to 15 years before they are widely adopted. Others suggest that fuel cells already provide a competitive source of backup power today. Some skepticism lingers, however. One interviewee noted, "Experts have been saying that fuel cells have been two years from commercial viability for many years now." Another indicated that some fuel cell companies have done the industry a major disservice by overpromising and underdelivering.

Currently, the majority of users with whom the research team spoke are employing their fuel cells in grid parallel applications, several of which are also co-generating heat. Some of the users interviewed are also relying on fuel cells as backup and grid independent power sources, and to a lesser extent for special applications. PEMFC systems are being demonstrated across grid parallel, combined heat and power, grid independent and backup power applications. Notably, none of the electric generating station users with whom the research team interviewed are using larger fuel cell systems in grid connected applications, to provide a continuous source of power to the grid (Table ES-1). Also, while the focus of this study is on stationary applications, it is interesting to note that the venture capital (VC) community is investing most heavily in fuel cells for portable applications, with some targeting stationary applications.

Current use, however, does not necessarily track with the expected near-term applications of fuel cells. Almost all stakeholder groups believe that backup power – particularly for the less-cost sensitive premium power applications – is most likely to be early adapters of fuel cells. Members of the research and development (R&D) and agenda-setter stakeholder groups also believe that the market for grid independent applications (e.g., remote residential, telecom towers) would eventually evolve. Neither grid parallel nor grid connected applications were mentioned by the stakeholder groups as markets that are likely to be penetrated by PEMFC in the near term (by 2015). While utilities do not appear to be jumping on the fuel cell bandwagon to power the grid, it was noted by one utility interviewee that electric utilities are in a unique position to capitalize on stationary distributed technologies. A key benefit cited was the ability to defer investments to replace aging transmission lines.

Table ES-1. Fuel Cell Systems and Applications of Interviewees

Organization Type/Name	Type	Applications						Date Installed	Still in use? (Y/N)
		Grid Parallel	Grid Independent	Grid Connected	CHP	Backup	Special Applications		
Commercial Sector									
Energy technology company	100 kW PEMFC		X					1999	N
Telecommunications company	5 kW PEMFC					X		2003	Y
Banking sector company	250 kW MCFC	X						2002	Y
Banking sector company	200 kW PAFC	X						1999	Y
Hotel	250 kW MCFC	X			X			2002	Y
Automotive company	250 kW MCFC	X						2001	N
Energy technology company	200 kW PAFC	X			X	X		2001	Y
Energy technology/power generating systems company	250 kW MCFC	X						2003	Y
Public Sector									
Yellowstone National Park	5 kW PEMFC		X		X			2002	N
US Navy - Naval Air Station Patuxent River	5 kW PEMFC	X			X			2004	Y
US Air Force – Shaw AFB	5 kW PEMFC	X						2003	N
US Army - Watervliet Arsenal	200 kW PAFC 5 kW PEMFC	X			X	X		1997	N
US Army - Fort Jackson	5 kW PEMFC	X	X		X	X		2002	Y
US Air Force – McChord AFB	500 watt PEMFC		X			X		2002	Y
Multi-Agency Radio Communications System	1 kW PEMFC					X		2004	Y
NASA's Kennedy Space Center	unknown						X		N
Electric Generating Stations									
New York Power Authority	200 kW PAFC	X	X					1996	Y
Omaha Public Power District	200 kW PAFC	X						2001	Y
Arizona Public Service Company	5 kW PEMFC						X	2001	Y
Chugach Electric Association	200 kW PAFC	X			X			2000	Y

Current fuel cell users cited a wide range of factors they consider when evaluating fuel cells as a prospective investment; however, a few factors consistently rose to the top of the list: cost, reliability, and durability. Commercial and public sector users also placed heavy emphasis on environmental and energy efficiency considerations. While capital cost was mentioned by

virtually all users as a critical decision factor, in some cases, reliability, durability, and environmental/energy efficiency benefits were cited as more important decision factors than capital cost. Users from electric generating stations were unique in citing power size as an important factor. While these users are not currently using the fuel cells to power the grid, a much higher power output (greater than 1 MW) will be required for grid connected applications.

It should be noted that most of these users are participating in demonstration projects and the typical criteria applied to investment decisions (or perhaps level of rigor) may not have been applied to their fuel cell decision. The majority of interviewees installed the fuel cell to take advantage of government financial incentives. Just a few interviewees said they would have acquired the fuel cell without government financial incentives.

As key influencers of the PEMFC industry, VC investors in the energy sector were also asked to describe the priority criteria considered when evaluating fuel cell technology investments. Five themes emerged from the VC responses: a major return on investment is expected (one considered a return of about 10 over the life of the investment); near-term commercially viability is expected (one specified 4 to 7 years); a sizeable market demand must exist; the technology must be better than the alternatives; and, a clear strategy for delivering value must be defined.

There was significant overlap between the most critical decision factors identified above and the factors that interviewees believe to be driving the widespread commercialization and adoption of fuel cells. Table ES-2 below provides a summary view of priority factors thought to be driving the commercialization of fuel cells. A rating was applied to indicate the relative importance of the factor to each stakeholder group based on a scale of 1 to 3, with 1 being most important.

The majority of interviewees consider lower cost to be the most critical commercialization driver, followed by the need for improved reliability and durability. With respect to cost, most interviewees think that government financial incentives will continue to be crucial to encouraging fuel cell adoption, until fuel cells are much more cost competitive.

The R&D stakeholders offered a slightly different take on priorities, specifying that significant breakthroughs in research and technology development are the key to achieving the required customer requirements of cost, reliability and durability for PEM fuel cells. They identified priority R&D needs in reformer development, membrane enhancements, catalysts, system integration, and hydrogen storage. Specifically, they emphasized the need to look at membrane permeability, and development of membranes that are not poisoned at parts per million levels of contaminants.

Several stakeholder groups also think it is important to address various issues associated with the fuel source for PEMFC (e.g., storage, infrastructure, safety). There was not a strong consensus on the need to invest in reformation issues versus hydrogen infrastructure development. The efficiency of producing hydrogen was cited as a critical issue that requires immediate attention. The environmental consequences of PEMFC hydrogen production are viewed to be problematic by some, who encourage the R&D community to pursue renewable fuel sources.

Table ES-2. Priority Factors Driving Commercialization

Stakeholder Group	Cost	Reliability	Durability	Fuel Source Requirements	Public Outreach	Energy Efficiency	Government Incentives/ Demonstration Projects	Market Demand/User Acceptance	R&D/Breakthrough Technologies	Codes/Standards
Commercial Sector	1	3	2		3					
Public Sector	1	2		3						
Electric Generating Stations	1	2	3							
Venture Capital Firms	1	3		3				2	3	
Policymakers, Regulators, Agenda Setters	1	3	3				2			
R&D Community	2	3	2	2		3	3		1	
Manufacturers	1	2	2	2				2		3

Just two groups – the agenda-setters and R&D community – identified government incentives and support of demonstration projects among their priority commercialization drivers. The VC and fuel cell manufacturer groups were the only two to emphasize the need to build a strong market demand for fuel cells. Public outreach and education were identified by some interviewees as important mechanisms for building this demand.

While environmental/energy efficiency considerations are important decision factors for both commercial and public (government) users, they are not considered critically important to fuel cell commercialization at this time. It was suggested by a few interviewees, however, that government-established emission or carbon standards could have a dramatic influence on fuel cell adoption.

Table ES-3 below provides a list of additional commercialization factors identified by at least one interviewee in each stakeholder group.

Table ES-3. Additional Commercialization Factors

Commercial Sector: • Start-up time • Physical size • Ease of use • Fuel source requirements	**Public Sector:** • Public outreach • Durability • Standby charges/utility fees • Environmental regulatory standards • Balance of plant
Electric Generating Stations: • Fuel source requirements • Ease of use • Environmental regulatory standards	**Venture Capital Firms:** • Political leadership • Physical size • Public outreach/education
Policymakers: • Energy efficiency • Environmental regulatory standards • Public outreach • Codes and standards • Fuel source requirements • Standby charges/utility fees	**Manufacturers:** • R&D/breakthrough technologies • Government incentives (policies and demonstrations) • Competing technologies • Manufacturing breakthroughs • Environmental regulations
R&D Community: • Government incentives • Codes and standards	

Finally, the policymaker/agenda-setter stakeholder group provided some specific input on the importance of codes and standards and the effectiveness of different government incentives in encouraging fuel cell adoption. The majority of interviewees familiar with fuel standards and codes recognize the value of having commonly agreed-upon codes and standards defined; however, they generally do not view this as a major barrier to commercialization of stationary fuel cells. One interviewee argued that people either “don’t realize that the standards are available or they don’t realize that they do not need standards.” Hydrogen was the one area where several interviewees recognize the need to develop common standards.

As far as incentives, buy-down programs that reduce first costs were thought to be more effective than usage incentives. Tax credits and exemptions, net metering laws, and establishing renewable portfolio standards were all mentioned by multiple interviewees as potentially effective incentives. It was pointed out, however, that such incentives are often provided for distributed generation (DG) technologies, and fuel cells may still have difficulty competing with photovoltaic (PV) and other technologies for which discounts are offered.

Table of Contents

Executive Summary i

Introduction 2

Study Objectives *2*

Methodology *2*

Analysis of Stakeholder Perspectives on PEM Fuel Cells 5

Current and Candidate Users *5*
- Commercial Sector 5
- Public Sector 12
- Electric Generating Stations 18

Key Influencers *24*
- Venture Capital Investors 24
- Policymakers, Regulators and Other Agenda-setters 29

Industry Stakeholders *34*
- R&D Community 34
- Fuel Cell System and Component System Manufacturers 40
- Fuel Suppliers 43

Next Steps 48

Appendices

Appendix A: Interview Protocols and Surveys *A1*

Appendix B: List of Interviewees *B1*

Appendix C: Additional Stakeholders Perspectives on the Hydrogen Economy *C1*

References R1

List of Tables and Figures

Table ES-1. Fuel Cell Systems and Applications of Interviewees ii

Table ES-2. Priority Factors Driving Commercialization iv

Table ES-3. Additional Commercialization Factors v

Figure 1. Stakeholder Involvement Methodology 4

Table 1. Overview of Current User Interviewees from Commercial Sector 6

Table 2. Overview of Current User Interviewees from Public Sector 13

Table 3. Overview of Current User Interviewees from Electric Generating Stations 19

Table 4. Importance of Drivers to Commercialization of Stationary PEM Fuel Cells 42

Introduction

Study Objectives

To identify markets and economic barriers to the market acceptance of polymer electrolyte membrane fuel cells (PEMFC) for stationary power, it is important to identify stakeholders and determine from them what factors are most critical. The objective of Task 3 in the Economic Analysis of PEM Fuel Cell Systems project is to collect and analyze first-hand input from key stakeholders to help augment the analysis being conducted in the other tasks of the project. Identifying technology acceptance issues and understanding the basis of these issues will help technology developers and DOE to define the most appropriate markets and define investment strategy for stationary PEM fuel cells. This feedback can help inform research and technology deployment plans in order to better position PEM fuel cells for adoption.

Methodology

During the first year of this project, initial stakeholder input was collected primarily through interviews and surveys with stakeholder groups that would offer potentially unique and important perspectives on the viability of PEM fuel cells. (Interview and survey protocols can be found in Appendix A). The stakeholder groups interviewed included:

Current and Candidate Users

- Commercial users
- Public (government) users
- Electric generating station personnel

Key Influencers

- Venture capital investors
- Policymakers, regulators and other agenda-setters

Industry

- Fuel cell and component manufacturers
- R&D community
- Fuel suppliers.

A total of 83 individuals were interviewed and surveyed from the stakeholder groups listed above (see Appendix for a list of interviewees). Stakeholders were asked for their opinions on PEM fuel cell system stationary applications in the 1kW to 250kW range. Interview protocols were tailored to each stakeholder group, but in general, questions aimed to understand: current uses of fuel cells; critical factors influencing the decision to use fuel cells; factors considered most important to widespread adoption of fuel cells; competing technologies and technical performance parameters; and perspectives on the long-term viability of PEM fuel cells. While questions emphasized PEM fuel cells, many interviewees couched their responses in terms of the fuel cell market in general and did not differentiate among types of fuel cells (e.g., phosphoric acid fuel cells, molten carbonate fuel cells). The research team thought it was

important to talk with users of fuel cell types, other than PEM, that have a longer track record in the market in order to learn from this experience.

Surveys were employed to collect data from fuel cell manufacturers and component makers. The research team was able to take advantage of their involvement in a focus group for Task 2 and collect additional data on the perspectives of these stakeholder groups. In addition to the interviews and surveys, the research team reviewed findings from a set of stationary fuel cell reports (e.g., Frost and Sullivan, 2003; ABI, 2001).

The research team adopted a common set of terms and definitions for describing and classifying user applications of fuel cells. During a meeting with members of the fuel cell industry, it was suggested that the following list of terms be used to describe the different uses of fuel cells. These terms are used throughout the discussions on users and applications.

- **Grid independent** – Continuous, stand-alone power source that is not connected to the grid (off-grid). For example, a fuel cell might support all energy needs for either a single building or multiple homes in lieu of the grid. Off-grid applications serve baseload power needs, for example at remote sites.
- **Grid parallel** – Continuous supply of auxiliary power to a user connected to the grid; when user needs are fully met by the fuel cell, excess power may be supplied to the grid. The grid could provide the primary power source or serve as secondary power to the fuel cell. Grid parallel applications serve baseload power needs, and also provide peak shaving opportunities.
- **Grid connected** – Continuous, one-way supply of power that is supplied to the grid. These fuel cells are generally operated by a utility or, in deregulated cases, by the customer or substation. Grid connected applications serve baseload power needs.
- **Backup power** – Standby or emergency power source used to ensure uninterrupted service. Fuel cells could provide electricity that meets standard backup requirements, for example in brownout or blackout conditions, as well as quality power backup for customers such as banks and telecoms who are willing to pay more to ensure uninterrupted service.
- **Combined heat and power (CHP)** – The fuel cell provides electricity to the user and also produces heat. For example, CHP may be used by a community to heat a swimming pool and provide power to the pool center.
- **Special applications** – Fuel cells used for special niche applications, such as powering the space shuttle.

Stakeholder involvement will intensify during FY 2005 (Year 2 of the project). The research team will continue to conduct interviews for the purpose of filling information gaps and validating findings to date. A more focused approach to understanding user requirements for various markets will be employed. Greater emphasis will be placed on direct stakeholder interaction through focus groups, directed surveys, and phone interviews. The research team will design and conduct three focus groups during FY2005. In addition to providing important feedback on findings to date, the focus groups will provide an important mechanism to identify and select candidates for a stakeholder partnership team. The stakeholder partnership team will be responsible for providing guidance and peer review for the subsequent technology and market analysis.

The final product of this task is to develop a stakeholder communication guidebook, synthesizing issues ascertained from various stakeholders (see Figure 1 below). The audience for this guidebook will be DOE staff responsible for PEM fuel cell development and stakeholder involvement, fuel cell developers interested in stakeholder acceptance issues associated with PEM fuel cells, and trade associations planning stakeholder outreach. Training materials associated with this guidebook will also be developed. This guidebook and supporting training will represent the culmination of Task 3.

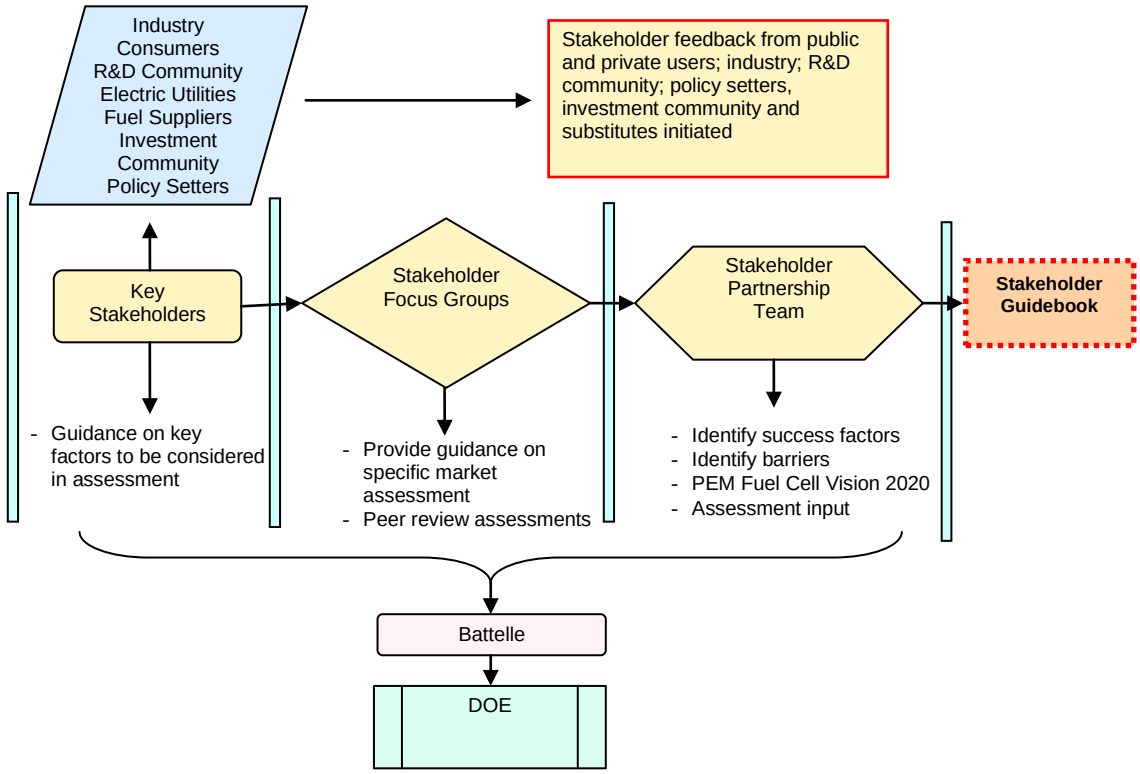

Figure 1. Stakeholder Involvement Methodology

Analysis of Stakeholder Perspectives on PEM Fuel Cells

Current and Candidate Users

Commercial Sector

Summary of Key Findings

Commercial sector interviewees expressed overall satisfaction with their fuel cell experience and optimism about the potential for fuel cells to be successful someday in select markets (e.g., communications, hotels). In fact, several interviewees said they would consider installing another fuel cell. Some of the benefits observed by these fuel cell users included higher reliability and reduced emissions than generators. Some users, however, experienced problems with reliability. Most of the current users interviewed are using large fuel cell systems in grid parallel applications.

Cost, reliability, and environmental/energy efficiency considerations were cited as the most important factors that commercial users took into account when making their fuel cell purchase decision. Seven of the eight commercial users interviewed, had taken advantage of a government financial subsidy to make the fuel cell affordable and just three users claimed they would have purchased the fuel cell without the subsidy. Cost was also by far the most important issue that the commercial users thought needed to be addressed to encourage widespread adoption. Government subsidies were considered essential to attracting fuel cell users until production costs decrease dramatically. Improved durability was a second important factor mentioned as a critical commercialization driver. Some thought that having manufacturer warranties in place would provide a good indicator and guarantee of improved durability.

Users and Applications

The research team interviewed commercial users of fuel cells to understand their current or potential applications, critical purchase decision factors, and performance parameters. Eight current users and two candidate users were interviewed from the telecom, hotel, banking, automotive, and energy/electricity sectors. Interviewees asked not to be associated with specific comments, so industry descriptors have been substituted for commercial organization names to provide the reader with an understanding of the importance of different applications to users in the specific industry. An overview of the systems used and associated applications is provided in Table 1 below. The team found numerous large, long-term fuel cell projects used phosphoric acid fuel cells (PAFC) and molten carbonate fuel cells (MCFC), as well as some PEMFC. A decision was made to interview non-PEMFC users to understand their requirements and perspectives on these larger fuel cell applications.

Table 1. Overview of Current User Interviewees from Commercial Sector

Organization Type/Name	Type	Applications						Date Installed	Still in use? (Y/N)
		Grid Parallel	Grid Independent	Grid Connected	CHP	Backup	Special Applications		
Banking sector company	250 kW MCFC	X						2002	Y
Banking sector company	200 kW PAFC	X						1999	Y
Hotel	250 kW MCFC	X			X			2002	Y
Automotive company	250 kW MCFC	X						2001	N
Energy technology company	200 kW PAFC	X			X	X		2001	Y
Energy technology/power generating systems company	250 kW MCFC	X						2003	Y
Energy technology company	100 kW PEMFC		X					1999	N
Telecommunications company	5 kW PEMFC					X		2003	Y

A company in the banking sector is currently operating two 250 kW molten carbonate fuel cells (MCFCs) in a ***grid parallel*** application installed in 2002***.*** The fuel cell is providing baseload power to a commercial building and its electronic data processing center. Additional electricity generated by the fuel cell is provided back to the grid and any power shortages to the facility are supplemented by the grid. In addition to the two fuel cells, the company has two backup diesel generators that will provide power if the fuel cell and grid go down. The interviewee indicated that the company's plans to build a new corporate headquarters provided the impetus for considering fuel cells as an energy source for the building. The company consulted with other members of their industry who had adopted fuel cells and designed a similar system.

A second banking sector company reported using a phosphoric acid fuel cell (PAFC) system powered by four 200 kW fuel cells since 1999. The company uses the fuel cell in a ***grid parallel*** application to supply baseload power to one of its major technology centers. According to a presentation delivered at a fuel cell investment summit, secondary power is provided by the grid and backup diesel generators. This company was first introduced to the fuel cell concept at an industry meeting where it was discussed as a potentially more reliable power source.

A company in the hotel industry installed two 250 kW MCFCs in 2002 and is in the process of installing a third fuel cell. The fuel cells are used in ***grid parallel*** and ***CHP*** applications; they provide baseload power, combined with other sources, to the company's hotel facilities, as well as a heat source for the hotel's water. The company became interested in fuel cells when it was

approached by an organization interested in installing the fuel cell and selling the power back to the hotel at a discounted rate.

An automotive company teamed with a fuel cell manufacturer and two electric generating companies on a demonstration project to study the performance of fuel cells and promote the use of environmentally friendly energy sources. The company operates two 250 kW MCFCs: one at a production plant and the second at a company museum. Both fuel cells operate as ***grid parallel*** power sources.

Three companies in different segments of the energy industry are operating fuel cells in their own facilities (or own and operate fuel cells for a third party) with the goal of demonstrating the viability of their fuel cell systems and creating new market opportunities. One energy company is using a 200 kW PAFC (installed in 2001) to power its data processing center. The fuel cell is being used in a ***grid parallel*** system to provide supplementary power to the data processing center. This system also provides heat to the building's boilers **(*CHP)*** and serves as an emergency ***backup power*** resource in the event of disruption in the grid power supply. The second company – a developer of power generating equipment – is operating a 250 kW MCFC power plant as a ***grid parallel*** application at one of the company's buildings.

A third energy company operated an integrated photovoltaic (PV) and PEMFC system for a third party, utilizing a 100 watt PEMFC. The ***grid independent*** PEM fuel cell system provided supplementary power to the PV system for a remote telecommunications system transceiver. Hydrogen in high-pressure cylinders provided the fuel source. The PEMFC operated for eight months before it was shut down in 2000 when a reduction in the power load made it unnecessary.

A final current commercial user interviewed uses a 5 kW PEMFC to provide ***backup power*** to a telecommunications hut serving parts of an international airport. The company is collaborating with a fuel cell manufacturer and a state power company on a one-year demonstration project, which was initiated in 2003. The prospect of increasing system reliability was the primary driver behind this project.

Of the two candidate users interviewed, one wireless telecom company is considering the use of 3 to 5 kW PEM systems for ***grid independent*** (remote) and ***backup*** applications for wireless hub sites and cell sites. Currently lithium-ion batteries are being used for backup power, and batteries combined with diesel and propane generators are being used in remote sites. The company is also considering flywheels, ultracapacitators, and microturbines, in addition to PEMFCs.

A second candidate user interviewed, representing an energy services company, has given little consideration to fuel cells at this point because of cost and the fact that fuel cells are not yet commercially viable.

<u>Critical Decision Factors</u>

Current and candidate commercial users of fuel cells described the importance of the following factors in their decision to buy fuel cells. It is important to note, while not all the users interviewed use PEMFC, the following decision-making factors identified by interviewees are key when considering purchase of alternative energy technologies.

- **Cost** – Cost was an important factor influencing commercial users' decisions to invest in fuel cell applications. Seven of the eight current commercial users interviewed had taken

advantage of either federal or state government financial incentives or financial incentives from manufacturers. Most noted that these incentives did influence their decision to participate in fuel cell demonstration projects, but three commercial users stated they would have pursued fuel cells with or without government incentives. Cost was identified as a secondary consideration to reliability for applications requiring premium power, including wireless communications hub sites and banking technology centers.

- **Reliability** – Six of the ten interviewees identified reliability as one of the most important factors influencing their capital purchase decision, and the two companies in the banking sector cited reliability at *the* single most important consideration, because customers require reliable banking services 24 hours a day, 7 days a week. One of the banking industry companies specified the need for "six 9's" reliability (99.9999%). For others the benchmark of reliability was the performance of battery power for backup applications.
- **Durability** – The durability or longevity of the fuel cell system was a factor that influenced the fuel cell investment decision for four interviewees. A banking company wants a fuel cell that will last 20 to 25 years. A telecom company expects the fuel cell to last longer than the life of a battery (i.e., 6 years) and to handle a minimum of 72 hours continuous run time. The availability of warranties, as "proof of durability," was a decision factor for one telecommunications company.
- **Environmental and energy efficiency** – Environmental and energy efficiency concerns were cited as either critically or moderately important decision factors to nine of the ten interviewees. This would skew the decision factors in the summary. One energy company recognized that the fuel cell was not the best choice in economic terms, but decided that environmental stewardship was more important and invested. Another energy services company considering fuel cells is seeking out power sources that produce lower emissions than conventional electricity. The one company for which environmental and efficiency parameters were not a consideration noted that because the manufacturing facility was already well below emissions criteria, this was not a driver.
- **Power size** – In general, power size was not considered an important factor to those using the fuel cell in grid parallel applications where the fuel cell is one part of a broader power supply mix. Power size was identified as an important decision factor to just one company, which was using the fuel cell in a grid independent application for telecommunications. The interviewee stated that power requirements vary for wireless telecom applications, with cell towers requiring 15 to 20 kW systems and hub sites (20,000 in number) requiring 3 to 5 kW systems. Scalability of the fuel cell unit was considered an important factor to another company. That interviewee stated that the ability to increase power with MCFC units affected their decision to select a MCFC over a PEMFC.
- **Startup speed** – Start up speed was only identified by one interviewee as a high priority decision criterion. Other users of fuels cells interviewed indicated that it was not a critical factor when making purchase decisions for their specific applications.
- **Fuel source requirements** – Most interviewees identified fuel source requirements as a moderate concern. Because natural gas was the only continuously supplied fuel source available, two of the commercial users identified fuel requirements as an important consideration in their purchase decision. A MCFC user was deterred from purchasing a PEMFC because they are more susceptible to impurities in natural gas. A PAFC user was forced to install a $1 million filtering system to reduce the nitrogen levels in the natural gas. Two other interviewees emphasized the flexibility in fuel requirements as a

benefit they considered in evaluating fuel cells. For example, one remote site user currently uses compressed hydrogen, but considers using a reformer in the future. Finally, a candidate commented that hydrogen availability, distribution, storage, and safety will all play a role in his company's fuel cell purchase decision.

- **Physical size** – Just two companies identified unit size as a moderately important decision factor. For example, one company powering a data processing center had a 10X18X18 foot size requirement and the 200 kW PAFC fit well with those parameters. Another was concerned with the weight of the 87,000 pound MCFC system, as it would be installed on an upper level floor in a hotel.
- **Safety** – Two interviewees with current and planned grid independent applications expressed concerns about hydrogen storage safety.
- **Ease of use** – The two telecom interviewees cited ease of use as very important because their field technicians are typically "generalists." One said that "plug and play" modules are very attractive for their applications.
- **Demonstrating technology leadership** – Three commercial users with an interest in developing and promoting their own fuel cell capabilities to others believed that their fuel cell projects would provide the opportunity to demonstrate the value of fuel cells to others. Two companies identified the "leading edge" image that fuel cell use would convey as an important decision factor.
- **CHP potential** – One company selected a MCFC in part because of the potential to utilize its high-grade heat for cogeneration.
- **Permitting requirements** – One telecom company will consider permitting requirements when making their purchase decision.
- **Likelihood of acceptance** – Two commercial users considered the likelihood that fuel cells would be accepted and supported by internal management and staff.

Factors Driving Commercialization

The current and candidate commercial users with whom the research team spoke identified several critical factors they believe to be driving the commercialization and widespread adoption of fuel cells. Cost was the most frequently cited factor, followed by durability, reliability, public outreach, and others.

- **Cost** – Nine of ten commercial interviewees believe that the high costs associated with producing and installing fuel cells are among the most important factors driving commercialization. A telecom interviewee thought that fuel cells would need to reach $1,000/kW to be commercially viable. The exception will be companies that have a need for reliable power that outweighs the importance of cost. Federal and state subsidies and mass production were identified as two important mechanisms for cost reduction. Most current users have received some sort of subsidy, and this will need to continue until costs are more competitive. One interviewee thought that manufacturers should place greater emphasis on value engineering to identify where costs could be reduced.
- **Durability** – Three interviewees stated that durability must improve to encourage commercialization. This is an important factor for the telecom industry if they are to use fuel cells as the primary power source in remote locations. Also, warranties to ensure durability are thought to be an important step toward commercialization. According to one telecom company interviewee, a 10-year warranty on backup applications must be in place to attract more commercial users, and the warranties must to be guaranteed by the government or industry in the event that the warrantor goes out of business.

- **Reliability** – Two interviewees think reliability is a critical commercialization driver. One specifically mentioned the need for improved performance with requirements that include step load characteristics (e.g., microwaves at cell sites).
- **Public outreach** – Two of the energy sector companies indicated that greater awareness and education concerning fuel cells must be promoted if they are to compete effectively with the grid.
- **Start-up times** – A banking company interviewee believes startup times must be shorter if fuel cells are to be adopted.
- **Physical size** – A hotel using fuel cells believes that fuel cells must be reduced in size.
- **Codes and standards -** Just one company, which develops power generating systems, identified the lack of consistent codes and standards as an important commercialization driver.
- **Fuel source requirements** – One interviewee operating a fuel cell in a remote location thinks that issues associated with hydrogen safety, storage, and sourcing must be addressed.
- **Ease of use** – Just one company, an energy services company, identified ease of use as an important commercialization driver.

General Perspectives on Experience and Future Use of Fuel Cells

Overall, the interviewees provided an optimistic perspective on the potential for fuel cells to penetrate select markets/applications (e.g., backup stationary and portable), *if* the critical commercialization factors discussed above were addressed. Most fuel cell users expressed satisfaction with their overall experience. Users also identified some of the issues and challenges encountered through their experiences with fuel cell systems, which suggest opportunities for further development.

One of the current users from a company that develops power generating systems expressed that the company would probably use a fuel cell again. While maintenance costs were fairly high, the fuel cell system was described as “clean, quiet, efficient, and sustainable,” and it has been easily accepted. They found the demonstration to be valuable in that the company now understands how to integrate a fuel cell with another energy system for combined heat and power applications.

Another energy technology company views fuel cells as an important addition to their portfolio of distributed generation (DG) products. They expect to help demonstrate the viability of fuel cells for commercial applications and position themselves for new business as a fuel cell dealer.

The energy company that deployed a telecommunications system application for a third party was also very pleased with the performance of the fuel cell system as a clean backup power source to the PV system. However, the interviewee does not believe that fuel cells will be adopted as a source of primary power by this end user because PV is more cost-effective.

The current PEMFC user in the telecom sector expressed confidence in the viability of PEMFC for backup power to cell towers, remote terminals, and huts. Until reformer technology is perfected, he believes that these will be the priority telecommunications applications. The interviewee noted, however, that the company still needs to evaluate the results of the demonstration project, the economics of using fuel cells versus lead-acid batteries or backup generators, and specifications for DC to DC field application in their telecommunications network.

A candidate user in the telecom sector also believes that fuel cells will be adopted in select markets. They expect the primary adopters will use fuel cells for communications (e.g., telecom, amateur radio, aviation, railroad, police, and fire), and possibly in hospitals and hotels.

The hotel industry interviewee expressed satisfaction with that company's fuel cell installation. There were no problems with installation or implementation, and the company benefited from a reliable power source, discounted cost (through subsidies), reduced emissions, and a fair amount of press. The company is currently installing another fuel cell in another of its hotels.

One of the banking industry interviewees conveyed that the company had a very positive experience with fuel cells and it would definitely install them again if it was to construct another building. The company believes that the high reliability has given the company a competitive advantage and has helped it to attract new customers. Other benefits identified through secondary information on this company included low maintenance and repair (system can continue to operate), a 2000 hour mean time between failures, no emissions, high power quality, and remote monitoring. The major problems experienced included the delay in configuring to grid independent mode (3 to 5 seconds), accommodating only an 80 kW step load in grid independent mode, and system issues when the grid is unstable.

The representative of the other banking company interviewed would consider installing additional fuel cells to support the company's data processing center and office building if required. However, the interviewee expressed concern about complications the company experienced during installation (despite holding two design planning meetings with the manufacturer) and problems with the fuel cells shutting down in cold weather.

The automotive company was the only current commercial user interviewed to state explicitly that it would not continue to use fuel cells without an extremely compelling reason. There were many times when the unit went off line, so reliability was an issue. The company currently receives very good power rates from the state power company and its emissions are below the standards so the typical drivers do not apply to this company.

Finally, the candidate user in the energy services sector doubted that fuel cells would be adopted any time soon. The interviewee believed that large commercial establishments would probably be the first adopters. This company tends to be a technology follower. The company will not likely consider adding fuel cells to its power mix until issues such as emissions (from hydrogen production as well as the fuel cell) and energy intensity have been evaluated to determine whether they are really "cleaner."

Public Sector

Summary of Key Findings

The research team identified several PEM fuel cell users in the public sector, primarily through Department of Defense PEM demonstration projects. The users interviewed are demonstrating fuel cells in a variety of applications including grid parallel, backup, CHP, grid independent, and special applications. Nearly all of the public sector interviewees believe that fuel cells will be adopted some day, if critical commercialization factors are addressed. Backup applications are the most likely near-term market for fuel cells according to public users. While many believe that widespread adoption is five to ten years down the road, at least one user thinks that fuel cells provide a competitive source of backup power today.

Cost, reliability, fuel source requirements, durability, and environmental/energy efficiency considerations were among the more important decision factors for public users. The availability of government financial support was also an important consideration to five of the eight interviewees in this group. For some, environmental, durability, and reliability factors took precedence over cost in the fuel cell installation decision. Three of these factors were also considered very important to the ultimate commercialization of PEM fuel cells: cost, reliability, and fuel source requirements. With respect to reliability, PEM fuel cells need to be better able to adjust to load swings and withstand a higher level of contamination. Government and university users also emphasized the need to place greater emphasis on finding renewable fuel sources if PEMFCs are to be widely adopted.

Users and Applications

Eight current users and three candidate users of fuel cells from public agencies and universities were interviewed. Current users included representatives from Yellowstone National Park, Naval Air Station Patuxent River (MD), Shaw Air Force Base (SC), Watervliet Arsenal (NY), Fort Jackson (SC), McChord Air Force Base (WA), Multi-Agency Radio Communications System (OH), and NASA's Kennedy Space Center. Most of these users were participants in the Department of Defense fuel cell demonstration project managed by the Army Construction Engineering Research Laboratory (CERL). Candidate users interviewed represented Colorado State University, University of Wisconsin, and Oregon State University. Fourteen other candidate government users have been contacted but have either not yet returned the researchers' calls or declined to participate because they are not considering fuel cells. An overview of the systems used and associated applications is provided in Table 2 below.

Table 2. Overview of Current User Interviewees from Public Sector

Organization Type/Name	Type	Applications						Date Installed	Still in use? (Y/N)
		Grid Parallel	Grid Independent	Grid Connected	CHP	Backup	Special Applications		
Yellowstone National Park	5 kW PEMFC		X		X			2002	N
US Navy - Naval Air Station Patuxent River	5 kW PEMFC	X			X			2004	Y
US Air Force - Shaw AFB	5 kW PEMFC	X						2003	N
US Army - Watervliet Arsenal	200 kW PAFC 5 kW PEMFC	X			X	X		1997	N
US Army - Fort Jackson	5 kW PEMFC	X	X		X	X		2002	Y
US Air Force – McChord AFB	500 watt PEMFC		X			X		2002	Y
Multi-Agency Radio Communications System	1 kW PEMFC					X		2004	Y
NASA's Kennedy Space Center	unknown						X		N

Yellowstone National Park installed a 5 kW PEM fuel cell at a park entrance station in 2002. The propane-fueled PEMFC was used in a ***grid independent CHP*** application, powering portions of the entrance station and providing co-generated heat for the entrance operations office. The fuel cell is not currently in service as it was removed by Plug Power after the company bought H-Power. However, the park plans to install another PEM fuel cell at the park headquarters in Mammoth Hot Springs, Wyoming, by the spring of 2005.

The Naval Air Station Patuxent River installed two 5 kW Plug Power PEM fuel cells in January 2004. Both are ***grid parallel*** applications, one fueled by natural gas for residential use and the other fueled by propane to support the critical load of a building on the base. The latter fuel cell is also being used for ***CHP*** to heat a reservoir of hot water connected to the building's boiler. The fuel cells were installed in cooperation with CERL and are operated in cooperation with Southern Maryland Electricity Cooperative.

Shaw Air Force Base installed its 5 kW PEM unit in April 2003, and the unit was scheduled to be removed during the spring of 2004. The fuel cell was used continuously in a ***grid parallel*** application, providing about half of the power required to fuel a residence on the base.

The Watervliet Arsenal installed two fuel cells in 1997 when they were approached by ERDC. One was a 200 kW PAFC, ONSI Corporation Model PC25B, used in a ***grid parallel*** application

to generate electricity directly for the Arsenal, a ***CHP*** application to preheat the broiler, and a ***backup*** application for emergency outages. The other was a 5 kW Plug Power PEM fuel cell providing ***grid parallel*** electricity for a residence. Both units were removed in 2002; however, the DoD fuel cell program website states that ten additional 5 kW PEM units were commissioned in three separate facilities at the arsenal in 2002.

The Army Training Center at Fort Jackson installed a 5 kW Plug Power PEMFC (ReliOn Independence 500) in 2002. The fuel cell was installed in a ***grid parallel*** application, which provides electricity and heats water ***(CHP)*** for an officer's residence on the base. The unit also has the ability to provide power during electrical service outages. The fuel cell was still in operation at the time of the interview.

In 2002, the McChord Air Force Base installed six 500 W (3 kW total) PEMFCs to provide backup power for a Radio Transmit Receive (RTR) site. The radio equipment is powered by the grid and has a backup battery bank. The fuel cells provide a source of ***backup*** power to the battery bank***.*** The objective of this installation is to test the ability of the fuel cell to respond to a primary power outage, and continue to meet the needs of the load under various operating conditions.

The Multi-Agency Radio Communications System (MARCS) is an Ohio Department of Administrative Services initiative to ensure interoperable communications for public safety responders. MARCS has four 1 kW PEMFCs on each of its four radio towers to provide emergency ***backup power.***

PEM fuel cells are the primary source of power on board the NASA Space Shuttle. This is a ***special*** application. No information was provided on fuel cell size.

Finally, of the three candidate users interviewed, none of them are seriously considering fuel cells at this time. At Oregon State University, fuel cells have been mentioned as a potential source; however, the university is more focused on renewable energy sources including biofuels, solar, and wind. Two interviewees commented that if their institutions decide to explore fuel cells in the future, it would likely be for backup power to replace generators and grid parallel applications to support peak-shaving. The third said that fuel cells might be considered for independent (remote) and grid parallel applications for certain research facilities.

Critical Decision Factors

Cost, reliability, durability, environmental and energy efficiency, and fuel source requirements were among the most important decision factors for the public users. These and other factors are described below.

- **Cost** – Cost (both initial and maintenance cost) was identified as an important decision factor by nine of the 11 interviewees. The availability of government financial incentives through cooperation with CERL or the state was *the* deciding factor to install a fuel cell system for Fort Jackson, Watervliet Arsenal, Naval Station Patuxent River, and MARCS, and it would be a factor for candidate user Colorado State University. The Fort Jackson interviewee added that while government incentives were the initial driver, he would recommend that the base purchase fuel cells over less expensive but more polluting technologies. Oregon State University, University of Wisconsin, and Yellowstone National Park also cited environmental and energy efficiency considerations as decision factors that may take precedence over cost. Finally, the McChord AFB noted that while cost plays an important role, reliability, power quality and durability are more important,

since the base could lose up to $1 million at day at their larger airports (e.g., SeaTac International Airport) if their RTR site goes down.

- **Reliability** – Most of the current government users considered reliability among their decision factors, regardless of application. For one interviewee, having the vendor readily available to service the units and help ensure reliability was considered an important asset. An interviewee from the Naval Air Station Patuxent River expressed a concern with the PEMFC system tripping offline when power demand falls. That person believes reliability could be improved if PEMFCs were designed to better handle swings in power demand.
- **Fuel source requirements** – Fuel requirements were mentioned by seven of the interviewees. Two required natural gas, while others had some flexibility (e.g., propane). Yellowstone Park fuel cells must now run renewable energy sources; while the fuel cell currently operates on propane, a future installation is expected to run on canola oil. A unique case, the space shuttle requires high-purity liquid oxygen.
- **Durability** – Durability in terms of unit lifespan and replacement of stacks and other components was identified as an important decision factor by five interviewees. Concerns were expressed about fuel cell stacks degrading faster than expected. For example, the PEMFC stacks at the Naval Air Station Patuxent River required replacement after 2,000 hours as opposed to the 10,000 hours expected. Frequent fuel cell stack replacement obviously also has major operating cost implications. Another concern that affected the longevity of the unit for the Watervliet Arsenal was model obsolescence.
- **Environmental and energy efficiency** – Five interviewees cited “clean” operation and energy efficiency as critical decision factors. As noted above, several interviewees from both public agencies and universities said that these factors may outweigh costs as a decision factor. The University of Wisconsin has even committed to purchasing 3% of its annual electricity demand at a premium of $25,000 to support green power projects, although the program covers only renewable energy from wind and biomass.
- **Start-up speed** – Four interviewees stressed the importance of start-up speed, particularly for backup/emergency and niche (space shuttle) applications.
- **Power size** – Just one interviewee commented that power size was an important decision factor. The most useful power sizes for Shaw Air Force Base would be 10, 20, and 50 kW fuel cells. A few of the users had modular configurations, with multiple fuel cells powering a single facility.
- **Physical size** – Physical size was not an important consideration for any of the public sector interviewees. Because military bases are not typically in densely populated areas, they tend to have fewer space limitations. It is expected that this parameter would be more important to government agencies operating in urban areas.
- **Safety** – Three of the interviewees commented that safety was a decision factor.
- **Codes and standards** – Adherence to operational codes and standards was identified by Oregon State University, NASA, Fort Jackson, and McChord as of importance to their capital investment decision. The McChord interviewee pointed out that the base’s ability to obtain required certifications from the FAA was important, since McChord’s application was linked to airport communications.
- **Ease of use** – Four interviewees emphasized the importance of usability and easy maintenance.

- **Track record** – Fort Jackson, and two candidate users – University of Wisconsin and Oregon State University – indicated that it was important to have the opportunity to learn from the experience of other organizations before investing in fuel cells.

Factors Driving Commercialization

- **Cost** – Seven interviewees stressed the importance of reducing the cost of fuel cells so that they are more competitive with alternative energy sources (e.g., diesel generators for backup). According to the McChord interviewee, reducing the cost of the reformer is a bigger issue than operating cost. Two commented on the need for additional federal and state funding sources to support fuel cell adoption.
- **Reliability** – Reliability and performance were seen as critical issues for four interviewees. Improving the fuel cells' ability to adjust to swings in load is a critical reliability requirement that must be met, according to the Naval Air Station Patuxent River interviewee. The NASA interviewee emphasized the importance of fuel cell membranes being able to better withstand levels of contamination in the parts per million, without shutting down. Two other interviewees stressed the importance of having the infrastructure for maintenance and repair of fuel cells in place to ensure high performance.
- **Fuel source requirements** – Both the Oregon State University and the Yellowstone National Park interviewees emphasized the need to find a renewable energy source for hydrogen as a commercialization driver. The McChord Air Force Base also sees the lack of fuel storage technologies as a barrier to overcome. Another identified the need to address the economics of fuel sources.
- **Public outreach and education** – A lack of awareness about fuel cell technology was identified by the University of Wisconsin interviewee as a barrier to commercialization. According to the Fort Jackson interviewee, the states should play a more active role in raising awareness about fuel cells' environmental and energy efficiency benefits.
- **Standby charges and other utility fees** - According to one interviewee, a local utility was charging his organization 4 cents per kW for every kW the fuel cell produced. While the user was eventually able to negotiate elimination of this with the utility, the interviewee stressed that such practices would need to be eliminated if fuel cells are to be widely adopted.
- **Durability** – The McChord AFB interviewee sees durability as the most important potential barrier to widespread commercialization.
- **Environmental regulatory standards** – The implementation of federal regulations restricting greenhouse gas emissions and deregulation of the electrical grid were regulatory policies identified by the Fort Jackson interviewee as critical commercialization drivers.

General Perspectives on Market Viability of PEM Fuel Cells

Nearly every interviewee in the public sector indicated that fuel cells would be adopted someday if the critical commercialization issues were addressed. Interviewees again stressed the need to reduce capital cost, provide financial incentives, address problems with the reforming process, solve hydrogen storage problems, increase durability, and achieve a level of reliability that is competitive with generators. One interviewee commented that he hoped fuel cells would be adopted one day, but that utility companies—fearing competition and bureaucratic regulations—would continue to hold back the technology.

Backup applications are the most likely near-term market for fuel cells according to several interviewees. As far as timing, various interviewees asserted that fuel cells would be widely adopted in “five years,” “ten years,” or “way down the road.” The McChord interviewee suggested that fuel cells are competitive in the backup power market today, and described the FAA as a niche market for backup power applications, with about 10,000 sites where fuel cells could be installed. The Naval Air Station Patuxent River interviewee believes that becoming grid independent will open the door to wider adoption particularly at remote sites. The Shaw Air Force Base interviewee thought standby and backup power applications would probably be the first adopted by Air Force bases, although this will vary according to base-specific needs (e.g., northern bases may be more motivated by the advantage of heat recovery).

As far as future use by the government organizations interviewed, two interviewees plan to install additional fuel cells in the near future. Yellowstone National Park plans to install another PEM fuel cell at the park headquarters in Mammoth Hot Springs, Wyoming, by the spring of 2005. The interviewee expects that fuel cells will eventually be used at remote sites throughout the park. One anticipated use is to provide power to the Yellowstone Institute, in the Lamar Valley, and to other remote locations.

The McChord Air Force Base interviewee commented that the base had a positive experience with its PEMFC performance overall and also plans to install additional fuel cells. The McChord Air Force Base has already purchased three fuel cell systems for installation at its Great Lakes sites, and plans to install a fuel cell at their Spokane, Washington site. The interviewee commented that the fuel cells were easy to use and identified important benefits including the ability to snap together modular stacks and the remote monitoring and computer diagnostics capabilities to facilitate maintenance. He saw the PEMFC as providing a significant advantage over generators.

The University of Wisconsin interviewee believes that universities may be particularly interested in fuel cells in the future as environmental stewardship is becoming more important to higher education.

Finally, the NASA interviewee offered recommendations for future R&D. The interviewee believes R&D should focus on durability and reliability of fuel cells’ anodes, cathodes, and membranes. Specifically, he suggests looking at membrane permeability, and development of membranes that do not plug up and “poison” the system at parts per million levels of contaminants. Research might focus on the development of self-cleaning fuel cells, or cells that can operate with contamination at the parts-per-thousands or parts-per-hundreds levels. He also suggests research to improve the resistance of anodes and cathodes to corrosion.

Electric Generating Stations

Summary of Key Findings

In general, the electric generating stations were perceived to be slower adopters of fuel cells than the public and commercial users. Most agree that they will eventually adopt fuel cells, but probably several years after the major issues are ironed out. The electric generating stations interviewed are predominantly operating fuel cells in grid parallel applications for third party users. None of the four current users are utilizing fuel cells to provide a one-way source of power to the grid; however, two of the candidate users are considering grid connected applications. While electric generating stations seemed generally more risk averse than other categories of users, it was thought by one interviewee that utilities could be uniquely positioned to benefit from fuel cell and other DG technologies.

Electric generating stations identified a wide range of priority factors influencing their decisions to invest in fuel cells. As was the case with other user groups, cost was the most critical determinant in the decision to buy and use fuel cells. Other factors considered important to electric generating station interviewees included durability, reliability, power size, physical size, and environmental issues. This user group was unique in citing power size as an important factor. While current fuel cell sizes work well for DG customer applications, it was noted that having fuel cells with an output of 1 MW or more becomes more important as utilities consider grid connected applications. Three of these factors – cost, reliability and durability – were also thought by electric generating station interviewees to be the critical drivers behind commercialization of fuel cells. Interviewees tended to emphasize the need to reduce capital cost over O&M costs, although both were viewed as important.

Users and Applications

The research team interviewed representatives from four electric generating stations that are current users of fuel cells or that have installed and are operating them for a third party. Current users interviewed included: New York Power Authority (NYPA), Omaha Public Power District (OPPD), the Arizona Public Service Company (APS), and Chugach Electric Association. In addition, the research team interviewed four candidate users of fuel cells from electric generating stations: the City of Palo Alto Public Utility, American Electric Power (AEP), WE Energies (WI), and a private utility that asked not to be identified in the report. An overview of the systems used and associated applications is provided in Table 3 below.

Table 3. Overview of Current User Interviewees from Electric Generating Stations

Organization Type/Name	Type	Applications						Date Installed	Still in use? (Y/N)
		Grid Parallel	Grid Independent	Grid Connected	CHP	Backup	Special Applications		
New York Power Authority	200 kW PAFC	X	X					1996	Y
Omaha Public Power District	200 kW PAFC	X						2001	Y
Arizona Public Service Company	5 kW PEMFC						X	2001	Y
Chugach Electric Association	200 kW PAFC	X			X			2000	Y

The NYPA began its fuel cell program in 1996 and currently has the largest fuel cell distributed power program in the country. NYPA operates 12 PAFCs (200 kW each) that serve the city's baseline power requirements. These include both ***grid independent*** applications (e.g., Central Park Police Station) and ***grid parallel*** applications, where the fuel cells switch between operating grid-independently and supplying power to the grid. The PAFCs run on natural gas or biogas produced by anaerobic digestion of biological materials from a wastewater treatment plant. The Authority is also in the process of buying a 250 kW MCFC for installation at a facility of the State University of NY.

The OPPD currently operates a 200 kW PAFC at the Omaha Zoo, which was installed in 2001. The unit operates as a ***grid parallel*** application and supplies 50% of the power requirements to one of the zoo buildings. The utility plans to install a 5 kW propane-fueled PEM unit during 2004 at Offutt Air Force Base. The units would be used to provide ***grid independent*** power to field offices.

APS is using small 5 kW PEM fuel cells primarily for public education and outreach (i.e., ***special applications***). The fuel cells are intended to demonstrate to shareholders that the utility is looking ahead to new power generating alternatives. APS's primary interest in future applications of fuel cells is for ***backup power*** to ensure uninterrupted power supply (UPS). The utility is currently watching the development of SOFC with some interest.

Chugach Electric of Alaska has conducted three fuel cell projects in recent years, all using 200 kW PAFCs. One provided ***CHP*** to a local YMCA, a second provided ***CHP*** to a National Guard building, and the third installation of five 200 kW systems provided ***CHP*** to the U.S. Postal Service in Anchorage. All are ***grid parallel*** applications. Chugach is also providing support to a 5 kW PEMFC system at Elmendorf Air Force Base; however the utility is not considering PEMFCs due to performance and output limitations as demonstrated by current PEMFCs in the marketplace. They are considering an SOFC demonstration project with a private manufacturer.

As for candidate users, the City of Palo Alto Public utility plans to evaluate fuel cells as part of a two-year feasibility study it will conduct on options for local power generation. The utility is not yet considering specific types, but the fuel cells would likely be ***grid connected*** and used to meet baseload requirements.

In the near- to mid-term, AEP is considering megawatt-class ***grid connected*** applications, while in the long-term, as costs become more competitive, AEP will consider multi-kilowatt fuel cells (probably ***grid independent*** or ***grid parallel***) for commercial and residential customers. Eventually, AEP expects to be interested in multi-megawatt scale central electric generation plants.

A third candidate utility user is currently participating in the installation of a 10 kW SOFC at a national park. They are also considering 5 to 10 kW units for residential (***grid parallel*** or ***grid independent)***, possible aggregations of grid connected units to provide grid support at substations, and small hydrogen-powered units to supplement batteries for use in telecommunications, emergency support, and biological applications such as prosthetics.

WE Energies of Wisconsin is not a current user; however the utility will be providing support to a Plug Power PEMFC demonstration project with the University of Wisconsin–Milwaukee and Independence First, which offers housing assistance for the disabled. WE Energies has also worked with EPRI to demonstrate other energy alternatives, including a ***grid parallel***/peak shaving application with a 30 kW Capstone Microturbine and an 80 kW Bowman Microturbine.

Critical Decision Factors

Current and candidate utility users/operators of fuel cells described the importance of the following factors in their decision to buy fuel cells:

- **Cost** – Total cost (both capital and O&M costs) was cited by most interviewees as the single most important determinant in the decision to buy and use fuel cells. Economic value for some is calculated through payback analysis. Financial incentives from government were considered by some to be critical to reducing total costs of fuel cell demonstration systems, although utilities have had limited participation in these demonstrations. OPPD received a $200k grant from DOE, which reduced its total system cost by 17%. NYPA also indicated that DOE and state CERDA grants were important to its purchase decision. However, an interviewee from WE Energies commented that incentives are not currently important to utilities, but they may be when utilities are convinced of the advantages of distributed generation.
- **Power size** – Two interviewees indicated that single-digit megawatt systems would be required to pique their interest. One stated, “It is hard to get anyone in public utility management excited [about fuel cells] until you talk about megawatts.” Another added that minimum size requirements for utility operation are 500 kW. Others said that power size needs would vary depending on the application. If a utility customer requests distributed generation, these would be in the range of 60 to 200 kW. For NYPA, power size has little importance, since all fuel cells are used to meet baseline power requirements.
- **Reliability** – Fuel cell reliability was cited as a critical decision factor for the 200 kW users and some candidate users. Furthermore, the perception that fuel cells have low reliability was cited as a barrier to adoption among candidate users. According to the APS representative, great reliability may eventually compensate for the high cost; currently, however, the utility has little confidence in the use of fuel cells for essential

services. An interviewee said he would be “laughed out of the room” if he suggested installing fuel cells for essential services. For Chugach Electric, the benchmark for reliability is the grid, which is 96 to 97% reliable.

- **Durability** – Five current and candidate users identified durability as an important decision factor. Two interviewees indicated that a fuel cell system should operate for a minimum of 40,000 hours, and preferably 80,000 hours according to one person. For a current PAFC user, the durability and replacement costs of fuel cell stacks are also important considerations. Another interviewee indicated that the benchmark for wider adoption of fuel cells would be 5-year stack durability. Today, stacks may require replacement every year.
- **Start-up speed** – The importance of start-up speed depends on the fuel cell’s application, but it this consideration was very important to at least two interviewees. Grid connected applications providing supplemental power at a substation would allow for longer start-up times. For example, the OPPD’s 200 kW PAFC takes 4 hours to start-up; because the unit is connected to the grid, start-up time was not a critical decision factor. If the utility were interested in peak shaving applications, start-up time would be more important, perhaps requiring a 10 minute start-up, well within PEMFC capabilities.
- **Fuel source requirements** –The price volatility of natural gas and other fuels make fuel source requirements an important consideration to some. Many of the utilities rely on natural gas. NYPA, which uses natural gas and biogas (methane), indicates that the company is constantly looking for other possible fuel sources.
- **Physical size** – For two utilities, physical size restrictions are not a concern. Four others – NYPA, the City of Palo Alto Public Utility, Chugach, and WE Energies – described size restrictions as important. The high cost of real estate in Palo Alto ($1 million an acre) makes size and modularity desirable system features. Size may also be a more important factor for DG systems that are deployed at customer sites, as “customers want the devices but do not necessarily want to see the device.”
- **Environmental and energy efficiency** – NYPA indicated that energy efficiency and environmental features were critical to the utility’s decision to buy the PAFCs, while the OPPD characterized this performance parameter as important but second to cost and quality. Two candidate users cited low emissions as a benefit to help meet permitting requirements and California Renewable Energy Portfolio Standards, which stipulate that 10% of the utility’s power must come from renewable sources by 2008. AEP noted that future carbon constraint mandates would make this an even more important decision factor. However, for WE Energies and Chugach Electric, environmental and energy considerations were not considered relevant to the fuel cell investment decision.
- **Safety** – Three interviewees identified safety as an important decision factor. One interviewee cited hydrogen as a concern, while a second commented that natural gas is more flammable and dangerous than hydrogen. A third interviewee recognized that while hydrogen should be treated with respect, through good engineering, high quality construction, and system monitoring, safety-related events could be controlled. Chugach Electric put additional safety valves and other switches in place to safely disconnect the system from the grid.
- **Proven track record** – Two interviewees cited track record as an important consideration. Their organizations need to know how fuel cells have been deployed, how they perform in a variety of applications, how they perform under load, and how they respond to the demands of the grid. Unfortunately, the track record is not good, according to one interviewee, who commented that some fuel cell companies did the industry a major disservice by overpromising and underdelivering. As a result, the entire

industry “got a black eye.” For two others, track record was not an important consideration, as they relied more on their own demonstration projects.

- **Demonstrating technology leadership** - Two interviewees indicated that the opportunity to be on the forefront of energy technology R&D was an important decision driver.

Factors Driving Commercialization

While a wide range of factors described above were considered important drivers behind each organization’s decision to invest in fuel cells, interviewees from electric generating stations identified five factors as key to the ultimate commercialization and widespread adoption of fuel cells:

- **Cost** – Capital cost was cited as the most important issue by one interviewee and was among the most important issues to all of the other interviewees. One interviewee suggested that fuel cells need to be designed for mass production, preferably using existing infrastructure, in order to lower capital costs. “You have to have automotive costs but aerospace precision.” Others emphasized the importance of government discounts if fuel cells are going to compete with other DG technologies.

  Operating and maintenance costs were also considered important to commercialization. The cost of delivering electricity to a customer’s particular application by way of a fuel cell is far from competitive at this time. The AEP representative said that fuel cells need to get closer to the average retail cost of electricity of 7 cents/kWh in order to be competitive. Furthermore, the frequency of stack replacement needs to be dramatically reduced in order to bring down maintenance costs.
- **Reliability** – Six interviewees emphasized that fuel cells need to demonstrate greater reliability if they are to be widely commercialized. A current user believes that the surge control issue must be addressed if fuel cells are to become more reliable. Another interviewee said that the benchmark for reliability that PEM should be aiming for is 3-nines, which is the standard for the U.S. electrical supply system.
- **Durability** – Five interviewees said that the extending the life of the capital asset and demonstrating long-term performance is of paramount importance. One interviewee stated that utilities require service from a technology in the range of 20 years, not 2, as is the case with some fuel cells. Another indicated that 5-year stack durability was the appropriate target for the widespread commercialization of fuel cells. Warranties were thought by one interviewee as an important indicator of durability, which should be put in place.
- **Environmental regulatory standards** – The NYPA identified clean emissions as a factor that provides an important edge that must be maintained if fuel cells are to be widely adopted. The introduction of mandated carbon constrains would “change the playing field enormously [for fuel cells]” according to the AEP representative.
- **Fuel source requirements** - One interviewee believes that fuel cells will need to run on fuels less valuable than natural gas in order to be widely commercialized.
- **Ease of use** – One interviewee cited ease of use as a major barrier to widespread adoption of fuel cells.

General Perspectives on Market Viability of PEM Fuel Cells

According to the AEP, electric utilities are uniquely positioned to capitalize on the broad range of benefits from stationary distributed technologies, such as fuel cells. These benefits include asset deferral (i.e., deferring the need for additional transmission lines), the potential to provide premium power, peak-shaving and load-leveling, and support in meeting more stringent environmental regulations. At the same time, investor-owned electric utilities have a fiduciary responsibility to shareholders and are not likely to take risks (e.g., pay higher prices) to demonstrate a technology that is not yet commercial. The interviewee believes that most demonstration projects will continue to come from public sources. Another added that "technology adoption in the utility industry is a slow process."

Most agree that utilities will eventually take advantage of fuel cells, but not anytime soon. An interviewee from the City of Palo Alto Public Utility commented, "I am not optimistic about fuel cells [in the short term]"; however, he believes that they will eventually be adopted in a time frame of 3 or 4 years *after* they have solved the problems of cost, durability, and reliability. According to the Chugach interviewee, it could take 10 years to iron out the technology challenges. The City of Palo Alto representative estimates that there will be growth in fuel cell use over the next 5 to 10 years with wide adoption in 15 years if the technology can overcome the challenges it faces.

Key Influencers

Venture Capital Investors

Summary of Key Findings

Venture capital (VC) firms with fuel cell investments see the greatest potential for portable fuel cell applications in the near-term. They see a strong and clear demand for these applications (e.g., computer with a long-running battery) and believe customers are willing to pay a premium price for superior performance. Stationary applications are expected to provide a viable market for fuel cells after the portable market is established. Backup power is expected by VCs to be the first stationary market pursued. As a result, most of the VC firms interviewed are focusing their investments on fuel cells for portable applications, and some are also investing in stationary uses. Five of the six interviewees are investing in PEMFCs, as well as other fuel cell technologies, perhaps suggesting greater confidence in the fit between PEMFCs and these near-term applications. None of the VCs interviewed are investing in fuel cells for grid parallel or grid connected power. Most VC investments are continued investments from previous years; there appears to be very little new VC investment in fuel cells.

The VC firms interviewed identified several priority investment factors that drive their decisions. These can be distilled to five basic concepts: a major return on investment is expected (x10); near-term commercially viability is expected (i.e., 4 to 7 years); sizeable market demand exists; technology is better than the alternatives; and, a clear strategy for delivering value is defined.

As far as the long-term commercialization of fuel cells, like most other interviewees VC firms considered the need to reduce production cost as the most critical factor influencing adoption. Other important commercialization drivers identified included the emergence of a strong market demand, an increase in R&D (emphasizing breakthrough technology developments), and improvements in reliability.

Description of Investors and FC Investments

Six VC firms from the U.S. and Canada were interviewed with the goal of understanding the VC community's perspectives on private sector investment trends in fuel cell technologies, investment decision factors, critical issues driving commercialization, and the overall viability of the PEM fuel cell market. All six of the VCs interviewed specialize in energy technology. While the interviewees requested that names of the VCs be omitted from this report, a description of each VC's investments in fuel cells is provided below.

One VC affiliated with a large electricity producer invests in a suite of technologies linked to the company's core business. The investment arm of the business was established at a time when the company needed to find near-term, alternative methods to producing energy that would yield a financial return. At that time, there was the belief that fuel cells would receive a return in 5 to 7 years. Over the past 5 years the company has invested several million dollars in fuel cell companies. These include producers of SOFC for portable applications; Zinc Air Fuel Cells (ZAFC) for backup, portable, and vehicular applications; and PEMFCs for various low and medium voltage applications.

A second VC was established in 2001 by its electricity generating parent company to invest in emerging energy technologies. Just one of the ten companies that the VC is investing in works with fuel cells, and the VC has no plans to increase its fuel cell activity at this time. The

company receiving investment is developing a micro PEMFC for portable power and battery replacement applications.

A third VC was established as an independent venture funds company, which focuses exclusively on fuel cells and related hydrogen technologies. This VC has funded six fuel cell companies to date. The company's investments include a PEMFC for backup power in the telecom sector, PEMFCs for portable applications (e.g., batteries in forklifts), DMFCs for portable applications (e.g., electronics), and companies developing fuel cell stacks. This VC typically invests $1 million to 3 million in a fuel cell company.

A fourth energy technology VC interviewed has been investing in fuel cells since 1997. Initially, this VC was drawn to fuel cells as a technology with the potential for high efficiency, low emissions, and lower costs. They currently have investments in two fuel cell companies, which develop a 5 kW PEMFC for backup applications and a 1 to 2 watt DMFC for portable applications (e.g., cell phones).

A fifth VC interviewed invests only in hydrogen or fuel cell technologies. Since this VC was formed by a group of hydrogen and fuel cell producers in 2001, it has funded seven companies. The VC typically invests $3 million to 4 million in each company; however total investment needs to be around $20 million to 40 million. The companies receiving investment funds are producing PEMFCs for backup and portable applications, SOFCs for portable applications, and DMFCs for portable applications (e.g., laptops). The VC also funds ancillary services such as a hydrogen sensors and reformers. This VC considers that its investments in the fuel cell and hydrogen industry are doing well, as all have attracted follow-on funding.

The final VC interviewed also invests in a variety of energy technologies. Currently the VC has two fuel companies in its portfolio. One company is developing a next generation micro fuel cell system for portable electronics and wireless applications. The second company is developing a methanol fuel cell technology. This VC is also focusing on portable markets because they require a lower investment, have a better chance of success (competing with the battery market rather than the grid) and there is currently a higher demand for portable solutions. Consumers are more willing to pay a premium for these technologies.

VC Investment Trends in Stationary Fuel Cells

Recent research on the fuel cell investment climate suggests that after a period of continued growth during the late 1990s, private sector investment has declined significantly in the past few years. Between 1997 and 2001, corporate venture funding for fuel cells averaged at least $100 million annually. However, 2002 saw a dramatic decline in corporate venture funding. While early corporate venture funding was focused on the stationary and vehicle applications, recent funding has been directed at portable applications (Breakthrough Technology Institute, 2003).

VC or angel funding has played a relatively modest role in funding fuel cell industry, investing an average of $17.6 million annually over the past 6 years (excluding the year 2000 when an $81 million investment was made in two stationary companies). According to the Breakthrough Technology Institute study, VC companies have shown a relatively consistent level of interest in stationary applications in recent years, and a growing interest in portable applications, which received over $20 million in 2002 (Breakthrough Technology Institute, 2003).

The research team's interviews with VC firms corroborated the findings of the Breakthrough Technology Institute study with respect to applications. The VCs interviewed are focusing their investments on more near-term fuel cell technologies – most are focusing on ***portable***

applications; however some are also focusing on ***stationary backup*** applications***.*** Notably, none of these VCs are investing in grid connected or grid parallel applications for baseload power. The VCs are not banking on any one fuel cell type to address these applications. Together, they are investing in a variety fuel cells and components, including SOFCs, PEMFCs, ZAFCs, and DMFCs. Five of the six interviewees are investing in PEMFCs, perhaps suggesting greater optimism about the near-term prospects of PEMFCs to serve these markets. One interviewee considers PEMFCs best suited for backup power applications that require frequent switches between on and off modes, and SOFCs best for long runtime applications where there is a flat baseload. DMFCs were thought to be useful for the smaller applications (<1kW) because they do not require hydrogen.

The VCs interviewed shared mixed responses with respect to trends in levels of investment. According to one interviewee, the VC community is generally uninterested in fuel cells and most VCs have little interest in energy technologies, estimating that just 5% of VCs invest in this area. He indicated that not all energy-focused VC investors have much interest in fuel cells, although most have invested in some fuel cell-related technology. There appears to be very little new VC investment in fuel cells. Most VC investment in fuel cells is reinvestment into previously funded companies. The industry has moved beyond the emerging technology phase; there have been few success stories, and fuel cells require extremely large investments. Investment levels required are often above what a VC typically provides with a much longer term investment horizon than many VCs are willing to accept.

Another interviewee offered a different perspective, namely that the VC community was slowly becoming more interested in fuel cells. This person noted that some of the larger funds are beginning to make investments, and anticipates that the level of interest will increase once fuel cell companies begin to generate revenue.

Critical Investment Factors

Fuel cells provide the potential for a major shift in the way energy is generated today. Major shifts also take time and can be met with resistance from established industries that stand to be eliminated. While VC firms often look for disruptive technologies, they are cautious of technologies that require significant paradigm shifts.

Management, technology, and market potential are the general considerations that drive VC investment decisions. Interviewees were asked what specific factors tend to drive investment decisions around fuel cells. Respondents cited several:

- Potential for value creation
- Well-defined value proposition and access to customers
- Likelihood of market adoption (e.g., Is there a need in the market that can be met in a better way by a new fuel cell technology?)
- Potential to achieve real milestones in a 2 year timeframe
- “Huge” market demand
- Return of about 10 over the life of the investment
- Strong strategic partnerships established
- Clear strategic plan with a path to market penetration in place
- Company is known by the public
- Provides a lower cost alternative

- Provides greater reliability
- Understanding of safety risks associated with the technology.

One interviewee from an energy fund says that the fund has a 10-year time horizon in which it expects to see returns on its investments. This forces the VC to look at technologies that will be commercially available in 4 to 7 years.

Factors Driving Commercialization

VC interviewees commented on the most important factors they believe to be driving the commercialization of fuels. Cost, R&D, market demand, fuel source/infrastructure issues, and reliability were at the top of the list, followed by several others:

- **Cost** - It is critical that manufacturers get costs down so that fuel cells can be priced competitively, yet this is a major challenge in light of the current size of market demand. One interviewee observed, "You can forecast what it will cost to produce 100,000 units, but how do you finance the losses between the 200 that consumers will buy and the 100,000 that is economically feasible?" According to one interviewee, fuel cells must be easily manufactured in mass quantities using inexpensive materials. Support from the government was also thought to be critical to building this demand and increasing production levels so that prices can come down.
- **Research and development** – Three interviewees commented on the need for a more robust technology to achieve the necessary cost and performance parameters. According to one VC, incremental fuel cell technology will not be enough to make them easier to manufacture and ultimately reduce the cost of fuel cells; a breakthrough technology will be required to accomplish this. Another said that government technology development support will be critical to overcoming the technical barriers prior to commercialization.
- **Strong market demand** – It is important that fuel cells be developed to meet priority user needs and be deployed in those application areas.
- **Fuel source requirements** – There are several challenges associated with hydrogen as a fuel source, including having an accessible fuel infrastructure and a stable fuel supply. One VC notes that government partnerships with industry will be necessary to develop an effective fuel infrastructure solution. Acquiring the hydrogen from natural gas may be a difficult sell with gas prices climbing.
- **Reliability** – Reliability of fuel cells must be improved if they are to adopted commercially and compete with current technologies, according to two interviewees.
- **Physical size** – Because space costs money, it will be important to reduce the size of the physical footprint of the fuel cell to make it more attractive to potential users.
- **Political leadership** – Leadership on the part of politicians is required to ensure that the appropriate incentives are in place to advance the technology and help create the market.
- **Public outreach and education** – One VC believes that public education is required to help eliminate the fear of fuel cells.

General Perspectives on the Viability of the PEMFC Market

Few respondents spoke specifically to the viability of the market for PEM versus other fuel cell technologies. However, five of the six interviewees are investing in PEM fuel cells, as well as other fuel cell technologies.

In general, the VC interviewees believe that the market for portable applications holds the most promise in the near-term, followed by stationary applications, then vehicle applications. In the portable market, for example, consumers would buy a laptop with a 16 hour power supply and would be willing to pay a higher price for it. Many also think that fuel cells will be successful in grid independent applications such as cell phone towers, where fuel cells are lighter and easier to transport than battery packs.

Stationary applications are expected to provide a viable market for fuel cells in the mid-term. Backup power will be one of the first stationary applications pursued, but is anticipated to be a challenge as the whole system cost needs to be considered. Currently, there is little demand for fuel cells to provide backup power, but there is potential when prices and performance are competitive. For example, hotels are interested, but they do not want to pay a premium.

Automotive applications are not expected to be adopted any time soon, according to some interviewees. Hybrid electric vehicles will be widely commercialized first. There is skepticism that the hydrogen infrastructure will happen in this lifetime. It is possible that a smaller scale battery replacement technology will reach this market in the next 10 years.

Policymakers, Regulators and Other Agenda-setters

Summary of Key Findings

The agenda-setter stakeholder group generally believed that fuel cells would be adopted someday if the critical barriers to adoption were effectively addressed in the near-term. However, some interviewees expressed skepticism, pointing out that fuel cells have taken much longer to develop than promised by the industry. Backup power and grid independent power were considered by this group to be the most promising applications for PEM fuel cells.

Cost was also thought by this stakeholder group to be the most significant barrier to fuel cell commercialization. Additional factors identified as important were continued support for demonstration projects, and significant improvements in reliability, durability, and energy efficiency. With respect to energy efficiency, concern was expressed that actual PEMFC performance is falling short of manufacturer product specifications. The development of universal codes and standards was *not* viewed as a major barrier to commercialization by this stakeholder group, which included experts on standards, with the exception of hydrogen standards.

Stakeholders in this group also commented on a wide variety of incentives that they perceived to be an effective mechanism for encouraging fuel cell adoption. Buy-down programs that reduce first costs were thought to be more effective than usage incentives. It was pointed out, however, that such incentives are often provided for DG technologies and fuel cells may still have difficulty competing with PV and other technologies for which discounts are offered. Tax credits and exemptions, net metering laws, and the establishment of renewable portfolio standards were all mentioned by multiple interviewees as potentially effective incentives.

Description of Stakeholder Group

Policymakers, regulators, public sector investors, and other “agenda-setters” play an important role in the advancement and potential commercialization of fuel cells. The research team spoke with 14 different representatives from this broad stakeholder group to understand their perspectives on the viability of the fuel cell market, barriers to adoption, and the effectiveness of policy and financial incentives. Interviewees in this category included representatives from: the California Energy Commission, California Air Resources Board, Next Energy (Michigan), U.S. Fuel Cell Council, Clean Energy States Alliance, American Council for an Energy Efficient Economy (ACEEE), Center for Energy Efficiency and Renewable Technologies (CEERT), Natural Resources Defense Council (NRDC), Fuel Cell Today, National Institute of Standards and Technology (NIST), National Renewable Energy Laboratory (NREL), CSA America, and an independent contractor. The last three representatives listed provided input specifically on the role of codes and standards in promoting or inhibiting the growth of the fuel cell market.

Because these stakeholders offer more of a policy than a technical perspective, many of these interviewees couched their responses in terms of the general fuel cell market, and did not differentiate among types of fuel (e.g., PEMFC vs. SOFC).

General Perspectives on the Viability of the PEM Fuel Cell Market

There were mixed responses to the question of whether stationary PEMFCs would be widely adopted someday. Most interviews said that the viability of the fuel cell market depends on the ability to address the key issues described in the next section. One representative from the California Energy Commission captured the growing skepticism of a few interviewees, stating,

“Experts have been saying that fuel cells have been two years from commercial viability for many years.” Despite the fact that fuel cells have taken longer to develop than anticipated, most respondents thought the barriers would eventually be overcome.

A recent stationary fuel cell study by the American Council for an Energy Efficient Economy (ACEEE) supports the idea that PEMFCs, SOFCs, and MCFCs would eventually compete with non-renewable technologies such as natural gas engines and turbines. The ACEEE findings reflected the opinion of several of our interviewees, who believe that production barriers will begin to disappear within 10 years and that it is reasonable to expect to see commercially viable fuel cells for each of these fuel cell technology types in the next 10 to 15 years (Shipley and Elliot, 2004). One interviewee from the Clean Energy States Alliance was more optimistic about the time frame for fuel cell commercialization, estimating a period of 5 to 10 years before widespread commercialization. Another interviewee from an independent research firm doubted that PEMFC would ever be viable. A representative from NIST believes that PEM manufacturers have a window of about two more years to begin making money on PEMFC units, or they may not survive.

The two application areas that this stakeholder group thinks are most promising for PEM fuel cells are ***backup power*** for UPS and emergency power needs, and ***grid independent*** power for remote residential and private telecom towers. The ACEEE study suggests that 5 to 10kW PEMFCs will be the dominant fuel cell technology for residential and small commercial users. While 100 to 200kW PEMFCs are expected to be more widely used in commercial and small industrial applications, the ACEEE believes that PEMFCs will have difficulty competing with 200 kW MCFCs and SOFCs over the long term as prices come down. MCFCs and SOFCs have higher efficiencies and do not require a reformer. An independent market researcher also stated that SOFCs would likely eventually replace PEMFCs in telecom tower applications.

Factors Driving Commercialization

The agenda-setter stakeholder group was also asked what factors they thought would most likely drive the adoption of PEMFCs.

- **Cost** – Seven interviewees identified cost as a major, if not the biggest, barrier to commercialization of fuel cells. At $4500 per kW installed, a 200 kW PEMFC cannot currently compete with reciprocating engines, which cost less than $1000 per kW installed, and microturbines at $1500 to 2000 per kW installed. ACEEE research indicates that the cost of PEM fuel cells must reach the range of $1500 to 2000 per kW installed in order to compete with these technologies. Reaching this cost range is estimated to require a six-fold increase in installed capacity (Shipley and Elliott, 2004).

  Capital costs are not the only consideration. An interviewee from the U.S. Fuel Cell Council pointed out that while capital costs are higher than people would like, improvements in PEMFC efficiency, durability, and reliability may make PEMFCs more attractive from a lifecycle cost perspective even if capital costs remain slightly higher.
- **Reliability and durability** – According to two interviewees, the industry goal for PEMFC is to achieve a useful life of over 40,000 hours. An independent market researcher noted that no PEMFC is close to reaching that goal and that many in the industry doubt that it can be attained. Another interviewee suggested that PEMFCs need to achieve a stack life of just 2 to 3 years before they are a commercially viable. Even this target, he doubted, was attainable before 2015.
- **Government demonstration projects** – Government supported demonstration projects, focused on likely near-term markets for PEMFCs, were thought by four

interviewees to be a necessary precursor to fuel cell commercialization. However, for advanced demonstration projects to support broader fuel cell deployment, they must also be accompanied by a reduction in capital costs.

- **Energy efficiency** – Two interviewees indicated that overall efficiency improvements are necessary before PEMFCs are widely adopted. A NIST interviewee said that PEMs are touted as getting 30% to 40% efficiency, yet in the NIST fuel cell test facility their PEM unit has only been achieving 20% to 25% efficiency. According to this interviewee, these numbers are consistent with what the DoD saw in its fiscal year 2001 fuel cell demonstration projects as presented at the 2003 Fuel Cell Seminar. (Josefik, N., et al. 2003)
- **Environmental regulatory standards** – Fuel cells benefit from having attractive NOx and SOx emissions as compared to some competing technologies. Interviewees from the California Energy Commission and the Clean Energy States Alliance both believe that increasingly restrictive regulations on emission standards (e.g., in California) will help drive the adoption of all fuel cells.
- **Fuel source requirements** – Reformer requirements for PEMFCs add to both the cost and the physical footprint of the fuel cell installation, presenting a significant barrier to PEMFC adoption, according to an ACEEE interviewee.
- **Public outreach and education** – The NRDC and California Air Resources Board interviewees each pointed out that fuel cell technology is still not very well-known or understood by the public, suggesting that a public education campaign may be an important step in the move toward commercialization.
- **Standby charges and exit fees** – As long as some utilities are imposing standby charges and exit fees on fuel cell users connected to the grid, it will be difficult for fuel cells to compete economically with other electricity sources, according to a CEERE representative.
- **Common codes and standards** - There are four general categories of codes and standards that related to stationary fuel cell applications: 1) Hardware/System Design, 2) Installation/Interfacing, 3) Fuels, and 4) Testing and Evaluation. ANSI/CSA America FC1 is the national system standard published in February 2004, which provides design, construction, operating and quality requirements for fuel cell power systems up to 10 MW. This standard covers fuel cells operating on hydrogen gas, natural gas, methane, and other fuels. The standards for the installation of stationary fuel cells – both outdoor and indoor installations – are defined under NFPA 853 (published in 2003). An important milestone was achieved with the recent establishment of electrical interface standards. IEEE 1547, established in July 2003, defines the requirements and criteria for interconnecting distributed resources with the grid. Several states are in the process of adopting this standard. Two other interconnection standards, NFPA 70 and NFPA 110, provide direction on the electrical link between fuel cells and buildings, and on requirements for emergency power systems, respectively.

  The majority of interviewees familiar with fuel standards and codes recognized the value of having commonly agreed upon codes and standards defined; however they generally ***did not view this as a major barrier to commercialization*** of stationary fuel cells. One person argued, “People use [the lack of common standards and codes] as an excuse. They either don’t realize that the standards are available or they don’t realize that they do not need standards. They just need to know the right people to work with.” In fact, an ACEEE interviewee suggested that it is still too early to expect codes and standards issues to be resolved considering that the technology is still being developed.

A few of the interviewees indicated, however, that there is one important area where codes and standards have not yet been fully developed – the handling of hydrogen fuel. Hydrogen infrastructure, storage and distribution, as well as safety issues (e.g., leak detection) are issues that are currently being evaluated by standards working groups. NFPA and ICC standards for hydrogen are not expected to be established for another 2 to 3 years.

Effective Incentives

Many states offer financial incentives such as grants, loans, and tax incentives, and to a lesser extent financial usage incentives to encourage the adoption of fuel cells and other DG or renewable technologies. Policy and regulatory incentives, such as portfolio standards and net metering, have also been widely adopted. Interviewees were asked what types of current and future financial, regulatory, and policy incentives were thought to have the greatest impact on the adoption of fuel cells. Few of these incentives are directed exclusively at fuel cells; most encourage a suite of DG and/or renewable energy technologies, which include fuel cells.

- **Buy-down or rebate programs** – In general, first cost incentives may be more effective than usage incentives at encouraging the adoption of DG technologies, according to a U.S. Fuel Council interviewee. The interviewee noted that people tend to emphasize up front costs even if usage cost reductions might provide lower life-cycle costs. Several interviewees saw government buy-down or rebate programs as essential to fuel cell adoption.

  In California, such incentives have been very effective for PV technologies; however, fuel cells have not yet benefited from these programs in California. For example, California's Emerging Renewables Rebate Program provides a $3.40 per watt rebate for fuel cell systems up to 30 kW that operate on renewable fuels. While the financial incentive certainly makes fuel cells more cost effective, three interviewees noted that the program has had little impact on fuel cells compared to PV and other DG technologies supported by the program. Similarly, California's Self Generation Incentive Program provides financial incentives to install PVs, wind turbines, fuel cells, microturbines, small gas turbines, and internal combustion engines, focusing on industrial applications of up to 1 MW. Fuel cells using non-renewable fuels qualify for a $2.50 per watt rebate and those using renewable fuels qualify for $4.50 per watt rebate. Yet fewer people have taken advantage of fuel cell systems than the other eligible technologies. While such incentives have proven effective to encourage DG technology adoption, fuel cells still need to be cost and quality competitive with other technologies offered in these programs in order to have an impact.
- **Tax credits and exemptions** – Four interviewees offered state level sales tax credits or tax exemptions as potentially effective incentives for fuel cell adoption. One interviewee thought that federal level tax deductions like those applied to the purchase of hybrid automobiles should be put in place for fuel cells.
- **Portfolio standards** – An interviewee from Fuel Cell Today argued that regulatory approaches are generally more cumbersome than effective; however, state mandates to achieve a specified percent of the electricity portfolio from renewables may be an exception. Three other interviewees agree that setting fuel cell energy production targets as part of the broader energy portfolio would provide an important incentive. They may not effectively support fuel cell commercialization, however, if targets for different renewable technologies are not specified. For example, California state law requires all state utilities to increase their renewable portfolio to 20% by 2010. The timing of this

effort could hinder fuel cell commercialization in California because users are more likely to adopt the more mature technologies.

- **Fuel mix and emissions disclosure** – Several states require electricity suppliers to disclose to customers information pertaining to the mix of fuels used and corresponding emissions associated with electricity production. One interviewee mentioned disclosure as a potentially useful incentive.
- **Utility surcharge policies** – A Fuel Cell Today representative cited Connecticut's Clean Energy Fund as an attractive policy tool that encourages early adopters. The Fund applies a surcharge on Connecticut ratepayers' utility bills and reinvests the funds in renewable energy projects, including fuel cell demonstrations.
- **Net metering laws** – Policies that allow electricity produced by a distributed generator to bank electricity with the utility until it is needed were identified by three interviewees as important incentives to encourage fuel cell use. It was noted however, that net metering will only be effective if utilities agree to pay or are required to pay fuel cell providers competitive rates for electricity sold back to the grid.
- **Standby fees and exit fee exemptions** – Standby and exit fees were enacted in California to help utilities recover their "stranded costs" during the move toward deregulation. The California Public Utility Commission ruled in May 2003 to exempt ultra-clean technologies (fuel cells, reciprocating engines, and other DG technologies that produce emissions below state-established limits) from both standby and exit fees. It is difficult to know to what extent this has helped; however one interviewee believes that this will encourage the adoption of DG technologies, including fuel cells.
- **Emissions standards** – Creating output-based standards for pollutants in emissions (e.g., lbs/MWh) would allow fuel cells and CHP fuel cells to take credit for increased fuel utilization (Shipley and Elliot, 2004). Just one interviewee offered emission standards as a potentially effective means of encouraging fuel cell adoption.

To summarize, a wide variety of incentives are perceived to be potentially effective, with an emphasis on cost reduction incentives. Yet none in and of themselves are expected to have a major impact on fuel cell adoption. Some incentives that provide broad support to DG technologies may put fuel cells at a disadvantage as long as more cost effective and reliable alternatives are available under the same incentive programs.

Industry Stakeholders

R&D Community

Summary of Key Findings

The R&D community believes that the major, long-term market opportunity for PEM fuel cells is in automotive applications, yet they recognize the need to first demonstrate their viability in stationary and other markets. The first market segments that the R&D community expects to open up to PEM fuel cells are the premium power markets for backup applications (e.g., the telecom sector) and the residential, commercial, and military markets for grid independent applications. Significant breakthroughs in research and technology development were seen as paramount to achieving the required customer requirements of cost, reliability, and durability for PEM fuel cells. Priority R&D needs identified included reformer development, membrane enhancements, catalysts, system integration, and hydrogen storage.

The R&D community also highlighted some of the advantages and disadvantages of PEM over competing fuel cell technologies. Some of the key benefits of PEM fuel cells noted were the high power density and relatively compact physical size, low operating temperature, and faster start-up time compared to SOFCs and MCFCs. A common disadvantage cited was the requirement to use a noble-metal catalyst, which is costly and has a low tolerance to contamination. Reliability and durability were considered critical problem areas, and one respondent suggests that the PEM fuel cell industry questions the ability to achieve customer targets. Finally, low operating temperature is also considered a disadvantage because it limits the use of PEM systems for CHP.

Analysis of R&D stakeholders

The research team surveyed the R&D community to better understand some of the advantages and disadvantages of PEMFC, as well as their perspectives on the likelihood of broad fuel cell adoption and the ultimate viability of the industry. The PEM fuel cell R&D community is comprised of stakeholders from various segments including national laboratories, universities, independent research laboratories, fuel cell test and evaluation centers, and fuel cell companies. Since researchers and product developers from fuel cell companies develop, produce, and market complete products, perspectives from these stakeholders are discussed in the fuel cell manufacturer analysis section.

From the broader R&D stakeholder group, fuel cell test and evaluation centers, universities and independent research laboratories were targeted for the first round of surveys for this stakeholder category. A total of 12 stakeholders were contacted and eight responded. Respondents included: Fuel Cell Test and Evaluation Center, Fideris, Inc, University of Connecticut's Connecticut Global Fuel Cell Center, Houston Advanced Research Center (HARC), Georgia Tech's Center for Innovative Fuel-cell and Battery Technologies, the University of Alaska-Fairbanks' Arctic Energy Technology Development, the University of South Carolina's Center for Fuel Cell Research, and Foster Bryan Ltd.

Advantages and Disadvantages of PEM Fuel Cells

PEM fuel cells emerged in the 1960s and until the late 1980s were primarily used by the Army and Navy for a variety of applications. Since then the R&D community has been working to increase the reliability and durability of PEM fuel cells for commercial, automotive, and

stationary applications. PEM fuel cells are low temperature fuel cells with characteristics that make them good candidates for supporting stationary energy requirements. Interviewees from the R&D community identified several characteristics of PEMFCs that corroborate commonly cited advantages.

- **Power density, low weight** – A primary advantage cited by several interviewees from the R&D community is that PEM fuel cells have a higher power density than other fuel cells, which makes PEM fuel cells relatively compact compared to other commonly used stationary fuel cells like phosphoric acid fuel cells (PAFCs) and solid oxide fuel cells (SOFCs). The power density is roughly a factor of 10 greater than other fuel cell systems. This feature also suggests that PEM fuel cells can be miniaturized and brought down in cost for specific applications.
- **Low temperature** – Interviewees from the R&D community consistently mentioned the low operating temperature (60 to 100ºC) of PEM fuel cells as an advantage. One interviewee noted that PEM fuel cells can be air-cooled such that thermal management is minimal. Low temperature allows PEM fuel cells to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. Several interviewees cited low temperature as both an advantage and a disadvantage; see discussion of disadvantages below.
- **Quick-start capability** – Interviewees from the R&D community consistently noted that, compared to other technologies like SOFC or MCFC, PEM fuel cells can be turned on and off quickly and for a larger number of cycles. This is of significant importance for automotive applications and specific stationary applications including grid parallel, peak shaving, and backup power.
- **Lower cost** – Three interviewees from the R&D community stated that PEM fuel cells appear to be lower in cost than other fuel cell technologies, also noting that automakers' interest in PEM technology is creating a large market pull. This large market opportunity may drive industry to lower the cost and increase the reliability of PEM fuel cells in the future.
- **Ease of manufacturing** – Two interviewees from the R&D community cited the low complexity and relative ease of manufacturing of PEM fuel cells as an advantage. Since the polymer film is used as an electrolyte as well as a separator, issues such as sealing, assembly, and handling are less complex than those of other fuel cell systems.
- **Low emissions** – Several interviewees from the R&D community identified the lack of gas emissions from the PEM fuel cell as an advantage. Gaseous emissions from reforming of fuel to be supplied to the fuel cell are recognized as potential source of carbon dioxide.

Interviewees from the R&D community identified the following disadvantages of PEM fuel cells:

- **Use of platinum** – PEMFC requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons. The high cost of platinum contributes to the high cost of the PEM fuel cell, and as observed by one interviewee, this cost will increase considerably as demand for fuel cell automobiles increases. Another disadvantage cited by several interviewees from the R&D community is the extremely low tolerance of the catalyst to poisons such as sulfur and carbon monoxide. This makes it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost.

Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

- **Low temperature/heat output** – Several interviewees from the R&D community noted that the low operating temperature of PEM fuel cells has several disadvantages. Low temperatures contribute to catalyst poisoning; impurities like carbon monoxide bind to the platinum sites and reduce the number of sites available for oxidation. Also, the overall efficiency of the system is lowered as heat produced by PEM fuel cells is limited by the lower operating temperature. This restricts the use of these systems in combined heat and power applications at this time.
- **Cost** – Two interviewees from the R&D community stated that the high cost of PEM fuel cells is an important disadvantage. One noted that the cost of PEM fuel cells will be influenced (lowered) by the emerging automotive market applications.
- **Reliability and Durability** – Several interviewees from the R&D community mentioned reliability and durability concerns. Interviewees noted that the goals for PEM operation are in the range of 40,000 to 60,000 hours, and that the current performance of 1,000 to 5,000 hours is not close to reaching this goal. One interviewee indicated that in stack tests conducted by their organization, stack life did not exceed more than 100 hours before parts has to be swapped. Another interviewee noted that many involved in the PEM fuel cell industry think that PEM fuel cells cannot attain the desired reliability.
- **Fuel reforming** – One interviewee from the R&D community identified the technical challenges of fuel reforming as a disadvantage. Another interviewee also indicated that considering the energy required for hydrogen production, fuel cells are actually less efficient than internal combustion engines.
- **Energy use** – Production of hydrogen for PEMFC is recognized as fairly energy intensive and environmentally hazardous. A majority of the interviewees emphasized that hydrogen should be generated with renewable resources. A life-cycle analysis of hydrogen generation and use in fuel cells might suggest that more serious consideration be given to hydrogen from solar energy or biomass sources.

When questioned about the most likely competing technologies to PEM fuel cells in 2015, most interviewees indicated that PEM fuel cells are the most applicable technology for automotive applications. They could face competition from batteries and oil, if the price were to become more competitive. One interviewee also stated that the only competing technology with PEM fuel cells in the near future is the use of bio-energy. For stationary applications, several interviewees mentioned SOFCs as the primary competing technology for PEM fuel cells in 2015. The higher efficiency, direct intake of natural gas, and production of AC electricity were cited as advantages of SOFCs. Other interviewees noted that conventional technologies, including electricity from the grid, natural gas turbines, diesel generators, etc., provide ongoing competition. The interviewees identified small residential applications as the most likely markets for PEM fuel cells.

PEM Fuel Cell Stationary Applications

Interviewees from the R&D community provided the following input on the likely evolution of stationary markets for PEMFCs. The categories have been arranged in the order of importance as cited by the interviewees:

- **Backup** – A majority of interviewees indicated that backup premium power markets are the most likely to evolve in the short-term, noting that server farms, call and computer

centers, manufacturing operations (electronics), and cell phone towers have already adopted this technology. While one interviewee from the R&D community considered standard backup power for brownout or blackout conditions as the most likely short-term market (1 to 2 years), other interviewees did not identify standard backup power as a likely market.

- **Grid independent** – Interviewees from the R&D community consistently identified grid independent applications as a market that will most likely evolve, specifically mentioning the possible market for residential use. Remote homes were also cited as a possible market for fuel cell technology. One interviewee noted that the off-grid (grid independent) market will evolve and will create opportunities for the entire fuel cell industry.
- **Special applications** – Interviewees from the R&D community named several likely special applications for PEMFC, such as lift trucks, cathodic protection for pipelines, and pump stations. The interviewees noted that many of these applications have not been fully explored, and encouraged DOE to find and pursue these opportunities. One interviewee also mentioned the propane industry, commercial vehicle fleet users (e.g., FedEx), military and aviation ramp support, the U.S. Postal Service, and city buses as groups currently exploring or experimenting with PEM fuel cells that should be pursued to adopt PEM fuel cells. One interviewee also suggested military applications, which require low-noise and low thermal signature energy sources.
- **Combined heat and power (CHP)** – Only one interviewee from the R&D community noted that fuel cells in grid independent configuration will evolve to supply power and heat for individual institutions such as hospitals, and that these applications are not necessarily limited to PEM fuel cells.
- **Grid connected and grid parallel** – Interviewees from the R&D community did not identify grid connected or grid parallel applications as a likely market.

Early adopters in the stationary PEM fuel cell market were identified as niche, premium backup power users, which included the telecom industry, grid independent homes, the military, large manufacturing facilities, institutions, and facilities in areas that do not meet the National Ambient Air Quality Standards (NAAQS), also known as non-attainment areas. One interviewee indicated that current adopters are using “other people’s money” as it is still not a commercially viable technology.

Factors Driving Commercialization

Interviewees from the R&D community provided input on the critical factors influencing the widespread adoption and commercialization of PEM fuel cells. When asked about codes and standards, public policy support (financial incentives and rules), and R&D, the interviewees tended to identify R&D as the most critical, while noting that all of the requirements are important. The following summarizes their input on each requirement:

- **Research and development** – All interviewees from the R&D community identified research as a major area where more attention is needed, specifically on membranes, catalysts, systems integration, and hydrogen storage (described below). Government funding for R&D is particularly important considering the long commercialization life cycle of fuel cells. One interviewee suggested that DOE should place more of an emphasis on understanding the fundamentals of the technology rather than supporting demonstration projects, noting that it is difficult to compete with prototypes in Japan that are strongly supported by the Japanese government.

- **Reformer development** – Several interviewees identified the development of a reformer as critical to the commercial success of PEM fuel cells for stationary applications. Interviewees suggested that natural gas and propane based reformers be developed for generating hydrogen on-site for stationary applications. Over half of the interviewees from the R&D community stated that the government should focus its efforts on reformer development or other means of on-site hydrogen generation, such as the use of renewable energy and electrolysis. Another interviewee noted that the reformer is already relatively mature and perhaps research into alternative technologies for producing hydrogen should be addressed.
- **Availability of hydrogen, storage and safety** – Just under half of the interviewees stated that the government should support the *development of hydrogen infrastructure* to supply hydrogen as a commodity to homes, rather than focus on reformer development. Several interviewees stated that a hydrogen infrastructure will not be practical because it is too costly, and one interviewee suggested that a regional or site-specific distribution infrastructure (e.g. a small town that would distribute hydrogen to homes) as a more practical alternative. Onsite generation using fuel delivered to homes including propane and natural gas is another option.

  Other interviewees emphasized the need for more research on *hydrogen storage*, suggesting both solid-state and liquid storage as viable options. It was suggested that unitized regenerative fuel cells could be a good option for *in-situ* hydrogen and electricity generation. Another interviewee indicated that the hydrogen economy is within the realm of chemistry and physics, but engineering issues like the cost of equipment and safety have driven the price too high.

  Most of the interviewees from the R&D community stated either that *hydrogen safety* is not a major issue for the public, or that they do not follow the issue of the public's perception of hydrogen safety. However, they recognize that public perception of hydrogen has been marred by the Hindenburg disaster. Several interviewees suggested that public familiarity and information about hydrogen will mitigate safety concerns.
- **Systems integration** – Two interviewees from the R&D community identified systems integration as an area that requires development to facilitate the adoption of PEM fuel cells. There are varying views regarding optimal systems design. One interviewee believed that fuel cells should be designed to fit a specific application (e.g., backup power applications for telecom, residential CHP) rather than as a component replacement. Another interviewee thought that integrated systems using renewable sources to produce hydrogen with the fuel cell should be developed to bring down the overall cost of systems. These systems could be widely applied in remote areas where fuel sources are not available.
- **Cost** – Several interviewees from the R&D community noted that cost (specifically, a better cost-to-performance ratio) will drive PEM stationary fuel cell adoption. One interviewee noted that the cost of PEM fuel cells is quickly becoming competitive for premium backup power applications for small commercial and military applications. Another commented that the cost of PEM fuel cells will be reduced if automotive companies continue to push the technology. Fuel cell cost may be less when one considers the high costs associated with electricity distribution systems that could be avoided by developing distributed, off-grid systems.
- **Durability** – Most interviewees from the R&D community noted that stack durability/reliability is an important issue that needs to be addressed if PEMFCs are to be widely adopted. One interviewee indicated that this issue can be solved while another interviewee doubted that the required targets of 40,000 to 60,000 hours are achievable.

- **Energy efficiency** – Several interviewees from the R&D community identified efficiency as an impediment to commercialization, and noted that PEM fuel cells may not be able to compete with a modern combined-cycle gas turbine. The PEM fuel cell is only 35% to 45% efficient and has limited ability to capture heat.
- **Government incentives** – Three interviewees suggested that financial incentives that encourage fuel cell use (e.g., tax credits) would encourage PEM commercialization for stationary applications. One interviewee suggested that sales tax exemptions, industry recruitment, and financial incentives to manufacturers would accelerate the commercialization of fuel cells. Another interviewee estimates that a government investment of approximately $100 billion is needed in the coming years to push the commercialization of fuel cells.
- **Codes and standards** – Two interviewees from the R&D community noted that the development and maturing of codes and standards (e.g., National Fire Protection Association, building codes and standards, fuel codes) is important. One interviewee noted that codes are needed to allow the design of facilities with hydrogen or a reformer, and that fire protection and first responder personnel need to know information such as critical system components and location of hydrogen shut-off. Another interviewee stated that the American Society of Mechanical Engineers has been a leader in this area.

General Perspectives on Viability of the Industry

Interviewees from the R&D community provided input on the overall viability of the PEM fuel cell industry that closely mirrored the critical requirements and barriers to adoption that have been gathered from the literature. The reformer, stack, and systems integration were each identified by different interviewees as areas that will undergo critical change in the next 10 years. Reformers were also identified as a critical area of research and a required need for successful stationary PEM fuel cell development. Other critical research and development needs identified include the stack membrane and catalysts to increase reliability and durability of the fuel cell. One interviewee emphasized that power conditioning (e.g., connecting DC power to the grid or automotive applications) needs to be further developed. With respect to government funding for fuel cell research, one interviewee suggested that the DOE Small Business Innovation Research (SBIR) program has become too product-specific in working toward a finished product rather than funding innovative research. The interviewee also noted that technology companies like Polyfuel (an Intel Company) and Neopower are quite innovative and that DOE should consider providing funding to these types of technology companies.

The general feeling in the R&D community is that the market opportunity for PEM fuel cells in large automotive markets will drive application in stationary and other markets. However, to achieve this, significant breakthroughs in research and development will have to occur. In the meantime, success in smaller stationary markets will provide revenues, testing platforms, and public acceptance of fuel cell technology.

Fuel Cell System and Component System Manufacturers

Summary of Key Findings

Not surprisingly, stakeholders in the fuel cell system and component system industry are optimistic about the future of PEM fuel cells. They also have a strong understanding of the limitations of the technology and the ability of PEM fuel cells to compete with other technologies in stationary applications. The vast majority of companies surveyed expect backup power to be the first viable market for PEM fuel cells. In order get beyond niche applications and to widespread adoption of PEM fuel cells, manufacturers believe that five factors will be most critical. These include lowering life-cycle costs; developing a hydrogen infrastructure; ensuring end user acceptance; improving product efficiency, reliability, and durability; and developing universal codes and standards.

Description of Fuel Cell Manufacturer Stakeholders

The stationary PEM fuel cell industry is comprised of different groups of stakeholders, including fuel cell system manufacturers, component system manufacturers, system integrators, and installers. Manufacturers of PEM fuel cells develop and produce complete products by integrating various components into systems to meet required specifications. Over the past several years, numerous mergers and acquisitions have occurred and some manufacturers have emerged as leaders in the PEM fuel cell industry for stationary applications. Suppliers to the PEM fuel cell industry range from manufacturers of bipolar plates, to membrane developers, catalyst suppliers, and balance of plant components. System integrators and installers have emerged more recently as distribution channels for PEM fuel cell products for various communication applications.

Representatives from these manufacturer groups were contacted for more information on their products, and for their perspectives on important PEM fuel cell commercialization drivers for stationary applications and the overall viability of the industry. All data from this stakeholder group were collected through surveys during the first phase of this project. The survey was conducted at Battelle's second scenario analysis workshop in Washington D.C. on May 12, 2004. There were 17 respondents to the initial survey of fuel cell manufacturers. Formal interviews will be instituted for these stakeholders during Year 2 of this project. These interviews are expected to help the research team identify potential participants in the Stakeholder Partnership Team.

Factors Driving Commercialization

Battelle developed a list of 19 key drivers considered critical to the commercial success of PEM fuel cells and asked the fuel cell manufacturers to rank order them on a scale of 1 to 5, with 5 being very important and 1 being not important at all. The five most important commercialization drivers identified by this group are listed below, followed by their observations on other important commercialization factors. Table 4 at the end of this section provides a quantitative summary of the importance of each driver to the commercialization of stationary PEM fuel cells.

1. **Product efficiency, reliability and durability** – Nine of the 17 respondents identified product efficiency, durability, and reliability as key drivers for commercial success of PEM fuel cells. Additional R&D for key components, along with field demonstrations, was identified as a necessity to achieve required durability.

2. **Lowering life-cycle costs** – Ten of the 17 respondents identified the need to lower life-cycle costs, including capital, operating, and maintenance costs, as a key requirement to commercialization success. To achieve a significant breakthrough in manufacturing, improvements in balance of plant, development of incentives, economies of scale, establishment of common codes and standards and significant government investment will have to occur. Manufacturing breakthroughs could include technological advancements in the components, subsystems, products, and fuels for PEM fuel cells relative to technological advancements in fossil fuel technologies. Key advancements in power electronics, systems integration, and energy storage were also identified as important to reducing life-cycle costs.

3. **Hydrogen fuel infrastructure** – Nine of the 17 respondents identified the need for hydrogen infrastructure as a key requirement to drive adoption of PEM fuel cells in a variety of markets. Stakeholders indicated that getting hydrogen to the customer was a priority. Other critical needs identified were: practical renewable methods for production locally; hydrogen storage technologies; low-cost conversion technologies; and clean production of hydrogen.
4. **End user acceptance** – Nine of the 17 respondents identified end user acceptance as key to achieving wide commercial success. This factor was considered an absolute show stopper—without consumer acceptance the product will not be able to survive.
5. **Common codes and standards** – Six of the 17 respondents identified common codes and standards as a key driver for the commercial success of PEM fuel cells. Universal codes and standards for various markets will enable entry and application. Federal, state and local governments need to understand that fuel cells are a distributed energy option, and should provide required education for inspectors and other parties involved in permitting.

Other factors that the manufacturers indicated would influence PEM fuel cell commercialization included:

- **Funding for R&D** – Five of 17 respondents identified the need for funds for R&D and demonstration as critically important. Many stakeholders are concerned about the source of investment capital needed for fuel cell development and believe that the government can provide a means of support to push emerging technology commercialization.
- **Competing technology development** – Stakeholders identified development of SOFCs, clean diesel, stirling engines, batteries, and renewables as both potential barriers to and drivers behind PEM fuel cell application and development.
- **Government incentives** – More than 75% of the stakeholders recognized financial incentives to have the greatest impact on PEM fuel cell commercialization. In addition to the commonly suggested financial incentives, respondents provided several other recommendations including: funding for businesses intelligence and planning; forced regulation on gasoline and other fuels; a tax exemption for hydrogen fuel; and development of dual use stack technologies for automotive applications.
- **Other Key Drivers**
    - Three of the 17 respondents identified environmental demand and regulations and the development of dual use technologies as a driver.

- Two of the 17 respondents identified national policy on fuel cells, federal and state incentives and grid reliability as key drivers.
- One of the 17 respondents received identified manufacturing breakthroughs, success and failure of first market introduction and balance of plant as key drivers.

Table 4. Importance of Drivers to Commercialization of Stationary PEM Fuel Cells

Driver	Very Important (Rated 5)	Important (Rated 4)	Less Important (Rated 3)	Not Important At All (Rated 1,2)
Hydrogen Fuel Infrastructure	53%	18%		29%
Manufacturing Breakthroughs	12%	58%	24%	6%
Lowering Life-cycle Cost	71%	29%		
Environmental Demands and Regulation	29%	29%	24%	18%
Grid Reliability	12%	29%	29%	29%
Federal/State Tax Credits and Incentives	6%	41%	12%	41%
Energy Storage Technologies	18%	29%	35%	18%
Balance of Plant Technology Development	24%	29%	24%	24%
Source of Big Capital	6%	29%	35%	29%
Product Efficiency and Reliability	76%	24%		
National Policy on Fuel Cells	18%	29%	35%	18%
Funding for Research	24%	18%	47%	12%
Success and Failure of First Market Introduction	24%	35%	29%	12%
Dual Use Technologies	18%	65%	12%	6%
Natural Gas Prices		47%	29%	24%
Energy Security	6%	41%	24%	29%
End User Acceptance	29%	59%	12%	
Common Codes & Standards	65%	29%	6%	
Competing Technologies	18%	41%	29%	12%

All respondents noted lowering life cycle costs, product efficiency, reliability and durability as very important or important. When asked to rate the importance of the driver, 71% of the stakeholders ranked lowering life-cycle cost as very important and 29% as important; over 90% believed that end user acceptance was either very important or important; 100% of respondents identified product efficiency, reliability, and durability as very important or important; and over 90% of the stakeholders identified common codes and standards as very important or important. It is important to note that of the 19 drivers, no stakeholder identified energy security as a critical driver for PEM fuel cell commercialization. Though 50% of the stakeholders surveyed rated it as important, they did not feel that it was critical enough to be ranked in the top five. Similarly, energy storage technologies, source of big capital, and natural gas prices were only considered important to 30% of the stakeholders surveyed.

Applications of PEM Fuel Cells

Stakeholders were asked to identify the stationary market likely to be commercialized first based on the current developmental status of PEM fuel cells. All respondents but one identified ***backup power*** as the first market that is likely to be commercialized. Stakeholders believed that premium power markets would emerge first, followed by conventional backup power markets. Just one respondent identified ***grid independent*** applications as the first market to be commercialized.

Responses from the stakeholders varied on the competitive cost per kW required to compete in these applications. They identified a range of $800 to $3000 per kW. Two respondents suggested that fuel cells may become cost competitive for backup power by 2005 at $3000 per kW, while others indicated that they would not be competitive until 2010. Batteries (i.e., lead-acid and lithium-ion), diesel and internal combustion engine generator sets, and microturbines were identified as the primary competing technologies to fuel cells for backup applications. For grid independent markets, the stakeholders indicated that PEM fuel cells could be cost competitive by 2012 with subsidies and tax incentives. The primary technologies that they will have to compete with for grid independent applications are diesel engines and microturbines.

General Viability of PEM Fuel Cells

Stakeholders in this community have a vested interest in the success of PEM fuel cells. They are generally optimistic about the future of PEM fuel cells, but understand the limitations of the technology and competition from other technologies for stationary applications. It is recognized that success in stationary applications will provide valuable development opportunities for the long-term automotive markets. It is interesting to note the recent shift in trend from pursuing purely automotive research and application to a stationary/vehicle dual-use technology approach. Some stakeholders believe that current and future stationary niche markets, such as premium power backup applications, are sufficient to build a business case for the product. Despite that, the industry is still in the precommercial or emerging stage and will require long-term government support to first overcome current technical challenges and next to achieve widespread market penetration in all stationary markets.

Fuel Suppliers

Summary of Key Findings

Like other industry stakeholders, fuel suppliers recognize that PEM fuel cells must be successfully commercialized in stationary applications before automotive applications are

pursued. Within the stationary market, most believe that backup power will be the first application to open to PEM fuel cells.

Comments from the hydrogen community highlight the classic chicken-egg conundrum, recognizing the importance of hydrogen availability to the commercialization of PEMFCs, fuel suppliers focused their comments on factors thought to be influencing the development of the hydrogen economy. The cost of hydrogen production, storage, and use; development of hydrogen codes and standards; and hydrogen-focused government incentives were considered among the most important factors. However, fuel suppliers also believe that the success of PEM fuel cells is critical to the establishment of hydrogen as an energy carrier, and therefore have a vested interest in the success of this technology.

Description of Hydrogen Stakeholders

Battelle's research on commercialization factors required for the success of PEM fuel cells suggests that availability of hydrogen on-site was an important precursor to the widespread adoption of PEM fuel cells in stationary applications. Though automotive markets are identified as the big prize to the hydrogen community, success in stationary markets is needed to push forward cost reductions and performance enhancements of PEM fuel cells.

Surveys were conducted with fuel suppliers to better understand the issues associated with hydrogen production, storage, and delivery as they relate to PEM fuel cell technology. Seven individuals were interviewed from technology venture groups and joint ventures of traditional oil companies, private industry research organizations, and industrial gas companies. Companies interviewed included: National Hydrogen Association, Conoco Phillips, Linde Gas, Air Products and Chemicals, Chevron Technology Venture, Texaco Ovonic Hydrogen Systems, and GE Global Research. Additional stakeholder perspectives on the hydrogen economy can be found in Appendix C.

Factors Driving Commercialization

Fuel suppliers identified four factors thought to be critical to the adoption and commercialization of PEM fuel cells:

- **PEM fuel cell costs** – The barrier to adoption that was consistently mentioned by fuel suppliers was the cost of PEM fuel cells (both capital and operating costs). One interviewee noted that mass production of PEM fuel cells is required to achieve economies of scale savings, and that a large investment in fuel cell manufacturing plants is needed. Another interviewee stated that PEM stationary fuel cells must become more attractive economically than hydrogen internal combustion engines in order to be adopted.

  It was noted by one interviewee that PEM fuel cells are cost competitive for small applications (e.g., a 1 kW fuel cell that uninterruptible power supply (UPS) is using for backup power), and may be more cost-effective if used to supply base power. Fuel cell cost may be less important to companies for which power outages are extremely expensive (e.g., glass manufacturing); it was thought by one interviewee that certain manufacturers would be willing to pay up to $5,000 per kW for fuel cell power. On the other hand, automotive manufacturers may be willing to pay only $35 to $40 per kW.
- **Reliability and Durability** – Several fuel supplier interviewees noted that stack durability/reliability was a potential barrier to adoption in both stationary and automotive

markets. Technical challenges with membranes were cited as key drawbacks of the technology.

- **Structure of the electric industry** – One interviewee from the fuel supply industry noted that electric utilities tend to resist fuel cells because fuel cells may be seen as encroaching on their turf. The interviewee also stated that regulations for supplying power to the electric grid differ from state to state, and a great deal of regulatory streamlining could be done to promote the connection of fuel cells to the electric grid. The interviewee noted that these barriers are at least as big as the technical and cost barriers described above.
- **Government incentives for fuel cells** – One interviewee indicated that government incentives are required to encourage early adopters of fuel cells.

Interviewees identified several specific factors influencing the development of the hydrogen economy, which may also impact the adoption of PEM fuel cells.

- **Cost of hydrogen production, storage and use** – The barrier to adoption that was consistently mentioned by interviewees from the hydrogen community was the cost of hydrogen production, storage, and use technologies, as well as costs of the hydrogen infrastructure. Several interviewees from the hydrogen community stated that hydrogen must be available to consumers at a cost similar to fossil fuels to be adopted, noting that this will be achieved through low-cost production methods and incentives. One interviewee indicated that his company's cost of production at point of use was approximately $3 to $4 per kilogram. To be a viable alternative, hydrogen will have to be cost competitive with gasoline in the $1.5 to $2.0 per kilogram range.
- **Hydrogen codes and standards** – Several interviewees in the fuel supply industry noted that consistent regulations, codes, and standards for hydrogen are required. Interviewees noted that the industry is resorting to adapting codes from other substances, and that hydrogen codes that do exist treat hydrogen as a highly hazardous gas rather than as a fuel.
- **Political uncertainty** – One interviewee from the fuel supply industry noted that fear, uncertainty, and doubt about global warming in the public and government arenas provide an excuse for not developing the required hydrogen infrastructure.
- **Sustained low oil prices** – One interviewee stated that sustained low oil prices ($20/barrel) would undermine the attractiveness of hydrogen.
- **Competing technology improvements** – Continued performance improvements in hybrid vehicles or internal combustion gasoline engines were also thought to impede the growth of a hydrogen economy.
- **Hydrogen reforming** – One interviewee identified onboard reforming as the best option to produce hydrogen, regardless of whether it is made from water, propane, or methane. This interviewee also noted that the current "gas station" mentality needs to be avoided, and suggested instead that individual houses could have reformers connected to their natural gas pipelines.
- **Government incentives for hydrogen** – Many interviewees noted that the government should provide incentives to promote the hydrogen economy, and stated that there are little or no economic incentives driving the commercial deployment of hydrogen technologies. Interviewees from the fuel supply industry suggested that the U.S. government add a 25 cent tax on gasoline to fund hydrogen research, or mandate stricter emission standards for conventional fuels (noting that this would not necessarily

lead to hydrogen and could promote other alternatives). One interviewee also noted that political support could accelerate adoption of hydrogen, but is unlikely to cause a wholesale change. The interviewee provided the example that if the Kyoto Protocol was ratified and the signatory countries made a commitment to greenhouse gas reductions, there would be an increased global impetus toward hydrogen.

- **Development of hydrogen storage technologies** – Hydrogen storage is a key requirement to sustain long run-time stationary applications and automotive applications. Several interviewees cited the need to develop economical storage applications for hydrogen.
- **Public outreach and education** – Two interviewees from the fuel supply industry suggested that the most critical need is that government, industry, and the general public work together to promote the development of the hydrogen economy. The interviewee stated that the government needs a "good vision" and plan for the hydrogen economy, and that the public needs to be educated about the hydrogen economy to foster support and create a market driver.
- **Demonstration vehicle systems** – One interviewee from the fuel supply industry suggested that cost-effective demonstration vehicle systems are needed, and that these demonstration vehicles will build demand. The interviewee noted that these systems must have the range and performance that is required for specific applications (e.g., hybrid delivery vehicles, buses, off-road vehicles).
- **Application of transition technologies** – One interviewee from the fuel supply industry suggested the application of transition technologies, such as hydrogen/internal combustion hybrid engines, is required to build the credibility of hydrogen use.
- **Environmental stewardship** – Multinational companies, including major oil companies and automakers, face growing demands from shareholders to operate in a more sustainable manner. One interviewee stated that in order to protect their global market positions, these companies may need to promote their capabilities in hydrogen as a sustainable energy source. That same interviewee commented that global environmental stewardship is not as a strong a factor in the U.S., hence emissions and climate change are not thought to be meaningful drivers. Another interviewee believed, however, that consideration of the total emissions of hydrogen, when factoring in hydrogen production, distribution, and use, could accelerate or hinder the hydrogen transition, depending on the fuel source.

PEM Fuel Cell Stationary Applications

Interviewees from the fuel supply industry provided a wide range of responses on the primary stationary markets for fuel cells and on the order in which they will likely evolve.

- **Backup Power** – While backup power, including premium, UPS, and power for brownout or blackout conditions, was identified by five interviewees from the fuel supply industry as a likely initial market, two other interviewees believe that backup power will be the last market to develop. One interviewee stated that backup premium power applications already exist, and that other backup power applications will drive new markets for fuel cells.
- **Special applications** – Two interviewees from the fuel supply industry stated that special applications (e.g., semi-stationary applications such as ground-power units for aircraft) will evolve either first or after backup applications.

- **Portable power** – One interviewee from the fuel supply industry stated that portable power applications will evolve first.
- **Grid connected** – One interviewee stated that grid-sited power (e.g., large utilities) will be a difficult market because of the large infrastructure that is already in place for utilities.
- **Grid parallel** – One interviewee from the fuel supply industry stated that peak shaving power may evolve in National Ambient Air Quality Standards (NAAQS) non-attainment areas if a cost of approximately $500 per kW can be achieved.
- **Grid independent** – One interviewee suggested that grid independent power for small communities managed by public power purchasers or investor-owned utilities are possible markets for fuel cells. However, PEM fuel cells may have to compete with SOFC technology in this category.

Interviewees from the fuel supply industry stated that stationary applications of PEM fuel cells will be successfully commercialized before automotive applications because the price targets for stationary applications are not as extreme as for automotive applications. Specifically, several interviewees noted that small and medium stationary applications will be commercialized first (1 to 5 kW applications in 3 to 5 years, and applications up to 100 kW in 8 to 12 years), and that this would overlap with certain automotive applications (5 to 7 years for off-highway and specialty use vehicles). One interviewee noted that some small and medium stationary applications are already in operation, such as a 75 kW General Motors fuel cell at a Dow Chemical plant in Texas. Interviewees stated that the last steps in commercialization of PEM fuel cells would be automotive applications for personal highway vehicles (10 to 15 years), and large stationary applications (15 to 20 years for 1 to 5 MW applications).

General Perspectives on Market Viability of PEM Fuel Cells

Fuel suppliers believe that the success of PEM fuel cells is critical to the establishment of hydrogen as an energy carrier. They underlined the importance of government support through public policy and funds for research and development and demonstration to push the commercialization of PEM fuel cells for both stationary and automotive applications. At this time, they believe that government resources are spread over too many areas. To allocate resources appropriately, interviewees suggested that the government needs to have clear objectives on the required economics of the hydrogen economy.

Most interviewees believe that the benefits of PEM fuel cell commercialization in stationary markets are small, and the technology could face stiff competition of developing and existing alternatives. Interviewees highlighted in importance of public-private partnerships like the California Fuel Cell Partnership to foster collaborative research and development and address issues like safety, codes, and standards.

Next Steps

This study has provided a summary of the perspectives of various stakeholders in PEM fuel cell commercialization, including current and candidate users, key influencers, and industry members. The research team's analysis of the views of these stakeholder groups on the timing and likelihood of PEM fuel cell adoption, priority applications areas, critical decision factors driving fuel cell investment decisions, and issues driving PEM commercialization, will be further validated with stakeholders and expanded upon in Year 2. The following next steps have been identified for Year 2 of the Stakeholder Involvement task:

- Distribute Year 1 findings – The interim report will be distributed to all interviewees and survey respondents for this study. This is expected to better connect industry members with end users and other key influencers.
- Conduct surveys and telephone interviews – The research team will conduct additional surveys and telephone interviews in order to fill in information gaps and validate findings from the interim report. Emphasis will be placed on current and candidate users in target market segments identified. The market assessment from Task 1 will be used to identify other candidate and current users to survey and interview.
- Conduct focus groups – The team will conduct at least three focus groups with the different users and with industry stakeholders. The first focus group will involve current and candidate PEMFC users from a variety of targeted market sectors. A second focus group will involve members of the R&D and manufacturing community. Focus group participants will be identified largely through contacts established to date by the research team. A third focus group will be conducted with either policy/agenda setters or a specific user community. The focus will depend on information needs and research gaps at the time to support commercialization strategies or user community acceptance.
- Based on availability of Year 2 funds, Battelle will analyze policies that support PEM fuel cells – The research team will work with policymakers and other key agenda-setters to determine how existing government policies and incentives support, inhibit, or preclude deployment of PEM fuel cells in demonstration projects and ultimately mainstream markets. The analysis will focus on a specific state that has implemented progressive fuel cell policies (e.g., California, Connecticut, Ohio) and assess the impact these policies and incentives are having on the development of the market for fuel cells.
- Participate in fuel cell conferences – The team will participate in fuel cell seminars and working sessions, and seek out opportunities to present research findings at these meetings.
- Establish the Stakeholder Partnership Team – The Stakeholder Partnership Team will be responsible for providing guidance and peer review for the technology and market analyses. During Year 2, candidate members of the team will be identified and invited to participate. Once finalized, the team will meet to review the research team's analyses.

Key deliverables from these planned stakeholder development activities in Year 2 include:

- An assessment of specific user requirements in priority market segments.
- A policy assessment of the impact government incentives in one state are having on the adoption of PEMFC.

Appendices

Appendix A

Interview Protocols and Surveys

Appendix A: Interview Protocols and Surveys

Questions for Current Fuel Cell Users

Interviewer:

Interviewee/Affiliation/Title/Contact info for them:

Date:

Opening:

Hi, my name is _____ with Battelle Memorial Institute. We are currently working on a project for U.S. Department of Energy to help them understand the needs of both public and private users of fuel cells, specifically the Proton Exchange Membrane (PEM) hydrogen-based fuel cell for stationary applications. We would like to get your input on this subject. Is this a good time? (If yes, continue, if not set up a time for later). The interview should take around 20-30 minutes.

The Department of Energy is interested in understanding the economic and implementation issues associated with the adoption of fuels cells and what it will take for fuel cells to be accepted by consumers. The Department of Energy will use this information to help make funding decisions, to narrow and direct their R&D efforts in fuel cells to feed into their strategic planning process, and possibly to influence policy and regulations.

1. Are you a current user of fuel cells?

   If yes, continue survey.

   If no, then ask: Are you considering using fuel cells at work or home sometime in the future? If yes, then go to "Questions for Candidate Users of Fuel Cells" survey. If no, thank them for their participation and end survey.

2. How is your organization currently using fuel cells? (open ended question to get them to talk)

3. For what application are you currently using fuel cells?

   - Backup power (assumes the FC system is not connected to the grid)
   - Remote power (assumes the FC system is not connected to the grid, but this is the users full-time power source, example is Central Park's Police Station where they didn't want to run transmission lines into the Park.)
   - Peak shaving power (could be on-grid or off-grid BUT assumes that the user is typically on-grid and this unit would be used to lower their costs during peak time. They could be selling power back on to the grid with it too.)
   - premium power (could be on-grid or off-grid but they need high-quality, consistent power(e.g., cell towers, banking, FAA))
   - Special/other (like used in Space Shuttles)

4. How did you become interested in fuel cells? Was there a champion? If so, what are the characteristics of the champion?

5. How did you learn more about fuels cells related to your application?

6. What factors led you to consider fuel cells?

7. What type of fuel cell system are you currently using? (*PEM, SOFC, Etc.)* Please tell me more about the system.

    - How long have you had it installed?

    - Which vendor's unit are you using? (If we know the model, we can determine the electrical parameters. The following, then, are useful only for determining what is important to the customer.)

8. What factors influenced your decision to select the unit you did?

9. I'm going to run through some performance parameters and ask you about your requirements for each parameter and how important each parameter is to you.

    - Power size (kW)
    - What fuel source requirements do you have a*re you flexible or would your system have to run on a particular fuel (e.g., natural gas?*
    - What physical, size restrictions do you have (its footprint)?
    - Describe your unit's reliability (# power failures/yr, length (time) of average or typical one. Is this meeting your needs? If not, what is your requirement?
    - Durability (Warranty you have? Expected design life?)
    - Is start up speed important to you? (#sec or min?)
    - Ease of use?
    - Safety measures?
    - Adheres to operational codes and standards? *(e.g. Institute of Electrical and Electronics Engineers (IEEE) standards)*
    - Other factors you took into account?
        - Government incentives available? Are these important to you?
        - Track record with others using it? Is this important to you?

10. I'd like to now ask you about the role cost plays in making your purchase decision.

11. How is a capital purchase decision made? (*Is it driven by lowest initial capital cost, calculating the payback period (which means estimating operational and maintenance costs), or return on investment (which is basically discounted payback)?*

12. Who makes the decision (job title) to purchase the system?

13. How important are environmental and energy efficiency concerns in making your decision? (Walk through the 3 options below to get some sense of their decision process).

    - Critical – if it is better for the environment and higher energy efficiency we would buy it, even at a slightly higher (5-10%) cost

- tie-breaker – if it is better for the environment and higher energy efficiency we would buy it, if cost and quality are as good as the alternatives
- not relevant – never considered them.

14. What alternatives did you consider? Why did you not select them?

15. How would you characterize the experience?

    - What are the benefits?
    - What are the issues or unexpected indirect costs from using fuel cells?

16. What were the key elements that led to successful implementation of your fuel cell system?

17. What were the major barriers and obstacles you had to overcome?

18. Given this experience, do you see your company continuing to use fuel cells in the future?

    If yes, ask for details on cost, applications, types, specs, etc.
    If no, then why not? What are the issues and/or barriers? How important is track record – use by others in your industry and confidence in the technology?
    What would it take to overcome these issues/barriers?

19. What benefits do you feel fuel cells could provide in the future that are important to your purchase decision?

20. Do you think fuel cells will be widely adopted?

    - If so, by whom, why, and when do you think this will happen?
    - How about for your specific industry?
    - In general, how do you think others in your industry feel about fuel cells?

21. What 3-5 factors do you see as the most important to driving the commercialization of fuel cells?

22. Is there anything else you would like to add?

23. Are there other people that I should talk to?

Thank you for taking the time to talk with me. Would be it okay for me to call you again, should we need additional information?

Questions for Candidate Users of Fuel Cells

Interviewer:

Interviewee/Affiliation/Title/Contact:

Date:

1. Are you a current user of fuel cells?
   If yes, then go to "Questions for Current Fuel Cell Users" survey.
   If no, then ask: Are you considering using fuel cells at work or home sometime in the future? If yes, proceed to next question and continue survey. If no, then thank them for their participation and end survey.

2. What are your current stationary energy needs and how are they met?

3. How did you go about evaluating alternatives for meeting your stationary energy needs?

4. What energy alternatives have you considered?

5. For what applications have you conducted your assessment?
   - backup power (assumes the FC system is not connected to the grid)
   - remote power (assumes the FC system is not connected to the grid, but this is the users full-time power source, example is Central Park's Police Station where they didn't want to run transmission lines into the Park.)
   - peak shaving power (could be on-grid or off-grid BUT assumes that the user is typically on-grid and this unit would be used to lower their costs during peak time. They could be selling power back on to the grid with it too.)
   - premium power (could be on-grid or off-grid but they need high-quality, consistent power(e.g., cell towers, banking, FAA))
   - special/other (like used in Space Shuttles)

6. What consideration have you given fuel cells?

7. (If so) What type of fuel cell system are you considering? (PEM, SOFC, etc.) Which vendor's unit are you considering?

8. What factors are influencing your decision?

9. I'm going to run through some performance parameters and ask you about your requirements for each parameter and how important each parameter is to you. Please indicate high, medium, low.
   - Power size (kW)
   - Fuel source requirements (are you flexible or does your system have to run on a particular fuel (e.g., natural gas))?
   - Physical, size restrictions (its footprint)

- Reliability requirements (how reliable is your current system (# power failures/yr, length (time) of average or typical one?).
- Durability (warranty of your current system and what you would want. Design life wanted.)
- Is start up speed important to you? (# sec or min?)
- Ease of use
- Safety measures
- Adheres to operational codes and standards
- Other factors you are taking into account?
    - Government incentives available? Are these important to you?
    - Track record with others using it? Is this important to you?

10. Describe the role cost plays in making your purchase decision.

11. How is a capital purchase decision made? (*Is it driven by lowest initial capital cost, by calculating the payback period, or by return on investment?)*

12. Who makes the decision (job title) to purchase the system?

13. How important are environmental and energy efficiency concerns in making your decision?
    - critical – if it is better for the environment and higher energy efficiency you would buy it, even at a slightly higher (5-10%) cost
    - tie-breaker – if it is better for the environment and higher energy efficiency you would buy it, if cost and quality are as good as the alternatives
    - not relevant –would not consider them.

14. What do you see as the barriers or obstacles to adopting fuel cells?
    - How important is track record – use by others in your industry and confidence in the technology?
    - What would it take to overcome these barriers?

15. What do you see as the future for fuel cells for stationary power? PEM? Others?

16. Do you think fuel cells will be widely adopted?
    - If so, by whom, why, and when do you think this will happen?
    - How about for your specific industry?
    - In general, how do you think others in your industry feel about fuel cells?

17. What 3-5 factors do you see as the most important to driving the commercialization of fuel cells?

18. Is there anything else you would like to add?

19. Are there other people whom I should talk to?

Questions for Policy Entities / Regulators / NGOs / Agenda Setters for Fuel Cells
Interviewer:

Interviewee/Affiliation/Title/Contact info for them:

Date:

1. What is your general perspective on the viability of the fuel cell industry?
2. Do you think stationary PEM fuel cells will be widely adopted some day?
   - If so, when and by whom do you think this will happen?
3. What factors do you think will most likely drive PEM stationary fuel cell adoption?
4. What do you see as the biggest barriers to adoption of PEM stationary fuel cells?
5. What incentives currently provided by policymakers, regulators or others are having the greatest impact on the adoption of fuel cells?
   - *Financial* incentives, such as rebate programs, sales tax exemption, industry recruitment?
   - *Rules, regulations, and policy incentives*, such as green power purchasing, fuel mix disclosure, construction/design standards that encourage stationary FC use, interconnection standards?
6. What additional incentives might be required to create a viable market for FCs?
7. Do you think that the lack common codes and standards is inhibiting the acceptance and growth of the fuel cell market?
8. Which codes and standards are the most problematic for the adoption of fuel cells? (installation? Product standards? Interconnection? Other?)
9. Are you aware of any public-private partnerships on stationary fuel cell implementation that may have merit?
10. Are there other people whom we should talk speak?

Questions for Standards and Codes Developers

Interviewer:

Interviewee/Affiliation/Title/Contact info for them:

Date:

1. What is the status of the development of fuel cell standards and codes? (i.e. what standards have been published and what standards are still under development?)
2. Do you think that the lack common codes and standards is inhibiting the acceptance and growth of the fuel cell market?
3. Which codes and standards are the most problematic for the adoption of fuel cells? (installation? Product standards? Interconnection? Other?)
4. When are standards for fuel cells expected to be complete?

Interview Questions for R&D Community

Interviewer:

Interviewee/Affiliation/Title/Contact info for them:

Date:

1. Can you briefly describe your organizations work with Fuel Cells?

2. Can you briefly discuss the advantages and disadvantages of the PEM fuel cell technology?

3. What is your general perspective on the viability of the fuel cell industry?
   - In your opinion, how is the PEM Fuel Cell technology going to evolve? What part of the system 1) reformer 2) stack or 3) systems integration will undergo critical change in the next 10 years?

   - Based on the current status of the technology, what will be the primary stationary markets to evolve?

Possible Stationary Power Application Include(s):
☐ Premium: *High-quality power for cell-phone towers, banking*
☐ Back-up: *Stand-by power that is used during grid failure (i.e.*
☐ Off-grid, Distributed: *Stand-by or continuous power for buildings*
☐ Grid, Sited: *Continuous power that is grid-connected*
☐ Special Applications

   - Who do you think will be the early adopters in these markets?

   - Has investment by private and government entities in PEM FC declined?

4. What do you see as the biggest technical and institutional barriers to adoption of PEM stationary fuel cells?

5. What factors do you think will most likely drive PEM stationary fuel cell adoption?

6. Hydrogen availability is critical to the success of the PEM FC technology.
   - Do you think the government should support the development of hydrogen infrastructure to deliver H2 as a commodity or support the development of reformers to generate H2 onsite?

- Hydrogen safety is an issue that needs to be addressed. What will it take to change public perception on the safety of hydrogen?

- What other issues regarding H2 should be considered?

7. Identify the critical areas in the industry that require immediate attention to drive the commercialization of fuel cells?
    - Codes and Standards
    - Public Policy support
        - Financial incentives, such as rebate programs, sales tax exemption, industry recruitment?
        - Rules, regulations, and policy incentives, such as green power purchasing, fuel mix disclosure, construction/design standards that encourage stationary FC use, interconnection standards
    - Research and Development
        - Membranes
        - Catalyst
        - Reformer
        - H2 Storage
        - Others _____

8. Until now, we have been speaking to current private and public sector PEMs stationary FC users like Telecom, FAA etc. We would like to speak with other candidate users in the public sector. Can you refer us to any candidate users in the public sector, who might consider FC use but are not currently using them?

9. Other stakeholders in the R&D community that we should speak with?

10. Other Comments?

Questions for Venture Capital Investors

Interviewer:

Interviewee/Affiliation/Contact info for them:

Date:

1. Does your company currently have investments with companies involved in Fuel Cells?

2. How did your company become interested in this area? (How long ago?)

3. What role does each of the companies have with Fuel Cells (manufacturing, R&D, selling, using, etc.)

4. What are your criteria for making investment decisions around fuel cells? (e.g., Risk, Safety, Performance)

5. How are these companies performing? (growing, declining, mergers, acquisitions etc.)

6. What types of fuel cells are the companies you are involved with using and do you have any sense for why they selected the one(s) they did?

7. What other factors are you are taking into account?

8. Can you talk about the level of investment you are making in this area?

9. What do you feel the general perception is about Fuel Cell in the VC community?

10. Is it important that fuel cells could be an alternative energy source?

11. What do you see as the barriers or obstacles to adopting fuel cells?
    What would it take to overcome these barriers?

12. What do you see as the future for fuel cells for stationary power? (PEM, Other?)

13. Do you think fuel cells will be widely adopted?

14. What 3-5 factors do you see as the most important to driving the commercialization of fuel cells?

Interview Questions for Fuel Suppliers
Interviewer:

Interviewee/Affiliation/Title/Contact info for them:

Date:

1. What is the primary business focus of _____? What aspects of the developing hydrogen economy is _____ involved in? Can you briefly describe your organizations work in this area?

2. Is the hydrogen economy a reality? What is the current status of the Industry? When do you think we will see a H2 economy?

3. What are the critical success factors and barriers to the successful development of a Hydrogen Economy?

4. Hydrogen production is considered energy intensive. What is the most economical method of producing hydrogen? Do you have any idea what the cost of producing this hydrogen is?

5. There has been significant debate on the cost of building the H2 infrastructure, what are your thoughts on delivering and storing Hydrogen? What will be the most economic and efficient method of delivering hydrogen to the end user? Would this scenario be different for end users in stationary markets?

6. What is the current cost of a Kg of Hydrogen?

7. Will the price of Hydrogen in the future be affected by rising natural gas or oil prices?

8. How critical is the success of PEM fuel cells to the Hydrogen Economy? Are there other emerging H2 dependent technologies that could drive the H2 marketplace?

9. What do you see as the biggest technical and institutional barriers to adoption of PEM stationary fuel cells?

10. What factors do you think will most likely drive PEM stationary fuel cell adoption?

11. When do you think PEM fuel cells will be commercialized for 1) automotive applications and 2) stationary applications?

12. Stationary markets seem to be emerging earlier than automotive markets. Based on the current status of the technology, what will be the primary stationary markets to evolve?

Possible Stationary Power Markets Include(s):
☐ Premium: *High-quality power for cell-phone towers, banking*
☐ Back-up: *Stand-by power that is used during grid failure (i.e.*
☐ Off-grid, Distributed: *Stand-by or continuous power for buildings*
☐ Grid, Sited: *Continuous power that is grid-connected*
☐ Special Markets

- What applications in these markets are likely to emerge first?
- For other stationary markets to emerge, how should the issue of Hydrogen source be addressed?

13. Hydrogen availability is critical to the success of the PEM FC technology.
    - Do you think the government should support the development of hydrogen infrastructure to deliver H2 as a commodity or support the development of reformers to generate H2 onsite?
    - Hydrogen safety is an issue that needs to be addressed. What will it take to change public perception on the safety of hydrogen?
    - Do you think a lack of common codes and standards fro H2 use has been problematic for the adoption of FC technology? Can you discuss some of the work that is on-going with H2 codes and standards?
    - What other issues regarding H2 should be considered?

14. Other stakeholders that we should speak with?

15. Other Comments?

Survey for Fuel Cell and Component Manufacturers

Battelle is utilizing stakeholder input to identify the critical barriers and success factors for the commercialization of stationary PEM fuel cells. Please provide your expert opinion to the questions outlined below.

Identify the importance of the drivers outlined below to the commercialization success of PEM Fuel Cells. Rate their importance on a scale of 1 to 5, 1 being not important and 5 being very important.						
	Commercialization Drivers	**1**	**2**	**3**	**4**	**5**
☐	Hydrogen fuel infrastructure	☐	☐	☐	☐	☐
☐	Manufacturing breakthroughs	☐	☐	☐	☐	☐
☐	Lowering life cycle cost	☐	☐	☐	☐	☐
☐	Environmental demands/regulations	☐	☐	☐	☐	☐
☐	Grid reliability	☐	☐	☐	☐	☐
☐	Fed/State tax credits/incentives	☐	☐	☐	☐	☐
☐	Energy storage technologies	☐	☐	☐	☐	☐
☐	Balance of Plant technology development	☐	☐	☐	☐	☐
☐	Source of big capital	☐	☐	☐	☐	☐
☐	Product efficiency and reliability	☐	☐	☐	☐	☐
☐	National policy on fuel cells	☐	☐	☐	☐	☐
☐	Funding for research	☐	☐	☐	☐	☐
☐	Success/failure of first mass market introduction	☐	☐	☐	☐	☐
☐	Dual use technologies, research and development in automotive and stationary applications	☐	☐	☐	☐	☐
☐	Natural gas prices	☐	☐	☐	☐	☐
☐	Energy security	☐	☐	☐	☐	☐
☐	End-user acceptance	☐	☐	☐	☐	☐
☐	Common codes and standards	☐	☐	☐	☐	☐
☐	Competing technology development	☐	☐	☐	☐	☐
☐	Other:	☐	☐	☐	☐	☐
☐	Other:	☐	☐	☐	☐	☐
☐	Other:	☐	☐	☐	☐	☐
☐	Other:	☐	☐	☐	☐	☐

From the above list, identify the five most important drivers for commercialization stationary PEM Fuel cells? Please further describe, from your point of view, how the challenges faced by them can be addressed.	

Based on the current status of PEM fuel cell technology development, which stationary market is likely to be commercialized first?
☐ Premium: *High-quality power for cell-phone towers, banking operations, etc.*
☐ Back-up: *Stand-by power that is used during grid failure (i.e. UPS Systems)*
☐ Off-grid, Distributed: *Stand-by or continuous power for buildings*
☐ Grid, Sited: *Continuous power that is grid-connected and operated by electric utilities*
☐ Special Applications: *Dual Use- RV Parks*

In the stationary market likely to be commercialized first,	
At what cost per kW will fuel cells become competitive?	
What year will fuel cells achieve this cost target?	
In this marketplace, what competing technologies will fuel cells have to displace?	
Are their emerging technologies that fuel cells should be concerned about?	

What government policies or incentives would have the greatest impact on commercialization, and why?		
☐ Financial Incentives	☐ Educational Incentives	☐ Other Policy Incentives
In your opinion, what is the ideal model for the commercialization of PEM fuel cells for stationary applications?		
Would you be interested in participating in Stakeholder Focus Groups that will be initiated shortly to guide Battelle Assessments? If so, please provide your name and contact information.		

Additional Notes: For example, if there are specific factors you would like us to consider in our assessments.

Thank you!

Appendix B

List of Interviewees

Appendix B: List of Interviewees

Stakeholder Group	Organization	Current user?
Commercial sector	Telecommunications company	✓
	Telecommunications company	✓
	Energy / Power generating systems company	✓
	Energy technology company	✓
	Automotives company	✓
	Hotel company	✓
	Banking company	✓
	Restaurant company	✓
	Energy technology company	
	Telecommunications company	
Public sector	U.S. Army – Fort Jackson	✓
	U.S. Army - Watervliet Arsenal	✓
	U.S. Army - Army Training Center	
	Georgia Institute of Technology - Air Force ROTC Building	✓
	U.S. Air Force - McChord Air Force Base - FAA) Radio Transmit Receive Site	✓
	U.S. Air Force – Shaw Air Force Base	✓
	U.S. Navy - Naval Air Station Patuxent River	✓
	NASA Kennedy Space Center	✓
	National Park Service - Yellowstone National Park	✓
	University of Wisconsin - OshKosh	
	Oregon State University	
	Colorado State University	
	MARCS (Multi-Agency Radio Communications System)	
Electric Generating Stations	Arizona Public Service Company	✓

	New York Power Authority	✓
	Omaha Public Power District	✓
	American Electric Power	
	First Energy Corporation	
	City of Palo Alto Utility	
	Chugach Electric Association, Inc	
	We Energies	
	Green Mountain Energy	
Public Funders, Policymakers & Agenda-setters	California Energy Commission	
	California Stationary Fuel Cell Collaborative	
	Next Energy	
	NIST - Advanced Technology Program	
	American Council for an Energy Efficient Economy	
	Center for Energy Efficiency and Renewable Technologies	
	U.S. Fuel Cell Council	
	Fuel Cell Today	
	Natural Resources Defense Council (NRDC)	
	National Renewable Energy Laboratory (NREL)	
	CSA International / CSA America	
	Independent consultant	
	Clean Energy States Alliance / Clean Energy Group	
Venture Capital Investors	Company A (Confidential Withheld by Request)	
	Company B (Confidential Withheld by Request)	
	Company C (Confidential Withheld by Request)	
	Company D (Confidential Withheld by Request)	
	Company E (Confidential Withheld by Request)	
	Company F (Confidential Withheld by Request)	

R&D Community	Colorado State University	
	Fideris Inc (formerly Lynntech, Industries)	
	University of Connecticut - Connecticut Global Fuel Cell Center	
	Houston Advanced Research Center (HARC)	
	Georgia Tech Research Institute - Center for Innovative Fuel-cell and Battery Technologies	
	Electric Power Research Institute	
	Foster Bryan Ltd	
	University of South Carolina, Center for Fuel Cell Research	
***Fuel Cell Manufacturers**	Plug Power	
	Nuvera	
	Ballard	
	Hydrogenics	
	Proton Energy Systems	
	Ion Power, Inc.	
	Engelhard	
	Johnson Matthey Fuel Cells	
	Graftech	
	Dupont	
	3M	
	Gore Technologies	
	Porvair Fuel Cell Technologies	
	Caterprillar	
	Army Corps of Engineers	
	NextEnergy	
	Methanex	
Fuel Suppliers	National Hydrogen Association	

	Conoco Phillips	
	Linde Gas	
	Air Products and Chemicals	
	Texaco Ovonic Hydrogen Systems	
	GE Global Research - Hydrogen Energy Technology Projects	
	Chevron Technology Ventures	

*Surveys were used instead of interviews to collect data from this stakeholder group.

Appendix C

Additional Stakeholders Perspectives on the Hydrogen Economy

Appendix C: Additional Stakeholders Perspectives on the Hydrogen Economy

The vision of the hydrogen economy by stakeholders, government and academia is based on the production of hydrogen from domestic energy sources so it is efficient and environmentally sound and applications utilizing hydrogen (fuel cell vehicles or hydrogen ICE engines) can gain market share in competition with alternatives (gasoline powered vehicles, coal burning power plants). The interviewees from the fuel supply industry generally stated that certain aspects of the hydrogen economy, like hydrogen production, already exist. For example, hydrogen is used as an industrial gas (over 50 megatons of hydrogen are produced annually). Demonstrations of hydrogen as an economically viable fuel for internal combustion engines also exist. One interviewee also identified the availability of fueling infrastructure (gas stations). All interviewees agree that the hydrogen economy is in a state of development and numerous challenges exist (these challenges are identified in greater detail in the sections below).

Interviewees gave a wide range of responses (5 to 30 years) for when the hydrogen economy will be fully realized in the United States, stating that premium stationary applications of fuel cells and special vehicle applications (off-road vehicles and fleets) will occur within 5 to 7 years. Several interviewees noted that the hydrogen economy will be dependent upon increased government support of R&D and demonstration projects. They thought that the government ultimately needs to make hydrogen economically viable because the transition to the hydrogen economy will be driven by economics. Two interviewees also noted that financial and technical resources are spread thin because of the many methods of producing and using hydrogen that are being explored, and another noted that DOE's time targets for the hydrogen economy are reasonable. One interviewee emphasized the need to understand the objectives of developing a hydrogen economy and to develop economics and policies based on those objectives. Such examination, he believes will identify whether hydrogen is the right energy choice.

Many interviewees noted that public perception of the hydrogen economy is focused on hydrogen-fueled vehicles, an aspect of the hydrogen economy which is not yet widely established in the United States. Interviewees stated that hydrogen-fueled vehicles will not appear in large numbers in the United States until hydrogen vehicles are comparable in cost and performance to conventional vehicles, estimating that this would occur in 10 to 30 years for individual passenger vehicles, and sooner in Japan, Canada, and Europe.

PEM Fuel Cells and the Success of the Hydrogen Economy

Interviewees from the fuel supply industry stated that the success of PEM fuel cells is very critical for the hydrogen economy, especially if the hydrogen economy is focused on vehicles. The interviewees noted that PEM fuel cells offer the potential for a low-cost, low-emissions option, although cost and long term durability still pose barriers to be overcome. One interviewee noted that there are other competing types of fuel cells (solid oxide or molten carbonate) that generate waste heat which could drive or contribute to the hydrogen economy in the stationary market. Interviewees generally agreed that other technologies such as various types of fuel cells and hydrogen internal combustion engines are only "bridging" or "transient" technologies and that they are not the best long-term solutions because of their emissions and efficiency. One interviewee indicated that it would be hard for industry to justify investment in developing the hydrogen infrastructure based on the needs of transitional technologies, without the promise of more efficient technologies like fuel cells.

Hydrogen Codes and Standards

As discussed above, most interviewees from the fuel supply industry stated that a lack of common hydrogen codes and standards has been problematic for the adoption of fuel cell technology and the hydrogen economy. The interviewees generally noted that there is considerable ongoing work on hydrogen codes and standards and that collaboration on many levels is needed. The National Fire Protection Association (NFPA) is preparing to issue codes for hydrogen fueling stations (titled NFPA-57, expected to be released January 1, 2005), and there is currently a great deal of inconsistency between fire marshals in individual jurisdictions. One interviewee noted that the NFPA standards may not cover liquid hydrogen because it is currently viewed as a novelty fueling source. Other groups working on hydrogen codes and standards include the American Society of Mechanical Engineers, Society of Automotive Engineers, American National Standards Institute, Canadian Standards Association, European Union working groups, and the International Organization for Standardization. Issues that remain to be addressed include hydrogen transport through tunnels and parking location limitations for cars with hydrogen tanks.

Interviewees from the fuel supply industry emphasized the need for effective collaboration between government, industry, and academia, stating that representation and consistency is needed at the national and international levels. One interviewee noted that data-based decision making is needed that avoids creating inadvertent barriers to the marketplace that do not improve safety. The interviewee also noted that priorities need to be established and resources aligned to evaluate potential safety risks and impacts on commercialization. Another interview noted that the development of codes and standards will ultimately serve as the “laws” of the hydrogen economy, and therefore will take a long time to develop, adopt, and implement. One interviewee indicated that codes and standards development needs to be ahead of the technology to allow smooth transition for early adopters of the technology. In contrast another interviewee suggested that codes and standards need to be in sync with the development of the technology, to realize technology capabilities and its limiting factors.

Hydrogen Production and Cost

Hydrogen can be produced from a variety of sources, however, the most appropriate energy and environmentally efficient methods still need to be determined. Interviewees provided conflicting conclusions on the most economical method for producing hydrogen. In the order of importance, interviewees identified steam methane reforming from natural gas, electrolysis, and use of renewables with electrolysis as economical methods of hydrogen production. One interviewee indicated that the energy cost of hydrogen production is $0.40-0.80/kg, and consumer costs is $1.50-1.80/kg from steam methane reforming (depending on the cost of natural gas [$3-6/mmBTU]), and that the energy cost for electrolysis is about the same (starting at about $0.56/kg hydrogen), although it can be up to $1.80/kg hydrogen assuming retail cost for electricity used for the process of electrolysis. Three interviewees also noted that hydrogen production from coal with carbon sequestration and nuclear energy may be viable in the long-run although the cost is currently too high. Other interviewees stated that non-fossil based hydrogen is currently too costly, but may eventually be part of local solutions based on local circumstances (i.e., strong wind resources nearby could favor wind-powered generation of hydrogen).

Interviewees from the fuel supply industry indicated that the consumer cost for hydrogen varies widely depending on where it comes from. Hydrogen prices range from $1.50 to $4/kg from an

existing hydrogen pipeline (of which there are two in the United States) or delivered as a bulk gas, to $20 to $30/kg in small, high-pressure cylinders or for remote locations.

Most interviewees indicated the cost of hydrogen production will be affected by changes in natural gas prices. Consumer parity index will be set against gasoline and oil prices. Another interviewee stated that unless gas prices rise considerably, there will only be a small effect on hydrogen prices in the short-term, but by adding carbon dioxide management there could be a significant increase in the cost of hydrogen from natural gas in the long-term. Another interviewee noted that public anxiety is a factor in energy prices, and that it is difficult to predict whether hydrogen prices will rise or fall with natural gas and/or oil prices.

Hydrogen Delivery, Infrastructure and Safety

All interviewees from the fuel supply industry suggested that, depending on the application, amount and location of the hydrogen need, a combination of hydrogen infrastructure and onsite generation will be the most economic and efficient method of delivering hydrogen to the end user for both mobile and stationary applications. Other interviewees suggested onsite generation (either by reformers or electrolysis) will be the most economic and efficient method for both mobile and stationary applications, and still others suggested that the best delivery method depends on the progress of technology in the coming years.

The following summarizes the input of those interviewees suggesting a combination of hydrogen infrastructure and onsite generation. The only scenario for which a hydrogen pipeline was suggested as the best method of delivery is for large, geographically co-located markets. In stationary markets, it was suggested that locally produced and stored hydrogen will be the best, from electrolysis or truck-delivered tanks for very small users. For vehicles, the best method will be locally produced hydrogen (e.g., by electrolysis or distributed reforming of natural gas in the United States). For smaller and more remote markets, local delivery using composite pressurized tank trucks was suggested. Some interviewees suggested for stationary markets, the DG model for production from electrolysis and delivery of hydrogen may be appropriate. These small DG models can then be replicated for other communities. For small remote user, hydrogen from truck delivered tanks may be most economical. One interviewee also noted that solid state storage is the most economic and efficient method of storing the hydrogen because of its density for both mobile and stationary applications, regardless of its source (infrastructure or local generation). Another interviewee noted that one of the benefits of hydrogen is its flexibility, also stating that if carbon dioxide control is ultimately required then central production of hydrogen will be favored.

Interviewees that suggested onsite generation of hydrogen as the most economic and efficient method of delivering hydrogen to the end user stated that clean generation of hydrogen is critical, whether by electrolysis or reformers. Several interviewees suggested that reformers are the best option, either onboard or at individual houses connected to natural gas pipelines for vehicles, and that delivery of natural gas with a small reformer plant will be best for stationary markets. Two interviewees suggested that small, low-cost electrolysis with medium pressure gaseous storage is best for stationary markets.

Most interviewees from the fuel supply industry stated that the government should support both onsite generation (such as reformers and electrolysis) and the development of hydrogen infrastructure, while one interviewee stated that the government should only support electrolysis for environmental reasons. The interviewees recommending government support for both onsite generation and infrastructure emphasized that a broad approach is needed to deliver short term

value while continuing basic research and development for “next generation” technologies and to stimulate healthy competition.

One interviewee expressed opposition to small scale reformers if they do not control the release of carbon dioxide, and suggested that electrolysis can be done with electricity from coal with carbon abatement strategies, or from renewable energy.

Most of the interviewees from the fuel supply industry stated that the safety of hydrogen is a major issue for the public. They believe that public familiarity and information about hydrogen will help to ameliorate these concerns about safety.

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Appendix C: Interim Report on the Economics of Stationary Proton Exchange Membrane Fuel Cells

INTERIM REPORT

ON THE

ECONOMICS OF STATIONARY PROTON EXCHANGE MEMBRANE FUEL CELLS

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TABLE OF CONTENTS

Page

1 Introduction 1
1.1 Goals: Questions Being Answered 1
1.2 Scope of the Economic Analysis Report 2
1.3 Framework for Analysis 2
1.4 Approach and Methods 3
2 Market Analysis 5
2.1 Methodology 5
2.2 Importance of Market Segmentation and Early Adopter Markets 6
2.3 Consumer Value of Electricity and Opportunities for Distributed Generation 8
2.4 U.S. Electricity Consumption Patterns and Trends 11
2.5 Review of Typical Applications for PEM Fuel Cells 12
2.6 Key Drivers for Commercialization of Stationary PEM Fuel Cells 14
2.7 Market Opportunities for PEM Fuel Cells 16
2.8 Commercial Market Overview 17
2.8.1 Electricity Consumption Patterns 17
2.8.2 Commercial Market Sector Opportunities for PEM Fuel Cells 18
2.9 Institutional Market Overview 22
2.9.1 Electricity Consumption Patterns 22
2.9.2 Institutional Sector Opportunities for PEM Fuel Cells 22
2.10 Industrial Sector Overview 25
2.10.1 Electricity Consumption Patterns 25
2.10.2 Industrial Sector Opportunities for PEM Fuel Cells 25
2.11 Residential Sector Overview 29
2.11.1 Electricity Consumption Patterns 29
2.11.2 Residential Sector Opportunities for PEM Fuel Cells 30
2.12 Electric Utility Sector Overview 30
2.12.1 Electric Utility Sector Opportunities for PEM Fuel Cells 31
2.13 Opportunities for PEM Fuel Cells 31
2.13.1 Timeline of Opportunities 31
2.14 Early Adopters 33
2.15 Detailed Analysis of Three Early Adopter Markets 38
2.15.1 Financial Services Market - Banking and Supporting Business Sector ... 38

2.15.2 Telecommunications Market 41
2.15.3 Hotels Market 46
2.16 Market Analysis Conclusions 49
3 Economic Analysis of Two PEM Fuel Cell Systems 51
3.1 Economic Analysis of a 5 kW Direct Hydrogen PEM Fuel Cell System and a 50 kW Propane Reformer PEM Fuel Cell System 51
3.1.1 5 kW Direct Hydrogen PEM Fuel Cell System Engineering Specifications 51
3.1.2 50 kW Propane Reformer PEM Fuel Cell System Engineering Specifications and Cost Assumptions 55
3.1.3 Methodology for PEM Fuel Cell Engineering Cost Estimation 57
3.1.4 Lifecycle Costing Analysis: Methodology and Assumptions 58
3.2 Cost Analysis of 5 kW Direct Hydrogen PEM Fuel Cell System 60
3.2.1 Cost Breakdown of Subsystems 60
3.2.2 Cost Analysis of Fuel Cell Subsystem 62
3.2.3 Cost Analysis of Fuel Cell Stack System 63
3.3 Cost Analysis of 50 kW Propane Reformer PEM Fuel Cell System 65
3.3.1 Cost Breakdown of Subsystems 65
3.3.2 Cost Analysis of Hydrogen Delivery System 67
3.3.3 Cost Analysis of Fuel Cell Subsystem 67
3.3.4 Cost Analysis of Fuel Cell Stack System 68
3.4 Major Cost Elements of 5 kW Direct Hydrogen PEM Fuel Cell System and 50 kW Propane Reformer PEM Fuel Cell System 69
3.4.1 Lifecycle Cost Sensitivity Analysis: 5 kW Direct Hydrogen PEM Fuel Cell System 69
3.4.2 Lifecycle Cost Comparison of 5 kW Direct Hydrogen PEM Fuel Cell and Battery-Generator System 71
3.4.3 Engineering Cost Sensitivity Analysis: 5 kW Direct Hydrogen PEM Fuel Cell System 72
3.4.4 Lifecycle Cost: 50 kW Propane Reformer PEM Fuel Cell System 75
3.4.5 Lifecycle Cost Sensitivity Analysis: 50 kW Propane Reformer PEM Fuel Cell System 76
3.4.6 Engineering Cost Sensitivity Analysis: 50 kW Propane Reformer PEM Fuel Cell System 78
3.4.7 Conclusions for Cost Analysis of 5 kW Direct Hydrogen PEM Fuel Cell System and 50 kW Propane Reformer PEM Fuel Cell System 81
3.5 Analysis of Potential Technology Impacts on the Cost of PEM Fuel Cells 81
3.5.1 High-Temperature Membranes 82

3.5.2 Non-Ruthenium High Carbon Monoxide Tolerant Catalysts 85
3.5.3 Non-Platinum Catalysts 87
3.5.4 Technology Impacts Analysis Conclusions 89
3.6 Analysis of Impacts of Technological Improvements at High Production Volumes on Engineering and Lifecycle Costs 89
3.6.1 Analysis of Fuel Cell Stack Cost Sensitivity to Technology Breakthroughs 90
3.6.2 Analysis of Fuel Cell Subsystem Cost Sensitivity to Technology Breakthroughs 92
3.6.3 Combined Conclusions from Lifecycle and Technology Impact Analysis 93
4 Overall Conclusions 95
4.1 Significant Findings from Market Analysis 95
4.2 Significant Findings from Economic Analysis 96

Appendix A: Survey Form on Market Requirements A-1
Appendix B: Financial Services Sector Market Summary B-1
Appendix C: Market Analysis: Telecommunications Focus Group Meeting Minutes C-1
Appendix D: Telecommunications Sector Market Summary D-1
Appendix E: Hotel Market Survey Findings E-1
Appendix F: Engineering Cost Analysis – Assumptions and Component Classification System (CCS) F-1
Appendix G: Economic Analysis: Battelle Expert Focus Group Minutes G-1
Appendix H: Economic Analysis: Industry Stakeholder Expert Focus Group Minutes H-1

LIST OF TABLES

Table 2-1. Average cost per outage by customer. 10
Table 2-2. Current and projected electricity consumption. 12
Table 2-3. Likely applications for PEM fuel cells in various sectors. 17
Table 2-4. Key drivers for PEM fuel cells in the commercial sector. 19
Table 2-5. Characteristics of prospective markets in the commercial sector for PEM fuel cells. 20
Table 2-6. Key drivers for PEM fuel cells in the institutional sector. 23
Table 2-7. Characteristics of prospective markets in the institutional sector for PEM fuel cells. 24
Table 2-8. Key drivers for PEM fuel cells in the industrial sector. 26

Table 2-9. Characteristics of prospective markets in the industrial sector for PEM fuel cells. 27
Table 2-10. Timeline for commercialization of stationary PEM fuel cells. 32
Table 2-11. Listing of potential early adopters, application examples, key drivers, and fuel cell opportunities. 35
Table 2-12. Financial services market survey: market requirements for adoption of new energy technologies in backup and grid parallel applications. 39
Table 2-13. Decision drivers for adoption of new energy technologies in the financial services market. 41
Table 2-14. Telecommunications market: market requirements for adoption of new energy technologies for controlled environmental vaults. 43
Table 2-15. Telecommunications market: market requirements for adoption of new energy technologies for repeater stations/huts. 43
Table 2-16. Telecommunications market: market requirements for adoption of new energy technologies for central offices. 44
Table 2-17. Telecommunications market: market requirements for adoption of new energy technologies for switching stations. 44
Table 2-18. Decision drivers for adoption of new energy technologies in the telecommunications market. 45
Table 2-19. Hotels market: market requirements for adoption of new energy technologies for backup power. 47
Table 2-20. Decision drivers for PEM fuel cell adoption of a new energy technology in the hotels market. 48
Table 3-1. Key engineering specifications of the 5 kW direct hydrogen PEM fuel cell system . 52
Table 3-2. Membrane Electrode Assembly component costs ($) for 5 kW direct hydrogen PEM fuel cell system at 1,000, 10,000, and 100,000 unit annual production volumes. 54
Table 3-3. Key engineering specifications of the 50 kW propane reformer PEM fuel cell system. 56
Table 3-4. Membrane Electrode Assembly component costs ($) for 50 kW propane reformer PEM fuel cell system at 1,000, 10,000, and 100,000 unit production volumes. 57
Table 3-5. Key assumptions of the lifecycle analysis of the 5 kW direct hydrogen PEM fuel cell system. 59
Table 3-6. Key assumptions of the lifecycle analysis of the 50 kW propane reformer PEM fuel cell system. 60
Table 3-7. Cost breakdown of 5 kW direct hydrogen PEM fuel cell system. 60
Table 3-8. Total cost of 5 kW direct hydrogen PEM fuel cell subsystem. 62
Table 3-9. Cost of 5 kW direct hydrogen PEM fuel cell stack system. 64
Table 3-10. Cost breakdown of 50 kW propane reformer PEM fuel cell system. 65

Table 3-11. Total cost of 50 kW propane reformer PEM fuel cell subsystem. 68
Table 3-12. Cost of 50 kW PEM fuel cell stack system. 68
Table 3-13. Assumptions used to determine the net present value of fuel cells compared to batteries and generators for backup power applications. 72
Table 3-14. Twenty-year lifecycle cost analysis comparing a 5 kW direct hydrogen PEM fuel cell systems to a battery-generator system for backup power applications..... 72
Table 3-15. Twenty-year lifecycle cost analysis of the 50 kW propane reformer PEM fuel cell system. 76

LIST OF FIGURES

Figure 1-1. PEM fuel cells economic system framework. 3
Figure 1-2. Economic analysis of stationary PEM fuel cells. 4
Figure 2-1. Typical technology adoption cycle. 7
Figure 2-2. Key drivers affecting PEM fuel cell commercialization. 15
Figure 2-3. Electricity energy consumption by end use in the commercial sector. 18
Figure 2-4. Electricity energy consumption by end use in the residential sector. 29
Figure 2-5. Near-term markets in which early adopters exist 33
Figure 3-1. Schematic of 5 kW direct hydrogen PEM fuel cell system. 52
Figure 3-2. Schematic of 50 kW propane reformer PEM fuel cell system for baseload grid independent applications. 56
Figure 3-3. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (1,000 units). .. 61
Figure 3-4. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (10,000 units). 61
Figure 3-5. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (100,000 units). 62
Figure 3-6. Percent cost breakdown of 5 kW direct hydrogen PEM fuel cell subsystem costs. 63
Figure 3-7. Cost of total 5 kW direct hydrogen PEM fuel cell stack system. 64
Figure 3-8. Cost breakdown for 50 kW propane reformer PEM fuel cell system (1,000 units). 65
Figure 3-9. Cost breakdown for 50 kW propane reformer PEM fuel cell system (10,000 units). 66
Figure 3-10. Cost breakdown for 50 kW propane reformer PEM fuel cell system (100,000 units). 66
Figure 3-11. Primary cost drivers of 50 kW propane reformer PEM fuel cell hydrogen delivery system. 67
Figure 3-12. Cost of 50 kW propane reformer PEM fuel cell subsystem. 69

Figure 3-13. Sensitivity analysis of average annual lifecycle cost of 5 kW direct hydrogen PEM fuel cell system with ±10% changes in major cost drivers. 71
Figure 3-14. Sensitivity analysis of subsystem engineering costs, ±10%, on the cost of the 5 kW direct hydrogen PEM fuel cell system (100,000 units). 73
Figure 3-15. Sensitivity analysis of the cost of components, ± 10%, on the cost of the 5 kW direct hydrogen PEM fuel cell subsystem (1,000 units)..... 74
Figure 3-16. Sensitivity analysis of the cost of components, ± 10%, on the cost of the 5 kW direct hydrogen PEM fuel cell subsystem (10,000 units)..... 75
Figure 3-17. Sensitivity analysis of average annual lifecycle cost of 50 kW propane reformer PEM fuel cell system to major subsystem costs varied ± 10%. 77
Figure 3-18. Sensitivity analysis of lifecycle cost of electricity to changes in key factors in the 50 kW propane reformer PEM fuel cell..... 78
Figure 3-19. Sensitivity analysis of subsystem engineering costs, when varied ±10%, on the cost of the 50 kW propane reformer PEM fuel cell system (100,000 units)..... 79
Figure 3-20. Sensitivity analysis of the cost of components, varied by ±10%, on the cost of the 50 kW propane reformer PEM fuel cell subsystem (1,000 units). 80
Figure 3-21. Sensitivity analysis of the cost of components, varied by ±10%, on the cost of the 50 kW propane reformer fuel cell subsystem (10,000 units). 80
Figure 3-22. Interactions between the fuel cell components when a high-temperature membrane is introduced. 84
Figure 3-23. Schematic showing components (shadowed in blue) affected by the introduction of a high-temperature membrane. 84
Figure 3-24. Interactions between the fuel cell components when a high CO tolerance catalyst is introduced 86
Figure 3-25. Schematic showing components (shadowed in red) affected by the introduction of a high CO tolerance catalyst. 86
Figure 3-26. Interactions between the fuel cell components when a non-platinum catalyst is introduced. 88
Figure 3-27. Schematic showing components (shadowed in green) affected by the introduction of a non-platinum catalyst. 88
Figure 3-28. Sensitivity analysis of breakthrough technology impacts on stack costs in the 5 kW direct hydrogen PEM fuel cell system (100,000 units). 91
Figure 3-29. Sensitivity analysis of breakthrough technology impacts on stack costs in the 50 kW propane reformer PEM fuel cell system (100,000 units). 91
Figure 3-30. Sensitivity analysis of breakthrough technology impact on subsystem costs: 5 kW direct hydrogen PEM fuel cell system (100,000 units). 92
Figure 3-31. Sensitivity analysis of breakthrough technology impact on subsystem costs: 50 kW propane reformer PEM fuel cell system (100,000 units). 93

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1 INTRODUCTION

1.1 GOALS: QUESTIONS BEING ANSWERED

The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) has articulated support for and committed funds to the development and demonstration of proton exchange membrane (PEM, also known as polymer electrolyte membrane) fuel cell technology with the expectation that such development will lead to widespread use and provide important private and social benefits.[1] While transportation applications represent the largest long-term market opportunity for PEM fuel cells, stationary applications of PEM fuel cells may provide an early market opportunity for PEM fuel cells while leveraging technology development applicable to the transportation sector. Extensive application of stationary PEM fuel cells may provide various benefits while moving the technology through the commercialization process. These benefits include reduced dependence on fossil fuels, reductions in air and noise pollution, increased energy efficiency, and security.

For PEM fuel cells, EERE is focused on the development of next-generation technologies that can have a significant impact on the stationary and automotive marketplace. To facilitate product innovation, EERE is focused on aligning its investment decisions and its research and development (R&D) program targets with market requirements. The overarching objective of this project is to provide EERE with a comprehensive understanding of the economics of stationary PEM fuel cells systems and their associated markets. The analysis is intended to improve EERE's understanding of the technology and market factors driving the economics and commercialization of stationary PEM fuel cell systems. This will help EERE to derive the greatest impact from its PEM fuel cell related R&D investments.

This study aims to define the value proposition for PEM fuel cells in the 1 kW to 250 kW range in various stationary markets, through a comprehensive technology, market, and economic analysis. To accomplish this objective, the research team:

- Performed an economic analysis of PEM fuel cells and their associated markets. (What are the cost targets that will drive the commercialization of PEM fuel cell systems?)
- Identified large potential markets and/or strategic markets with high commercialization potential for stationary PEM fuel cell systems. (What market segments represent the early adopters where strategic factors or personal values may cause users to accept higher than market costs? What are the size and growth rate of the potential markets?)
- Developed product performance targets (e.g., durability, reliability, size) for early adopter market segments. (What quality does the market demand?)
- Identified critical success factors required for commercialization in a potential market. (What factors beyond price and quality [e.g., availability of low-cost hydrogen, appropriate codes and standards] are critical to penetration of a potential market?)

[1] For the rest of the report, "PEM fuel cells" refer to stationary systems unless otherwise indicated.

1.2 SCOPE OF THE ECONOMIC ANALYSIS REPORT

This study is focused on stationary PEM fuel cells in the 1 kW to 250 kW range for backup, grid independent, grid parallel, grid connected, and combined heat and power (CHP) applications. Complete market segmentation of the stationary marketplace was performed to identify opportunities for various PEM fuel cell applications and potential adopters of PEM fuel cell technology to 2015. For three potential early adopter markets – financial services, telecommunications, and hotels – market requirements for potential applications were identified. The market segmentation and early adopter market characteristics are detailed in section 2.0 of this report. In support of this work, more than 100 interviews were conducted with key stakeholders in a variety of markets where PEM fuel cells could likely play a role. Surveys with competing technology manufacturers were also conducted. Five expert focus groups and one user focus group were also conducted. A scenario analysis of commercialization pathways was completed and the results presented in a talk titled, "Scenario Analysis of the Commercialization of Proton Exchange Membrane Fuel Cells for Stationary Applications in the U.S. by the Year 2015," at the 2004 Annual Fuel Cell Seminar in San Antonio, Texas.

To further evaluate the market opportunities for PEM fuel cells, engineering and lifecycle cost analyses of backup power and grid independent systems were performed. The initial engineering cost analyses in this interim report were derived by performing a cost breakdown analysis on a reformer based PEM fuel cell integrated by Battelle, then modifying this analysis to account for variation in the fuel cell design. The backup power system is assumed to be a 5 kW direct hydrogen PEM fuel cell system. The grid independent baseload system is assumed to be a 50 kW propane reformer PEM fuel cell system. Details on the economic analyses of these systems, and the assumptions behind these analyses, are provided in section 3.0. To determine the competitive landscape for PEM fuel cells, Battelle conducted analyses of commercially available and emerging competing technologies in the marketplace. Analyses of batteries, reciprocating engines, photovoltaics, and microturbines were performed. Comparison of the lifecycle costs of the 5 kW direct hydrogen PEM fuel cell to a battery-generator system is presented in section 3.0.

1.3 FRAMEWORK FOR ANALYSIS

To guide the study, Battelle utilized a framework integrating market, economic, and technology analyses. Commercial success in a free market (i.e., without government intervention) requires: (1) the perceived value (cost and quality) of electricity delivered by PEM fuel cells be superior to substitutes, and (2) the fuel cell investment opportunity be sufficient to attract capital necessary to produce the PEM fuel cells demanded. Figure 1-1 illustrates Battelle's analytic framework showing that the economics of a PEM fuel cell product in a given market will depend on interrelationships among market requirements and demand; the cost and quality of fuel cell products relative to substitute (competitive) products; the industry's ability to supply fuel cells; and an infrastructure supplying fuel, standards, and other external enablers or drivers.

Within this framework, this project is focused on the current conditions and trends related to markets, the cost and performance of fuel cell products given volume and technological progress, and substitute products that may meet future market requirements.

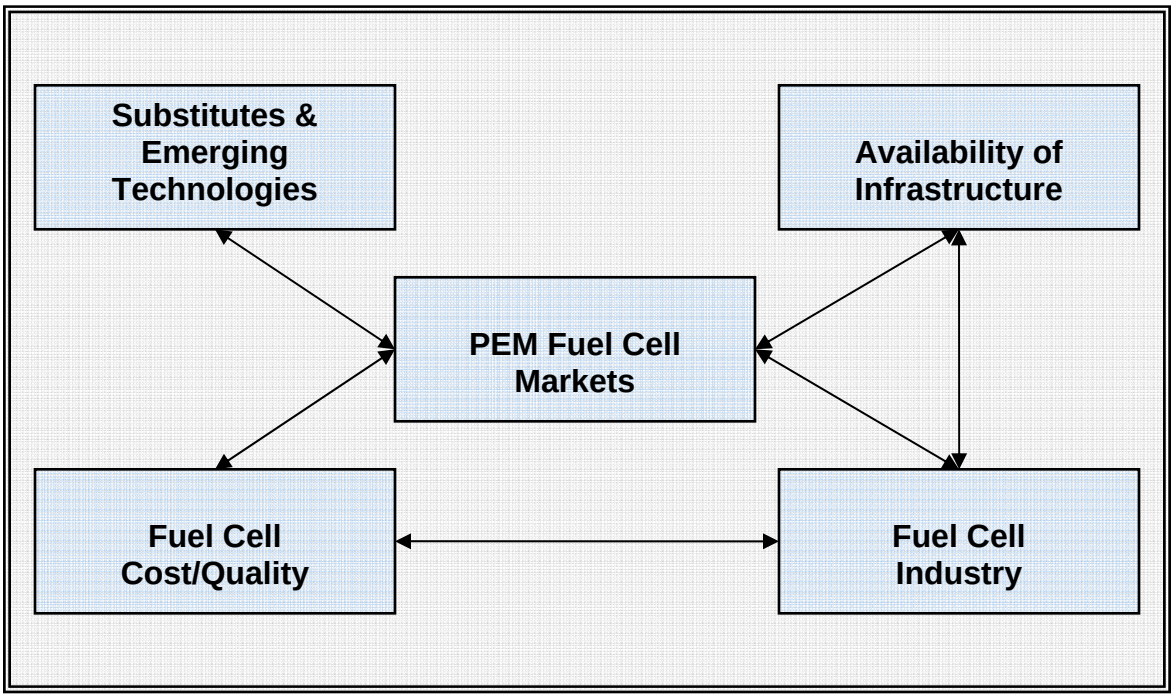

Figure 1-1. PEM fuel cells economic system framework.

1.4 APPROACH AND METHODS

Primary and secondary research was used to gather data on key factors influencing the elements in the system. Commonly accepted theories were reviewed, and economic models were developed and populated with these data. These models enabled the research team to quantify: (1) the engineering cost of PEM fuel cells with various levels of production volume and/or technological progress, (2) the lifecycle net present value (NPV) and the cost of electricity produced by PEM fuel cells for various applications,[2] and (3) the impact of PEM fuel cells in stationary markets.

The specific activities included in the approach, shown in Figure 1-2, and are as follows:

- **Market analysis**, with data collected from secondary sources, focus groups, surveys, and interviews, to characterize key market segments, including early adopter markets and total markets (by application), and to determine technical targets (user requirements) to enter those markets
- **Technology analysis** to evaluate the current cost and performance of PEM fuel cells and the current cost and performance of existing and emerging substitutes (competing technologies)

[2] Implicit in the lifecycle cost model is the existence of an appropriate infrastructure to deliver affordable fuel and system maintenance. Without such critical infrastructure the fuel cost will be prohibitively high; therefore, electricity costs from PEM fuel cells may not be competitive.

- **Engineering cost models** to analyze cost drivers, evaluate sensitivity, and model the potential impact of volume and technology breakthroughs on costs of PEM fuel cell systems

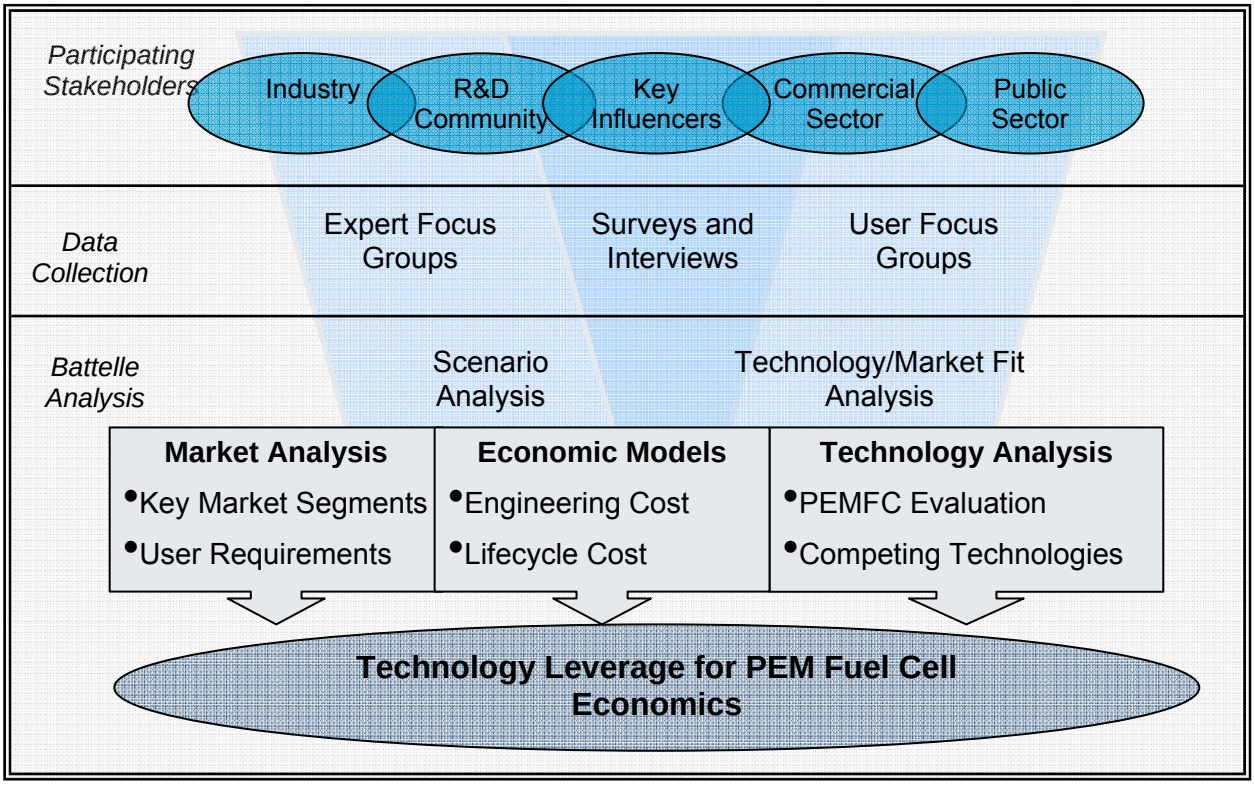

Figure 1-2. Economic analysis of stationary PEM fuel cells.

- **Lifecycle cost models**, using the assumptions of the Hydrogen Analysis (H2A) model, to calculate the cost of electricity produced by fuel cells (or, when appropriate, the NPV) and to compare these costs to the lifecycle costs of competing energy solutions
- **Analysis** to evaluate technology areas with where high cost leverage might be achieved through technology breakthroughs
- **Scenario analysis** to generate high-level insight into drivers impacting the future of stationary cells

Data collection involved secondary research, primary research with stakeholders, and consensus building using expert focus groups. Secondary research included literature review of government and academic publications, purchase of commercial reports on markets of interest for PEM fuel cell applications, and review of presentations and documents from fuel cell technology developers and manufacturers. Primary research tools included surveys, focus groups and interviews with various stakeholders. Stakeholders contacted included fuel cell users, potential users, manufacturers, suppliers, and key influencers of the industry. The Interactive Future Simulation (IFS™) software was used in conjunction with facilitated expert focus groups for the scenario analysis to identify important trends, issues and commercialization factors.

2 MARKET ANALYSIS

Market analysis research focused on assessing opportunities for stationary PEM fuel cells in the 1 kW to 250 kW size range to 2015 for backup, grid parallel, grid connected, and CHP applications. To determine target markets in this range, Battelle performed a complete segmentation of the stationary energy marketplace, and identified near-term, mid-term and long-term opportunities. Within the near-term opportunities, early adopter markets were identified, and a detailed analysis of market requirements for new energy technologies and opportunities for stationary PEM fuel cells was completed for financial services, telecommunications and hotel market segments.

2.1 METHODOLOGY

The benefit segmentation method[3] was adopted for the purpose of analyzing the applicability of PEM fuel cells in the stationary energy marketplace. PEM fuel cell technology and its unique benefits identified by reviewing product and application information were matched with specific user requirements in various stationary markets. For example, PEM fuel cells have the potential to offer customers specific benefits, such as reliability, power quality, scalability, ease of use (plug-and-play modules), and distributed power. Reliability and distributed power are key decision factors for users such as telecommunications companies that operate relay towers. Using the benefit segmentation method, the telecommunications market was defined as a unique market segment that desires a set of product benefits offered by PEM fuel cell technology. Complete market segmentation was performed using this approach for the stationary marketplace and for market segment applications in the commercial, industrial, institutional, residential, and utility sectors.

For each market segment, analyses were performed to characterize the energy consumption and usage, market size and growth potential, decision-making criteria, potential applications, current applications of fuel cells, and timing of opportunities. Competing technologies were noted, and an analysis of competing technologies was performed to obtain price and quality information. With this information, as well as expert judgment provided by various stakeholders through interviews and focus groups, and Battelle analysis, the stationary marketplace was classified into near-term, mid-term, and long-term opportunities.[4,5]

Within each market sector, early adopter markets that offer significant opportunities for the use of PEM fuel cells in various applications were identified using the following evaluation criteria:

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[3] Cooper, R. 2001. *Winning at New Products*. Perseus Publishing, Cambridge, Massachusetts.
[4] Judd, K., K. Mahadevan, J. Amaya, J. Upton, T. Petterson, E. Zell, G. Hund and J. Engel-Cox. 2004. Analysis of Stakeholder Feedback on PEM fuel cells for stationary applications. DOE Contract No. DE-FC36-03GO13110.
[5] Millett, S. and K. Mahadevan. 2004. Interim Findings on Scenarios of PEM Fuel Cell Applications for Stationary Power Generation and Commercialization in the United States by the Year 2015. DOE Contract No. DE-FC36-03GO13110.

- Risk of major economic losses associated with electrical availability, quality, and/or reliability
- Current market size and growth potential, electric consumption, and usage characteristics
- Fit of PEM fuel cells with priority user requirements that are more important than low cost (i.e., emphasizes reliability, power quality, and distributed power over cost)
- Ease of access to market segment; can be easily sold by manufacturer or distributor and market segment is not fragmented
- Pre-existing application of fuel cells in markets and sub-markets, through demonstrations or purchases by early adopters
- Competing technologies not currently providing benefits required by the market.

Each criterion was assigned a weight factor of low, medium, or high. Weighting factors were derived from literature review, interviews with users and competitors, discussions with fuel cell manufacturers, and expert judgment of Battelle staff. Markets that received a higher weighting were identified as target markets with the highest potential for adoption of PEM fuel cells, and key early adopters were identified. After consultation with EERE, three early adopter target markets (specifically financial services, telecommunications, and hotels) were selected as the first markets for further evaluation of user requirements and opportunities for application of PEM fuel cells.

Early adopter market analysis identified potential application opportunities, customer profiles, product requirements, and minimum user requirements for all three markets. The market requirements of each market segment are also intended to serve as technical targets that products must achieve for successful PEM fuel cell introduction. Each early adopter market was studied through targeted surveys, interviews, focus groups, and detailed secondary research. Market requirements gathered included information on size, cost, lifetime (durability), reliability, footprint, typical operating conditions, efficiency, and emissions. For each market segment, information on the health of the industry, its energy consumption patterns and electric load over time (if available) was also gathered.

2.2 IMPORTANCE OF MARKET SEGMENTATION AND EARLY ADOPTER MARKETS

The technology adoption lifecycle consists of numerous types of adopters in various markets who respond differently to new products. Initial product success in a market segment is highly dependent on meeting the requirements of the early adopters, rather than meeting the requirements of the market segment as a whole. Early adopters are typically users who buy into new product concepts very early in their life cycle. These users typically find it easy to imagine, understand, and appreciate the benefits of a new technology and relate these potential benefits to their concerns.

Figure 2-1 identifies a typical technology adoption cycle in a market segmented into innovators, early adopters, the early majority, the late majority, and the laggards.[6,7] Early adopters expect to gain strategic advantages from adopting new technology while the early majority wants to buy

[6] Rogers, E. 1962. *Diffusion of Innovations*. The Free Press, New York.
[7] Moore, G. 1991. *Crossing the Chasm*. HarperCollins Publishers, New York.

productivity improvements for existing operations. Due to these differences in user requirements, most emerging technologies fail to successfully move from a niche opportunity to the

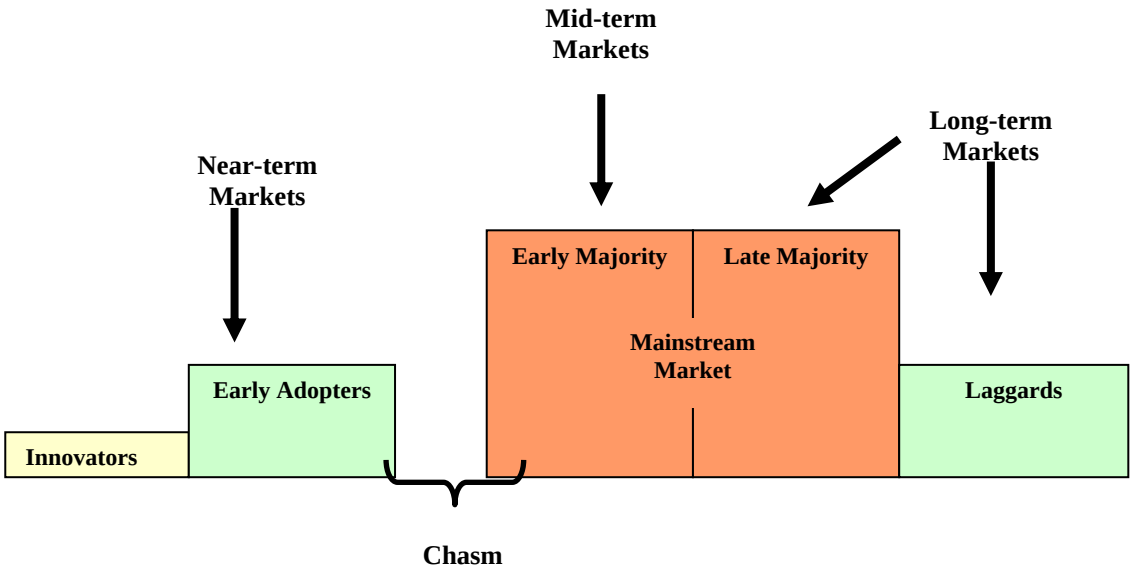

Figure 2-1. Typical technology adoption cycle.

mainstream market. New products require champions, and it is critical to find early adopters who are willing to adopt innovative technology for its strategic benefits. Early adopters provide new product opportunities for market penetration. Success with these users allows product developers to optimize their system for specific applications, test and improve reliability, and further refine the product. If early adopters are satisfied with their experience, products may be able to develop a reputation with users and expand beyond being a niche opportunity. Crossing the chasm to the early majority markets requires a proven track record meeting market-defined quality and demonstration of cost advantages. Early adopters provide the opportunity to demonstrate PEM fuel cell performance with an audience that is willing to take risks and pay more.

In order to prevent PEM fuel cells from becoming a niche product, it is critical to implement appropriate market segmentation methods to identify future target markets, their user requirements, and likely applications. This analysis identifies near-term, mid-term and long-term markets for PEM fuel cells. Near-term markets are typically composed of early adopters who see fuel cells as an emerging strategic opportunity. They are least price sensitive of any market segment and will provide the point of entry for PEM fuel cells. Products that dominate mainstream markets typically have a well-defined application profile, with highly visible benefits that match user requirements. The defined value proposition will be dependent on the product itself, the target customer needs, and the target application.

Demonstration projects in the target industries will also be critical to PEM fuel cell adoption in mainstream markets. A few companies in each early adopter industry may be willing to take a risk on a new technology. However, most companies are risk averse when it comes to adoption

of new technologies. They will require that any new technology has been successfully demonstrated in their industry and in the specific application where they want to use the PEM fuel cell. EERE's initiatives to engage industry members from early adopter market segments in discussions about user requirements and support for deployment and evaluation of PEM fuel cells in these applications is particularly valuable for providing credible performance data and bridging the gap to mainstream markets.

This analysis identifies early adopter market opportunities for various PEM fuel cell applications and user requirements for three market segments. It also identifies mainstream markets or high potential opportunities for stationary PEM fuel cells and critical drivers required for widespread commercialization of PEM fuel cells.

2.3 CONSUMER VALUE OF ELECTRICITY AND OPPORTUNITIES FOR DISTRIBUTED GENERATION

Electricity plays a central role in the production of goods and services, and affects the quality of life of private citizens. In the U.S. electricity is typically generated from large centrally located power plants and is distributed through transmission and distribution systems to the point of use. Electricity is produced from a number of sources including coal, natural gas, nuclear fuel, and renewable energy. The U.S. electric power generation system is one of the most dependable in the world, delivering power with over 99% reliability. The U.S. electricity distribution service is designed to provide a 60-cycle per second alternating current at a designated voltage, 120 volts for residential customers and 480 volts for many industrial and commercial customers. Total electric generation from power producers and on-site generation for electricity and combined heat and power are projected to increase from 3,626 billion kWh in 2002 to 5,421 billion kWh in 2025.

Today in 16 states, electricity is also produced by non-utility generators due to deregulation of generating assets.[8] The objective of deregulating electricity generating assets was to open generation up to competitive markets to reduce electricity prices, and its economic impacts have been varied. Electricity prices in California and several other markets fell soon after restructuring was initiated. Borenstein and Bushnell (2000) noted that prices were expected to decline during this period, even in the absence of restructuring.[9] An analysis of the competitiveness of deregulated energy markets estimated that, in California, energy purchase costs averaged ~16% above competitive levels in 1998 and 1999.[10] Furthermore, the power disruptions and spikes experienced by Californians in 2000 and 2001 became a symbol of the

[8] Rose, K. 2004. Case Studies: Performance Review of Electric Power Markets. For the Virginia State Corporation Commission. Available at http://www.scc.virginia.gov/caseinfo/reports/2004_rose.pdf.
[9] Borenstein, S. and J. Bushnell. 2000. Electricity Restructuring: Deregulation or Reregulation? Competition Policy Center, University of California Energy Institute POWER Paper CPC00-014. Available at http://www.ucei.berkeley.edu/PDF/pwp074.pdf.
[10] Borenstein, S., J.B. Bushnell, and F.A. Wolak. 2000. Diagnosing Market Power in California's Deregulated Wholesale Electricity Market. University of California Energy Institute POWER Working Paper PWP-064r. Available at http://www.ucei.berkeley.edu/PDF/pwp064.pdf.

failure of deregulation and served to slow the adoption of electricity restructuring plans by other states.[11]

In addition to deregulation, rising demand has placed increased stress on the grid, resulting in electric outages and other power quality problems. Incidents like the 2003 Northeast blackout have also increased consumer interest in ensuring reliable electricity on demand. Reliability events can be either sustained outages, when the voltages drop completely to zero, or power quality problems like sags and swells, which are subtle deviations in voltage. Although in the past, most electricity-consuming devices could ride through voltage sags, today many digital devices that are controlled by logic chips cannot tolerate even momentary drops in voltage. The U.S. bulk grid operates appliances, lights, and electric motors at an availability of about 99.96%, which is generally about 3.5 hours of downtime per year.[12] In this information technology and high security era, power outages can result in significant economic loss for power sensitive customers in commercial and industrial markets, and to a lesser extent for residential customers. Losses can be incurred through lost production, idle facilities and labor, data corruption and loss, burnt circuit boards, and damaged equipment in the commercial and industrial sector. Residential customers may experience losses by incurring direct out of pocket costs like food spoilage and damage to electrical equipment.

In 2001, the Electric Power Research Institute (EPRI)[13] estimated that the total impact of outages on the U.S. economy ranged from $104 billion to $164 billion in a typical year and that these impacts are primarily borne by the industrial and commercial sectors.[14] In another study, the economic impact was calculated at about $57 billion for the commercial sector, $20 billion for the industrial sector, and $2 billion for the residential sector. The study also determined that the cost of outages was driven by frequency of outage rather than the duration of the event. Momentary interruptions accounted for 67% of total outages and a loss of approximately $52 billion, and sustained interruptions accounted for 33% of total outages and approximately $26 billion in losses. Table 2-1 lists the average cost per outage for residential, commercial, and industrial customers.

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[11] Cuomo, R.J. 2003. Impact of Macro Shocks and Utility Restructuring on Energy Markets – Focus on Industries and Markets. Business Economics 38(1): 55-57.

[12] Balducci, P.J., J.M. Roop, L.A. Schienbein, J.G. DeSteese, and M.R. Weimar. 2002. Electrical Power Interruption Cost Estimates for Individual Industries, Sectors, and the U.S. Economy. U.S. Department of Energy, Office of Distributed Resources. DOE Contract No. DE-AC06-76RL01830. Available at http://www.pnl.gov/energy/eed/etd/pdfs/pnnl-13797.pdf.

[13] CEIDS. 2001. The Cost of Power Disturbances to Industrial and Digital Economy Companies. Reference # 1006274. Available at http://www.epri-intelligrid.com/intelligrid/docs/Cost_of_Power_Disturbances_to_Industrial_and_Digital_Technology_Companies.pdf

[14] LaCommare, K.H. and J.H. Eto. 2004. Understanding the Cost of Power Interruptions to U.S Electricity Consumers. Report No. LBNL-55718. Available at http://certs.lbl.gov/pdf/55718.pdf.

Table 2-1. Average cost per outage by customer.[15]

Duration	Residential* ($)	Commercial* ($)	Industrial* ($)
<1 Second	2.18	605	1,893
1 Hour	2.70	886	3,253
Sustained Interruption[+]	2.99	1,067	4,227

*2002 U.S. Dollars. These costs can vary significantly with time of day, availability of backup power, type of operation or facility, etc.
[+] A sustained interruption is defined as an outage lasting several hours.

A study by the Meta Group in 2000 provides a sense for the impact of computer downtime and data loss on the specific industry sectors thought to be most sensitive to power outages. Some of the most impacted sectors include: energy, telecommunications, manufacturing, financial services, information technology, insurance, and retail.[16]

Research conducted by Battelle indicates that typical electric consumers have an approximate hierarchy of value characteristics, which is the need for reliability, followed by power quality, safety, access to service, and affordable electricity. Despite the reliability of U.S. electricity and customer satisfaction, recent incidents of outages, customer alerts, and load shedding have led to increasing concerns regarding the availability and reliability of electricity. Furthermore, realization that improved power supply and quality are critical for some applications has resulted in users looking for alternatives. Distributed generation operating as part of the grid or off-grid can offer a solution to meet increasing reliability and consumption demands and can provide benefits valued by the marketplace. Reliable power has been identified as the most important future application for distributed generation.[17] Distributed generation offers several opportunities, as detailed below:

- First, deregulation of electricity markets has forced competitive pricing of electricity in some parts of the United States, and utilities have opted for cheaper distributed generation options.[18] Distributed generation can be a cheaper alternative to traditional expansions of generation and transmission capacity. Distributed generation capabilities can also be used by electric utilities to stabilize the grid during a sudden drop in capacity or increase in demand.
- Second, customer on-site generation of electricity can provide supplementary power during peak usage periods. This occurs primarily in the industrial and commercial sectors. Utility pricing strategies may result in higher annual electrical rates based on a user's highest peak demand. Lowering this peak can, in some instances, lower the unit cost of electricity for an entire year.
- Distributed generation can also offer standby capacity. Power related problems significantly impact productivity despite being connected to a reliable distribution-level utility grid. Some industrial and commercial consumers of electricity historically have produced electricity and heat on-site using large technologies like gas turbines,

[15] See reference 14.
[16] Meta Group. 2000. IT Performance Engineering and Measurement Strategies: Quantifying Performance Loss.
[17] Pepermans, G., J. Driesen, D. Haeseldonckx, W. D'haeseleer, and R. Belmans. 2003. Distributed Generation: Definition, Benefits and Issues. Energy Transport & Environment, Centrum voor Economische Studiën (C.E.S.), Katholieke Universiteit Leuven (K.U. Leuven) Belgium. Working Paper Series n°2003-9.
[18] Resource Dynamics Corporation. 2004. Distributed Generation Sourcebook. 2004 Edition.

generators, and engines to supplement the grid. However, growing reliability needs of information technology applications (such as supervisory control and data acquisition systems [SCADA]), automated equipment, and manufacturing lines requiring "high 9's" availability suggest opportunities for using distributed generation sources.

- CHP can use the "waste heat" from the distributed generation of electricity in beneficial ways, thus lowering the total cost of energy at the site and resulting in energy savings.
- Distributed generation technologies are often fuel flexible, and can be applied in areas where cheap and alternative types of fuel are available. Fuels can range from landfill gasses to biomass to hydrogen by-product.
- Distributed generation provides opportunities for cleaner energy production, which are particularly important where environmental regulations require "greener" alternatives. This has been identified as the most important driver of distributed generation.[19]

2.4 U.S. ELECTRICITY CONSUMPTION PATTERNS AND TRENDS

As noted in section 2.3, total electric generation from power producers and on-site generation of electricity and CHP is projected to increase from 3,626 billion kWh in 2002 to 5,421 billion kWh in 2025 (Table 2-2). Total renewable generation capacities, including sources present at customer sites, are expected to increase from 339 billion kWh to 518 billion kWh.[20] Renewable energy generation is projected to grow slowly because of the competitive cost of electricity from fossil fuels, and adoption of less capital intensive methods of generation by restructured markets. Delivered average electricity prices are projected to decline, in constant dollars, from 7.2 cents per kWh in 2002 to a low of 6.6 cents per kWh in 2010 as a result of cost reductions in increasingly competitive markets and declining coal prices. Average electricity prices are expected to reach approximately 6.9 cents per kWh in 2025 (equivalent to about 13.2 cents per kWh in nominal dollars).

Total electricity consumption (supplied by power sector generation) for the residential, commercial, and industrial sectors from power producers and from on-site generation is projected to grow from 3,470 billion kWh in 2002 to 5,172 billion kWh in 2025.[21] Commercial power consumption accounts for approximately 35%, residential 36.5%, and industrial 29% of the total electricity consumed. Natural gas is the primary heating fuel delivered to over 90% of consumers in the commercial, residential, and industrial markets. Gas consumption is expected to increase significantly in all three sectors.

[19] See reference 18.
[20] Energy Information Administration (EIA). 2004. Annual Energy Outlook 2005 with Projections to 2025. Report No. DOE/EIA-0383(2005). Available at http://tonto.eia.doe.gov/FTPROOT/forecasting/0383(2005).pdf. Also available at http://www.eia.doe.gov/oiaf/aeo/.
[21] See reference 20.

Table 2-2. Current and projected electricity consumption.[22]

	UNITS	2002	2010	2015	2020	2025
Total Electricity Available to the Grid	Billion kWh	**3626**	**4242**	**4606**	**5004**	**5421**
Total Electric Power Sector Generation[a]		3443	4054	4423	4829	5257
Power Sector Combined Heat and Power[b]		183	188	183	175	164
Power Sector Renewable Sources[c]		309	404	424	446	464
End-Use Sector Generation[c]		157	202	231	264	299
Customer Sited Renewable Sources[c]		30	39	45	50	54
Customer Sited End Use Generators[d]		4	5	5	5	7
Total Electricity Generated		**3831**	**4510**	**4904**	**5335**	**5787**
Total Natural Gas Consumption	Quad Btu	**22.78**	**26.15**	**28.03**	**30.44**	**31.41**
Residential Natural Gas Consumption		5.06	5.69	5.84	6.08	6.26
Commercial Natural Gas Consumption		3.21	3.57	3.72	3.94	4.16
Industrial Natural Gas Consumption		7.43	8.62	9.12	9.84	10.58
Electric Sales by Sector	Billion kWh	**3470**	**4029**	**4400**	**4779**	**5172**
Residential		1268	1428	1531	1641	1747
Commercial		1208	1480	1653	1828	2003
Industrial		994	1120	1216	1310	1422
Average Electricity Prices (2002 Dollars)	Cents/ kWh	**7.2**	**6.6**	**6.8**	**6.9**	**6.9**
Residential End Use Prices		8.4	7.9	8.1	8.1	8.1
Commercial End Use Prices		7.8	7.0	7.2	7.2	7.3
Industrial End Use Prices		5.0	4.6	4.7	4.8	4.8

[a] Includes power plants whose primary business is to sell power to the grid.
[b] Includes CHP plants whose business is to sell heat and power to the grid.
[c] Includes CHP plants and electricity-only generation in the commercial and industrial sectors.
[d] Other end user generators include small on-site generating systems in the residential, commercial and industrial sectors primarily for their own use.

2.5 REVIEW OF TYPICAL APPLICATIONS FOR PEM FUEL CELLS

As with any other emerging technology, PEM fuel cells face various technical and other market entry barriers, including unproven product reliability and durability. However, PEM fuel cells are particularly well suited to transportation applications and for specific distributed generation applications. Like other distributed energy technologies, PEM fuel cells offer numerous potential benefits over the grid:

- Assured premium quality and reliable energy availability
- Good load following characteristics
- Potential for greener electricity and green image
- Opportunity for greater U.S. energy security by reducing reliance on imported fuels
- Flexibility in siting, installation and operation
- Lower maintenance costs

[22] See reference 20.

- High efficiency, particularly in combined heat and power applications
- The opportunity to provide new energy services such as utilities leasing fuel cells for peak-shaving or premium power at customer sites
- An alternative for utilities to make incremental investments to expand capacity or stabilize the grid (delaying major capital outlays).

Furthermore, PEM fuel cells offer several advantages over other types of fuel cells and alternative sources of power that can help to overcome adoption barriers. These advantages include: low weight and volume; low emissions and noise pollution; fewer moving parts; relatively fast warm-up time, and fuel flexibility with potential for using low cost fuels like propane.

There are many possible stationary applications for PEM fuel cells in the 1 kW to 250 kW range in a variety of market sectors. The opportunities for these applications will be dependent on a range of market and user defined cost and performance criteria. For purposes of this project, the various potential applications for PEM fuel cells include:

- **Backup** – Standby or emergency power source used to ensure uninterrupted service. Fuel cells could be used to provide electricity that meets standard backup requirements, for example in brownout or blackout conditions, as well as to meet high-quality backup power requirements for customers such as banks and telecommunications companies who are willing to pay more to secure reliable service. In backup applications efficiency is not as critical as reliability and availability of the system. Due to intermittent use of the system, PEM fuel cells as backup power sources are not expected to have a significant impact on energy efficiency or emissions savings.

- **Grid independent** – Continuous, stand-alone power source that is not connected to the grid. For example, a fuel cell might support all energy needs for either a single building or multiple homes in lieu of the grid. Power sources selected for these applications typically have high reliability, fuel availability, high efficiency, and low maintenance costs. Costs may be less important than in grid-competitive applications. Units are expected to run for a long time, typically over 6000 hours per year.[23] The power source is also expected to have good load following characteristics, as it is the sole source of power.

- **Grid parallel** – Continuous supply of auxiliary power to a user connected to the grid; when user needs are fully met by the fuel cell, excess power may be supplied to the grid. The grid could provide the primary power source or serve as secondary power to the fuel cell. Grid parallel applications serve baseload power needs and can also provide peak shaving support. If the fuel cell serves baseload power needs, it is expected to operate on a continuous basis for at least 6000 hours per year. Fuel cells for baseload applications, which are typically found in the industrial and commercial sectors, are expected to have high electrical efficiencies, low operation and maintenance costs, and low emissions. In peak shaving, the fuel cell is expected to operate between 200 and 3000 hours[24] per year

[23] See reference 18.
[24] See reference 18.

to support electricity cost reduction. It is most commonly used in commercial applications, due to higher peak demand to reduce the cost of electricity during high price periods. Criteria for adoption of peak shaving technology include low installed cost, quick start-up, and low operation and maintenance costs.

- **Grid connected** – Continuous, one-way supply of power that is supplied to the grid. These fuel cells are generally operated by a utility or, in deregulated cases, by the customer or substation. Grid connected applications serve baseload and peak power needs of the customer. Fuel cell operation is dependent on application, and systems are expected to be reliable, highly efficient, with low operation and maintenance costs.

- **Combined heat and power** – The fuel cell provides electricity to the user and also produces heat. For example, CHP from a fuel cell may be used by a community to heat a swimming pool and provide power to the pool center. Fuel cells used for these applications are expected to operate for at least 6000 hours a year, and heat supplied is typically used for water and space heating, and other thermal requirements. Fuel cells for this application should produce highly usable thermal heat, be highly efficient with low emissions, and have low operations and maintenance costs.

2.6 KEY DRIVERS FOR COMMERCIALIZATION OF STATIONARY PEM FUEL CELLS

PEM fuel cells in the 1 kW to 250 kW range have the potential to penetrate various market niches if they are able to meet the baseline user requirements. The value proposition for PEM fuel cells for specific market segments will be highly dependent on the type of application, as well as other economic and institutional factors. The best opportunity for near-term commercialization of PEM fuel cells lies with the set of early adopter market segments that identify performance parameters other than cost (e.g., reliability) as the critical drivers.

Addressing the investment decision factors that count the most to target users will be critical to driving the adoption of PEM fuel cells in early adopter market segments. In addition, for PEM fuel cells to move beyond early adopter markets and achieve higher levels of market penetration, PEM fuel cells must be able to satisfactorily address market needs for a wider set of commercialization drivers.

Figure 2-2 illustrates some of the key drivers behind PEM fuel cell commercialization, which were identified by Battelle research. While the relative importance of these factors will vary across sectors and market segments (e.g., within the commercial sector, financial institutions prioritize these drivers differently than hotels), there are several commonalities. When looking at a broad cross-section of potential end users, cost is the key driver behind PEM fuel cell commercialization, followed by the need for improved reliability and durability (i.e., performance relative to competing technologies).[25,26]

[25] See reference 4.
[26] See reference 5.

While not always recognized by the consumer, R&D investment in breakthrough technologies is also a key driver behind improved fuel cell performance and cost sufficient to meet market requirements. Public policy support for early stage R&D is widely known and well accepted for technology development. However, in early adopter markets, until cost requirements can be achieved, government incentives provide a critical means of driving down cost on both the market and production side in order to encourage fuel cell adoption. Government-supported demonstration projects provide a demonstrated track record of an acceptable level of performance, which most companies want to see before they will adopt a new energy technology.

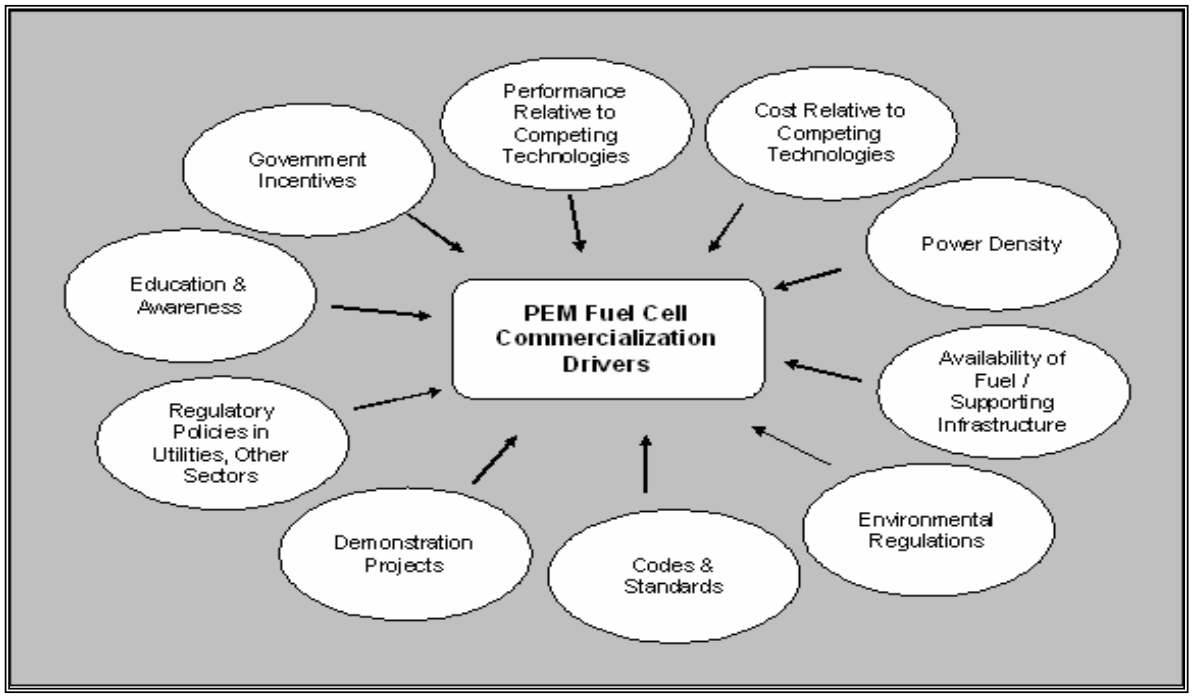


Figure 2-2. Key drivers affecting PEM fuel cell commercialization.

Environmental regulations targeted at electricity generation could facilitate adoption of PEM fuel cells as a distributed power source. The electric power sector has been responsive to air regulations through adoption of innovative technologies. Future regulations of greenhouse gases can be a key driver of PEM fuel cells in this sector. In backup power applications, current environmental regulations on emissions could provide a major impetus to adopt PEM fuel cells since they provide a distinct advantage over diesel generators. Regulatory policies can also be an important driver of PEM fuel cells by making it easy and cost-effective to connect and sell excess power to the grid.

Education and public outreach describing the performance and benefits of PEM fuel cells are considered other important commercialization drivers. Those will be necessary to help build market demand for PEM fuel cells. Currently, knowledge of fuel cells within the commercial, industrial, and residential sectors is limited. Even though many facility and energy managers

may be familiar with PEM fuel cells, they will need appropriate educational materials to convey the benefits of an investment in PEM fuel cells to decision-makers.

Uniform or compatible codes and standards for PEM fuel cells will play a role in fuel cell commercialization. An important milestone was achieved with the establishment of electrical interconnect standards (i.e., IEEE 1547) in July 2003. This standard defines the requirements and criteria for interconnecting distributed resources with the grid. However, one important area where codes and standards have not yet been fully developed is the handling of hydrogen fuel. Furthermore, these standards need to be adopted at the state level and become familiar to local fire marshals.

Fuel cell size and power output (power density) are critical factors for grid connected applications, and for many potential users in backup and grid parallel applications. As power density in buildings increases, power systems must be designed to match these requirements. Currently, the practical power output of PEM fuel cells limits their potential for widespread commercialization to applications needing more than 250 kW. In addition to performance of PEM fuel cells, cost and quality of the PEM fuel cell as compared to competing technologies will also be critical drivers for adoption in mainstream markets. Users will demand equal if not better performance from the PEM fuel cell product in early adopter markets.

Finally, while there is not a strong consensus among users and developers on how fuel should be delivered for stationary applications (e.g., on-site reformation versus hydrogen infrastructure development), there is a strong consensus that fuel source requirements for storage, infrastructure, and safety must be addressed if PEM fuel cells are to be a commercial success.

2.7 MARKET OPPORTUNITIES FOR PEM FUEL CELLS

Stationary market opportunities for the application of PEM fuel cells in the 1 kW to 250 kW range have been segmented into five sectors – commercial, institutional, industrial, residential, and electric utility. Each sector has been further segmented into specific market segments comprising a set of potential customers who have a common set of needs and wants, and who often consult with each other when making buying decisions. Opportunities for PEM fuel cells in all of the aforementioned applications were identified across all sectors, with the assumption that PEM fuel cells in the 1 kW to 250 kW size range could be developed to provide the minimum user requirements and benefits (including reliability, cost, and quality). The focus of the analysis presented in this section is to identify prospective markets, potential early adopters and their user requirements.

Table 2-3 reviews likely applications for PEM fuel cells in various target sectors based on sector requirements. For the purposes of this report, specific markets like hospitals and educational institutions, commonly classified as users in the commercial sector by electric utilities, will be called out separately as the institutional market sector because of similarities in user requirements.

Table 2-3. Likely applications for PEM fuel cells in various sectors.

Application of PEM Fuel Cells 1-250 kW	Residential	Commercial	Institutional	Industrial	Electric Utility
Backup	●	●	●	●	●
Grid Parallel	●	●	●	◘	◘
Grid Independent	●	◘	◘	◘	◘
Grid Connected	NA	NA	NA	NA	◘
Combined Heat and Power	●	◘	●	◘	○

● Good Fit ◘ Moderate Fit ○ Poor Fit

PEM fuel cells are extremely well suited to provide backup power and grid parallel (specifically peak shaving) support to various applications in all five market sectors. The PEM fuel cell is also suited to support grid independent applications in light commercial and residential applications. However, due to limitations in power size, durability, and load requirements, PEM fuel cells are not as well suited for applications in grid independent or grid connected mode in the industrial sector or electric utility sector, where requirements are often in megawatts. Reformer-based PEM fuel cells and high temperature membrane fuel cells are well-matched for various CHP applications especially in institutional, some commercial, and residential sectors where the need for space and water heating exists.

2.8 COMMERCIAL MARKET OVERVIEW

2.8.1 Electricity Consumption Patterns

The commercial sector includes non-manufacturing business establishments, such as retail stores, gas stations, hospitality industries, construction, telecommunications, data centers, entertainment and leisure industry, and radio and TV broadcasting. The commercial sector has over 4,859,000 buildings[27] across the country, with commercial floor space expected to grow 1.5% per year between now and 2025. To support this sector, commercial electricity sales and natural gas consumption are expected to grow.[28] Specific markets like hotels have on-site generation to meet electricity and heat needs; however, exact estimates are unavailable.

Commercial electricity prices are higher than prices paid by industrial users and are expected to decrease from 7.8 cents to 7.3 cents per kWh by 2025 (which is about 12.5 cents per kWh in nominal dollars).

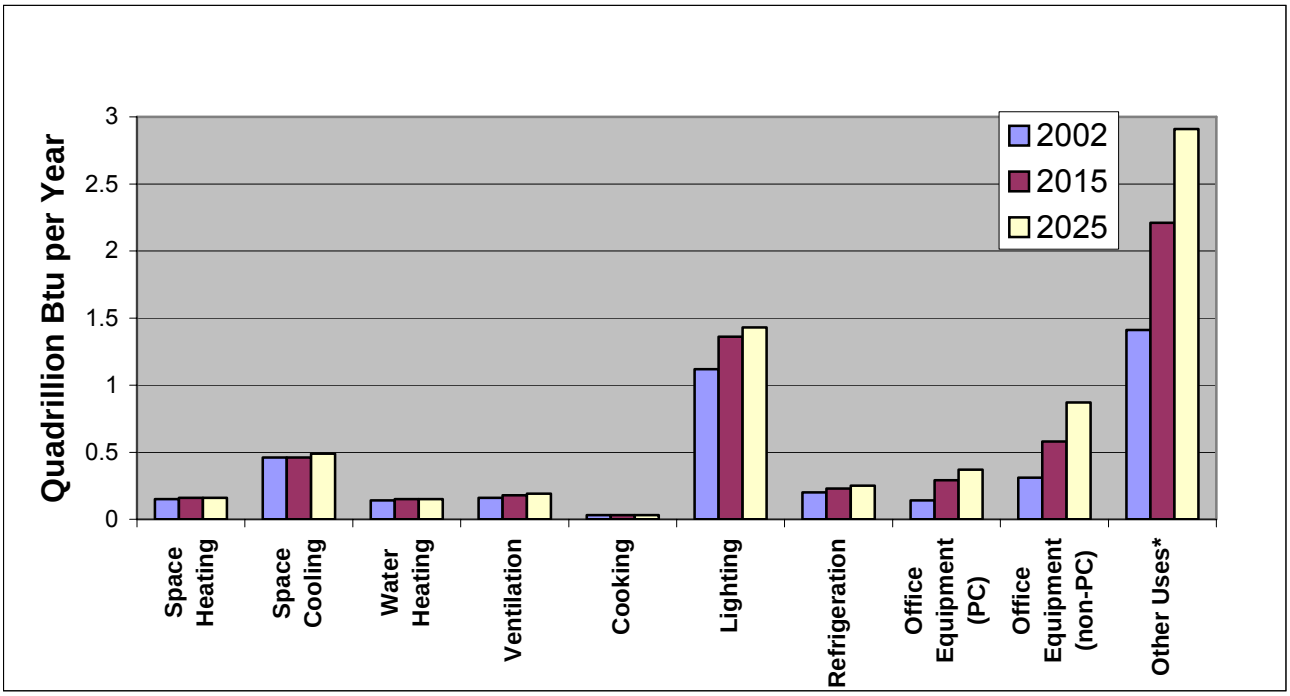
Electricity accounts for 76% of the fuels consumed (followed by natural gas [18%]) by the commercial sector. In the commercial sector, lighting needs lead consumption of electricity,

[27] EIA. 2003. Commercial Buildings Energy Consumption Survey - Commercial Building Characteristics. Accessed May 14, 2005. Available at http://www.eia.doe.gov/emeu/cbecs/contents.html.
[28] See reference 20.

followed by space cooling, non-PC office equipment, and refrigeration (Figure 2-3). Other uses like telecommunications, medical imaging technologies, and automatic teller machines are expected to significantly increase the need for reliable electricity.

2.8.2 Commercial Market Sector Opportunities for PEM Fuel Cells

Outages and power quality problems have a significant economic impact on the commercial sector. Growing demands on computers and electronics have made commercial sector operations extremely sensitive to power disruptions. In 2002, the average estimated cost of one power outage (averaged over all durations, ranging from 1 second to 12 hours) for large commercial users was approximately $70,634 per event, and the average cost per power outage (all durations) for small and medium commercial customers was approximately $2,735 per event.[29] Interruption costs vary based on customer demand characteristics, with financial institutions, telecommunications, eating and drinking places, amusement and recreation services having higher outage costs than hotels and retail services.[30] Although the average cost of outages for commercial customers is less than the average cost for industrial customers, the overall cost to the commercial sector is higher than the cost to the industrial sector because of the



*Other uses include small electric devices, heating elements, and motors.

Figure 2-3. Electricity energy consumption by end use in the commercial sector.[31]

larger number of commercial customers (16,636,448 commercial sector customers compared to 719,748 industrial sector customers).[32] The high economic cost of outages has led many

[29] See reference 14.
[30] See reference 12.
[31] EIA. 1999. Commercial Building Energy Consumption Survey. Accessed May 12, 2005. Available at http://www.eia.doe.gov/emeu/cbecs/contents.html.

commercial sector customers to invest in a wide variety of technologies to reduce their vulnerability to reliability related events. Commercial customers tend to be proactive and have opted to install backup power sources, including batteries and generators, and power quality modulators, like transient voltage surge suppressor devices, isolation transformers, and voltage regulators.

Based on the information presented above, there is a critical need for long-term planning to address consumer demand and reliability requirements. PEM fuel cells could offer alternatives to currently used modes of distributed generation in the commercial sector. To have the most significant energy impacts, PEM fuel cells will have to be utilized to provide general building electricity for lighting, office equipment requirements and office cooling needs. Key drivers that favor the use of PEM fuel cells in commercial applications are outlined in Table 2-4. Users in this sector typically can utilize PEM fuel cells to provide backup power for critical services like hub sites in telecommunications, in grid parallel applications for peak shaving in large office buildings, and to a lesser extent in CHP applications in hotels. In some cases, PEM fuel cells could be used in grid independent applications for remote locations such as telecommunication towers, at building construction sites, and at remote national park sites. Characteristics of prospective markets in the commercial sector are shown in Table 2-5.

Table 2-4. Key drivers for PEM fuel cells in the commercial sector.

Commercial Sector		
Backup Power	Drivers	- Need for reliability - Very high economic loss from downtime - Environmental and energy efficiency benefits
	Barriers	- Competing against mature technologies like batteries and generators - Reliability not demonstrated
Grid Parallel	Drivers	- Electric rates for grid power favor on-site generation for specific time of day - Loads and load-factors of specific small and medium commercial buildings favor application - Environmental and energy efficiency benefits
	Barriers	- Non-traditional market for on-site generation and requires new approaches to facilitate ownership and operation - Utility policies and regulations
Grid Independent	Drivers	- Electricity needs at remote locations
	Barriers	- Availability of competitively priced grid electricity and generator electricity
Combined Heat and Power	Drivers	- Reasonably attractive thermal and electric loads in specific markets
	Barriers	- Other than hotels, other users may be unfamiliar with cogeneration units - Low electric rates - Utility policies and regulations

[32] EIA. 2005. Electricity U.S. Data. Accessed May 12, 2005. Available at http://www.eia.doe.gov/cneaf/electricity/esr/table1abcd.xls#A259.

Table 2-5. Characteristics of prospective markets in the commercial sector for PEM fuel cells.

Market	Sub-markets	BP[1]	GP[2]	GI[3]	CHP[4]	Potential Adopters[5]	Electricity Consumption Characteristics	Typical User Requirements
Telecommunication	Wireline, Wireless and Online Communication	●	●	◘	○	59,062	High	Reliability, Power Quality, Cost, Ease of Use
Technical Services	Professional Scientific, and Technical Services	●	●	○	◘	778,612	Medium	Reliability, Cost, Energy and Environmental Efficiency, Available Service Infrastructure
Financial Services	Banking and Supporting Businesses	●	●	○	○	108,667	Medium	Reliability, Cost, Durability, Perceived Safety/Risk
Financial Services	Security and Commodity Exchanges and Supporting Businesses	●	●	○	○	40,705	Medium	Reliability, Cost, Durability, Perceived Safety/Risk
Financial Services	Insurance Agents and Supporting Businesses	●	●	○	○	197,054	Medium	Reliability, Cost
Retail	Grocery Stores	●	●	○	●	173,239	Medium	Cost, Reliability, Ease of Use, Available Service Infrastructure
Retail	Department Stores	◘	●	○	○	22,787	Medium	Cost, Ease of Use, Reliability, Available Service Infrastructure
Retail	Stores	◘	●	○	○	218,554	Low	Cost, Available Service Infrastructure
Retail	Gasoline Station	◘	●	○	○	68,216	Low	Cost, Available Service Infrastructure
Personal Services	Laundries	◘	●	○	●	36,541	High	Cost, Durability, Energy and Environmental Efficiency
Hospitality	Hotels	●	●	○	●	86,231	High	Cost, Reliability, Energy and Environmental Efficiency, Durability
Hospitality	Trailer Parks and Campsites	○	◘	●	●	10,092	Low	Cost, Durability, Energy and Environmental Efficiency
Hospitality	Restaurants	●	●	○	●	557,661	High	Cost, Reliability, Ease of Use, Available Service Infrastructure
Construction	Building Construction	●	◘	●	○	299,821	Medium	Cost, Durability, Reliability, Environmental and Energy Efficiency

[1] Backup power, [2] Grid parallel, [3] Grid Independent, [4] Combined Heat and Power; [5] Number of businesses that could adopt technology – does not include total market size which includes potential sites for application; ● Good fit; ◘ Moderate fit, ○ Poor fit

Table 2-5. Characteristics of prospective markets in the commercial sector for PEM fuel cells.

Market	Sub-markets	BP[1]	GP[2]	GI[3]	CHP[4]	Potential Adopters[5]	Electricity Consumption Characteristics	Typical User Requirements
Construction	Heavy Construction	●	◘	●	○	61,326	Medium	Cost, Durability, Reliability, Environmental and Energy Efficiency
Communication	Radio and Television Broadcasting Stations	●	●	○	○	29,230	Medium	Reliability, Cost, Ease of Use
Entertainment and Leisure	Amusement Parks	●	●	○	○	1,527	High	Reliability, Cost, Durability
Entertainment and Leisure	Racing	●	●	○	○	4,714	High	Reliability, Cost, Durability
Entertainment and Leisure	Sports and Recreation	●	●	◘	○	26,262	High	Reliability, Cost, Durability
Entertainment and Leisure	Gambling	●	●	○	○	782	High	Reliability, Durability, Cost
Entertainment and Leisure	Museums and Art Galleries	●	●	○	○	15,484	Medium	Cost, Reliability, Ease of Use, Available Service Infrastructure
Entertainment and Leisure	Botanical and Zoological Gardens	◘	●	○	○	982	Medium	Cost, Reliability, Energy and Environmental Efficiency
Entertainment and Leisure	National and State Parks	●	●	●	●	388	Medium	Cost, Energy and Environmental Efficiency

[1] Backup power, [2] Grid parallel, [3] Grid Independent, [4] Combined Heat and Power; [5] Number of businesses that could adopt technology – does not include total market size which includes potential sites for application; ● Good fit; ◘ Moderate fit, ○ Poor fit

2.9 INSTITUTIONAL MARKET OVERVIEW

2.9.1 Electricity Consumption Patterns

The institutional market is typically classified under the commercial sector by utility service providers. For this study, the market has been classified separately because of differences in market and user requirements. The institutional market includes healthcare, education, government, and non-electric utilities such as water and natural gas (electric utilities are handled separately in this study). The 2003 Commercial Building Energy Consumption Survey[33] indicates that there are approximately 386,000 education buildings, 129,000 healthcare buildings, 277,000 public assembly buildings, and 71,000 public order and safety buildings. Primary end uses of fuels consumed by the sector are space heating, water heating, cooking, and cooling.[34]

2.9.2 Institutional Sector Opportunities for PEM Fuel Cells

The economic impact of outages within the institutional sector is highly dependent on the market and end users. For example, government communications and emergency preparedness services will have different requirements than an educational facility. Balducci et al. (2002) indicated that a 20-minute interruption in educational services cost about $0.30 per kW, a 1-hour interruption cost $1.13 per kW, and a 4-hour interruption cost $4.27 per kW.[35] Users in this sector could use PEM fuel cells as backup power, in grid parallel applications for peak shaving, and in combined heat and power applications. In some cases, PEM fuel cells could be used in backup and grid independent applications, for instance, at remote railway crossings or in airport telecommunication towers. Table 2-6 provides a detailed listing of key drivers for PEM fuel cell applications in the institutional sector.

Specific users in the institutional sector, like hospitals and the government, have a critical need for reliable power. For specific applications, PEM fuel cells could provide strategic benefits to users including increased reliability, energy security, energy efficiency, and lower environmental impacts (Table 2-7). This sector also comprises users who could potentially drive the adoption of PEM fuel cells from numerous directions. Users could use PEM fuel cells to provide critical backup power support for SCADA systems in water distribution and wastewater treatment systems; monitoring of online systems for threat detection in water; medical equipment and hospital clean-rooms; CHP to buildings (in hospitals, schools); and peak shaving support in schools, colleges, and hospitals.

Potential early adopters in this sector include segments of the Department of Defense and Department of Homeland Security. Specifically, within this market, PEM fuel cells can be used by early adopters to supply power to mission critical facilities, data centers, air traffic control facilities, emergency management centers, and residential applications on army and naval bases.

Table 2-7 provides a detailed listing of prospective markets in the institutional sector, as well as other qualitative and quantitative market characteristics.

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[33] See reference 27.
[34] See reference 32.
[35] See reference 12.

Table 2-6. Key drivers for PEM fuel cells in the institutional sector.

Institutional Sector		
Backup Power	Drivers	- Need for reliability - Very high economic loss from downtime - Environmental and energy efficiency benefits - Energy security - Opportunity to educate the next generation on emerging technologies (use in educational market) - Low thermal signatures (defense applications) - High efficiency
	Barriers	- Competing against mature technologies like batteries and generators - Reliability not demonstrated
Grid Parallel	Drivers	- Electric rates for grid power favor on-site generation for specific time of day - Loads and load-factors favor application - Environmental and energy efficiency benefits
	Barriers	- Utility policies and regulations - Lack of government incentives
Grid Independent	Drivers	- Very limited opportunity. Only for electricity needs at remote locations
	Barriers	- Availability of competitively priced grid electricity and generator electricity
Combined Heat and Power	Drivers	- Attractive thermal and electric loads in specific markets
	Barriers	- Other than education and healthcare, other users may be unfamiliar with cogeneration units - Low electric rates - Utility policies and regulations

Table 2-7. Characteristics of prospective markets in the institutional sector for PEM fuel cells.

Market	Sub-Market	BP[1]	GP[2]	GI[3]	CHP[4]	Potential Adopters[5]	Electricity Consumption Characteristics	User Requirements
Healthcare	Skilled Nursing Care Facilities	●	●	○	●	26,330	Medium	Available Service Infrastructure, Efficiency, Reliability, Quality
Healthcare	Hospitals	●	●	○	●	22,085	High	Reliability, Availability, Efficiency, Available Service Infrastructure, Quality
Healthcare	Laboratories (includes Dialysis centers)	●	●	○	●	33,268	Medium	Available Service Infrastructure, Reliability, Durability
Education	Education	●	●	◘	●	175,079	High	Cost, Available Service Infrastructure, Durability
Postal Services	United States Postal Service	●	◘	◘	◘	33,333	Low	Available Service Infrastructure, Cost, Ease of Use
Defense	United States Department of Defense	●	●	●	◘	14,130	High	Reliability, Durability, Power Quality
Defense	International Governments	●	◘	◘	◘	2,873	Low	Cost, Reliability, Durability
Transportation	Railways	●	●	◘	○	813	High	Reliability, Durability, Ease of Use, Power Quality
Transportation	Airports	●	●	○	○	6,082	High	Reliability, Durability, Power Quality
Public Administration	Government	●	●	◘	●	87,900	High	Cost, Combined Heat and Power, Reliability
Utility	Water Distribution	●	●	●	○	8,798	High	Reliability, Cost, Durability
Utility	Sewerage Systems	●	●	○	○	1694	Medium	Reliability, Cost, Durability
Utility	Waste Treatment and Disposal Systems	●	●	◘	○	19,519	High	Reliability, Cost, Durability

[1] Backup power, [2] Grid parallel, [3] Grid Independent, [4] Combined Heat and Power; [5] Number of businesses that could adopt technology – does not include total market size which includes potential sites for application; ● Good fit; ◘ Moderate fit, ○ Poor fit

2.10 INDUSTRIAL SECTOR OVERVIEW

2.10.1 Electricity Consumption Patterns

In the industrial sector, delivered industrial energy consumption for all fuels is projected to increase at an average rate of 1.3% per year between 2002 and 2025 (Table 2-2). In 1999, this sector comprised over 268,214 establishments operating over 512,840 building sites. To support this sector, industrial electricity sales are expected to grow from 994 billion kWh in 2002 to 1,422 billion kWh in 2025. Electricity prices are expected to stay fairly low at about 4.8 cents per kWh (Table 2-2).[36] On-site generation accounted for approximately 21% of the total electricity and heat consumed by the manufacturing sector at 223 billion kWh in 1998.

Natural gas consumption in this sector is expected to grow from 7.43 quadrillion Btu in 2002 to 10.58 quadrillion Btu (Table 2-2).[37] The manufacturing sector is expected to grow 2.8% annually to 2025, and the non-manufacturing industrial sector, including agriculture, mining, and construction, is expected to grow by 1.8%. More than 70% of the energy consumed in the industrial sector is used to provide heat and power for manufacturing, with the rest used for non-manufacturing purposes. Petroleum refining, chemicals, and the pulp and paper industries are some of the largest consumers of energy.

2.10.2 Industrial Sector Opportunities for PEM Fuel Cells

Industrial operations are highly sensitive to power disruptions. A momentary outage can shut down a manufacturing operation for several hours, resulting in loss of production and damaged products and equipment. In 1996, it was estimated that 20 minutes of interruption cost the industrial sector on average approximately $6.29 per kW, 1 hour cost $13.03 per kW, and 4 hours cost $29.94 per kW.[38] However, certain industries are impacted more than others. For instance, according to Balducci et al. (2002), a plastic sheet manufacturing plant found that any power outage costs the plant a minimum of $38,000 in lost productivity and labor costs due to production set-up time.[39] They have also shown that interruption costs vary by demand characteristics; it is extremely low for agriculture and coal mining operations, and extremely high for oil and gas, food and the kindred products industry.

Industrial markets have typically enjoyed low electricity rates and have been driven to make distributed generation choices to ensure the reliability of their operations and to benefit their bottom line. This market already produces a significant amount of power on-site and actively looks for economic methods to utilize alternative sources of waste heat and energy.

Based on the requirement for reliability, opportunities for distributed generation exist in the industrial sector. However, PEM fuel cell applications in this market sector may be limited to niche applications due to power density and performance limitations of the PEM fuel cell technology. Key drivers of PEM fuel cells in the industrial sector are detailed in Table 2-8.

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[36] See reference 20.
[37] See reference 20.
[38] See reference 11.
[39] See reference 12.

Table 2-8. Key drivers for PEM fuel cells in the industrial sector.

Industrial Sector		
Backup Power	Drivers	- Need for reliability - High demand for electricity - Very high economic loss from downtime - Environmental and energy efficiency benefits - Very high economic loss
	Barriers	- Competing against mature technologies like engines, batteries and generators - Small power size of PEM fuel cells may be limiting
Grid Parallel	Drivers	- Requirements for peak shaving favor on-site generation - Availability of fuels (hydrogen in chemical industry) - Environmental and energy efficiency benefits - Scalability of PEM fuel cells
	Barriers	- Loads and load-factors do not favor widespread application of PEM systems - Competition for large systems like turbines, stirling engines etc - Competitive grid pricing
Grid Independent	Drivers	- Very limited opportunity. Only for electricity needs at remote locations
	Barriers	- Size limitations of PEM fuel cells to supply power - Attractive on-site generation with other competing technologies
Combined Heat and Power	Drivers	- Attractive thermal and electric loads in specific markets
	Barriers	- Heat requirements may be much higher than PEM fuel cells can support - Low electric rates

The nature of the industrial market and the type of manufacturing process will dictate the types of applications for PEM fuel cells. Users in this sector could favor PEM fuel cells as backup power specifically for power sensitive operations like clean rooms, integrated manufacturing; in some cases for grid parallel applications for peak shaving (e.g., based on the availability of hydrogen at a chemical plant), and for certain CHP applications as in the food and beverage industry. Critical functions such as computer related operations in manufacturing, specific processing equipment, and emergency lighting and alarms could be supplied with power from PEM fuel cells. Table 2-9 provides a detailed listing of prospective markets in the industrial sector, as well as other qualitative and quantitative market characteristics.

Table 2-9. Characteristics of prospective markets in the industrial sector for PEM fuel cells.

Market	Sub-Market	BP[1]	GP[2]	GI[3]	CHP[4]	Potential Adopters[5]	Electricity Consumption Characteristics	User Requirements
Animal Agriculture	Feedlots (Beef Cattle, Hog, Turkey, Chickens)	●	●	◘	●	38,407	High	Reliability, Durability, Energy and Environmental Efficiency, Cost
Animal Agriculture	Dairy Farms	●	●	◘	●	33,856	High	Reliability, Durability, Cost
Animal Agriculture	Eggs (Chicken and Turkey)	●	●	◘	●	3,376	High	Reliability, Durability, Cost
Animal Agriculture	Animal Aquaculture	●	●	◘	●	860	Medium	Reliability, Availability, Cost, Low Maintenance
Mining	Oil and Gas Extraction	●	◘	●	◘	20,236	High	Reliability, Availability, Low Maintenance
Manufacturing	Food	●	●	◘	●	26,375	High	Reliability, High Combined Heat and Power Efficiency, Durability, Cost
Manufacturing	Beverage and Tobacco Products	●	●	◘	●	2,990	Low	Cost, Reliability, Durability, High Combined Heat and Power Efficiency
Manufacturing	Textile Mills and Textile Product Mills	●	◘	◘	◘	7,313	Low	Cost, Reliability, Energy and Environmental Efficiency
Manufacturing	Apparel	●	◘	◘	◘	12,506	Low	Cost, Energy and Environmental Efficiency
Manufacturing	Leather and Allied Products	●	◘	◘	◘	1,516	Low	Cost, Ease of Use, Available Service Infrastructure
Manufacturing	Wood Products	●	●	◘	●	16,846	High	Energy and Environmental Efficiency, Durability, Cost, Reliability
Manufacturing	Paper	●	●	◘	●	5,485	High	Energy and Environmental Efficiency, Durability, Cost, Reliability
Manufacturing	Printing and Related Support Activities	●	●	◘	●	37,172	Low	Cost, Durability
Manufacturing	Petroleum and Coal Products	●	●	●	●	2,278	High	Durability, Energy and Environmental Efficiency, Reliability, Cost
Manufacturing	Chemical Manufacturing	●	●	●	●	13,098	High	Durability, Energy and Environmental Efficiency, Reliability, Cost

[1] Backup power, [2] Grid parallel, [3] Grid Independent, [4] Combined Heat and Power; [5] Number of businesses that could adopt technology – does not include total market size which includes potential sites for application; ● Good fit; ◘ Moderate fit, ○ Poor fit

Table 2-9. Characteristics of prospective markets in the industrial sector for PEM fuel cells.

Market	Sub-Market	BP[1]	GP[2]	GI[3]	CHP[4]	Potential Adopters[5]	Electricity Consumption Characteristics	User Requirements
Manufacturing	Plastics and Rubber Products	●	●	◘	◘	15,205	Medium	Cost, Reliability, Durability,
Manufacturing	Nonmetallic Mineral Products	●	◘	●	◘	16,521	High	Energy and Environmental Efficiency, Durability, Reliability, Cost
Manufacturing	Primary Metals	●	◘	●	◘	5,955	High	Reliability, Durability, Cost
Manufacturing	Fabricated Metal Product	●	●	◘	○	60,655	Low	Cost, Reliability
Manufacturing	Machinery	●	●	◘	○	28,220	Medium	Cost, Reliability
Manufacturing	Computer and Electronic Product	●	●	●	○	15,697	Medium	Reliability, Durability, Energy and Environmental Efficiency
Manufacturing	Electrical Equipment, Appliance and Components	●	●	○	○	6,380	Medium	Cost, Reliability, Energy and Environmental Efficiency
Manufacturing	Transportation Equipment	●	●	○	○	12,309	Medium	Cost, Availability, Ease of Use
Manufacturing	Furniture and Related Product	●	●	○	○	21,930	Low	Cost, Ease of Use

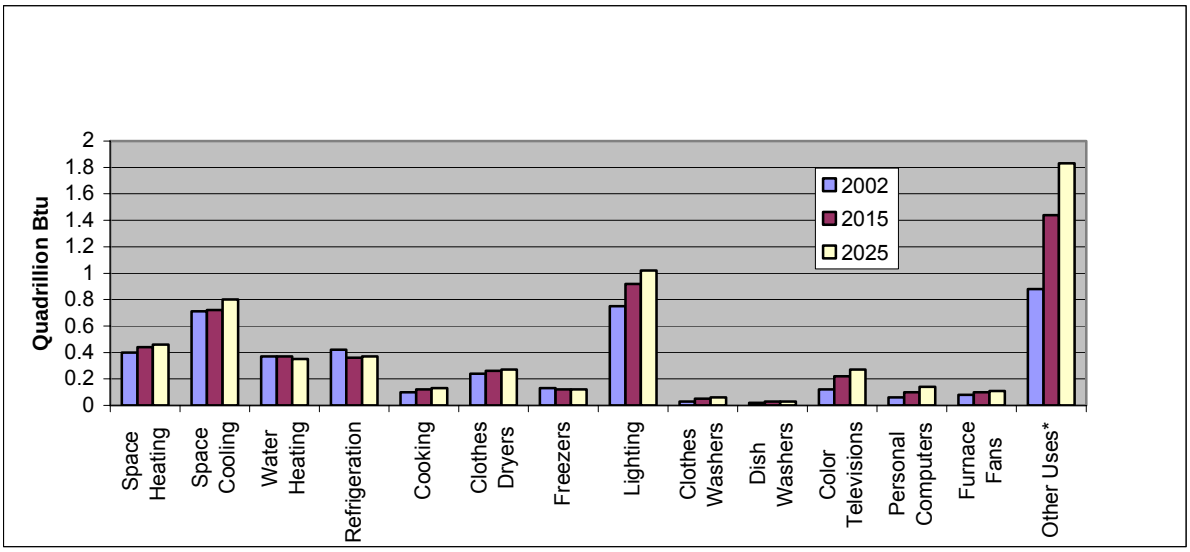
[1] Backup power, [2] Grid parallel, [3] Grid Independent, [4] Combined Heat and Power; [5] Number of businesses that could adopt technology – does not include total market size which includes potential sites for application; ● Good fit; ◘ Moderate fit, ○ Poor fit

2.11 RESIDENTIAL SECTOR OVERVIEW

2.11.1 Electricity Consumption Patterns

Average residential electricity consumption is projected to grow at an average rate of 1% per year between 2004 and 2025 to 14.2 quadrillion Btu. To support this sector, commercial electricity sales are expected to grow from 1,268 billion kWh in 2002 to 1,747 billion kWh in 2025 (Table 2-2). Figure 2-4 shows the electric energy consumption by end use in the residential market sector.

The most rapid energy growth is expected in the demand for electricity. Today approximately 76% of the total fuel consumed by the residential sector is used to produce electricity, which is primarily used to power computers, electronic equipment, and appliances (Figure 2-4). The total household market is projected to grow from 110.28 million homes in 2002 to 137.79 million homes in 2025. New homes today are approximately 26% larger, leading to greater needs for lighting, cooling, and heating.



*Other uses include small electric devices, heating elements, and motors

Figure 2-4. Electricity energy consumption by end use in the residential sector.[40]

Natural gas consumption in the residential sector is expected to increase from 5.06 quadrillion Btu to 6.26 quadrillion Btu in 2025. Over 70% of the natural gas is used for space heating, approximately 23% for water heating and about 4% for cooking. It is expected that more homes will turn to natural gas for home heating needs than electricity or heating oil. Natural gas prices are expected to increase by 9% from 2002 to 2025 for the residential customer.

To a more limited extent, propane or liquefied petroleum gas is used in the residential sector to support space and water heating needs. Only about 9.4 million households in 2001 used

[40] See reference 20.

propane, of which 6.6 million households used it for space heating. Propane consumption is expected to grow 28% in the United States by 2025, to approximately 0.64 quadrillion Btu.

2.11.2 Residential Sector Opportunities for PEM Fuel Cells

The residential market serves as the largest long-term market opportunity for stationary PEM fuel cells. However, the economic impacts of outages are very low compared to those in commercial and industrial markets. Niche opportunities are available for the application of PEM fuel cells, but consumer characteristics of this sector indicate that users will be slower adopters and will be part of the mainstream market. PEM fuel cells can be applied for reliable backup power in estate homes, multifamily dwellings, and homes with life-saving medical equipment relying on electricity; in grid independent mode for remote and vacation homes; and in CHP applications for single family and multifamily homes. Single family residential applications have power requirements that are low (in the 1 to 10 kW range) with small thermal power requirements that can currently be met by commercially available fuel cells for backup power, grid parallel, and CHP applications. Multifamily dwellings and apartment buildings have greater requirements, between 50 kW and 150 kW, and can utilize PEM fuel cells in grid parallel mode.

Distributed generation technologies have had limited success in residential markets, because drivers for adoption are mainly economic factors. However, numerous studies have shown that some customers have a greater willingness to pay for electricity that benefits the environment. Surveys conducted by Fahar (1999) indicate that many residential customers are willing to pay at least a modest amount more per month for energy from renewable resources. Seventy percent were willing to pay at least $5 more per month, 38% were willing to pay at least $10 more per month, and 21% were willing to pay at least $15 more per month.[41] Opportunities for adoption exist if PEM fuel cells can provide environmental and energy benefits, produce reliable electricity competitively priced with the grid, and offer reliable heat and power.

2.12 ELECTRIC UTILITY SECTOR OVERVIEW

Electric utilities are responsible for providing electricity at a reasonable cost to all consumers in their service territories. Decision-making drivers and adoption characteristics for new technologies in this sector differ significantly from other sectors, in that for electric utilities, electricity is the product being sold and decisions more directly impact profits.

There are approximately 3,170 traditional electric utilities and 2,110 non-utilities[42] which include cogeneration facilities and independent power producers that produce and sell heat and electricity in the United States. Electric utilities include investor-owned, publicly owned, cooperatives, and federal utilities. Power marketers are also considered electric utilities. These entities buy and sell electricity, but usually do not own or operate generation, transmission, or distribution facilities.

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[41] Farhar, B.C. 1999. Willingness to Pay for Electricity from Renewable Resources: A Review of Utility Market Research. National Renewable Energy Laboratory. NREL-TP.550.26148. Available at http://www.nrel.gov/docs/fy99osti/26148.pdf.

[42] EIA. 1999. Electric Power Industry Overview. Report No. DOE/EIA-0562 (99). Available at http://www.eia.doe.gov/cneaf/electricity/corp_str/corpcomb.pdf.

2.12.1 Electric Utility Sector Opportunities for PEM Fuel Cells

Electric utilities are perceived to be slower adopters of fuel cells than commercial and residential users. Utilities may operate fuel cells for third-party users in grid parallel applications, but are expected to lag behind in adoption of PEM fuel cells as a strategic opportunity and as a source of additional capacity. Electric generating stations have identified a wide range of priority factors influencing their decisions to invest in fuel cells, including capital, operation and maintenance costs, durability, reliability, power size, physical size and safety. PEM fuel cells have limited opportunities for providing additional generating capacity due to their small power size.[43] Despite that, electric utilities are uniquely positioned to capitalize on the broad range of benefits from stationary distributed technologies, including fuel cells. These benefits include asset deferral (i.e., deferring the need for additional transmission lines); the potential to provide their customers with options to access premium power, address peak-shaving and load-leveling needs; and support in meeting more stringent environmental regulations.

2.13 OPPORTUNITIES FOR PEM FUEL CELLS

2.13.1 Timeline of Opportunities

Near-term opportunities for applications of PEM fuel cells in the 1 kW to 250 kW range have been identified (see Table 2-10) based on Battelle research.[44, 45]

The largest near-term opportunities for PEM fuel cells are expected to be a combination of backup, grid parallel, and grid independent applications in the commercial, institutional, and industrial sectors. Early adopters are likely to be in the commercial and industrial markets because of recognized potential strategic benefits. Backup power will likely be the earliest strategic opportunity to emerge for PEM fuel cells in the near-term because of lower efficiency and durability requirements as compared to other applications. As shown in Section 3, PEM fuel cells for backup applications can be justified from a technical and economic standpoint as well.

Near-term opportunities, with relatively low energy impact, exist for grid independent applications at remote sites or where reliable electricity is not available from the grid and in grid parallel applications for single and multifamily homes operated by the user in coordination with the electric utility. However, in these markets, adoption may be driven by several factors including areas which require low noise, low emissions, and minimal maintenance, or regions where total cost of ownership is valued. For these markets, the lifecycle cost of providing electricity becomes a major factor. As shown in Section 3.2, lifecycle cost is tied to the durability of the fuel cell system. Penetration in these markets is expected only as durability approaches 40,000 hours for total life of the system.

[43] See reference 4.
[44] See reference 4.
[45] See reference 6.

Market opportunities for grid parallel applications are expected to develop more slowly than grid independent applications because these markets have similar requirements to grid independent markets with the added challenge of low cost, interconnection to the grid, and mechanisms to sell excess power to the grid.

The highest total market potential will be commercial and residential markets because of the total number of users, but this will be a long-term opportunity. Opportunities will be limited in industrial markets because of multiple factors, including the need for power sizes larger than 250 kW, higher thermal requirements, and cheaper existing alternatives including the grid.

Table 2-10. Timeline for commercialization of stationary PEM fuel cells.

	Near-Term Opportunity (2015)	Mid-Term Opportunity (2015-2020)	Long-Term Opportunity (>2020)
Commercial Sector	– Telecommunications – Financial Services – Professional Scientific, and Technical Services (Information Technology) – Grocery Stores and Large Department Stores – Casinos – Hotels – National Parks – Amusement Parks – Sports and Recreation (stadiums) – Radio Television and Broadcasting	– Building and Heavy Construction – Laundries – Museums – Art Galleries – Zoological Parks – Restaurants	– Retail Stores – Gasoline Stations – Trailer Parks and Campsites
Institutional Sector	– Healthcare – Government Defense and Homeland Security – Railways – Airports – Water Distribution	– Education – Government Buildings – Sewerage System	– Government
Industrial Sector	– Food – Petroleum and Coal Products – Chemical Manufacturing – Computer and Electronic Products – Oil and Gas Manufacturing – Transportation Equipment	– Animal Agriculture and Diary Farms – Wood Product Manufacturing – Paper Manufacturing – Printing – Plastics and Rubber Products – Machinery – Electrical Equipment – Mining	– Textile Manufacturing – Transportation Equipment – Furniture Manufacturing
Residential Sector	– Remote homes	– Single-family dwellings – Multi-family dwellings	
Electric Utility	– Customer Driven	– Micro-Grids – Sub-Station Distributed Generation	– Central Station Generation

CHP opportunities offer the highest efficiency and will make the most economic sense on a lifecycle cost basis for those applications where demand enables balanced production of heat and power. PEM fuel cells face tough challenges from other competitors in the CHP market. Opportunities for CHP exist in specific niche markets in the institutional and industrial sectors, and within single family and multifamily residences, and can be realized in the mid-term. Chances of application at a residential level are greater in the long-term, if valued benefits can be provided. Widespread adoption of fuel cells for grid connected applications by the electric utility sector is considered a long-term opportunity, unless it is customer driven.

2.14 EARLY ADOPTERS

Early adopters for PEM fuel cell technology will develop within each market segment as cost and performance approach competitive market entry requirements. Users in the commercial, institutional, and industrial markets are likely adopters in the near-term. Various early adopter markets in the near-term are identified in Figure 2-5. While early adopters are typically less price sensitive than any other users in the technology adoption profile, they still expect to see an acceptable level of return on their investment and other clear benefits to switching that outweigh the risks. To be competitive, PEM fuel cells must offer superior value or strategic benefits over existing alternatives.

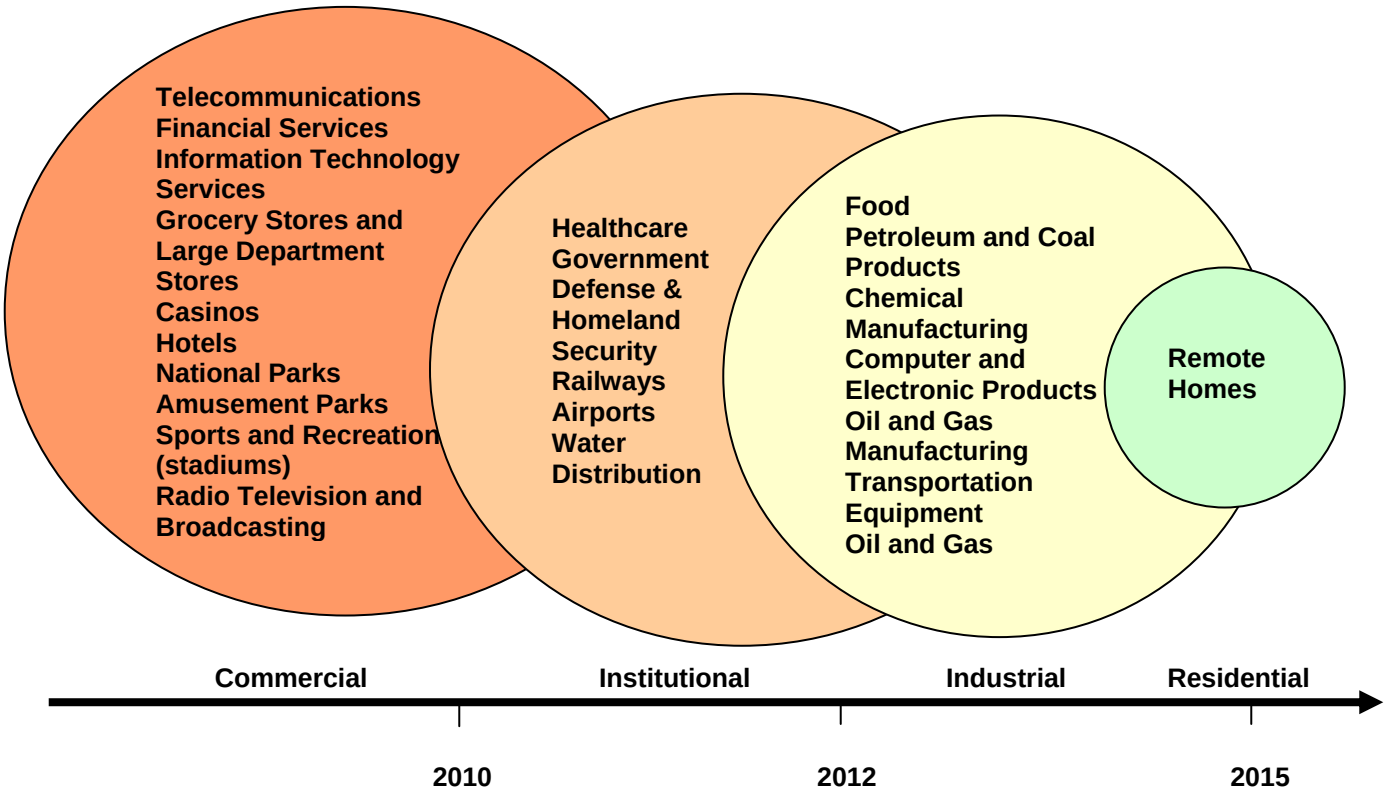

Figure 2-5. Near-term markets in which early adopters exist.

Table 2-11 provides a listing of potential early adopters, examples of applications, key drivers, and fuel cell opportunities. In the near-term, early adopters are users who need better sources of backup power, primarily as alternatives to generators and batteries. Early adopters choose technology to provide a strategic benefit to their business or personal values, and it may be in the form of reduced vulnerability to power outages, competitive positioning, environmental stewardship, protection of critical infrastructure, or reduction in energy expenditures. Key drivers for adoption of PEM fuel cells in this application are fuel cell reliability and quick-start capabilities.

Another early adopter segment includes those interested in applying PEM fuel cells for peak shaving solutions (grid parallel applications) to reduce electricity costs. Early adopters choose technology to provide redundancy to ensure reliability and to reduce consumption of grid electricity during peak usage. Key drivers for adoption of PEM fuel cells in this application are fuel cell reliability, fuel availability, ease of use, and availability of service infrastructure.

Early adopters could also include users interested in applying PEM fuel cells in specific niche grid independent applications like remote cell towers in telecommunications, remote homes, and national parks. Early adopters choose technology to provide electricity in areas where grid electricity is unavailable. Users in this segment are driven by a need for longer run times, as compared to competing alternatives, and environmental and energy efficiency benefits.

There is limited potential for early adopters to impact national levels of energy efficiency and emissions reduction in the near-term, as early adopters represent a very small proportion of the total market.

Table 2-11. Listing of potential early adopters, application examples, key drivers, and fuel cell opportunities.

Market	Potential Early Adopters (Examples)*	Potential Areas of Application (Examples)	Fuel Cell Application Drivers	Fuel Cell Application Barriers
Telecommunications	Verizon, Verizon Wireless, SBC, Sprint Communications, Bell South, Qwest Communications	Towers, Cell Sites, Controlled Environmental Huts	Need for Reliability, Increased Competitiveness, Customer Satisfaction	Unproven Reliability Ease of Use Availability of Fuel Infrastructure Cost
Information Technology Services	Microsoft, Oracle, SAP, IBM, BEA Systems	Data Centers, Server Farms, Online Web-hosting Services	Need for Reliability, Customer Satisfaction	Unproven Reliability
Grocery Stores and Large Department Stores	WalMart, Kroger, Wegmans, Target, Kohls, Sears	Emergency Lighting and Alarm Systems, Computer Systems, Refrigeration, Heating and cooling	Customer Satisfaction, Low Noise and Emissions, Grid Unreliability	Unproven Reliability Ease of Use Cost
Casinos	Argosy, Caesars, MGM Grand and Mirage, Mohegan Gaming, Trump Towers and Casinos	Slot Machines, Emergency Lighting and Alarm Systems, Computer Systems	Economic Impact Of Outage, Customer Satisfaction	Unproven Reliability
National Parks	Yellowstone National Park, Yosemite, Grand Canyon	Recreational and Lodging Facilities, Remote Power	Energy and Environmental Benefits	Durability, Operations and Maintenance
Amusement Parks	Disney, Six Flags of America, Paramount, NBC Universal Viacom, Cirque du Soleil Inc., MTV Networks	Computer Systems, Ticketing and Online Services, Equipment, Emergency Lighting and Alarm Systems	Need for Reliability, Economic Impact of Outage	Unproven Reliability
Sports and Recreation (stadiums)	National Football League Stadiums, Major League Baseball Stadiums, National Basketball Association, International Olympic Committee, NASCAR, Formula 1	Lighting and Alarm Systems, Computer Systems, Ticketing and Online Services	Need for Reliability, Low Noise, Low Emissions	Unproven Reliability and Durability
Radio Television and Broadcasting	NBC, ABC, FOX, CNN, E! TV, HARPO, Warner Brothers, Disney	Broadcasting Equipment, Computer Systems, Online Monitoring Equipment	Need for Reliability, Economic Impact of Outage, Customer Satisfaction	Unknown Reliability and Durability

Table 2-11. Listing of potential early adopters, application examples, key drivers, and fuel cell opportunities.

Market	Potential Early Adopters (Examples)*	Potential Areas of Application (Examples)	Fuel Cell Application Drivers	Fuel Cell Application Barriers
Financial services	Banks – Chase Manhattan, KeyBank, Wells Fargo, National City, Fifth Third Bancorp, Merrill Lynch Stock exchange - NYSE, NASDAQ, Chicago Stock Exchange	Data centers, Server Farms, Online Banking Services, Computer, Emergency Systems	Need for Reliability, Economic Impact of Outage, Customer Satisfaction	Unknown Reliability and Durability
Healthcare	Children's Hospital, Baptist Healthcare System, Catholic Healthcare System, Mayo Clinic, Cleveland Clinic	Healthcare Equipment, Clean Rooms, Operation Theatres, Emergency Lighting and Alarms, Heating	Need for Reliability, Loss of Life, Decline in Quality of Care	Unknown Reliability and Durability
Government Defense and Homeland Security	U.S. Army, U.S. Navy, National and State Emergency Response Centers	Soldier Warfare, Base Use, Emergency Backup for Critical Communication	Need for Low Thermal Signature, Energy Security, Loss of Life, Reliability, Energy and Environmental Benefits	Unknown Reliability and Durability
Railways	Metropolitan Transportation Authority MTA New York City Transit New Jersey Transit Corporation National Railroad Passenger Corporation Alaska Railroad Corporation Canadian National Railway Company	Railway Signals, Track Signal, Online Systems, Computer Systems, Emergency Communications	Need for Reliability, Cost, Low Operations and Maintenance	Unknown Reliability and Durability
Airports	Airports - Chicago Airport System Dallas/Fort Worth International Metropolitan Airports Commission Airlines – Delta, United Airlines, Northwest	Critical Emergency Systems, Online Terminals, Airport Towers, Landing Equipment, Baggage Screening	Need for Reliability, Customer Satisfaction Economic Impact of Outage	Unknown Reliability and Durability

Table 2-11. Listing of potential early adopters, application examples, key drivers, and fuel cell opportunities.

Market	Potential Early Adopters (Examples)*	Potential Areas of Application (Examples)	Fuel Cell Application Drivers	Fuel Cell Application Barriers
Water Distribution	American Water Works Company, Inc. California Water Service Group Aqua America, Inc. Aquarion Company Burbank Water and Power Bristol Water Group plc	SCADA, Critical Computer and Online Tools	Need for Reliability and High Durability	Unknown Reliability and Durability
Food	Nestle, P&G, ConAgra, General Mills, Anheuser Bausch, Heinz	Clean Rooms, Manufacturing Equipment, Refrigeration, Heating	Need for Reliability	Unknown Reliability
Petroleum and Coal Products	American Electric Power, Duke Energy Corporation, Exelon Corporation, Consolidated Edison, Pacific Gas and Electric,	Remote Power, On-site Power Using Hydrogen from Coal, Critical Power Support for Manufacturing Operations	Need for Durability and Reliability, Environmental Benefits	Unknown Reliability and Durability
Chemical Manufacturing	Pharmaceuticals – Astra, Bayer, Pfizer BASF, Atlas, DOW, DuPont, Kodak	Clean Rooms, Servers, Datacenters, Process Equipment	Need for Reliability, Environmental Benefits	Unknown Reliability
Computer and Electronic Products	Dell, IBM, Solectron, Sun Microsystems, AMD Devices, Sony, Intel	Clean rooms, Servers, Datacenters, Process Equipment	Need for Reliability	Unknown Reliability
Oil and Gas Manufacturing	Shell, BP, ConocoPhillips, Chevron Texaco, Marathon, Halliburton, Schlumberger, Hyundai Heavy Industries, Transocean Inc	Remote Power, On-site Using Hydrogen Generated for Manufacturing, Online and Data Farm Backup	Need for Durability and Reliability, Environmental Benefits	Unknown Durability and Reliability
Transportation Equipment	General Motors, Ford, Mercedes, BMW	Remote Power, Power for Process Equipment, Computer Systems	Need for Durability and Reliability	Unknown Durability and Reliability

*Early adopters have been identified from primary research, secondary research and by application of expert judgment of Battelle project staff. Note this listing is not comprehensive.

2.15 DETAILED ANALYSIS OF THREE EARLY ADOPTER MARKETS

The three near-term markets of financial services (including banking), telecommunications, and hotels were selected to analyze the profile and requirements of early adopters. Each market was selected for further analysis because of the potential economic impact of power loss; regulations requiring some businesses crucial to the national economy to resume operations within 24 hours of any disaster; the number of potential adopters for backup and potentially grid parallel applications; and the pre-existing application of fuel cells.

To gather user requirements, primary research was conducted by implementing surveys, with follow-up interviews to obtain additional information. The survey instrument is shown in Appendix A. Respondents were asked to evaluate a set of factors identified by Battelle in the survey instrument, which they considered critical to the commercialization of PEM fuel cells in their markets. Survey participants also identified a set of market requirements (or minimum user requirements) that a new energy technology would have to meet in order for them to consider adopting it. For the telecommunications market, a focus group was also conducted to further develop and help validate the critical user requirements identified through the survey (Appendix C). Other information, including electricity consumption, industry information, and load profile data, if available, was gathered from secondary sources.

The information gathered was synthesized into market requirements tables for specific users and applications within the three market segments. The market requirements identified do not encompass all the possible applications of PEM fuel cells in the three sectors, but rather the most likely applications in these sectors as determined by marketing research.

The market requirements for a new technology to be considered for adoption in many cases exceed the performance of any technology currently available in the market. A number of factors affect the willingness of companies to adopt a new technology (e.g. inertia, sunk costs in power infrastructure), and it is not surprising that many expect a new technology to perform much better than the alternative if it is to be seriously considered. Large differences between the performance of current energy technologies and the market requirements identified for new energy technologies provide an indication of the relative importance of those factors (e.g. reliability, durability) to the target user group. While the quantitative requirements defined by survey respondents are important, it can be expected that in some cases there will be a willingness on the part of users to accept lower requirements if they still exceed current performance.

2.15.1 Financial Services Market - Banking and Supporting Business Sector

The financial services sector is comprised of three major sub-sectors: (1) banking, (2) insurance, and (3) securities, commodities, and other investments. The entire sector represents a significant and growing proportion of the U.S. gross domestic product (GDP) – approximately 7.7% of GDP in 2002.[46] Power outages are extremely disruptive to financial service businesses. According to

[46] U.S. Department of Commerce, Bureau of Economic Analysis. Gross Product by Industry Tables. Accessed May 13, 2005. Available at http://www.bea.gov/bea/industry/gpotables/gpo_action.cfm?anon=337&table_id=5207&format_type=0.

a study by the Meta Group, downtime can cost the financial services industry $1.4 million of lost revenue per hour,[47] providing a strong impetus for high quality and reliable power.

Nine financial services institutions, both medium and large, participated in the survey and follow-up interviews. Most participants were from the banking and supporting businesses sub-sector, which is the largest of the three financial services sub-sectors. For more detailed information obtained from the survey, including characteristics of the industry, see Appendix B.

2.15.1.1 Market Requirements for Financial Services

Financial services institutions rely on backup power for critical systems to ensure business continuity even during a power outage, and recent power management planning regulations instituted by the federal government have made backup power requirements more stringent. Currently most companies rely on uninterruptible power supply (UPS) systems and generators to meet their backup power needs. The analysis of the financial services sector suggests that opportunities for PEM fuel cells exist, provided PEM fuel cells meet the minimum user requirements detailed in Table 2-12. Information presented in the table below presents Battelle's analysis of the minimum user requirements for a new energy technology based on interviews with key stakeholders and surveys.

Table 2-12. Financial services market survey: market requirements for adoption of new energy technologies in backup and grid parallel applications.

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Grid Parallel Power Applications
Size (kW)	>50	>250
Capital Cost ($/kW)	<300-3000	300-2000
Installation Costs ($)	3000-4000	3000-4000
Operations & Maintenance Costs ($/kWh)	.07-.12	.05-.12
Lifetime (years)	10-20+	15
Reliability (% time available)	99.999 - 99.99999#	99.99~
Footprint (L*B*W) (m^3)	Varies, can be no larger than competing alternative	Varies, can be no larger than competing alternative
Typical Operation Conditions (ºC)	-15 to 40	-15 to 40
Efficiency (%)	>55	>55
Emissions	Meets regulatory threshold	Well below the regulatory threshold

+ Lifetime requirements are dependent on use
# High reliability is of strategic importance for adoption of technology in this market sector
~ Reliability needs to be comparable to the grid at the very minimum

[47] See reference 16.

The market requirements or minimum user requirements from the survey in some cases exceed any technology available in the market. Therefore, these data should be interpreted as indicating relative importance of factors influencing the purchase of new technology. In backup applications, high reliability and a long lifetime of use are clearly important. For grid parallel applications reliability is of much lower importance; however, large power output and low emissions are important.

2.15.1.2 Opportunities for PEM Fuel Cells in Financial Services Sector

There is a critical requirement within the financial services sector to build redundancy in their backup power. PEM fuel cells may offer users in this sector a strategic opportunity to avoid economic losses and increase reliability with customers. If PEM fuel cells can be convincingly shown to improve reliability of backup power as compared to current alternatives, users may adopt the technology in the near-term.

Grid parallel applications are not considered an early adopter market opportunity, as these applications do not provide any immediate strategic benefits and are primarily driven by the cost of electricity. It is unlikely that opportunities in grid parallel applications exist in this sector in the near-term, unless the lifecycle cost of electricity from PEM fuel cells is less than the price of electricity supplied by the grid. Grid parallel opportunities will vary and will be highly dependent on the size of the institution, its locations, the price of regular and premium electricity, and the need for on-site generation.

Table 2-13 outlines key decision drivers for PEM fuel cells for adoption of new energy technologies in the financial services sector. Reliability is believed to be the single most important factor driving the adoption of fuel cells in this sector. Other factors considered very important to the financial services sector – but secondary to reliability – include capital cost, total lifetime, safety/low perceived risk, and installation cost.

Table 2-13. Decision drivers for adoption of new energy technologies in the financial services market.

Decision Driver	
Reliability	●
Capital Cost	●
Total Lifetime	●
Safety and Perceived Risk	●
Cost of Installation	●
Efficiency	◘
Scalability	◘
Low Emissions	◘
Ease of Use	◘
Size of Unit	◘
Code and Standards	◘
Environmental Regulations	○
Disposal Cost/Recyclability	○
Availability of Incentives	○

● Very Important ◘ Important ○ Not so important

2.15.2 Telecommunications Market

The telecommunications sector is comprised of two major sub-sectors: wireless and wireline. The Bureau of Economic Analysis combines telecommunications companies and other broadcasting companies in its analyses. Together, the GDP of the broadcasting and telecommunications industry was $283 billion in 2003, contributing 2.6 percent to the GDP.[48] The telecommunications network is integral to the U.S. communications infrastructure and supports critical customers like hospitals, public safety, government facilities, universities, and broadcast media. The telecommunications infrastructure needs to protect itself from homeland security threats and natural threats, and is constantly looking for ways to improve its service. As a result, there are increasing requirements to ensure the reliability and availability of service.

The telecommunications industry is also rapidly evolving into systems carrying internet and data traffic. Customer expectations have also risen with changes in technology, and as a result, reliability of service is critical. This rapidly evolving change in technology has also impacted the growth of the telecommunication sector, with increasing power and reliability requirements at various locations including controlled environmental vaults, huts, remote sites, cell sites, hub sites, digital loop carriers, private branch exchange (PBX), and cabinet sites.

Six large telecommunications companies participated in the survey and follow-up interviews. More than 16 participants contributed their ideas in a focus group following the Tel-NIQ'05 sessions in Fort Lauderdale, Florida, on April 14, 2005. Details of the focus group and meeting minutes are presented in Appendix C. Detailed information obtained from the survey and interview, including characteristics of the industry is presented in Appendix D.

[48] See reference 46.

2.15.2.1 Market Requirements for Telecommunications Market Sector

Telecommunications companies rely heavily on backup power for critical systems and on alternative sources to supply power at remote sites. Currently telecommunications sites obtain their power primarily from the grid and do not use on-site generation. However, due to explosive growth of the industry and increasing constraints on the grid, opportunities for grid parallel power may evolve. Currently, telecommunications companies utilize batteries and generators to meet their needs for alternative sources of power. Based on the priority of the site, batteries are generally backed up by generators. Batteries are sized to provide between 3 and 8 hours of run time, and generators are sized and provided fuel to run between 72 and 100 hours. Other alternatives have also been considered by users in the market including flywheels, ultracapacitors, and microturbines. Opportunities for PEM fuel cells exist in the telecommunications market, provided they meet the market requirements detailed in Tables 2-14 to 2-17. Information presented in the tables presents Battelle's analysis of the minimum user requirements for a new energy technology based on stakeholder interviews, surveys, and focus group discussion. Market requirements for prime power are for both grid independent applications and grid parallel for baseload applications.

The market requirements or minimum user requirements from the survey in some cases exceed any technology available in the market. In such cases the data should be interpreted as indicating the strategic importance of these factors in influencing the purchase of new technology. Thus, for example, decisions to use PEM fuel cells for backup power in controlled environmental vaults is likely to be driven by high reliability coupled with long life and low maintenance costs.

2.15.2.2 Opportunities for PEM Fuel Cells in the Telecommunications Market

There is a critical need for backup power at telecommunications sites in various size ranges from 2 kW at outside plant huts to over 200 kW at controlled environmental vaults, microwave stations, and central offices. To support various sites, backup power technologies are installed based on the priority of the site, which is determined by the number of customers and the critical infrastructure supported. The reliability of backup power systems today are typically improved by building redundancy in the system and over-engineering the backup power plant (i.e., designing a backup system with more batteries and generators). For remote sites, reliability is also ensured by providing enough backup run time to support extended outages. If the reliability of the PEM fuel cell can be compared to current alternatives and if PEM fuel cells can support extended outages at lower costs than competing alternatives, users will adopt the technology in the near-term. First opportunities for adoption will likely be locations where generators cannot be installed. While there is dissatisfaction with the operation and maintenance of batteries and generators, there are limited proven alternatives available for adoption. In this market, the benefits of utilizing PEM fuel cells will be strategic in that fuel cells will offer users an opportunity to avoid economic loss, increase reliability, and attract and retain customers.

Table 2-14. Telecommunications market: market requirements for adoption of new energy technologies for controlled environmental vaults.

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Prime Power Applications
Size (kW)	20-50	150-250
Capital Cost ($/kW)	600-1000	1000-2000
Installation Costs ($)	2000-3000	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03	<.03-0.05
Lifetime (years)	20+	20
Reliability (% time available)	99.99999#	99.99~
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	0-40	0-40
Efficiency (%)	>55	>55
Emissions	At regulatory threshold	At regulatory threshold

+ Lifetime requirements are based on forecasts developed by Telecommunications sector for new backup power support.
# High reliability is of strategic importance for adoption of technology in this market sector
~ Reliability needs to be comparable to the grid at the very minimum

Table 2-15. Telecommunications market: market requirements for adoption of new energy technologies for repeater stations/huts.

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Prime Power Applications
Size (kW)	20-200	150-250
Capital Cost ($/kW)	600-2000	600-1000
Installation Costs ($)	1000-2000	1000-2000
Operations & Maintenance Costs ($/kWh)	< .03	<.03 -0.05
Lifetime (years)	20+	20
Reliability (% time available)	99.9999#	99.99~
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	0-40	0-40
Efficiency (%)	> 35	>35
Emissions	At regulatory threshold	At regulatory threshold

+ Lifetime requirements are based on forecasts developed by telecommunications sector for new backup power support.
# High reliability is of strategic importance for adoption of technology in this market sector
~ Reliability needs to be comparable to the grid at the very minimum

Table 2-16. Telecommunications market: market requirements for adoption of new energy technologies for central offices.

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Prime Power Applications
Size (kW)	50-150	150-250
Capital Cost ($/kW)	1000-2000	1000-2000
Installation Costs ($)	1000-4000	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03	<.03
Lifetime (years)	18+	18
Reliability (% time available)	99.99999#	99.99999#
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	15-25	15-25
Efficiency (%)	>35	>35
Emissions	At regulatory threshold	At regulatory threshold

+ Lifetime requirements are based on forecasts developed by telecommunications sector for new backup power support.
# High reliability is of strategic importance for adoption of technology in this market sector

Table 2-17. Telecommunications market: market requirements for adoption of new energy technologies for switching stations.

Technical Parameters	Market Requirements: Backup Applications
Size (kW)	25-50
Capital Cost ($/kW)	600-2000
Installation Costs ($)	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03
Lifetime (years)	15+
Reliability (% time available)	99.99~
Footprint (L*B*W) (m^3)	Various
Typical Operation Conditions (ºC)	15-25
Efficiency (%)	>35
Emissions	At regulatory threshold

+ Lifetime requirements are based on forecasts developed by telecommunications sector for new backup power support.
~ Reliability needs to be comparable to the grid at the very minimum

Another near-term opportunity for adoption is the use of PEM fuel cells at remote locations in grid independent applications. As telecommunications services are expanding to provide connection across the United States, there is significant opportunity for the use of PEM fuel cells

at these sites. However, a critical requirement for use in remote locations is the availability and ease of obtaining fuel. Typically, these sites are fueled by propane or natural gas generator sets with a technician going to the site at regular intervals to provide additional fuel. Benefits offered by fuel cells in these applications will include reliability, durability, lower operations and maintenance costs, and lower noise and emissions.

Grid parallel applications in the market, to support peak shaving and baseload power, are likely to evolve in the mid-term after the PEM fuel cell has proven reliability and durability. Grid electricity is considered quite reliable, and the cost of installing new lines for most sites is fairly affordable. Grid parallel opportunities will vary and will also be highly dependent on the criticality of the site, and the location and need for on-site generation. This application cannot be considered an opportunity for early adopters as it does not provide any immediate strategic benefits, and is primarily driven by the cost of electricity.

Despite available market opportunity, technology diffusion into this industry is expected to be slow until reliability is proven. Reliability field trials, along with open access to results, are critical to demonstrate a proven track record to the market. In addition, appropriate certifications and approvals are a requirement to facilitate adoption, and standard requirements for the installation and operation of PEM fuel cells need to be developed by third-party organizations like Telcordia. Table 2-18 outlines critical decision drivers for PEM fuel cells in backup power applications in the telecommunications market. Top drivers for adoption in this market are reliability, cost, and ease of use.

Table 2-18. Decision drivers for adoption of new energy technologies in the telecommunications market.

Decision Drivers	
Reliability	●
Capital Cost	●
Ease of Use	●
Efficiency	●
Codes and Standards	●
Total Lifetime	●
Noise	●
Size of Unit	◘
Cost of Installation	◘
Environmental Regulations	◘
Low Emissions	○
Scalability	○
Availability of Incentives	○
Disposal Cost/Recyclability	○

● Very Important ◘ Important ○ Not so important

2.15.3 Hotels Market

In 2000, there were 53,500 lodging properties in the U.S., generating $108.5 billion in sales.[49] This figure represents steady growth from a low point in the early 1990s through 2000, when the industries posted record pretax profits of $23 billion, up 9% from 1999 and double the level in 1996.[50] However, profits fell to $16.7 billion in 2001, reflecting the impact of the September terrorist attacks on leisure travel in the United States. Profits of $17.2 billion were expected for 2002.[51] The hotel sector is included within the arts, entertainment, recreation, accommodation, and food services industry. Hotels with the principal activity of lodging rank second in the gross intensity of energy use among 12 commercial building types.[52]

In this market, early adopters are chain hotels, five-star hotels, spa and casino hotels that are interested in providing high levels of service and security to their clientele. They have several critical requirements for alternative power sources including the need for backup power for specific functions like emergency lighting, elevators, telephones and security; the need for additional power during peak hours for electric and hot water needs; supplementary sources of power to supply heating for pools, saunas, baking and laundry facilities; and sources of backup power with lower noise and emissions levels. Since these users are part of the service sector and image is important, the appeal of being viewed environmentally conscious could also drive adoption. Recent incidents like the extended outage at the Bellagio Casino and Hotel in Las Vegas have emphasized the need to install backup power and to make sure that all services are available. Especially for hotels that have other services attached, like casinos, every minute of an outage causes a significant economic impact. Several casino hotels have already implemented backup power upgrades. For instance, the Cannery Hotel and Casino in North Las Vegas, NV, has installed a single 1250 kW standby generator to power lighting, alarm systems, security systems for the cashiers' cages, restaurant kitchens, elevators, and gaming areas. In addition, the 7 million sq. ft. Venetian complex-casino – comprising 3,000 luxury hotel suites, high-end retail shops, the Sands Expo Convention Center, and a network of canals – has installed five 2,000 kW Caterpillar 3516B diesel generators.[53]

Market requirements reported are based on findings from eight hotels. While information on CHP requirements and grid parallel power was requested in addition to backup power, users were most interested in applications of PEM fuel cells for backup power. For more detailed information obtained from the surveys, including characteristics of the industry, see Appendix E.

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[49] Energy and Environmental Analysis, Inc. 2003. National Account Sector Energy Profiles. Submitted to The Oakridge National Laboratory. Available at http://files.harc.edu/Sites/GulfCoastCHP/MarketAssessments/NationalAccountSectorEnergyProfiles.pdf.
[50] See reference 49.
[51] See reference 49.
[52] See reference 27.
[53] O'Malley, P. 2004. Standby Power Plants Make Sure the Lights Stay On. Accessed May 13, 2005. Available at http://www.distributedenergy.com/de_0405_standby.html.

2.15.3.1 Market Requirements for Hotels

Many of the larger properties have diesel generator sets to provide backup power in case of outages. UPS systems are used to a limited extent, and are typically used to support computers, online terminals, and facility control systems (e.g., emergency lights and fire alarms).

Opportunities for PEM fuel cells in backup power may exist in the hotel market provided that certain minimum user requirements are met. Table 2-19 presents Battelle's analysis of stakeholder interviews and surveys.

Table 2-19. Hotels market: market requirements for adoption of new energy technologies for backup power.

Technical Parameters	Market Requirements: Backup Power Applications
Size (kW)	150-250
Capital Cost ($/kW)	300-600
Installation Costs ($)	2000-3000
Operations & Maintenance Costs ($/kWh)	<.03-.07
Lifetime (years)	10-15+
Reliability (% time available)	99.999 – 99.99999
Footprint (L*B*W) (m^3)	Varies, can be no larger than competing alternative
Typical Operation Conditions (ºC)	-15 to 40
Efficiency (%)	>65%
Emissions	Well below regulatory threshold

+ Lifetime is based on the performance of competing alternatives

The market requirements or minimum user requirements from the surveys in some cases exceed any technology available in the market. In such cases the data should be interpreted as indicating the strategic importance of these factors in influencing the purchase of new technology.

2.15.3.2 Opportunities for PEM Fuel Cells in Hotels

Market research suggests that hotels have requirements for backup power, due to the high economic impact of outages. Users would consider PEM fuel cells as an alternative backup power source provided they are financially viable and efficient, as compared to alternatives like batteries and generators. While PEM fuel cells have been demonstrated in various hotels as alternative power sources to the grid, most respondents consider the grid relatively reliable and would consider alternative energy sources in grid parallel applications only if it were lower in cost. Similarly, while hotels have requirements for CHP, users are relatively satisfied with the current mode of operation and would consider alternatives only if they are low cost, easy to use, and have high efficiency.

Battelle research indicates that the hotel market segment has an interest in PEM fuel cells as an alternative, but it appears that the main driver for adoption is the benefit to the bottom line. Table 2-20 outlines key decision drivers for the hotels. While reliability is also very important to hotels, operators tend to place a greater emphasis on investment and operating cost than on reliability. The primary drivers for adoption in this sector are capital and operating cost, cost of installation, and efficiency.

Table 2-20. Decision drivers for PEM fuel cell adoption of a new energy technology in the hotels market

Decision Drivers	
Capital Cost	●
Cost of Installation	●
Efficiency	●
Reliability	●
Total Lifetime	●
Low Emissions	●
Scalability	●
Environmental Regulations	●
Safety/Perceived Risk	●
Ease of Use	●
Availability of Incentives	◘
Code and Standards	◘
Disposal Cost/Recyclability	◘
Size of Unit	◘

● Very Important ◘ Important ○ Not so important

2.16 MARKET ANALYSIS CONCLUSIONS

The world market for electricity generation will continue to trend upward over the next two decades, and in the U.S. alone, electricity generation is expected to surge from 3,626 billion kWh in 2002 to 5,421 billion kWh by 2025. The growing demand for electricity coupled with an aging transmission and distribution infrastructure have resulted in a stressed power infrastructure in the U.S. As the economic consequences of power outages are rising particularly for users in the commercial and industrial market sectors, redundant systems that ensure reliable power are becoming increasingly important. Given this increased demand for electricity, the importance of reliability, recent trends in U.S. electricity deregulation, implementation of environmental air quality regulations, and other factors, the opportunities for distributed generation technologies look promising.

As an emerging distributed generation technology, PEM fuel cells have the potential to supply this growing demand if they are able to the meet baseline user requirements. While user requirements will vary by market, some of the key drivers identified through Battelle's research include cost, reliability and durability relative to competing technologies, environmental regulations, power density, government incentives, demonstration projects, education and awareness.

As PEM fuel cells are not currently cost competitive with many alternatives, the near-term opportunities for PEM fuel cells will lie with early adopter market segments. Early adopters will be critical to help demonstrate performance and build consumer confidence in the technology. Most early adopter applications of PEM fuel cells in the 1 kW to 250 kW range will be for backup power. Backup power users in early adopter market segments will place equal or greater emphasis on reliability than other factors, including capital cost, operating efficiency, and total lifetime of the PEM fuel cell. While the current system size of PEM fuel cells is more compatible with backup than with grid parallel applications, early adopters will also include some institutions interested in peak-load shaving (grid parallel applications) to reduce electricity costs, and some grid independent applications.

While, there is a potentially strong fit for backup applications of PEM fuel cells with all five market sectors analyzed, the greatest near-term opportunities will be in the commercial, industrial and institutional sectors. The residential sector represents the largest potential opportunities in terms of market size; however, this sector does not experience the same economic impacts of outages that drive commercial, industrial and institutional sectors to invest in reliable power supplies, and is therefore not likely to be an early adopter. Electric utilities are also expected to be slow adopters of fuel cells due to their emphasis on low capital costs, larger power sizes, and other factors.

Examples of potential early adopters in the commercial sector include telecommunications and financial services. In the institutional sector, government agencies, hospitals, water and wastewater utilities, railways and airports were among those market segments identified as potential early adopters. Three potential early adopter market segments including financial services, telecommunications, and hotels were examined to determine priority decision drivers as well as cost and performance requirements for adoption of alternative energy technologies.

In each of the three market segments analyzed, UPS systems and battery systems coupled with generators are the primary competing technologies for backup power.

Financial services companies have a critical need for backup power. Reliability, capital and installation costs, safety/perceived risk, and durability are all key decision drivers for these companies. The sample surveyed by Battelle indicated that they require up to seven 9's reliability and a system that will operate for at least 20 years.

Telecommunications companies have a critical need for backup power, as well as grid independent power for remote sites. Reliability, capital cost, and ease of use are among the more important decision drivers for telecommunications companies. User requirements identified by those surveyed varied depending on the specific application. In general, reliability requirements ranged from four to seven 9's.

Backup power is expected to be the primary application for the hotel sector in the near-term. This market appears to be slightly more price sensitive than the other two segments analyzed. Capital cost, installation cost, and efficiency were identified as the most important factors driving their decision to invest in an alternative energy technology, followed by reliability. Capital cost requirements for the hotel sector are much lower, with a maximum identified as $300 to $600 per kW. User requirements for efficiency requirements are greater than 35%, and for reliability, are five to seven 9's.

Analysis of early adopter markets indicates that PEM fuel cells in the 1 kW to 250 kW range do have the potential to penetrate these market niches if they are able to meet the baseline user requirements. For early adopter markets, PEM fuel cells must address the factors that matter most to users in those market segments. However, in order for PEM fuel cells to move beyond early adopter markets and achieve higher levels of market penetration, they must eventually address the broader set of factors thought to be driving their commercialization.

3 ECONOMIC ANALYSIS OF TWO PEM FUEL CELL SYSTEMS

The purpose of this analysis is to assist EERE in the development of stationary fuel cell systems by providing an analysis of the technical and economic system drivers of PEM fuel cell system cost and adoption. Specific objectives are to determine major drivers of PEM fuel cell system cost and lifecycle costs, and to identify opportunities for technological breakthroughs in materials or manufacturing to reduce system costs.

3.1 ECONOMIC ANALYSIS OF A 5 KW DIRECT HYDROGEN PEM FUEL CELL SYSTEM AND A 50 KW PROPANE REFORMER PEM FUEL CELL SYSTEM

Economic models were developed for two PEM fuel cell systems: (1) a 5 kW direct hydrogen system for backup power applications and (2) a 50 kW propane reformer PEM fuel cell system for grid independent applications. The 5 kW direct hydrogen PEM fuel cell was selected because marketing research suggests that near-term commercialization at this size may be achieved in backup power applications in the telecommunications market segment.

The 50 kW propane reformer PEM fuel cell system for grid independent applications was chosen because Battelle had access to a prototype fuel cell that could be used as a basis for a detailed cost breakdown analysis. This system allowed us to develop the economic models with a higher degree of confidence, since the team could refer back to hardware components on hand. The 50 kW fuel cell propane reformer PEM fuel cell system also represents a significant opportunity for use in grid independent applications. Propane was selected as the fuel for the grid independent application because propane is readily available at most remote sites that may represent an early adopter market. A palladium membrane separator based reformer was analyzed because it can provide high purity hydrogen to the fuel cell, thereby essentially eliminating issues of poisoning of the catalyst, reducing catalyst loading requirements and the need to include ruthenium in the anode-side catalyst.

The fuel cell costs were calculated assuming annual production volumes of 1,000 units, 10,000 units, and 100,000 units. The annual production volumes of 1,000 units span the likely range by 2015. The higher volumes of 10,000 and 100,000 units, while unlikely to be observed by 2015, allow evaluation of whether cost reductions arising from annual production volume alone are likely sufficient to achieve competitive pricing in the absence of technological breakthroughs.

Details of the engineering methodology used for this analysis can be found in Appendix F. To obtain stakeholder input into the design and analysis of the two systems, Battelle facilitated two expert focus groups. Experts from Battelle, industry, academia, and government participated in the focus groups and reviewed and provided feedback on engineering cost analysis design, inputs to the model and initial analysis of the two systems. Information from the two expert focus groups is presented in Appendix G and Appendix H.

3.1.1 5 kW Direct Hydrogen PEM Fuel Cell System Engineering Specifications

The 5 kW direct hydrogen PEM fuel cell system specifications and cost assumptions identified in Table 3-1 were used in the engineering cost analysis and in subsequent lifecycle cost analysis of the 5 kW direct hydrogen PEM fuel cell system. The schematic for the 5 kW direct hydrogen

PEM fuel cell system is shown in Figure 3-1. This system was specified as needing 99.999% reliability by early adopter markets like telecommunications for startup and availability at a low cost, with a design operating life of 5000 hours over a 15 year lifetime. However, for telecommunication backup applications, the PEM fuel cell system is assumed to operate only 60 hours (300 kWh) in a backup mode over a 15 year fuel cell life. Therefore, extended durability is not a requirement for this system.

Table 3-1. Key engineering specifications of the 5 kW direct hydrogen PEM fuel cell system.

Parameter*	Design Specifications[+]
Peak power	5 kW
Power density	0.5 W/cm^2
Current density	0.8 A/cm^2
Catalyst	Platinum, 0.6 mg/cm^2
Hydrogen fuel	99.995% in "K" cylinders (5.55 m^3)
Durability	5,000 hours over 15 years
Cells per stack	82
Membrane active area/cell	150 cm^2
Amount of membrane needed	12,328 cm^2
Number of bipolar plates	164
Power degradation, % over 8,760 hours of operation	20
Inverter efficiency, %	90

[+]Specifications are derived from market requirements for backup power systems and feedback from industry experts
*Assumes no membrane lost or catalyst lost to gasketing

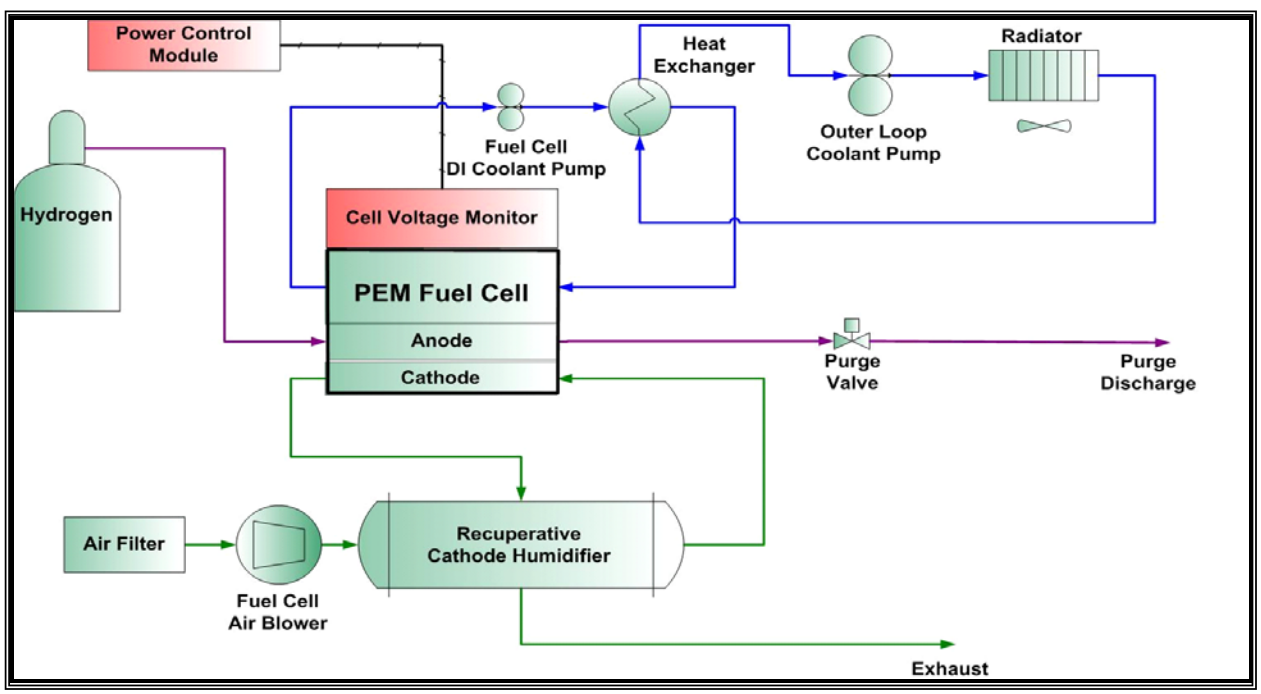

Figure 3-1. Schematic of 5 kW direct hydrogen PEM fuel cell system.

The 5 kW direct hydrogen PEM fuel cell system operates at atmospheric pressure (1 to 2 psig) and runs on purified hydrogen (99.995%) delivered in "K" cylinders using existing distribution systems. Hydrogen cost and tank rental are based on commercial quotations. The cost of hydrogen for this system, obtained from Praxair, is $38 per cylinder. In addition, annual tank rental is $22 per tank per year. There is a delivery and hazardous material charge of $20. Hydrogen "K" cylinders contain 5550 liters of hydrogen that is consumed at 75 slm at 5 kW.[54] Therefore, a "K" cylinder will provide about 1.23 hours of backup power at 5 kW. Comparable use rates have been indicated by Ballard.[55]

Power density is assumed to be 0.5 W per cm^2, and current density is assumed to be 0.8 A per cm^2 (0.625 V per cm^2). As durability and efficiency are not being optimized, high amperage and current densities are used to reduce the cost of the system by reducing the number of cells required. The system is assumed to have active water control to remove water from the cathode side and active humidification on the anode (hydrogen) side.

In the analysis, the material costs of the membrane, gas diffusion layer (GDL), and catalysts depend on the active membrane area required. The total active membrane area was determined using Equation 1. The number of cells was derived by dividing the total active membrane area by the assumed active membrane area per cell. It was assumed that no membrane is lost to gasketing. Endurance tests suggest that, at low current densities (0.2 A per cm^2), the annual percentage loss of voltage or power degradation is quite low (< 2%); at higher current densities (0.8 A per cm^2) the losses may be ~8 to ~20%, depending on conditions.[56,57] A conservative figure of 20% annual percentage loss of voltage was used in this analysis for the 5 kW direct hydrogen PEM fuel cell (using a less conservative 8% degradation rate in the model, reflecting current state of the art, does not change conclusions).

$$C = \frac{P_G \times (1+d)^N}{E \times P_d} \qquad \text{Equation 1}$$

Where:

C = Active membrane area
P_G = Peak power
E = Inverter efficiency
P_d = Peak power density
d = Power degradation (annual)
N = Designed operating life (years)

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[54] PlugPower, Inc. 2004. GenCore Systems: Fuel Cell Products for Premium Power Generation. Accessed May 5, 2005. Available at http://www.plugpower.com/products/pdf/GenCore_Telecom_Datasheet.pdf/
[55] MGE/Ballard/Praxair Q&A. 2004. AirGen™ Fuel Cell Generator.
[56] EG&G Technical Services, Inc. 2004. Fuel Cell Handbook, 7th Ed. Springfield, Virginia. For the Department of Energy. Under Contract No. DE-AM26-99FT40575. Available at http://www.netl.doe.gov/technologies/coalpower/distgen/seca/pubs/FCHandbook7.pdf.
[57] Fowler, M. 2004. Degradation and Reliability Analysis of PEM Fuel Cell Stacks. Accessed October 8, 2004. Available at http://watcar.uwaterloo.ca/pdf/reliability.pdf#search=%22Degradation%20and%20Reliability%20Analysis%20of%20PEM%20Fuel%20Cell%20Stacks.%20%22.

Costs of membrane, GDL, and bipolar plates utilized in the economic analysis are based on published projections or projections provided by manufacturers (Table 3-2). No particular manufacturing methods to achieve the projected costs of specific components are assumed. The cost of platinum is assumed to drive the cost of catalyst ink and to be independent of fuel cell production volume at the various production levels assumed in this analysis. Labor costs for the stack assembly are assumed to be 5% of the cost of the components.

Table 3-2. Membrane Electrode Assembly component costs ($) for 5 kW direct hydrogen PEM fuel cell system at 1,000, 10,000, and 100,000 unit annual production volumes.

5 kW PEM Fuel Cell	1,000 Units	10,000 units	100,000 units
Membrane (Nafion 2 mil), $/m^2	300	250	215
Gas Diffusion Layer, $/m^2	200	90	40
Catalyst Layer (Anode & Cathode), $/g	50	45	26
Gasket / Seals, $/cell	1.50	0.73	0.50
Bipolar Plates, $/plate	11.72	2.34	2.00

The membrane is assumed to be 2 mil Nafion. Projected prices for Nafion 112 (2 mil) products are based on future pricing projections presented by DuPont: ~$190 to $240 per m^2 at 100,000 m^2 annual volume and ~$60 to $80 per m^2 at 1,000,000 m^2 annual volume.[58] The current price of $300 per m^2 for large volume users was used for the cost at annual production volumes of 1,000 units. For annual production volumes of 100,000 units of 5 kW direct hydrogen PEM fuel cells, about 1,200,000 m^2 of membrane would be required. A midrange figure of $215 per m^2 was assumed based on DuPont projections. The cost of $250 per m^2 was assumed at annual production volumes of 10,000 units as an intermediate value between the known current cost and the projected cost at 100,000 m^2 of membrane. Bipolar plate costs are estimated from figures provided by Porvair[59] and from published analysis of carbon/carbon composite bipolar plate costs.[60, 61]

GDL is required on both the anode and cathode sides of the membrane electrode assembly (MEA). It is anticipated that a 50 cm^2 membrane would require 100 cm^2 of GDL. Scale-up of current GDL technology to 10,000 m^2 would yield a cost of $80 to $100. At very large volumes (100 million m^2) the cost is likely to remain >$10 per m^2.[62] Costs at other volumes were estimated by Battelle.

[58] Curtin, D., T. Henry, D. Lousenberg, P. Tangeman, and M. Tisack. 2003. Differentiated Membranes and Dispersions for Commercial PEM Fuel Cell and Electrolysis Systems. Fuel Cell Seminar (November 3–7), Miami Beach, Florida.
[59] Personal communication between Kathya Mahadevan (Battelle), and David Haack (Porvair). April 2005.
[60] Haack, D. 2004. Scale-up of Carbon/Carbon Bipolar Plates. 2004 DOE Hydrogen Fuel Cells & Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[61] Besmann, T., T.J. Klett, J. Henry, and E. Lara-Curzio. 2000. Carbon/Carbon Composite Bipolar Plate for Proton Exchange Membrane Fuel Cells. Journal of the Electrochemical Society 147(11): 4083-4086.
[62] Personal communication between Harry Stone (Battelle), and Wayne Triebold (Toray Composites America Inc.). February 2004.

Membrane substrate and gasket were not rigorously reviewed due to the small contribution to the cost. Figures were adjusted based on stakeholder feedback received at the industry focus group held on April 21, 2005, in New Orleans, LA (Appendix H).

The platinum catalyst is assumed to be 0.2 mg per cm^2 on the anode and 0.4 mg per cm^2 on the cathode. The catalyst costs are assumed to be driven by platinum cost with no additional economies of scale at high volumes. The catalyst costs are estimated to be $50 per g at the 1,000 unit production level. The catalyst costs are primarily driven by chloroplatinic acid costs of $43 per g.[63] A published list price of chloroplatinic acid in 30 g quantities is $51.60 per gram,[64] suggesting that, after discounts, but adding in other costs of preparing the ink, the $50 per g figure is a reasonable but possibly conservative figure. At high production volumes, the cost of chloroplatinic inks to MEA manufacturers is assumed to be two times the cost of platinum, based on recent platinum prices of ~$400/troy ounce. The markup for inks over the cost of platinum is expected to be minimal. The platinum price at high volumes is assumed to include the minimal costs of conversion to chloroplatinic acid, production of inks, and markups.

3.1.2 50 kW Propane Reformer PEM Fuel Cell System Engineering Specifications and Cost Assumptions

The fuel cell specifications and cost assumptions that follow were used both in the engineering cost analysis and in subsequent lifecycle cost analysis of the 50 kW propane reformer PEM fuel cell system. The design objective of the 50 kW propane reformer PEM fuel cell system is durability for continuous baseload operation in grid independent applications. The system is a propane fueled steam reformer operating at a temperature of 900 ºC with a palladium membrane separator operating at a pressure of 250 psig and a temperature of approximately 350 ºC. The schematic for the fuel cell is shown in Figure 3-2.

Key specifications of the propane reformer PEM fuel cell system are given in Table 3-3. Efficiency of propane conversion is assumed to be about 40%. The 50 kW propane reformer PEM fuel cell system is designed to operate 8,000 hours (400,000 kWh) in a continuous baseload mode over a 0.91 year fuel cell life. Power density is assumed to be 0.2 W/cm^2 and current density of 0.2 A/cm^2 to maximize durability. The system is assumed to have active water control to remove water from the cathode side and active humidification on the anode side. The fuel cell includes power conditioning, including conversion of direct current (DC) to alternating current (AC), which is assumed to be 90% efficient.

[63] Popov, B. 2004. Novel Non-Precious Metals for PEMFC: Catalyst Selection Through Molecular Modeling and Durability Studies. 2004 DOE Hydrogen Program Review (May 24–27), Philadelphia, Pennsylvania.
[64] ScienceLab.com, Inc. 2005. Homepage. Accessed April 16, 2005. Available at http://www.sciencelab.com.

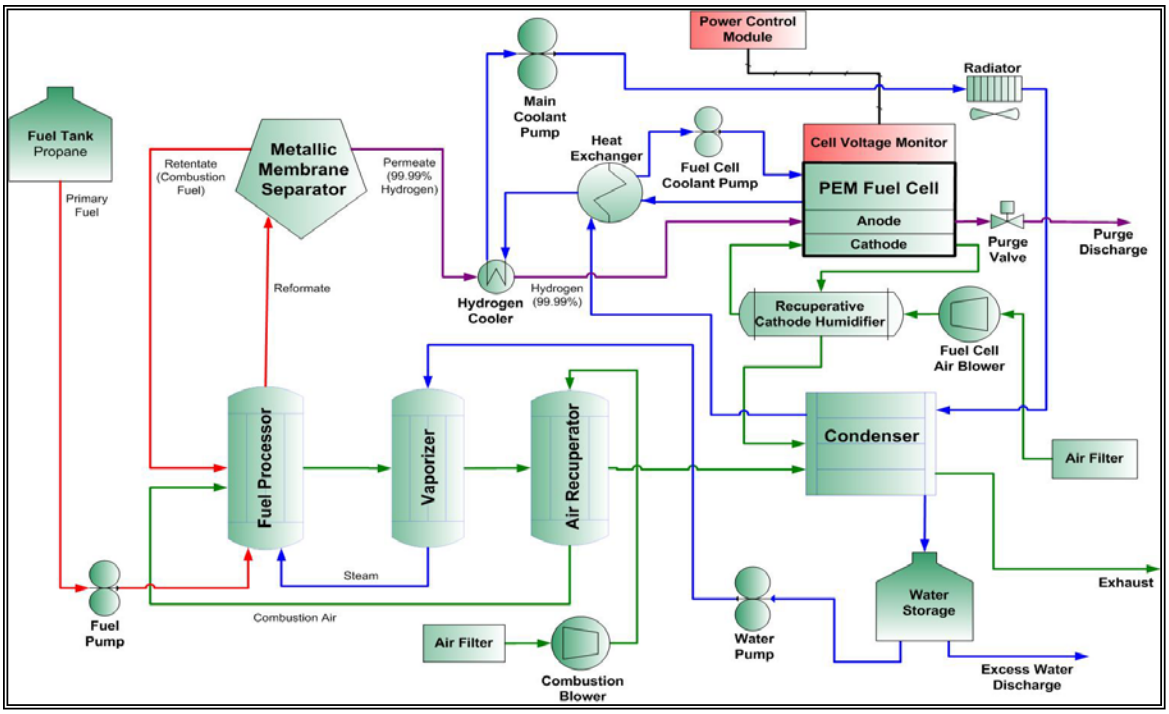


Figure 3-2. Schematic of 50 kW propane reformer PEM fuel cell system for baseload grid independent applications.

Table 3-3. Key engineering specifications of the 50 kW propane reformer PEM fuel cell system.

Parameter*	Design Specifications
Peak power	50 kW
Power density	0.2 W/cm^2
Current density	0.2 A/cm^2
Catalyst	Platinum, 0.6 mg/cm^2
Hydrogen Fuel	99.99% purified reformate
Durability	8,000 hours (0.91 year) continuous operation
Cells per stack	471
Membrane active area/cell	600 cm^2
Amount of membrane needed	282,828 cm^2
Number of bipolar plates	942
Power degradation, % over 1 year (8,760 hours) of operation	2
Inverter efficiency, %	90
Hydrogen purification	Palladium membrane separator
Fuel (to reformer)	Propane (desulfurized)

+Specification is based on best available PEM fuel cell technology
*Assumes no membrane lost or catalyst lost to gasketing

The platinum catalyst is assumed to be 0.2 mg per cm^2 on the anode and 0.4 mg per cm^2 on the cathode, made possible by pure hydrogen in the reformate. The polymer electrolyte membrane is assumed to be 2 mil Nafion. The costs for major MEA components are shown in Table 3-4. The

sources of data and assumptions are the same as those described above for the 5 kW stack in section 3.1.1. The price of the propane used in the 50 kW propane reformer PEM fuel cell system is based on the EERE figures for industrial consumers in 2004 of $1.22 per gallon.[65] The propane is assumed to be desulfurized; therefore, sulfur removal systems are not included in the design and cost analysis.

Table 3-4. Membrane Electrode Assembly component costs ($) for 50 kW propane reformer PEM fuel cell system at 1,000, 10,000, and 100,000 unit production volumes.

50 kW	1,000 Units	10,000 Units	100,000 Units
Membrane, $/m^2	250	215	70
Gas Diffusion Layer, $/m^2	90	40	18
Catalyst Layer (Anode & Cathode), $/g	45	26	26
Gasket / Seals, $/cell	3.03	1.86	1.25
Bipolar Plates, $/cm^2 ($/plate pair)	10.40	5.50	4.00

3.1.3 Methodology for PEM Fuel Cell Engineering Cost Estimation

3.1.3.1 Engineering Cost Analysis Model Assumptions

Designs for 5 kW and 50 kW PEM fuel cell systems were developed as a basis for engineering cost modeling (Figure 3-1 and Figure 3-2). Using this engineering design as a basis, Battelle developed a methodology for selecting manufacturing cost reduction factors as a function of production volume. Detailed information on the methodology adopted for the engineering cost analysis, including the component classification system, is provided in Appendix F.

Each fuel cell component specified by the design was classified to reflect the expected change in manufacturing cost with increased production volumes. Each component classification designation corresponds to a specific scaling factor as a calculated function of estimated and/or actual single-component costing. Components were then assigned to one of five classifications based on literature review and general engineering knowledge from hands-on product development of fuel cells, and interviews with manufacturers, component developers, and researchers. The engineering cost models, with component costs derived from the scaling factors, were used to estimate the costs of the fuel cell systems at annual production volumes of 1,000, 10,000 and 100,000 units.

The overall generic PEM fuel cell engineering cost analysis model was constructed with the following guiding principles to determine the level of manufacturing processes and efficiencies to be assumed:

- Volumes at 1,000 and 10,000 annual production units were based on current and/or novel application of technologies currently available in other industries to fuel cell component manufacturing.

[65] EIA. Petroleum Marketing Monthly. April 2005. Accessed May 12, 2005. Available at http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/historical/2005/2005_04/pdf/pmmtab14.pdf.

- Volumes at 100,000 annual production units assume a level of conservative advancement of manufacturing technologies from learning curves and incremental technological progress over the next 10 to 15 years.
- The significance of these two assumptions is that cumulatively they predict a level of advancement in manufacturing technologies to occur during the production ramp-up phases in the next 10 years of fuel cell technology development.

3.1.3.2 Engineering Cost Analysis System Organization Assumptions

The overall structure of both types of fuel cell systems regardless of fuel type (propane or direct hydrogen) is divided into four major subsystems:

1. Hydrogen Delivery (includes steam reformer and hydrogen cleanup for reformer system),
2. Fuel Cell System (includes anode and cathode side hardware and other fuel-cell connected systems),
3. Power Electronics & Systems Integration (includes conditioning and DC to AC conversion), and
4. System Assembly.

Balance of plant was not treated as a separate subsystem in this analysis. Instead, each major subsystem contains the required primary and secondary (balance of plant) components that provide dedicated functionality to that subsystem. Each component was included in the primary subsystem in which it is used (e.g., the fuel pump for the steam reformer is in the Hydrogen Delivery subsystem). Including the balance of plant components in appropriate subsystems provides a clearer picture of actual subsystem costs.

Details of the components included in the analysis, the component classification system, and the scaling factors applied to each classification are shown in Appendix F.

3.1.4 Lifecycle Costing Analysis: Methodology and Assumptions

Capital purchases by companies are typically made on the basis of a value proposition that includes the perceived quality of the product and the lifecycle cost of using the product. Lifecycle cost can be viewed from several perspectives. Cash flow and NPV provide two such perspectives. In this project the lifecycle costs are examined in several ways. First, the lifecycle cost is examined from an annual average cash flow basis. This examines how much cash, on average, is required to own and operate a fuel cell. For baseload power, the costs are divided by power generated to convert the figures to cost of electricity ($/kWh). These costs can be directly compared to grid prices. Sensitivity analysis of the average annualized cash flow projections (or cost of electricity) provides clear insight into leverage of improving various factors that impact the cost of ownership or the cost per kW of electricity.

A second lifecycle method, used for backup power, examines the lifecycle NPV (cost) of the PEM fuel cell. The NPV of the PEM fuel cell is then compared to the NPV of the current competing alternative backup power source in most markets – batteries with a diesel generator. The NPV analysis, often used by businesses in capital purchase decisions, provides cash flows discounted for the time value of money.

The H2A model developed by the DOE provides a standardized approach to calculate lifecycle costs of systems for generating and distributing hydrogen. However, outputs are in $ per kg of hydrogen. During this analysis, the H2A model was being modified to calculate the cost per kWh of electricity produced and was unavailable for use. The standard assumptions of the H2A model were used in the fuel cell electricity cost model developed for this analysis.

Assumptions made in the lifecycle analyses of the 5 kW direct hydrogen PEM fuel cell system and the 50 kW propane reformer PEM fuel cell system are shown in Tables 3-5 and 3-6, respectively. For backup power lifecycle analysis (Table 3-5), the entire fuel cell is replaced after 15 years. The stack in the 50 kW propane reformer PEM fuel cell system is assumed to have a 1 year life and to be replaced each year. After five years, the entire fuel cell is assumed to be replaced (Table 3-6). The NPV analysis assumes a discount rate but does not include tax implications.

Table 3-5. Key assumptions of the lifecycle analysis of the 5 kW direct hydrogen PEM fuel cell system.

5 kW Lifecycle Descriptor	Lifecycle Analysis Assumptions
Fuel Cell Cost, $	15,000 (3,000/kW)
Installation Cost, $	7,000
Residual Value of Fuel Cell at Close of Year 20, $	10,000
Annual O&M Cost (net of fuel), $	100
Annual Usage, kWh	20
Life of Fuel Cell, years	15
Ride-through Battery Life, years	5
Ride-through Battery Cost, $	400
Battery Disposal	50
Hydrogen Shelf Life, years	3
Hydrogen Cost (K Cylinder), $	38
Number of K Cylinders	7 (~9 hours at 5 kW)
Annual Tank Rental, $	21.90
Tank Delivery/ Hazmat Charge, $	19.5
Discount Rate, %	10

Table 3-6. Key assumptions of the lifecycle analysis of the 50 kW propane reformer PEM fuel cell system.

50 kW Lifecycle Descriptor	Lifecycle Analysis Assumptions
Fuel Cell Cost, $	150,000
Installation and Tank (1999 gal) Cost, $	45,739
Annual O&M Cost	1440
Fuel Cost/kWh	0.14
Average Annual Usage, hours	8760
Life of Fuel Cell (with stack replacement), hours	8760
Life of Stack, years	1
Stack Replacement Cost, $	40,000
Propane, $/gal	1.22
Efficiency, %	40
Discount Rate, %	10

3.2 COST ANALYSIS OF 5 KW DIRECT HYDROGEN PEM FUEL CELL SYSTEM

3.2.1 Cost Breakdown of Subsystems

As outlined in the previous sections, the PEM fuel cell system was divided into four subsystems; Table 3-7 outlines the cost of each subsystem for production volumes of 1,000 units, 10,000 units, and 100,000 units. Total system cost declines approximately 51% from $9,217 at the 1,000 unit production volume to $4,496 at the 100,000 unit production volume. With volume, the cost of fuel cell subsystem declines by approximately 55%, power electronics and systems integration by 38%, and system assembly by 80%.

Table 3-7. Cost breakdown of 5 kW direct hydrogen PEM fuel cell system.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Hydrogen Delivery System	553	400	338
Fuel Cell Subsystem	4,574	2,610	2,046
Power Electronics and Systems Integration	3,090	2,251	1,912
Systems Assembly	1,000	610	200
Total Cost	**9,217**	**5,871**	**4,496**
Cost per kW	**1,843**	**1,174**	**899**

Figures 3-3 to 3-5 show the percentage breakdown in cost for each of four fuel cell subsystems for 1,000, 10,000, and 100,000 unit production volumes, respectively. At each of these production levels, the fuel cell subsystem remains the largest cost driver in the 5 kW system at 45% to 49% of the total cost of the system. Power electronics and systems integration are also significant cost drivers and range from 34% to 43% of the total fuel cell system.

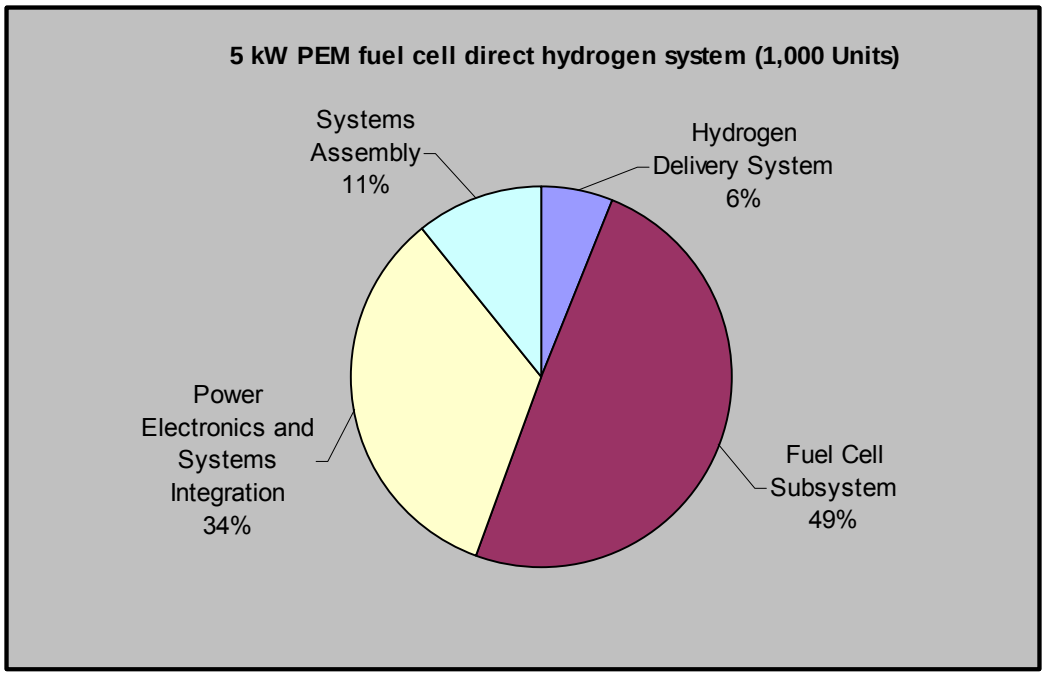


Figure 3-3. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (1,000 units).

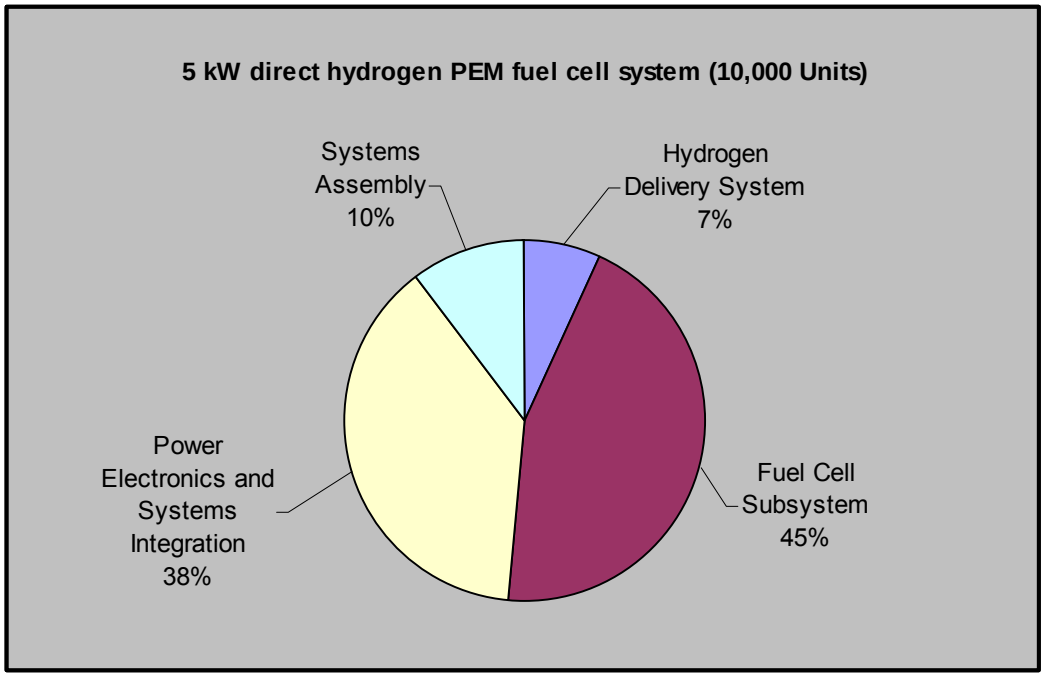


Figure 3-4. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (10,000 units).

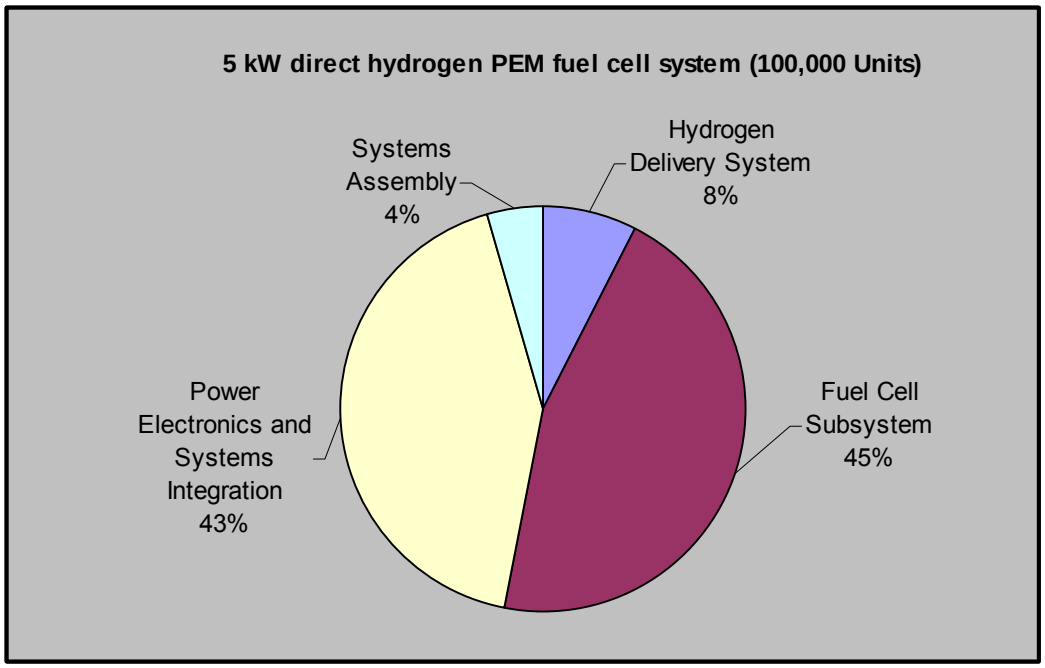


Figure 3-5. Cost breakdown for 5 kW direct hydrogen PEM fuel cell system (100,000 units).

3.2.2 Cost Analysis of Fuel Cell Subsystem

The cost breakdown in U.S. dollars for the 5 kW PEM fuel cell subsystem is shown in Table 3-8. Within the PEM fuel cell subsystem, the stack is the biggest cost driver, accounting for approximately 71% of the total cost of the fuel cell subsystem at a 1,000 unit production volume and approximately 60% at 100,000 unit production volume (Figure 3-6). With volume increases from 1,000 to 100,000 unit production volumes, the cost of the stack declines about 63%, from $3,258 to $1,220. Less impact of production volume is seen in other subsystems, as several components in them are commodities.

Table 3-8. Total cost of 5 kW direct hydrogen PEM fuel cell subsystem.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Fuel Cell Stack	3,258	1,633	1,220
Anode Side Support Hardware	466	347	298
Cathode Side Support Hardware	251	180	152
Cooling System	599	450	377
Total Cost	**4,574**	**2,610**	**2,046**
% of Total Fuel Cell Cost	**49.6**	**44.5**	**45.5**

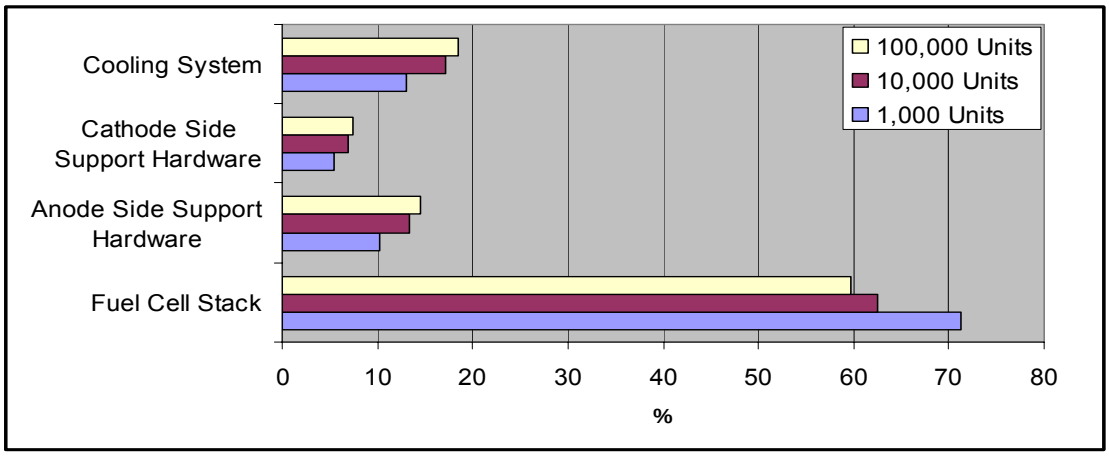


Figure 3-6. Percent cost breakdown of 5 kW PEM fuel cell subsystem costs.

3.2.3 Cost Analysis of Fuel Cell Stack System

Within the fuel cell stack system, the MEA costs decline with increasing production volume from $2,327 at 1,000 units to $763 at 100,000 units (Table 3-9 and Figure 3-7). The MEA is approximately 71% of the stack at the 1,000 unit production volume and declines to about 63% of the stack cost at the 100,000 unit production volume. When compared to the total cost of the fuel cell system, the MEA declines from approximately 51% of the total cost of the fuel cell system at the 1,000 unit production volume to 37% of the total cost of the fuel cell system at the 100,000 unit production volume. Within the MEA, the catalysts and membrane costs decline only about 28% and 48%, respectively, with increasing production volume. Bipolar plate costs decline about 83% at 100,000 units as low volume (1,000 units) machining is replaced by injection molding. Injection molding is introduced at annual fuel cell production volumes of 10,000 units.[66]

[66] See reference 59 and 60.

Table 3-9. Cost of 5 kW direct hydrogen PEM fuel cell stack system.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Ion Exchange Membrane	370	308	265
Membrane Substrate	6	2	1
Gas Diffusion Layer	493	222	99
Catalyst Layer (Anode & Cathode)	370	333	192
Gasket and Seals	125	61	41
Bipolar Plates	963	192	164
Total Cost of Membrane Electrode Assembly	**2,327**	**1,118**	**763**
Tie Rods	15	9	8
Insulators	40	23	22
End Plates	135	77	74
Current Collectors	55	31	30
Stack Housing	475	272	260
Stack Voltage Monitor	55	39	33
Assembly, Fuel Cell Stack	155	63	30
Total Cost of Stack System	**3,258**	**1,633**	**1,220**

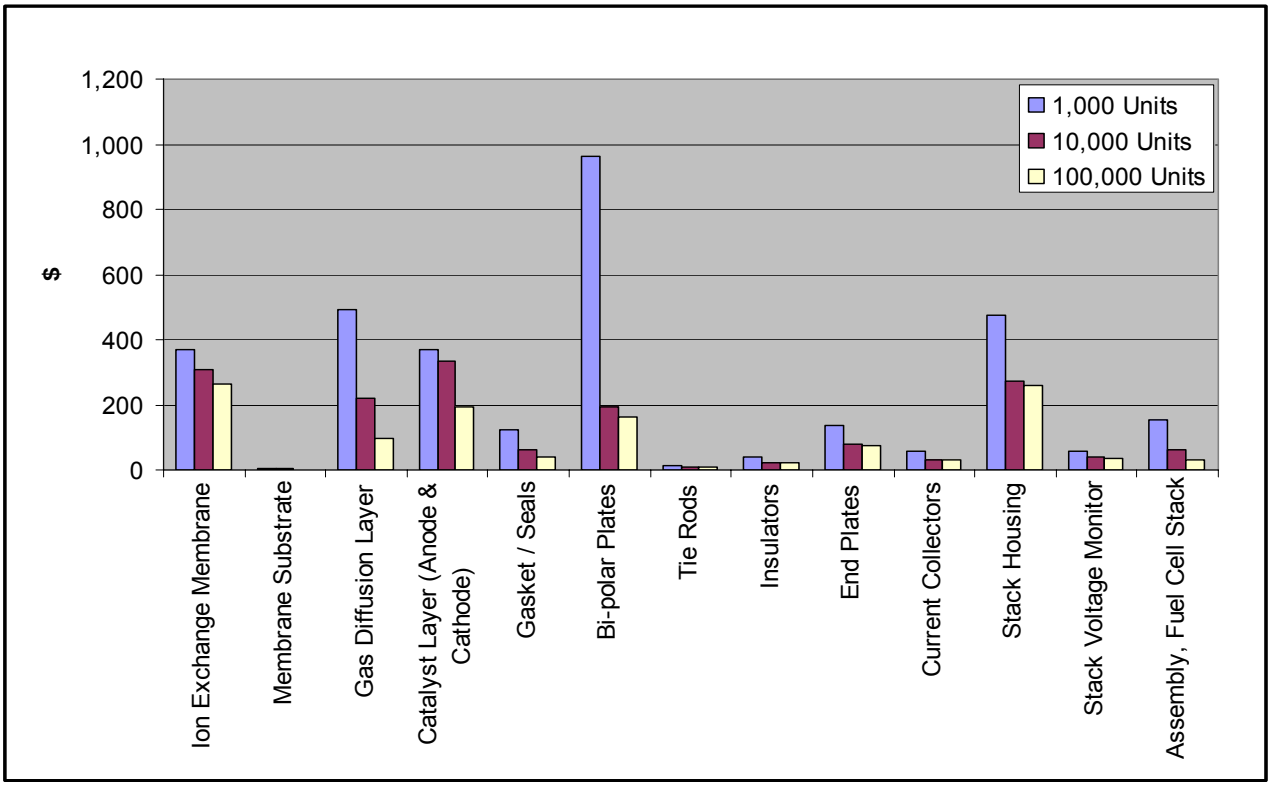


Figure 3-7. Cost of total 5 kW direct hydrogen PEM fuel cell stack system.

3.3 COST ANALYSIS OF 50 KW PROPANE REFORMER PEM FUEL CELL SYSTEM

3.3.1 Cost Breakdown of Subsystems

The cost breakdown of fuel cell subsystems for the 50 kW propane reformer PEM fuel cell system based on production volumes is detailed in Table 3-10. The engineering cost of the 50 kW propane reformer PEM fuel cell system declines from $135,901 at the 1,000 unit production volume to $50,201 at the 100,000 unit production volume. With production volumes, the costs of fuel processing, hydrogen cleanup, and the fuel cell subsystem decline by approximately 43%, 77%, and 63%, respectively.

Table 3-10. Cost breakdown of 50 kW propane reformer PEM fuel cell system.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Fuel Processing	25,971	19,059	14,786
Hydrogen Cleanup	48,838	21,651	11,165
Fuel Cell Subsystem	32,790	20,153	12,011
Power Electronics and Systems Integration	15,510	11,346	9,680
Systems Assembly	12,794	7,804	2,559
Total Cost	**135,901**	**80,013**	**50,201**
Cost per kW	**2,718**	**1,600**	**1,004**

Figures 3-8 to 3-10 illustrate the percentage cost breakdown of the subsystems of the 50 kW reformer PEM fuel cell system with production volume. For this system the primary cost drivers are the fuel processing (steam reformer and the hydrogen cleanup systems). The fuel cell subsystem remains between 24 and 25% of the total cost of the PEM fuel cell system.

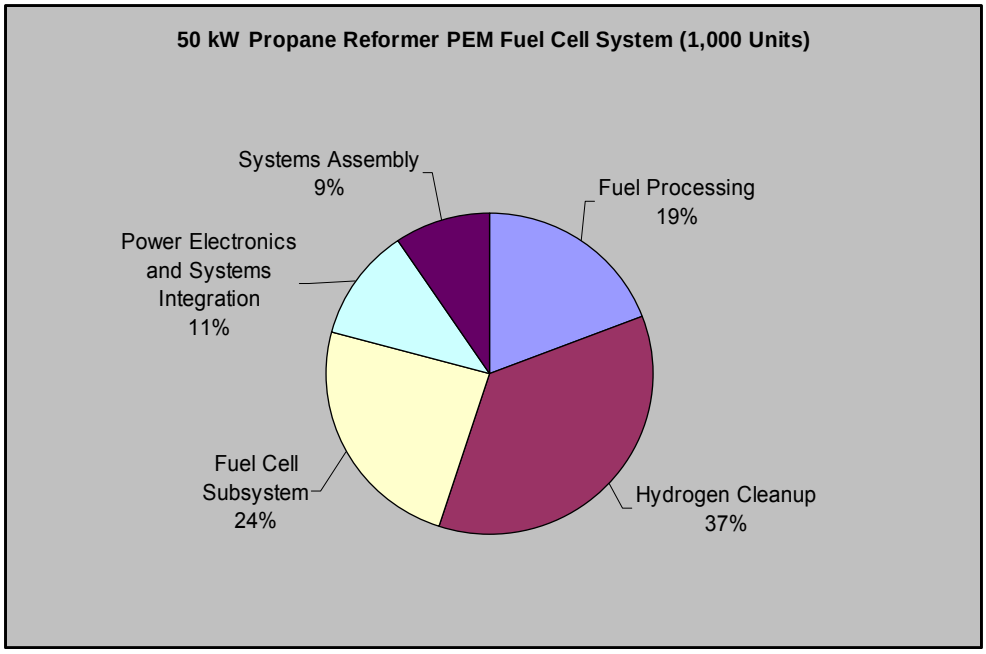


Figure 3-8. Cost breakdown for 50 kW propane reformer PEM fuel cell system (1,000 units).

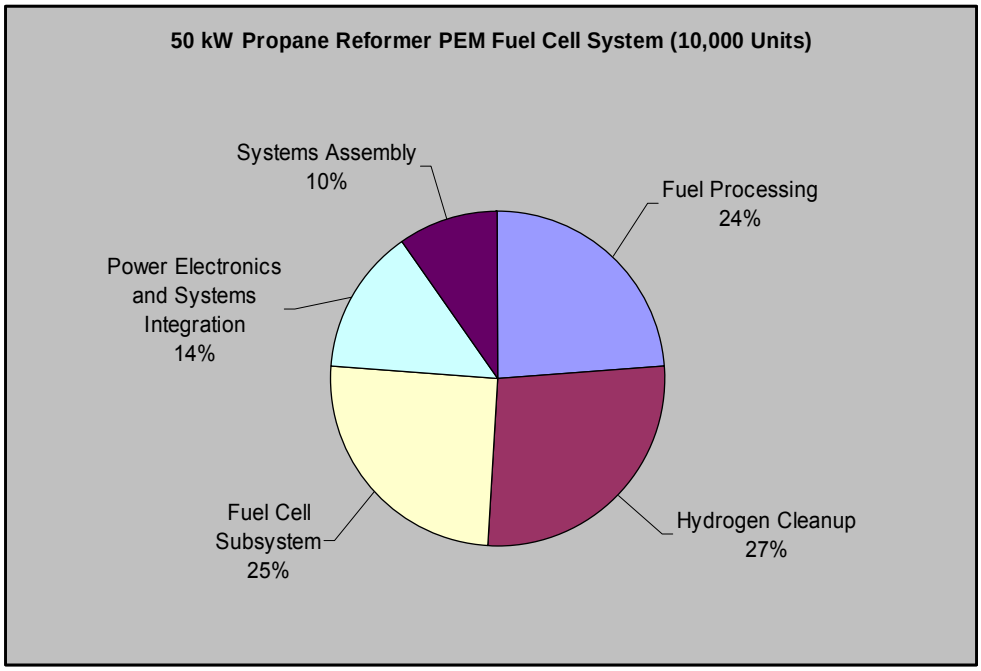


Figure 3-9. Cost breakdown for 50 kW propane reformer PEM fuel cell system (10,000 units).

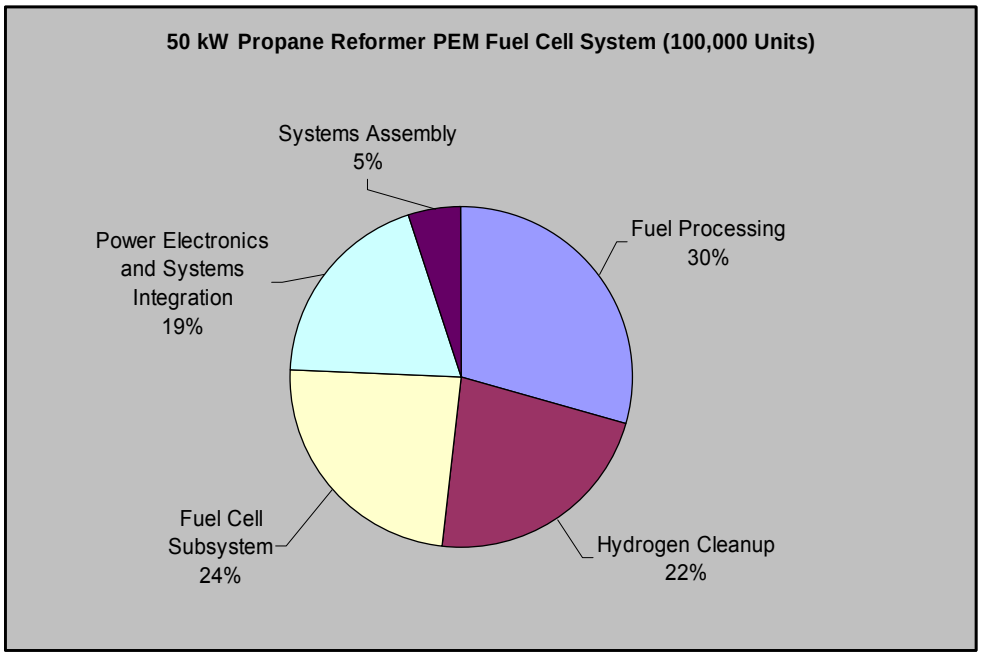


Figure 3-10. Cost breakdown for 50 kW propane reformer PEM fuel cell system (100,000 units).

3.3.2 Cost Analysis of Hydrogen Delivery System

The hydrogen delivery system has been subdivided into five subsystems and includes the fuel delivery, water delivery, coolant management, steam reformer, and hydrogen cleanup system (Appendix F). The cost of the hydrogen delivery system declines with volume increases from $74,809 at the 1,000 unit production volume to $25,951 at the 100,000 unit production volume. Figure 3-11 shows how the cost of individual components of the hydrogen delivery system changes as production volume increases. The palladium membrane separator is the biggest cost driver within the hydrogen delivery system; however, the cost is expected to decline with increasing production volume from $48,838 to $11,165 (going from 1,000 to 10,000 units) due to the use of high volume manufacturing techniques. This is followed by the reformer with integrated reactor, which declines from $8,651 at the 1,000 unit production volume to $6,283 at the 100,000 unit production volume.

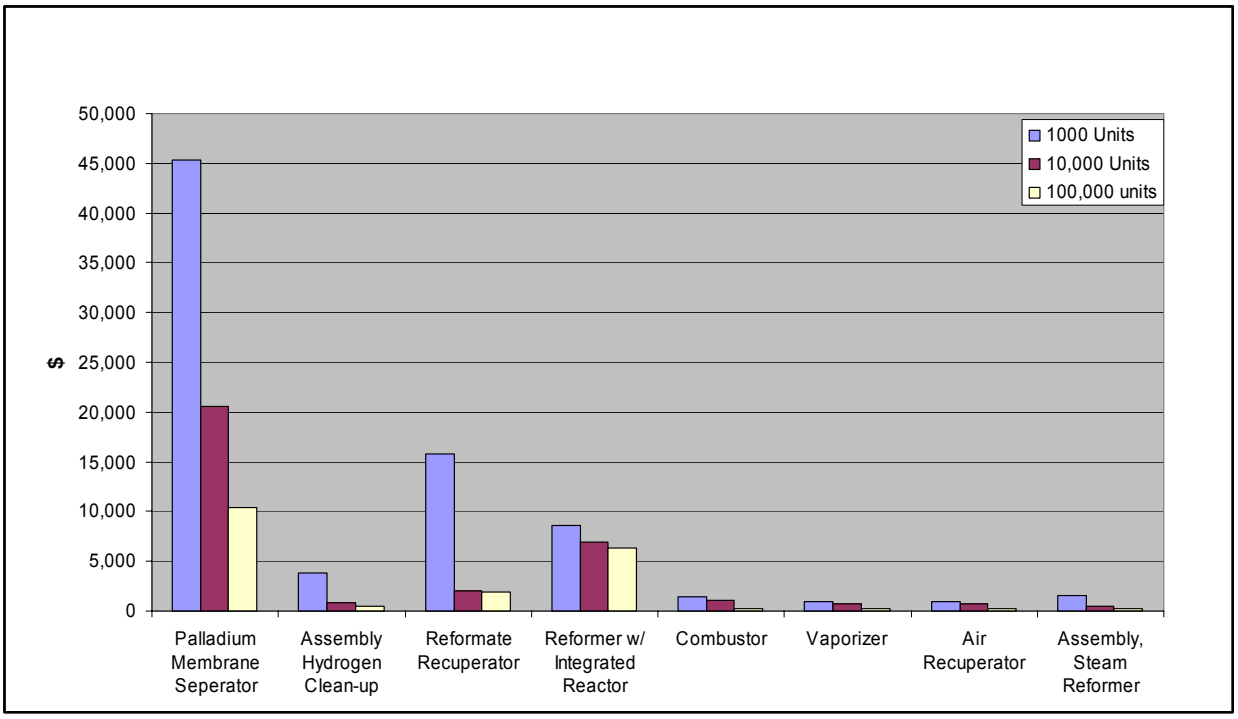


Figure 3-11. Primary cost drivers of 50 kW propane reformer PEM fuel cell hydrogen delivery system.

3.3.3 Cost Analysis of Fuel Cell Subsystem

Within the PEM fuel cell subsystem, the stack is the biggest cost driver, accounting for approximately 93% of the total cost of the fuel cell subsystem at a 1,000 unit production volume and approximately 88% at a 100,000 unit production volume (Table 3-11). With volume increases from 1,000 to 100,000 units, the cost of the stack declines about 65%, from $30,490 to $10,603, respectively. Less impact of production volume is seen in other subsystems because several components in them are commodities.

Table 3-11. Total cost of 50 kW propane reformer PEM fuel cell subsystem.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Fuel Cell Stack	30,490	18,492	10,603
Anode Side Support Hardware	628	466	399
Cathode Side Support Hardware	817	578	484
Cooling System	855	617	525
Total Cost of Fuel Cell Subsystem	**32,790**	**20,153**	**12,011**
% of Total Fuel Cell Cost	**24.1**	**25.2**	**23.9**

3.3.4 Cost Analysis of Fuel Cell Stack System

Within the fuel cell stack, the MEA costs decline with increasing production volume from $26,272 at 1,000 units to $9,914 at 100,000 units (Table 3-12 and Figure 3-12). The MEA is approximately 86% of the stack at the 1,000 unit production volume and increases to about 94% of the stack cost at the 100,000 unit production volume. When compared to the total cost of the PEM fuel cell system, the MEA is approximately 19% of the total cost of the PEM fuel cell system at the 1,000 unit production volume and 20% of the total cost of the fuel cell system at the 100,000 unit production volume. Within the MEA, the costs of catalysts and membrane decline by about 42% and 72%, respectively, with increasing production volume. Bipolar plate costs decline about 62% with increasing production volume through the use of lower cost production methods (injection molding rather than machining).

Table 3-12. Cost of 50 kW PEM fuel cell stack system.

	1,000 Units ($)	10,000 Units ($)	100,000 Units ($)
Ion Exchange Membrane	7,071	6,081	1,980
Membrane Substrate	141	28	28
Gas Diffusion Layer	5,091	2,263	1,018
Catalyst Layer (Anode & Cathode)	7,636	4,412	4,412
Gasket / Seals	1,431	878	590
Bipolar Plates	4,902	2,593	1,886
Total Cost of Membrane Electrode Assembly	**26,272**	**16,255**	**9,914**
Tie Rods	56	32	8
Insulators	151	83	22
End Plates	508	279	74
Current Collectors	207	113	30
Stack Housing	1788	980	262
Stack Voltage Monitor	55	39	33
Assembly, Fuel Cell Stack	1452	711	259
Total Cost of Stack System	**30,490**	**18,492**	**10,603**

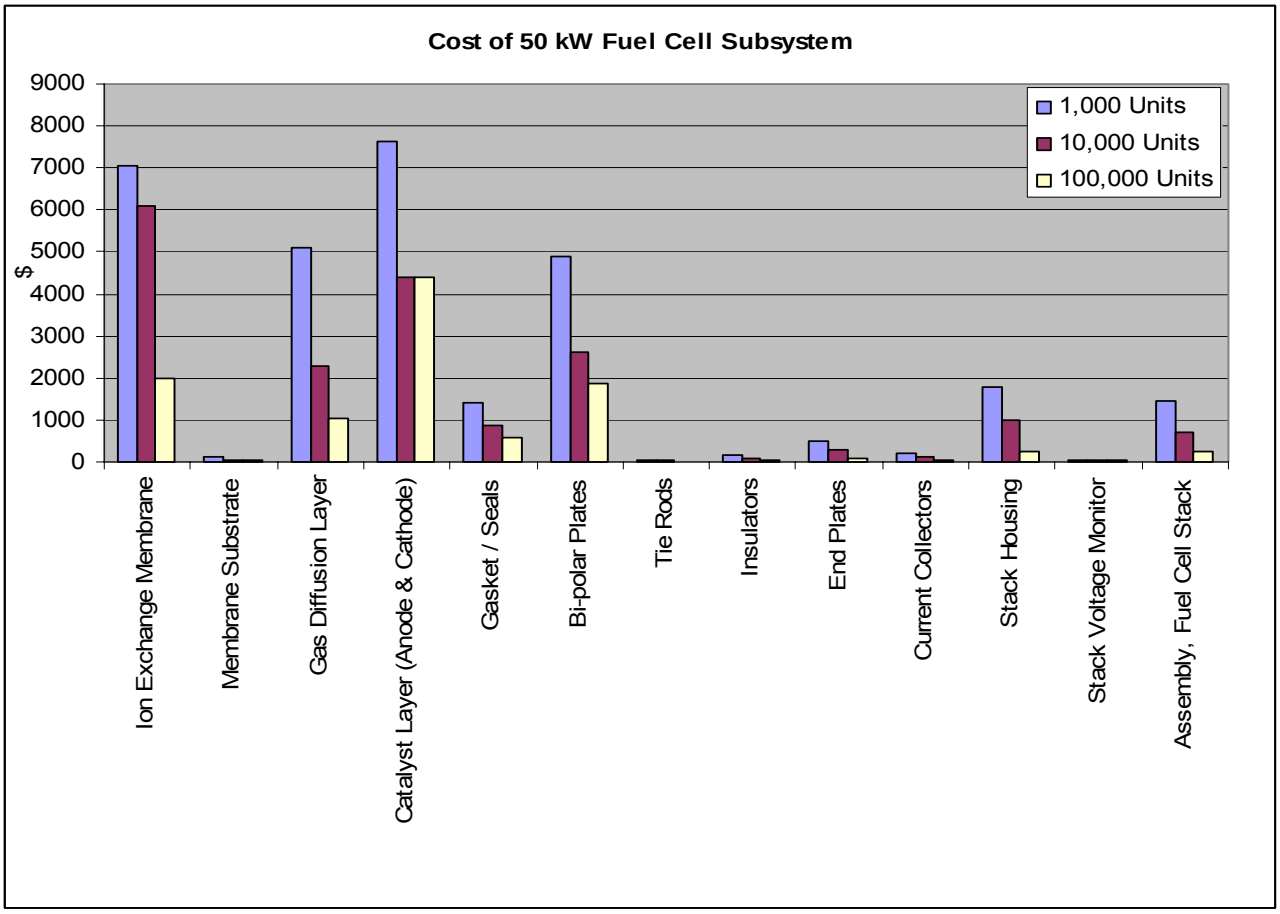


Figure 3-12. Cost of 50 kW propane reformer PEM fuel cell subsystem.

3.4 MAJOR COST ELEMENTS OF 5 KW DIRECT HYDROGEN PEM FUEL CELL SYTEM AND 50 KW PROPANE REFORMER PEM FUEL CELL SYSTEM

3.4.1 Lifecycle Cost Sensitivity Analysis: 5 kW Direct Hydrogen PEM Fuel Cell System

The purpose of the lifecycle cost sensitivity analysis for the 5 kW PEM fuel cell backup power system was to evaluate the impact of a ±10% change in major cost drivers on annual cash outlays required to own and operate the system. The average annual cash-based cost of owning and operating the 5 kW direct hydrogen PEM fuel cell backup power system over a 15 year life of the fuel cell, using current cost and performance conditions, was calculated using Equation 2 shown below. The base assumptions for the 5 kW direct hydrogen PEM fuel cell backup power system are shown in Table 3-5.

The lifecycle cost analysis of the 5 kW direct hydrogen PEM fuel cell backup power system assumes a $15,000 selling price quoted by commercial vendors in 2005 and a 15 year life when operated for about 4 hours per year (Table 3-5). The analysis also determines how much out-of-pocket cash it will cost each year, on average, to use a 5 kW direct hydrogen PEM fuel cell as a backup power source; which factors are most important cost drivers; and how sensitive out-of-pocket costs are to assumptions about the values of major cost drivers.

$$AC = \frac{FC + I}{FCL} + \frac{BC + D}{BL} + H + T + M \qquad \text{Equation 2}$$

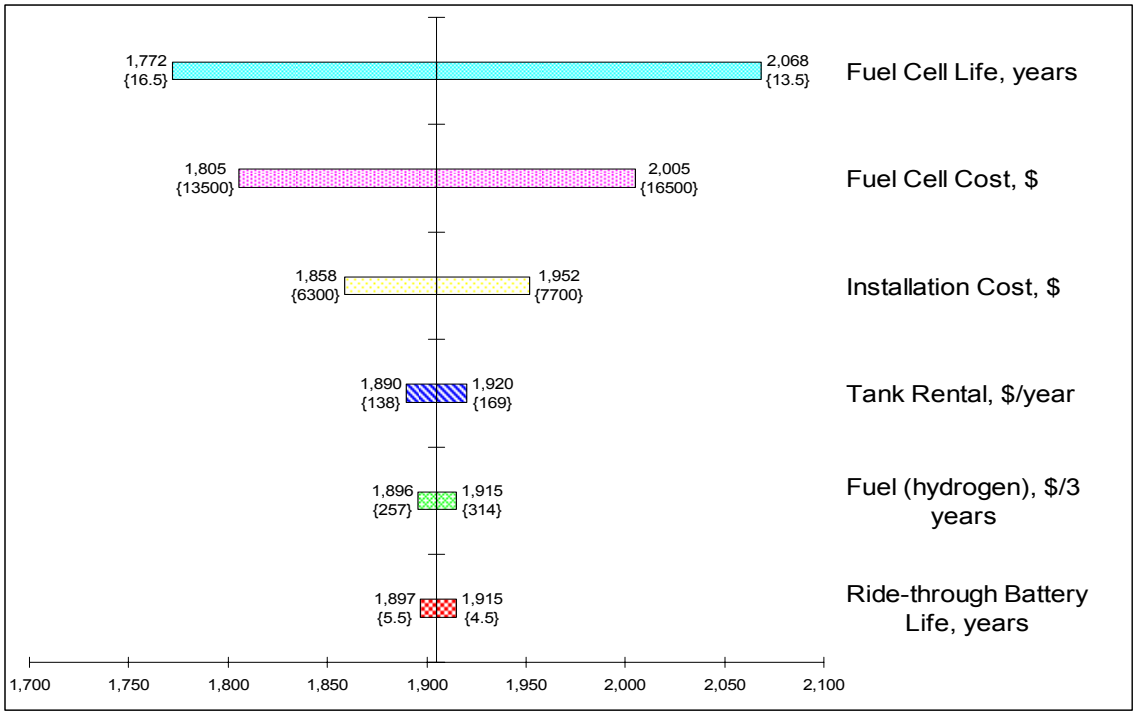
Where:

AC = average annual cash outlay for ownership over 15 years
FC = cost of fuel cell ($)
I = installation ($)
FCL = fuel cell life (years)
BC = battery cost ($)
D = disposal cost ($)
BL = battery life (years)
H = average annual hydrogen purchase and delivery ($)
T = annual tank rental ($)
M = average annual maintenance cost ($)

Figure 3-13 shows the sensitivity of the average annual cash flow of owning and operating PEM fuel cells for backup applications to a ±10% change in key factors. The results of the analysis indicate that the average annual cost (cash basis) of using a fuel cell is about $1,905. Increasing the life of the fuel cell by 10% (from 15 years to 16.5 years, shown in brackets to the left of the top bar in Figure 3-13) has the largest impact on average annual cost, reducing the average cost from $1,905 per year to $1,772 per year.

Reducing the cost of the fuel cell by 10% (from $15,000 to $13,500, shown in brackets to the left of the second bar in Figure 3-13) has the second largest impact. The annual cost of using PEM fuel cells for backup power are reduced from $1,905 to $1,805 (shown to the left of the bar in Figure 3-13) by lowering fuel cell cost by 10%.

Standardizing the installation process and reducing variability in siting requirements and permits might reduce these costs by greater than the 10% shown in the sensitivity analysis. In the backup power system, fuel cost is independent of fuel usage because fuel usage is low, but the tanks have only a three year shelf life and must be replaced.



X-axis is the annual cost ($) of owning and operating the fuel cell. Numbers in brackets are the values of the cost drivers. Costs are cash flow basis with no discount applied and no tax implications included. The analysis assumes 2005 selling price of fuel cells as quoted by vendors.

Figure 3-13. Sensitivity analysis of average annual lifecycle cost of 5 kW direct hydrogen PEM fuel cell system with ±10% changes in major cost drivers.

3.4.2 Lifecycle Cost Comparison of 5 kW Direct Hydrogen PEM Fuel Cell and Battery-Generator System

Cost is a primary factor for users when considering power alternatives as identified by marketing research. For backup power applications, the competing technology solution is often batteries coupled with diesel generators. The lifecycle costs of the 5 kW direct hydrogen PEM fuel cells and a battery-generator system for telecommunications application are examined in this section. Key assumptions for the fuel cell are shown in Table 3-5. The key assumptions for the battery-diesel generator system are shown in Table 3-13. The cost assumptions reflect the 2005 conditions. The PEM fuel cell cost to the user is assumed to be $15,000 ($3,000 per kW), the batteries were assumed to cost the user $7,200, and the generators were assumed to be rented at $440 per year in this case. Assumptions for battery backup costs were estimates provided by Verizon[67] or calculated by Battelle.

[67] Personal communication between Harry Stone (Battelle) and Marty Ross (Verizon Communications). April 2004.

Table 3-13. Assumptions used to determine the net present value of PEM fuel cells compared to batteries and generators for backup power applications.

Battery/Diesel Generator	
Descriptor	**Cost Assumptions ($)**
Installation	3,000
Batteries	7,200
Residual Value of Batteries at Close of Year 20, $	0
Battery Charger, $/year	100
Charger Electric	84
Load Transfer Equipment	100
Disposal	100
Generator Rental, $/year	440
Maintenance, $/year	695

At a 15 year fuel cell life, shown in Table 3-14, batteries require more cash and yield a slightly higher cost measured as NPV (10% discount rate) over a 20 year period. Further, in regions where battery life is less than 5 years because of environmental conditions, fuel cells will provide a relatively more attractive NPV when compared to batteries.

Table 3-14. Twenty-year lifecycle cost analysis comparing a 5 kW direct hydrogen PEM fuel cell system to a battery-generator system for backup power applications.

5 kW Fuel Cell vs. Battery Backup Power*	PEM Fuel Cell Total Cost ($)	Battery-Generator Total Cost ($)
Capital Cost	30,000	28,800
Installation	7,000	3,000
Fuel	1,999	0
Charger, Load Transformer & Electricity	0	1,880
Generator	0	8,800
Demurrage	3,066	0
Batteries	1,600	16,000
Disposal	100	400
O&M	2,000	13,900
Total Cash	45,765	56,980
Residual Value of the System	10,000	0
Net Present Value	25,718	28,172

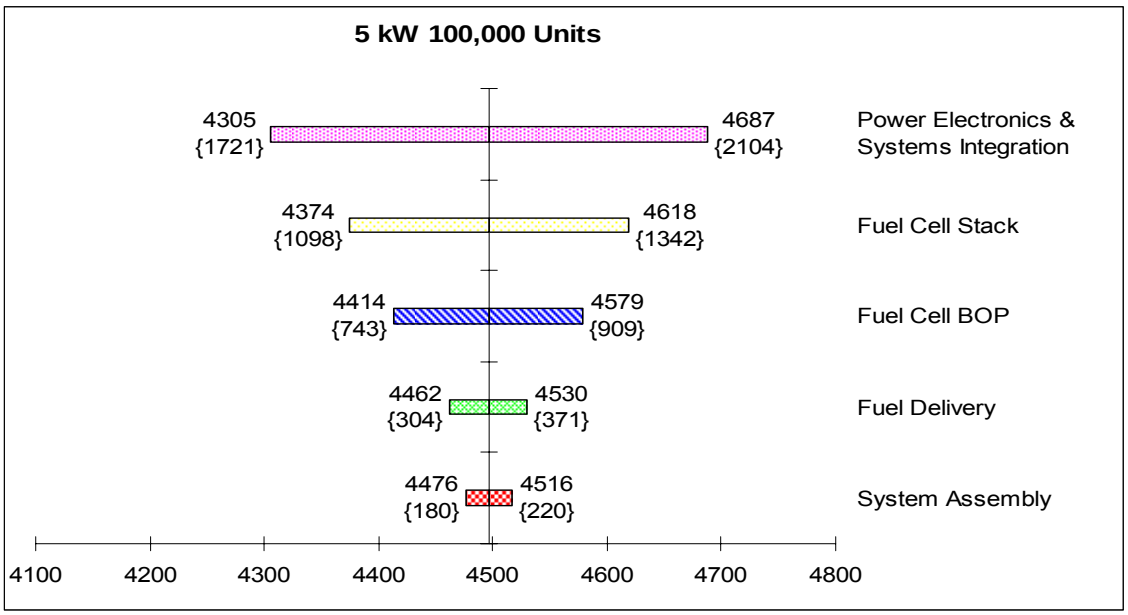
*Analysis assumes 15-year fuel cell life and 5-year battery life. Fuel cell is replaced at 15 years. Tax impacts are not included. At the end of 20 years, the fuel cell has 10 years of useful life remaining; new batteries are needed.

3.4.3 Engineering Cost Sensitivity Analysis: 5 kW Direct Hydrogen PEM Fuel Cell System

The sensitivity analysis of the engineering costs of the 5 kW direct hydrogen PEM fuel cell backup power system at 100,000 units analyzes which subsystem improvements have the most leverage on the cost of the system when volume-based cost reductions have been fully achieved.

The results of the sensitivity analysis at 100,000 unit annual production volume, shown in Figure 3-14, show a base cost of the fuel cell, from the engineering cost model, of $4,496. The subsystems with the highest cost, in order of importance, are (1) power electronics and system integration ($1,912), (2) fuel cell stack ($1,220), and (3) fuel cell balance of plant ($826). The fuel cell stack includes the MEA, bipolar plates, seals and gaskets, current collectors, and housing components. The fuel cell balance of plant includes the anode and cathode side hardware and stack cooling systems.

For the 5 kW system, the fuel cell subsystem (fuel cell stack and fuel cell balance of plant) provide the greatest cost leverage. Lowering the cost of the fuel cell stack subsystem from $1,220 to $1,098 and lowering the fuel cell balance of plant from $826 to $743 would lower the overall system cost from $4,496 to $4,291. A 10% reduction in power electronics and systems integration cost (from $1,912 to $1,721) would lower the overall system cost from $4,496 to $4,305.

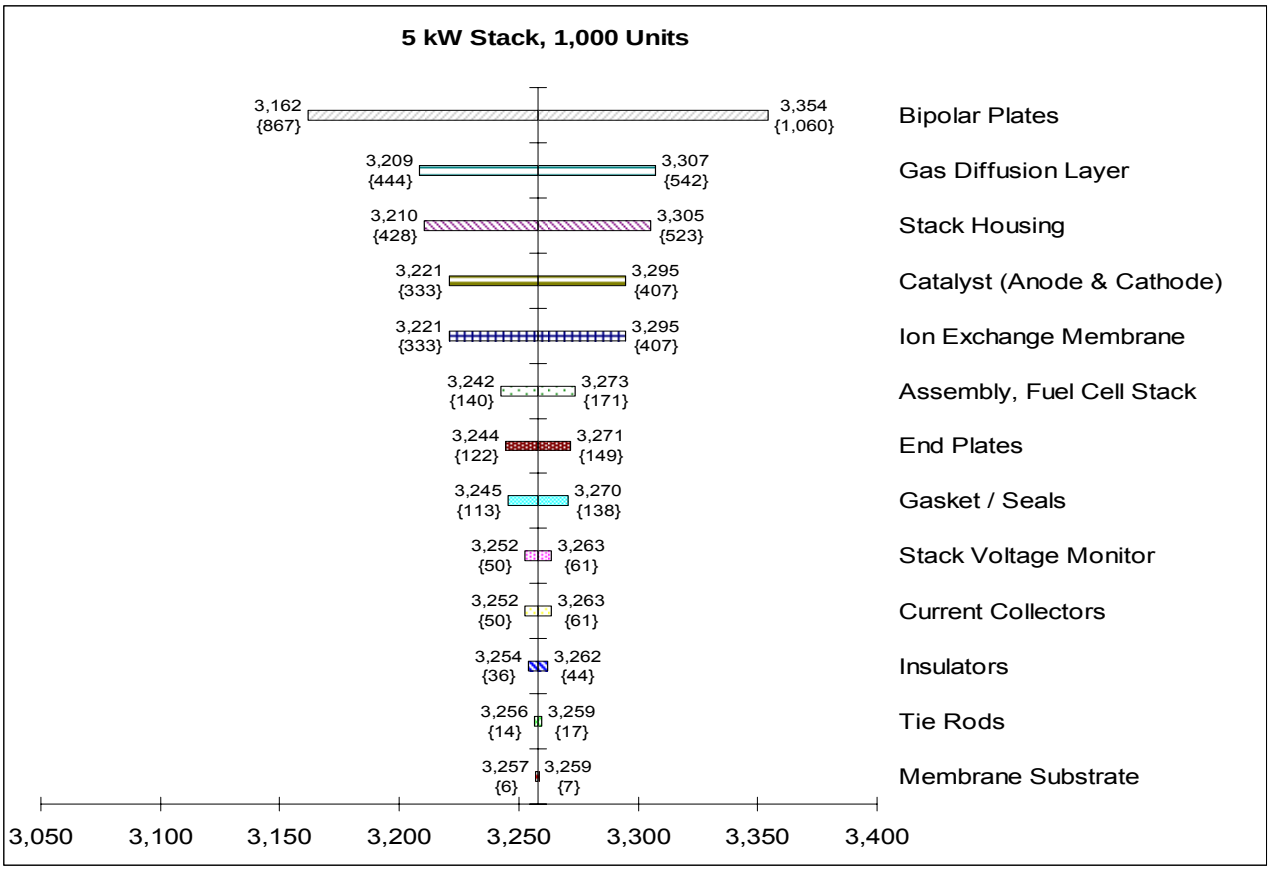


X-axis is the cost ($) of the fuel cell. Numbers in brackets are the costs ($) of the subsystems.

Figure 3-14. Sensitivity analysis of subsystem engineering costs, ±10%, on the cost of the 5 kW direct hydrogen PEM fuel cell system (100,000 units).

The component-level sensitivity analysis of the engineering costs for the 5 kW direct hydrogen PEM fuel cell system at 1,000 and 10,000 units analyzes which components contribute the most to the cost of the fuel cell stack and how sensitive the overall cost of the system is to stack costs. The sensitivity analysis of the 5 kW stack cost to a ±10% variance in cost for components at near-term annual production volumes (1,000 units) is shown in Figure 3.15. Each bar represents the change in cost of the stack, as a particular component's cost varies by ±10% while all other costs are held constant. This analysis uses the engineering cost data for the 5 kW direct hydrogen system, assuming an annual production rate of 1,000 units, as the base cost. The analysis shows that bipolar plates are the largest stack cost driver at annual production rates of 1,000 fuel cells. With a ±10% variance in cost of the bipolar plates ($867 and $1,060) the cost of

the stack would vary from $3,162 to $3,354, respectively (Figure 3-15). GDL and stack housing costs have a similar cost impact on the cost of the 5 kW direct hydrogen PEM fuel cell subsystem.

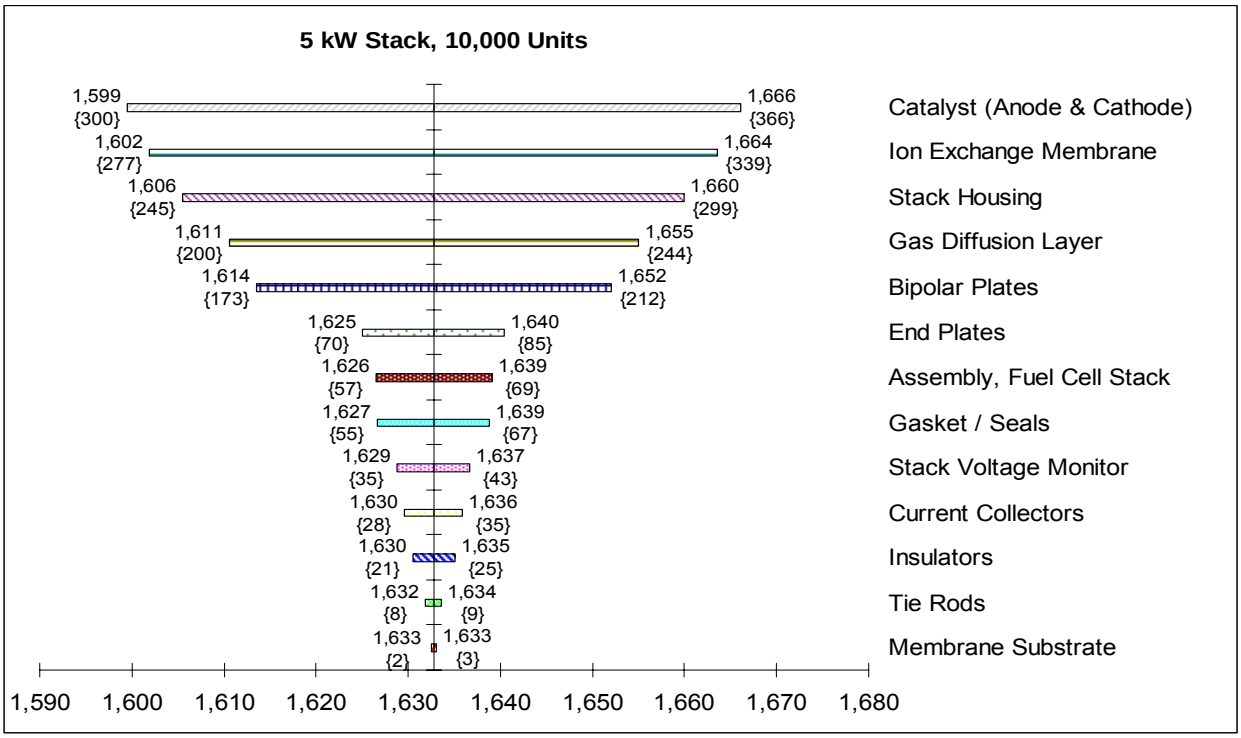


X-axis is cost ($) of fuel cell subsystem. Numbers in brackets are the costs ($) of the major subsystem components.

Figure 3-15. Sensitivity analysis of the cost of components, ± 10%, on the cost of the 5 kW direct hydrogen PEM fuel cell subsystem (1,000 units).

A similar sensitivity analysis of the stack cost to a ±10% variance in cost for the components in the 5 kW PEM fuel cell stack at an annual production rate of 10,000 units is shown in Figure 3-16. The analysis shows that catalyst is the largest stack cost driver at annual production rates of 10,000 fuel cells. With a ±10% variance in cost of the catalyst ($300 and $366), the cost of the stack would vary from $1,599 to $1,666, respectively (Figure 3-16).

At low production volumes (1,000 units), the cost of bipolar plates has the greatest impact on the stack costs. As production volumes increase to 10,000 units annually, high volume production methods lower the cost of the bipolar plates, resulting in the catalyst and the ion exchange membrane becoming the major cost drivers.



X-axis is cost ($) of fuel cell subsystem. Numbers in brackets are the costs ($) of the major subsystem components.

Figure 3-16. Sensitivity analysis of the cost of components, ± 10%, on the cost of the 5 kW direct hydrogen PEM fuel cell subsystem (10,000 units).

3.4.4 Lifecycle Cost: 50 kW Propane Reformer PEM Fuel Cell System

The total cash requirements and NPV of the cost of owning and operating a 50 kW propane reformer PEM fuel cell in continuous operation for 20 years are calculated. The average costs of electricity produced by a 50 kW propane reformer PEM fuel cell system at the 2005 selling price ($150,000) and performance are also determined. For this analysis, the stack was assumed to have a one-year life and was replaced annually at a cost of $40,000; the entire fuel cell was replaced after each five-year period. Tax implications are not included in this analysis. Assumptions for the system are shown in Table 3-6. NPV of the total cost of the 50 kW propane reformer PEM fuel cell system is $1,141,020 over the 20 year analysis period. The cost of electricity is 0.290$/kWh.

Table 3-15. Twenty-year lifecycle cost analysis of the 50 kW propane reformer PEM fuel cell system.

Descriptor	Twenty-Year Cost ($)
Fuel Cell	1,240,000
Installation	37,539
Propane Fuel	1,226,400
Tank Rental	8,200
O&M	28,800
Total Cash Outlays	**2,540,939**
Net Present Value	**1,141,020**
$/kWh	**0.290**

3.4.5 Lifecycle Cost Sensitivity Analysis: 50 kW Propane Reformer PEM Fuel Cell System

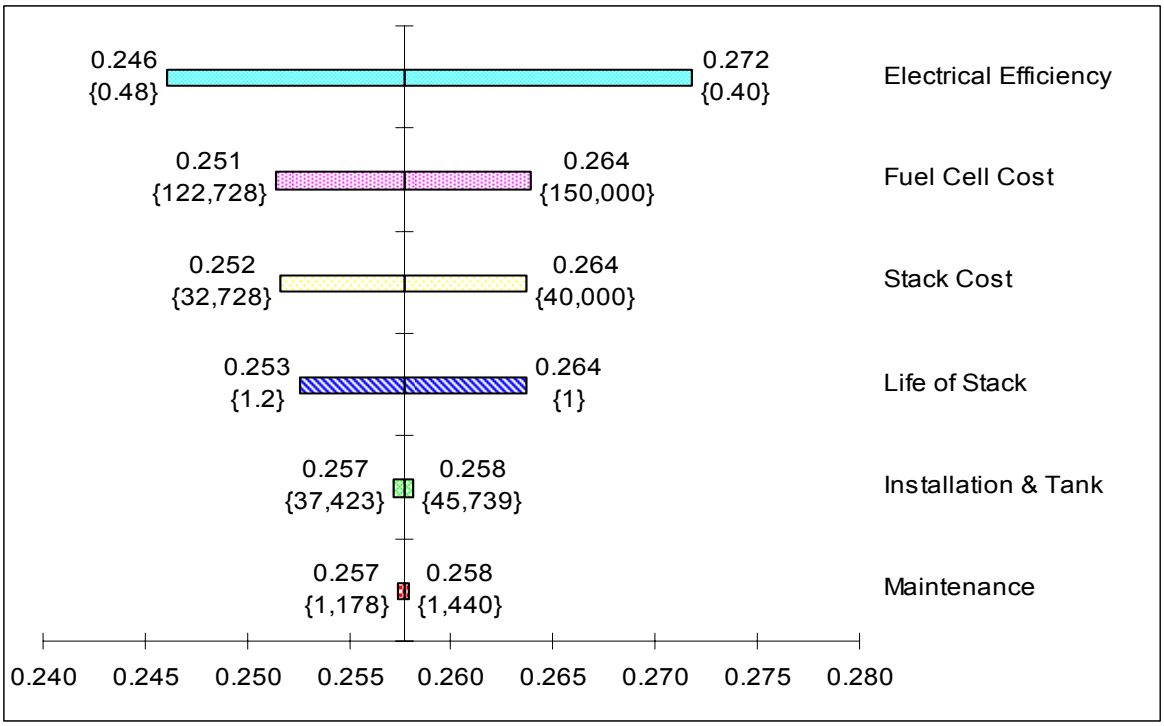
The sensitivity analysis of the lifecycle model measures the impact of a ±10% change in major cost drivers on the cost of electricity. This analysis uses a cash basis with no discount rate or tax implications included. Assumptions for the system are shown in Table 3-6. The analysis of the sensitivity of the cost of electricity produced by the 50 kW propane reformer PEM fuel cell system to key cost factors uses Equation 3 shown below:

$$\$ / kWh = \frac{\left(\frac{FC}{FCL} + \frac{SCx4}{SL} + \frac{HC \bullet 8760hrs \bullet 50kW \bullet 40\%}{E} + \frac{I}{20} + M \right)}{8{,}760hrs \bullet 50kW} \qquad \text{Equation 3}$$

Where:

$/kWh = lifecycle cost per kWh of electricity produced by the system
FC = cost of fuel cell ($)
FCL = fuel cell life (years)
SC = replacement stack cost, $
SL = stack life (years)
HC = hydrogen cost/kWh ($) at 40% electrical efficiency
E = electrical efficiency (%)
I = installation and tank, 20 year life, ($)
M = average annual maintenance cost ($)

The results of the analysis, shown in Figure 3-17, indicate that the cost of electricity, assuming a 10% improvement of all factors over the current status, is 0.258 per kWh. The top factor driving changes in lifecycle cost is electrical efficiency. Increasing efficiency from 0.44 to 0.48 reduces the cost of electricity to 0.246 per kWh. Three additional factors which have similar impacts on the cost of electricity are fuel cell cost, the stack cost, and the life of the stack. A 10% improvement in any of these factors lowers the cost of electricity by less than $0.001 per kWh.



X-axis is the cost of electricity ($/kWh). Numbers in brackets are the values of the cost drivers. Costs are cash flow basis with no discount applied and no tax implications included.

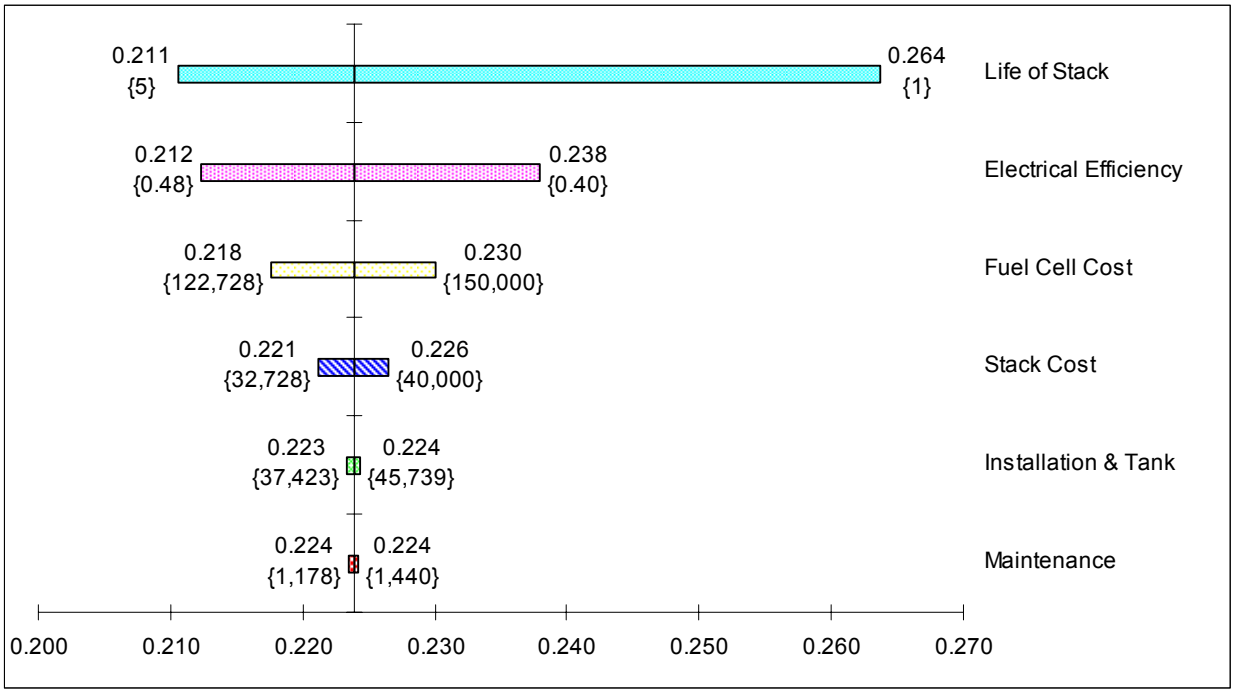
Figure 3-17. Sensitivity analysis of average annual lifecycle cost of 50 kW propane reformer PEM fuel cell system to major subsystem costs varied ± 10%.

A sensitivity analysis was also performed in which the life of the stack ranged from the current one-year life to a five-year life. In this run of the sensitivity analysis, all of the factors, except stack life, were adjusted by ±10% as in the previous analysis.

The most important factor necessary to meet market requirements of fuel cells for baseload electricity is durability of 40,000 hours (4.56 years). The PEM fuel cell at this level of durability should be cost competitive with the grid or other low cost sources of baseload electricity. Because a 40,000 hour durability of the fuel cell, including the stack, is generally considered to be a requirement for baseload applications, the sensitivity of fuel cell costs to substantially improved stack life is used in this analysis (rather than the 10% improvement used in the prior analysis). The life of the stack was set at 1 year (approximately current conditions), a 2.5 year (21,914 hours) stack life for the base conditions, and a 5 year (43,800 hour) stack life for the best conditions. The worst-case assumptions for the 50 kW propane reformer PEM fuel cell system are the current conditions shown in Table 3-6.

Figure 3-18 shows the results of this sensitivity analysis of the lifecycle cost of electricity produced by the 50 kW propane reformer PEM fuel cell. Improved stack life was shown to substantially reduce lifecycle cost of electricity produced by the fuel cells. As shown in Figure 3-18, an increase in stack life from 2.5 to 5 years and a 10% improvement in electrical efficiency have comparable impacts on the cost of electricity produced by the fuel cell ($0.211 and $0.212 per kW, respectively). Increasing the life of the stack (and fuel cell system) to about 5 years

(40,000 hours) is both a necessary condition to enter markets for baseload applications and is the most important factor for reducing lifecycle cost of electricity produced by the fuel cell. Achieving a fuel cell durability of 5 years simultaneously meets the market demand for longer fuel cell life and lowers the costs of electricity produced from $0.264 at a 1 year stack life to $0.211 per kWh at a 5 year life.



X-axis is the cost of electricity ($/kWh). Numbers in brackets are the values of the cost drivers. Costs are cash flow basis with no discount applied and no tax implications included.

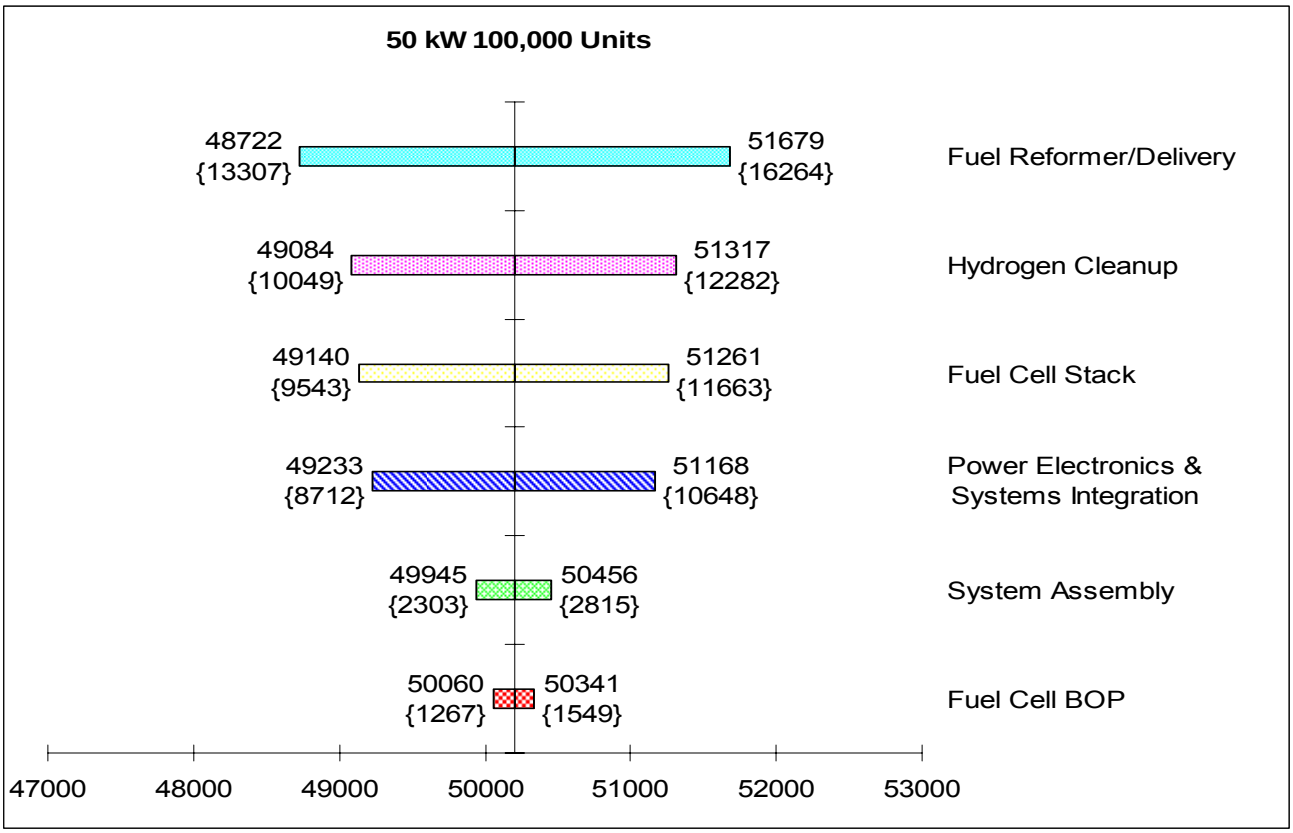
Figure 3-18. Sensitivity analysis of lifecycle cost of electricity to changes in key factors in the 50 kW propane reformer PEM fuel cell.

3.4.6 Engineering Cost Sensitivity Analysis: 50 kW Propane Reformer PEM Fuel Cell System

The sensitivity analysis of the engineering costs of the 50 kW propane reformer PEM fuel cell system at 100,000 units analyzes which subsystem improvements have the most leverage on the cost of the system when volume-based cost reductions have been fully achieved.

A sensitivity analysis (Figure 3-19) of major subsystems of the 50 kW propane reformer PEM fuel cell system, at 100,000 unit production volumes, indicate that the highest costs are in (1) the fuel reformer/delivery system, (2) the hydrogen cleanup, and (3) the fuel cell stack. The base cost for the system, from engineering estimates at 100,000 unit production levels, is $50,201. A 10% reduction in the fuel reformer/delivery cost (from $14,786 to $13,307) would lower the overall system cost from $50,201 to $48,722. Lowering the cost of the hydrogen cleanup subsystem from $11,166 to $10,049 would lower the overall system cost from $50,201 to $49,084. Lowering the cost of the fuel cell stack subsystem by 10% from $10,603 to $9,543 would lower the overall system cost from $50,201 to $49,140.

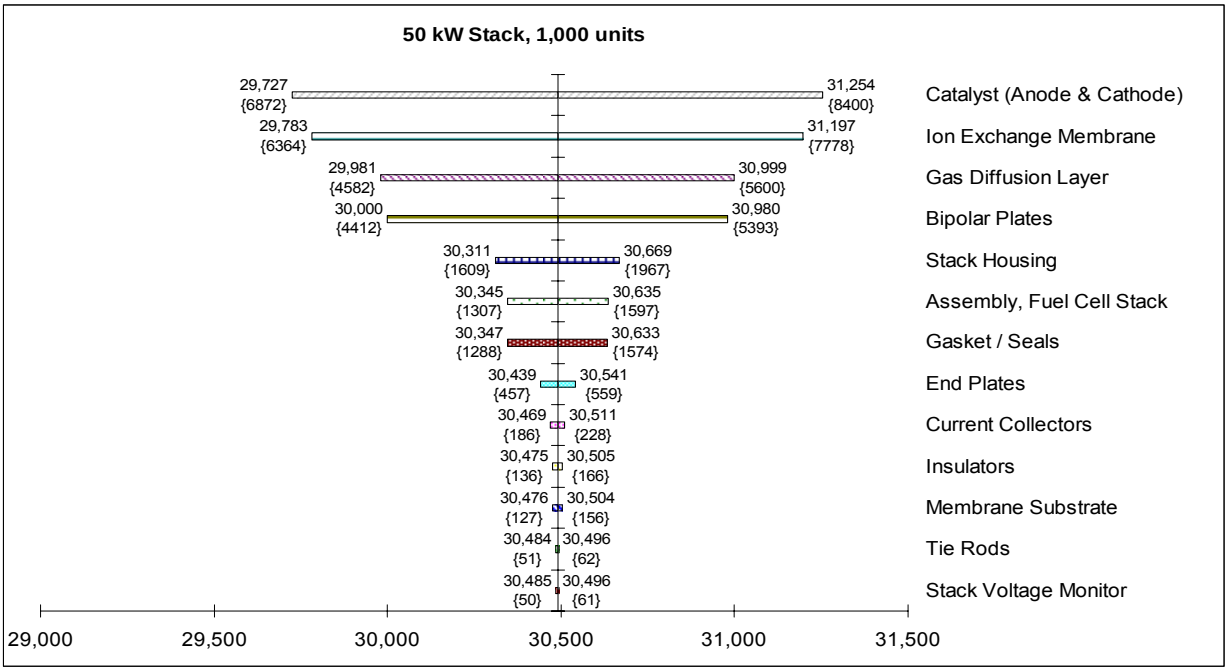
If alternative technologies to the costly palladium membrane separator are utilized, the cost of hydrogen cleanup is expected to drop substantially. In that scenario, however, the cost of the fuel cell stack is expected to increase to compensate for the lower quality reformate.



X-axis is the cost ($) of the fuel cell. Numbers in brackets are the costs ($) of the subsystems.

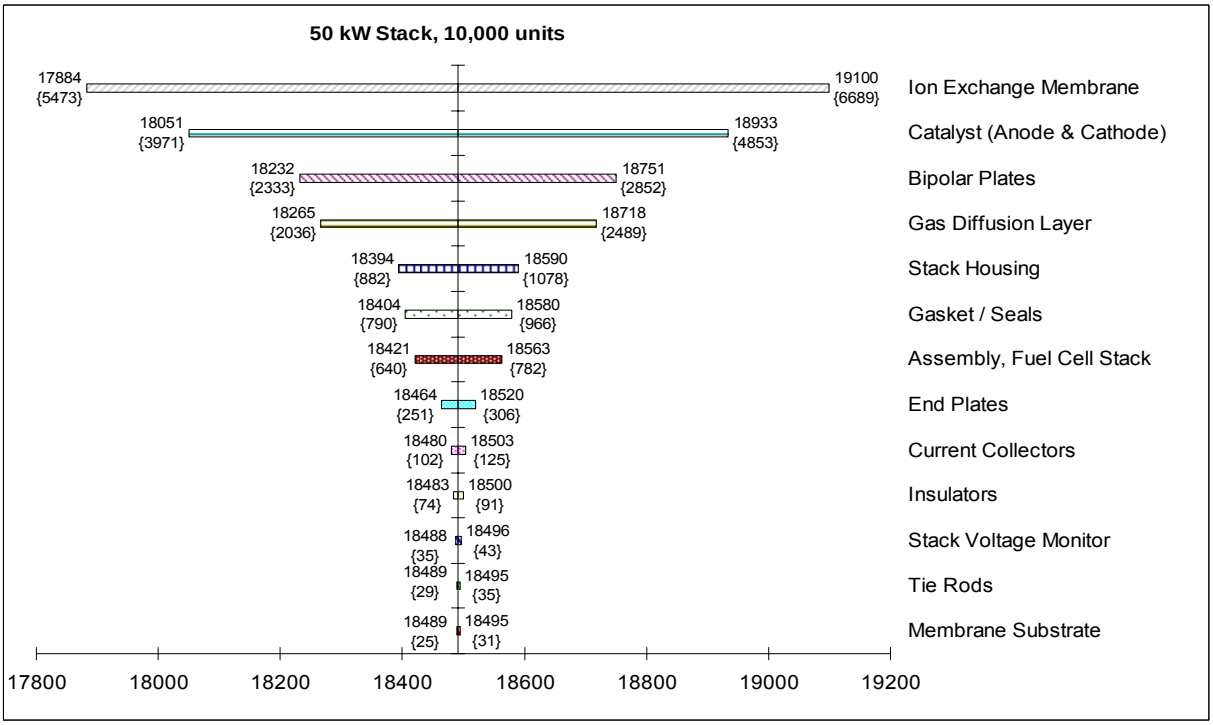
Figure 3-19. Sensitivity analysis of subsystem engineering costs, when varied ±10%, on the cost of the 50 kW propane reformer PEM fuel cell system (100,000 units).

The analysis for the 50 kW propane reformer PEM fuel cell system at 1,000 and 10,000 units examines which components contribute the most to the cost of the fuel cell stack and how sensitive the overall cost of the system is to stack costs. A sensitivity analysis of the 50 kW stack cost to a ±10% variance in cost for the components is shown in Figure 3-20. This analysis uses the engineering cost data for the 50 kW propane reformer PEM fuel cell system at an annual production rate of 1,000 units as the base cost. A similar sensitivity analysis of the stack cost to a ±10% variance in cost for the components assuming an annual production rate of 10,000 units is shown in Figure 3-21. At 1,000 unit annual production volumes, the costs of the catalyst, ion exchange membrane, and GDL are the major cost drivers in the 50 kW propane reformer PEM fuel cell system. At 10,000 unit annual production volumes, the costs of the ion exchange membrane, catalyst, and bipolar plates are, in that order, the major cost drivers in the 50 kW propane reformer PEM fuel cell system.



X-axis is cost ($) of fuel cell subsystem. Numbers in brackets are the costs ($) of the major subsystem components.

Figure 3-20. Sensitivity analysis of the cost of components, varied by ±10%, on the cost of the 50 kW propane reformer PEM fuel cell subsystem (1,000 units).



X-axis is cost ($) of fuel cell subsystem. Numbers in brackets are the costs ($) of the major subsystem components.

Figure 3-21. Sensitivity analysis of the cost of components, varied by ±10%, on the cost of the 50 kW propane reformer fuel cell subsystem (10,000 units).

3.4.7 Conclusions for Cost Analysis of 5 kW Direct Hydrogen PEM Fuel Cell System and 50 kW Propane Reformer PEM Fuel Cell System

The most important driver for lowering lifecycle costs of both the 5 kW backup power and 50 kW baseload PEM fuel cell system is increasing the life of the fuel cell, including the stack. For the 5 kW PEM fuel cell system, extending the life beyond 15 years is required; and for the 50 kW PEM fuel cell system extending the life to 5 years is necessary to drive the lifecycle costs down. Achievement of approximately a 5 year life (40,000 hours) for baseload applications is also necessary for market acceptance. For baseload applications, incremental improvements in electrical efficiency provide the greatest leverage for lowering electricity cost at the current (~1 year) stack life.

The hydrogen delivery system (reformer) is the major cost driver of the 50 kW propane reformer PEM fuel cell system. A lower cost method of delivering pure hydrogen could substantially lower the system cost.

The fuel cell stack is a major cost of both the 5 kW direct hydrogen and 50 kW propane reformer PEM fuel cell systems. Within the stack, some components unique to fuel cells, like membranes and bipolar plates, are relatively high in cost at the10,000 unit production volume. Catalyst costs are the major cost drivers for stack costs in both systems at high production volumes, as the market price of platinum does not decline with stationary fuel cell production volume.

Power electronics and system integration is the major cost driver for the backup power system manufactured in high volumes and is also an important driver for the 50 kW propane reformer PEM fuel cell system. The power electronics and system integration include standard rather than fuel cell specific components. Lowering the cost of this system is therefore likely to come from simplification and optimization of the system through engineering rather than volume driven cost reductions.

3.5 ANALYSIS OF POTENTIAL TECHNOLOGY IMPACTS ON THE COST OF PEM FUEL CELLS

In an attempt to determine the interrelated nature of technology advances, three potential technology breakthrough areas were identified during several expert panel discussions that were deemed of significant importance to the market penetration of stationary PEM fuel cells. Details of discussions from these expert panels can be found in Appendix G and Appendix H. Following expert panel discussions, three breakthrough areas were assessed, based upon available literature, interviews with vendors, and expert opinions, in a manner that identified both the direct subsystem cost impacts of the technology breakthroughs and the indirect impacts in other subsystems found in the 50 kW propane reformer PEM fuel cell system. The three technology breakthrough areas initially investigated in this effort are high-temperature membranes, high carbon monoxide (CO) tolerant catalysts, and non-platinum catalysts.

An analysis of the three technology breakthrough areas was performed to determine the best approach to reduce the costs and increase the market penetration of stationary PEM fuel cells. The analysis was a blend of quantitative and qualitative determinations on how a breakthrough in

one area of a PEM fuel cell system affects other areas and highlights the tradeoffs associated with advances in technology. This approach assumes several conditions, namely that the technology advances occur and that unforeseen failure modes do not occur.

3.5.1 High-Temperature Membranes

3.5.1.1 Current Approach

PEM fuel cells typically use a hydrated perfluorosulfonic acid polymer, such as Dupont's Nafion, that has a maximum operating temperature of approximately 80 °C.[68] Since this material requires near 100% relative humidity to operate at 80 °C, it requires CO concentrations in the fuel gas flow to be less than 10 ppm. There has been interest in developing membranes that can operate at a higher temperature. The higher temperature would allow for greater CO concentrations, and lower relative humidity requirements would allow for water management simplification.

3.5.1.2 Solution Description

High-temperature membranes capable of operating at temperatures up to 200 °C without humidification allow for the possibility of improvements in the system including size reduction and reduced overall fuel cell system complexity of the overall fuel cell system. Phosphoric acid doped polybenzimidazole (PBI) is a high-temperature membrane that allows for operation up to 200 °C at low relative humidity. This product was identified at Case Western Reserve University and is now being commercialized by PEMEAS GmbH.[69] Further work at universities and national laboratories continues to identify additional polymers that may eventually result in commercial membranes that are able to operate at high temperature and low relative humidity.[70, 71, 72, 73, 74]

3.5.1.3 Implementation Impacts

Since the baseline used in this study is a 50 kW propane reformer PEM fuel cell system designed to operate at approximately 80°C and 100% relative humidity, an increased temperature range and reduced humidification would have significant impacts on the system design, beyond that of just the fuel cell stack. To begin, a higher operating temperature allows the fuel cell to operate

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[68] See reference 56.
[69] Nair, B.R. 2004. High Temperature, Low Relative Humidity PEM Fuel Cell Membranes. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[70] Kerr, J., X.G. Sun, G. Liu, J. Xie and C. Reeder. 2004. New Polymeric Proton Conductors for High Temperature Applications. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[71] Gilbertson, R., Y.S. Kim, E.B. Orler, and B. Pivovar. 2004. DOE Hydrogen Fuel Cell and Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[72] See reference 62.
[73] Bellows, R. 2004. Development of High Temperature Membrane and Electrode Assembly for Proton Exchange Membrane Fuel Cell Device. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[74] Weiss, R. A., and M.T. Shaw. 2004. Polymer Blend Proton Exchange Membranes. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.

using hydrogen with higher concentrations of CO than the baseline system, which requires less than 10 ppm CO. Carbon monoxide concentrations as high as 50,000 ppm or 5% have been reported.[75, 76] At this concentration of CO, hydrogen cleanup becomes much simpler, and therefore much of the costs and size associated with the cleanup process can be removed from the system. Within the stack, water management problems are reduced or eliminated, thereby lowering fuel cell balance of plant costs. In addition to the apparent advantage of having a reduced hydrogen cleanup effort, the fact that operation of this system can occur near 200 °C substantially allows for heat cogeneration and reduces the complexity of the heat exchangers. Furthermore, the material cost of the high-temperature membrane is much less than the cost of Nafion, the most commonly used low-temperature membrane material. One interview with a manufacturer of high-temperature membranes expressed that costs could be nearly an order of magnitude less than the cost of Nafion.[77] Assuming that all of the questions about durability, catalyst dissolution, and manufacturability will be satisfactorily answered, several performance tradeoffs still exist when switching to high-temperature membranes. For example, the current density of the higher temperature membrane is less than Nafion. Therefore the physical size of the fuel cell stack will have to increase in proportion to the current density difference. The current density of high-temperature membranes has been reported to be roughly half that of Nafion,[78] which if accurate, would require a doubling in size of the fuel cell stack to achieve a similar power output. Figure 3-22 shows a table of the systems that would be affected by changing to a high-temperature membrane. This figure displays changes in cost, size and weight, and performance relative to the baseline system used in this study. Finally, Figure 3-23 shows the affected systems in a functional schematic of the 50 kW system.

[75] Meyers, J.P. 2004. Development of High-Temperature Membranes and Improved Cathode Catalysts. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24–27), Philadelphia, Pennsylvania.
[76] Ball, S. 2004. Investigation of PEMFC MEAS for Ultra-High CO Reformate. For DTI, F/02/00261/REP, URN 04/558.
[77] Personal communication between Jeffery Myers (Battelle) and Dr. Calundann (PEMEAS). April 2005.
[78] Wainright, J.S., M.H. Litt, and F. Savinell. 2003. *High-Temperature Membranes. Handbook of Fuel Cells, Fuel Cell Technology and Applications: Part 1, Vol. 3*. Eds. John Wiley & Sons, Ltd., Hoboken, New Jersey.

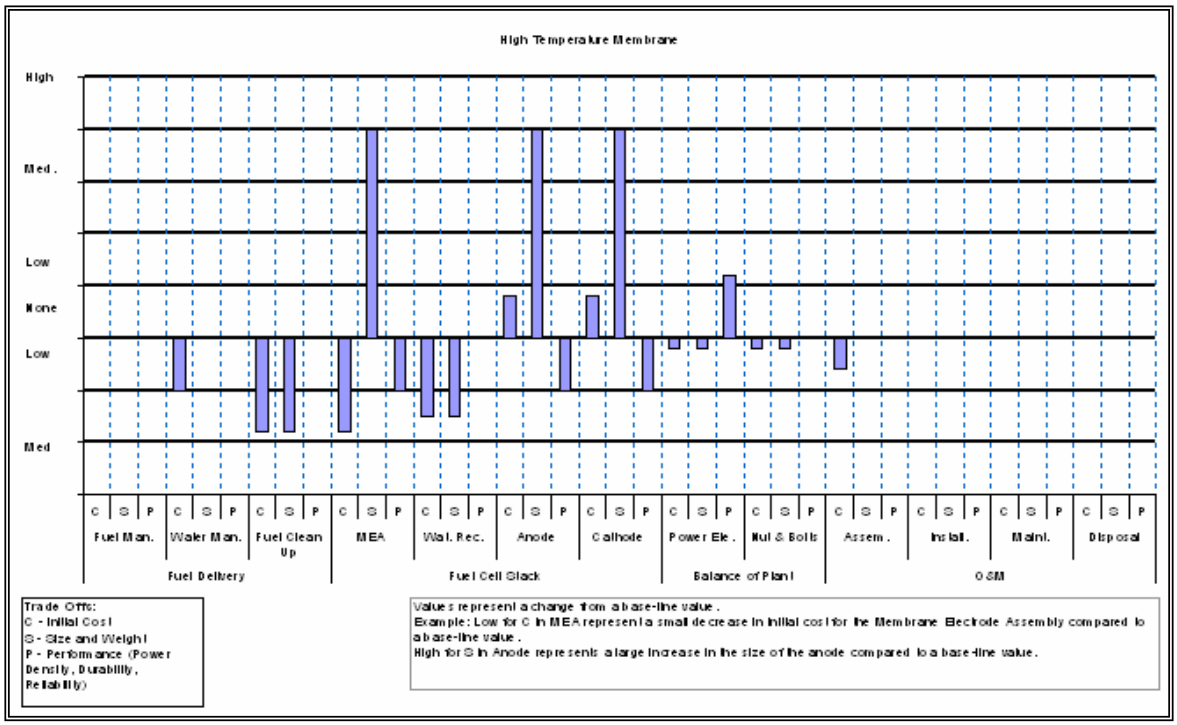

Figure 3-22. Interactions between the fuel cell components when a high-temperature membrane is introduced.

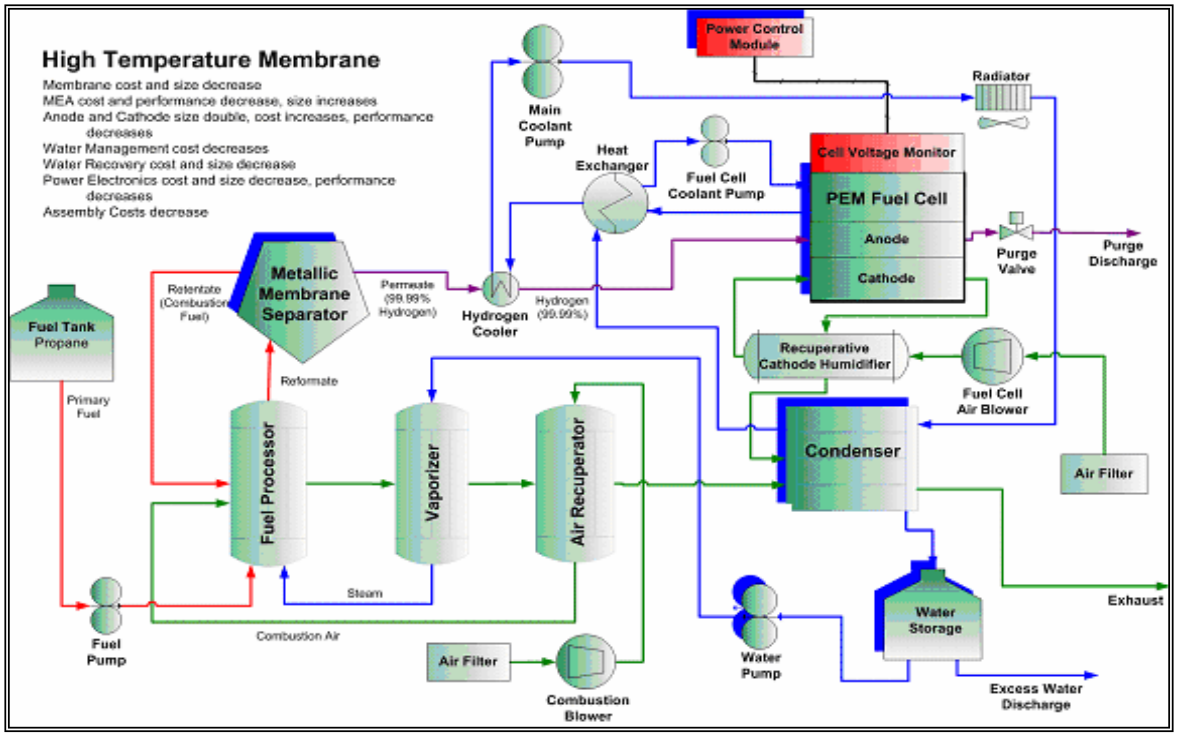

Figure 3-23. Schematic showing components (shadowed in blue) affected by the introduction of a high-temperature membrane.

3.5.2 Non-Ruthenium High Carbon Monoxide Tolerant Catalysts

3.5.2.1 Current Approach

Many fuel sources used in fuel cell systems result in hydrogen that contains concentrations of CO that cannot be tolerated by the fuel cell. One current approach to reducing, or eliminating, the degrading affect caused by CO adsorption onto the platinum catalyst has been to remove the CO that remains after reforming to well below 10 ppm (e.g., using a palladium membrane separator). Another approach has been to develop alloy catalysts such as ruthenium-platinum, that have been shown to tolerate up to 100 ppm CO at 80 °C,[79] and platinum-ruthenium (Pt/Ru) platinum-molybdenum catalysts that have been found to tolerate CO levels up to 2,000 ppm.[80] A standard method of increasing CO tolerance is to introduce air into the fuel gas stream. Because of the costs and natural scarcity of Pt/Ru, the size and costs of the components used to remove CO, and the increased size and costs associated with air-bleeding, research continues trying to solve the problem associated with CO in the fuel gas.

3.5.2.2 Solution Description

Developing a fuel cell stack that has high CO tolerance will simplify or eliminate the CO cleanup reactors. Development of catalysts with a high tolerance to CO is one approach to eliminate cleanup systems. Another approach "cleans" platinum catalysts, allowing the fuel cell to continue functioning in the presence of high CO concentrations. This approach uses voltage controls to oxidize CO to CO_2 on the anode. This system is a general approach that can be applied to any catalyst or membrane at low or high temperatures.

3.5.2.3 Implementation Impacts

Figure 3-24 shows a table of the systems that would be affected by changing to a high CO tolerance catalyst. This figure displays changes in cost, size and weight, and performance relative to the baseline system used in this study. Finally, Figure 3-25 shows the affected systems in a functional schematic of the 50 kW system propane reformer PEM fuel cell system.

[79] Si, Y., R. Jiang, J-C. Lin, H.R. Kunz, and J.M. Fenton. 2004. CO Tolerance of Carbon-Supported Platinum-Ruthenium Catalyst at Elevated Temperature and Atmospheric Pressure in a PEM Fuel Cell. Journal of the Electrochemical Society: 151 (11): A1820-A1824.
[80] See reference 56.

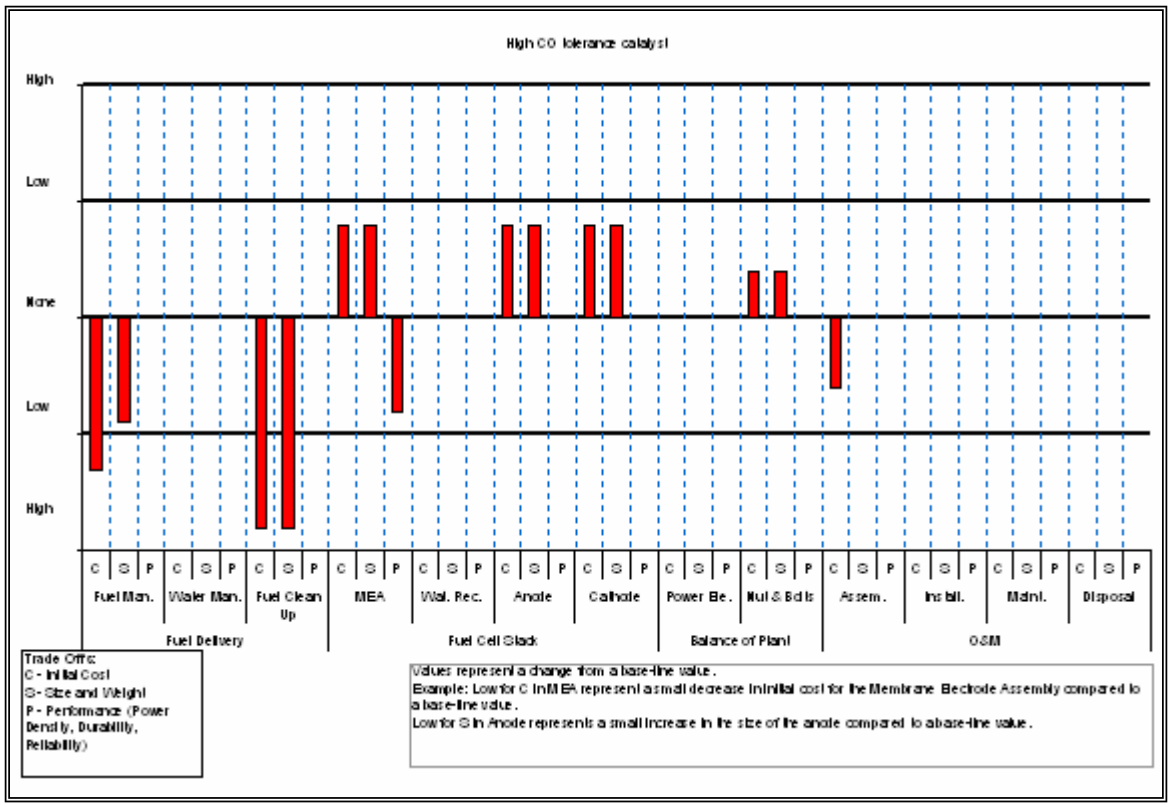

Figure 3-24. Interactions between the fuel cell components when a high CO tolerance catalyst is introduced.

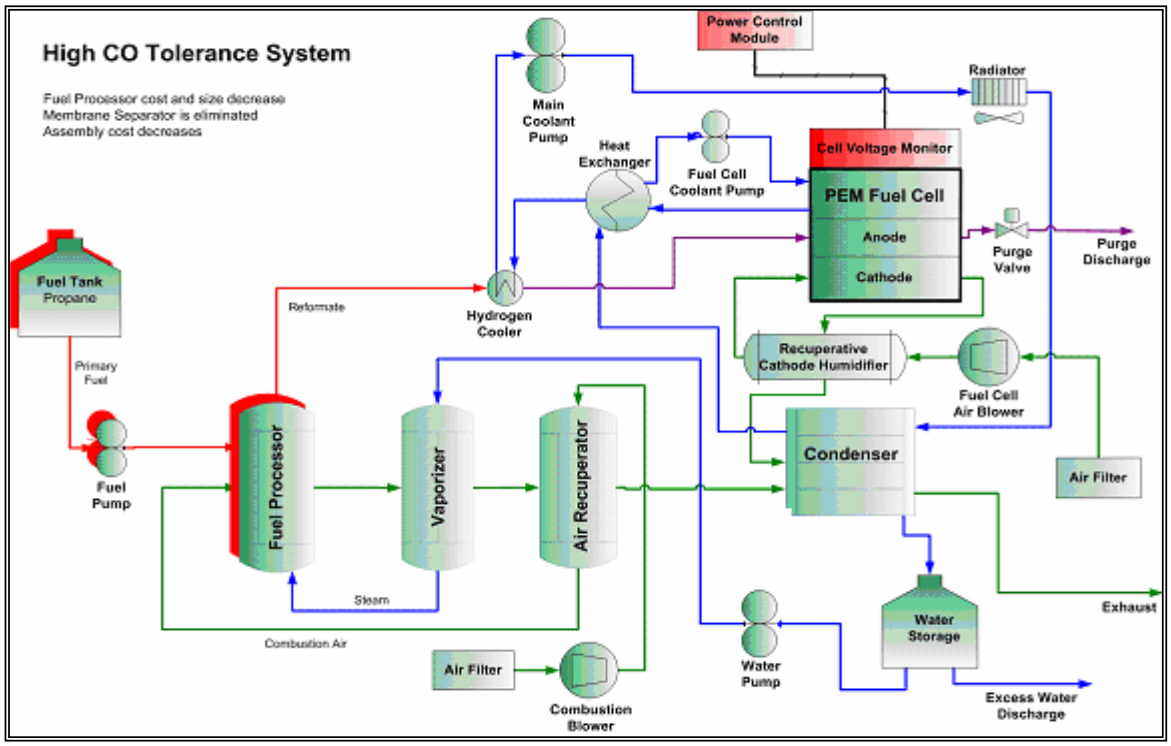

Figure 3-25. Schematic showing components (shadowed in red) affected by the introduction of a high CO tolerance catalyst.

3.5.3 Non-Platinum Catalysts

3.5.3.1 Current Approach

Platinum is the material typically used as a catalyst and is found in loadings on the order of 0.2 to 0.5 mg per cm.[81] Efforts to decrease the loading are driven by cost reduction goals, in order to meet the EERE target of reducing dependency on platinum to less than 0.2 g Pt per kW.[82]

3.5.3.2 Solution Description

Non-platinum catalysts are being developed to help achieve EERE's cost goals, while maintaining similar performance characteristics for durability and current density. The majority of this work continues to be conducted at universities or national laboratories.[83, 84, 85, 86] These research efforts focus on finding electrocatalysts with stability and electron carrying characteristics similar to platinum but at a reduced cost. Many of these studies are in the very early phases, and additional work will need to be conducted.

3.5.3.3 Implementation Impacts

Reducing dependence on platinum is targeted to reduce costs by 50% compared to a target of 0.2 g Pt/kW.[87] However, it is likely that switching to non-platinum catalysts will affect current density and MEA life. Figure 3-26 shows a table of the systems that could be affected by changing to a non-platinum catalyst. This figure displays changes in cost, size and weight, and performance relative to the baseline system used in this study. Finally, Figure 3-27 shows the affected systems in a functional schematic of the 50 kW propane reformer PEM fuel cell system.

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[81] Mathias, M., H. Gasteiger, R. Makharia, S. Kocha, T. Fuller, T. Xie, and J. Pisco. 2004. Can Available Membranes and Catalysts Meet Automotive Polymer Electrolyte Fuel Cell Requirements? American Chemical Society Meeting (August 2004), Philadelphia, Pennsylvania.
[82] See reference 74.
[83] Wang, X., D. Myers, D., and R. Kumar. 2004. Non-Precious Metal Electrocatalysts. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review (May 24-27), Philadelphia, Pennsylvania.
[84] Atanasoski, R.T. 2004. Novel Approach to Non-Precious Metal Catalysts. DOE Hydrogen Fuel Cells Infrastructure Technologies Program Review Meeting (May 24–27), Philadelphia, Pennsylvania.
[85] Wagner, F.T., H.A. Gasteiger, and S. Yan. 2003. What Performance Would Non-PT Cathode Catalysts Need to Achieve to be Practical for Transportation? Or: The Importance of A/cm^3, General Motors Fuel Cell Activities. DOE Workshop on Non-Platinum Electrocatalysts (March 21–22), New Orleans, Louisiana.
[86] See reference 56.
[87] See reference 75.

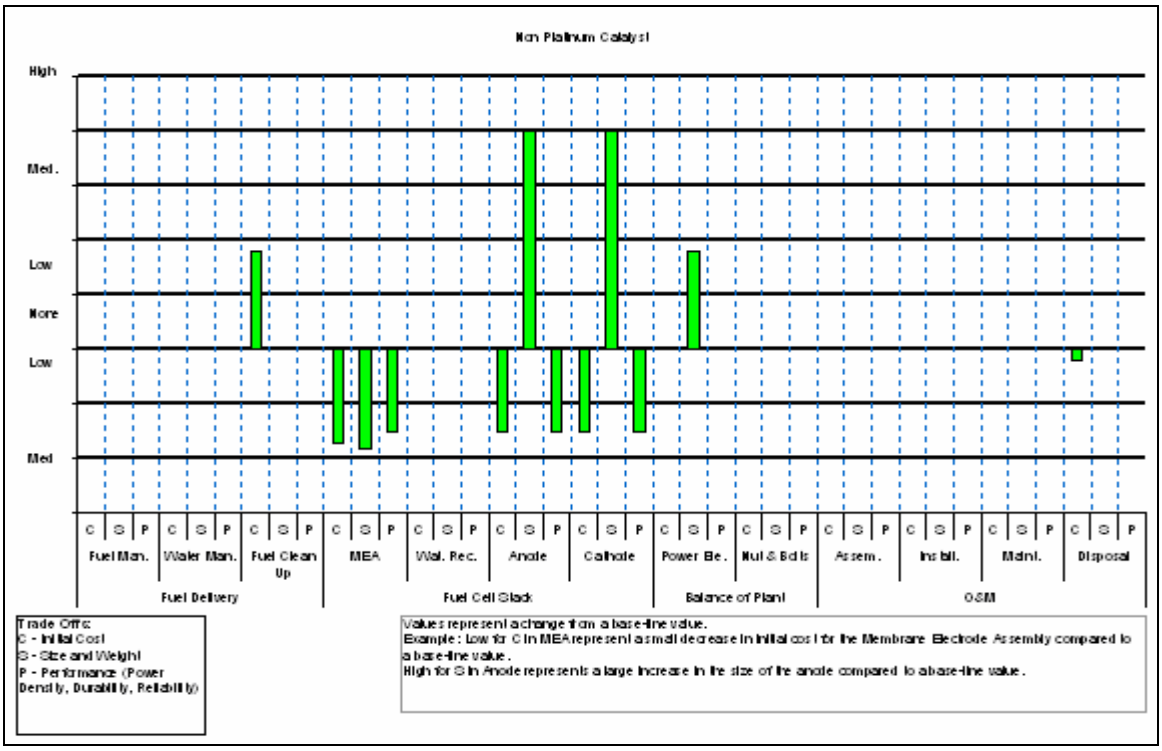


Figure 3-26. Interactions between the fuel cell components when a non-platinum catalyst is introduced.

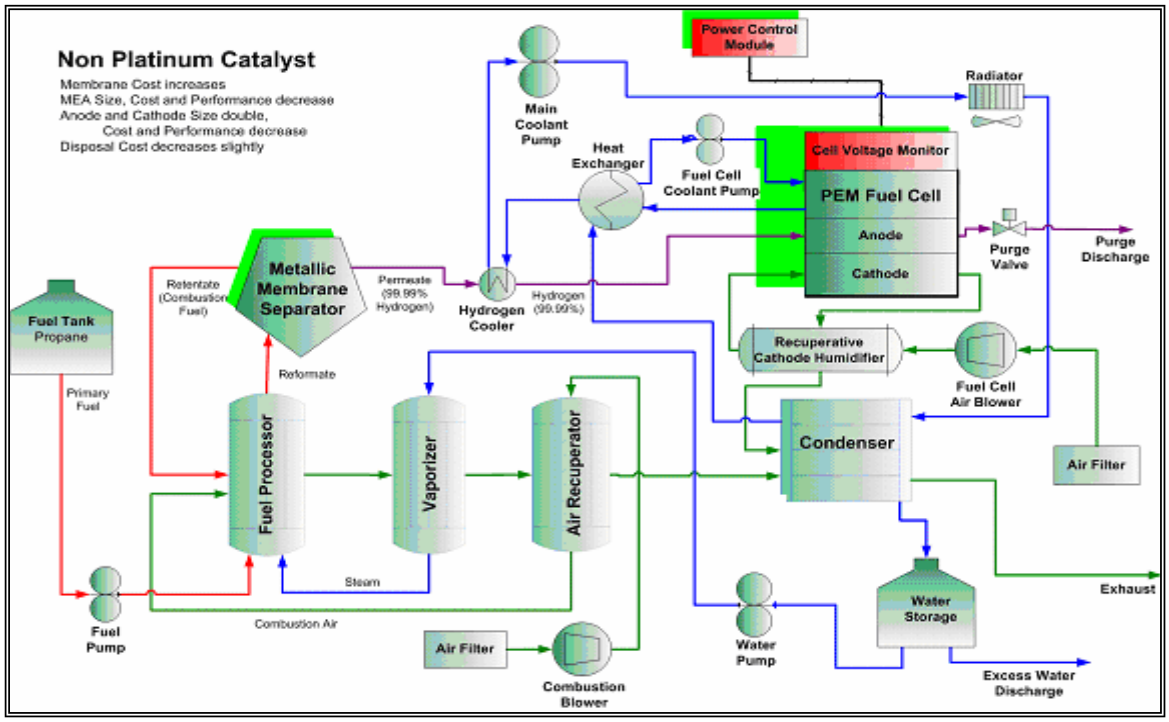


Figure 3-27. Schematic showing components (shadowed in green) affected by the introduction of a non-platinum catalyst.

3.5.4 Technology Impacts Analysis Conclusions

Switching to a high-temperature membrane has several advantages, such as increased CO tolerance, that could lead to a reduction in system complexity, cost, and size, as well as improved heat transfer characteristics that could allow for CHP. There are currently tradeoffs with power density that may counter some of these potential benefits. The major assumption is that durability is satisfactory. Breakthroughs will need to occur for this assumption to be realized.

The impact that the low current density of existing high-temperature membranes has on stack size may restrict its use where space is a limiting priority. Improving the power density of high-temperature membranes appears to be an important focus. In specific applications where size is not an issue, this feature may not be a driving factor.

In addition, it appears that fundamental work, such as morphological investigations and molecular modeling, is needed to determine the physical limits of the materials used for high-temperature membranes.

Non-ruthenium high CO tolerance catalysts are interesting because of the current problems associated with CO removal from the fuel gas flow and the cost and stability issues associated with ruthenium. Successfully realizing a high CO tolerant catalyst would allow significant reductions in the fuel cleanup system. Negative impacts would come from any reduction in current density requiring a corresponding increase in stack size for a fixed power output.

Non-platinum catalyst research is being conducted at universities and national laboratories. There continues to be a desire to reduce the costs of platinum in fuel cells, and while significant efforts are directed toward reducing platinum loading, fewer efforts are directed toward replacing platinum altogether. If this technology breakthrough were successfully accomplished, there would be interactions between replacing the catalyst and the size of the fuel cell stack, the costs of recycling the platinum from the system at the end of its life cycle, and the tolerance to CO in the fuel gas flow.

Finally, it should be considered that tradeoffs and their impacted subsystems should be referenced in context with a specific application. Since real-world 50 kW fuel cell systems are designed for a target market and application, the cost-benefit impacts of technology advances can only be discussed in detail as they apply to each specific system.

3.6 ANALYSIS OF IMPACTS OF TECHNOLOGICAL IMPROVEMENTS AT HIGH PRODUCTION VOLUMES ON ENGINEERING AND LIFECYCLE COSTS

Quantitative impacts of the R&D on subsystems were evaluated by adjusting factors in the engineering cost models to reflect technological breakthroughs. A first-order analysis has been completed and is shown here. This first-order analysis assumes that all other factors remain the same. As noted in Section 3.5, the introduction of technologies is expected to have tradeoffs that yield positive and negative system impacts. The full impact of the interactions arising from breakthroughs will be examined more fully on specific systems during the next year.

Shown here are three levels of analysis of potential breakthroughs. The first level examines the potential impact of technology breakthroughs combined with annual production volumes of 100,000 units on the cost of the stack. The second level examines the potential impact of technology breakthroughs combined with annual production volumes of 100,000 units on the fuel cell subsystems. The third level examines the potential impact of technology breakthroughs combined with annual production volumes of 100,000 units on the lifecycle cost of fuel cell systems.

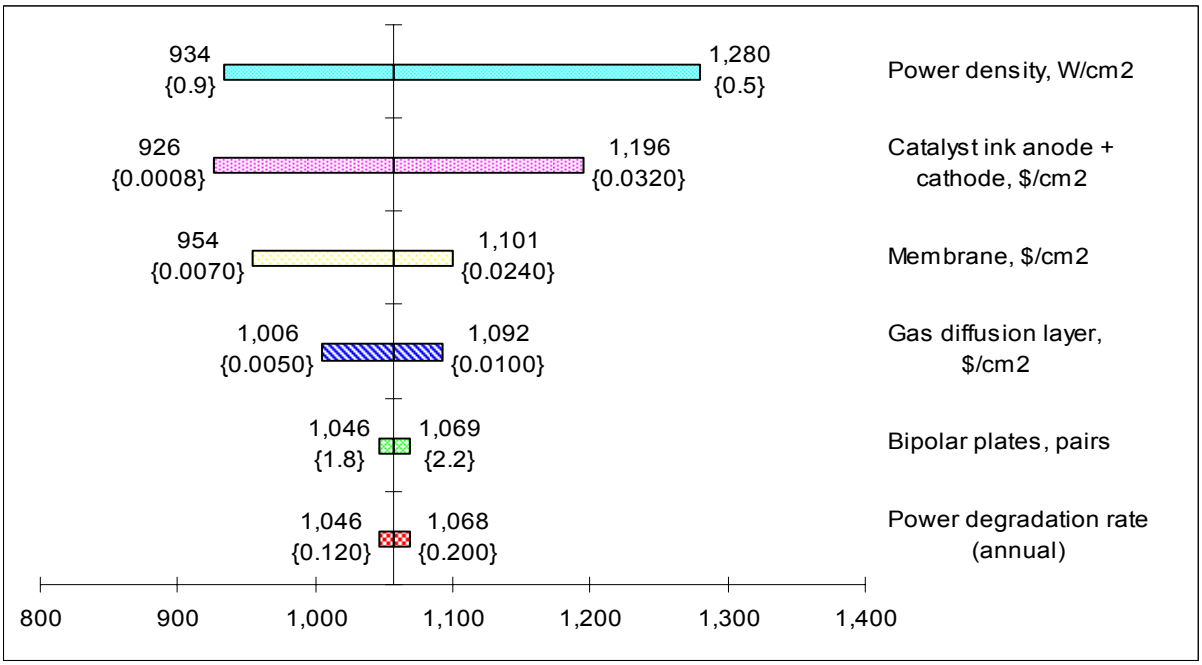
The value of the analysis is in identifying where technology breakthroughs can lead to cost reductions. In each of these analyses, potential impacts are presented without considering the cross impacts and tradeoffs. The subsystem and system costs should not be interpreted as predictions of, or even possible, costs that can be achieved through the identified technology breakthroughs.

3.6.1 Analysis of Fuel Cell Stack Cost Sensitivity to Technology Breakthroughs

The analysis of high volume production as detailed in section 3.4 showed the relative cost of the fuel cell stack and its components to the cost of the PEM fuel cell system. This analysis suggests that the stack contains many of the components unique to PEM fuel cells where technology breakthroughs could yield substantial cost reductions. For this analysis, the impact of technology breakthroughs in stack components on the cost of the stack was analyzed using a sensitivity analysis tool. Potential impacts on the cost of the PEM fuel cell stack of moderate R&D breakthroughs were used as the base case. Technological breakthroughs in current research that, if successful, may have the highest cost impact on the fuel cell stack were used as the best case conditions.

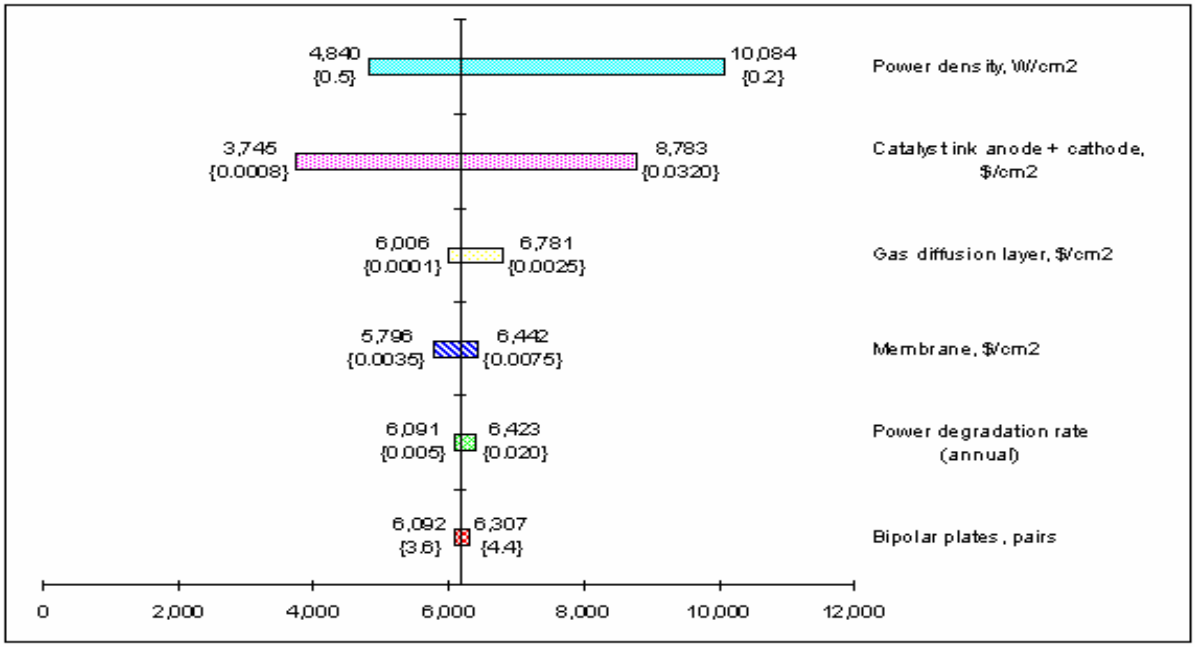
As shown in Figures 3-28 and 3-29, for fuel cell stacks of both the 5 kW direct hydrogen PEM fuel cell backup power system (optimized for cost) and 50 kW propane reformer PEM fuel cell baseload system (optimized for durability), the highest cost impacts are leveraged through technological breakthroughs in catalyst ink and power density. The current cost of catalyst inks is dominated by the cost of precious metals used as catalysts. The low cost for catalyst ink ($0.0008 per cm^2) in this analysis assumes breakthroughs in non-precious metal catalysis. The impact of non-precious metal catalyst inks will depend in part on power density tradeoffs.

As power density is increased, a variety of costs are reduced: the surface area of MEA decreases, the number of bipolar plates is reduced (for a given cell dimension), the amount of sealing and gasketing is reduced, the size of the packaging is reduced, and cathode and anode hardware is reduced. Progress in raising power density is being demonstrated by a number of research efforts. The value of the progress will depend, among other things, on the interaction with cost, manufacturability, and durability.



X-axis is cost ($) of the fuel cell stack. Numbers in brackets are the values of the major cost drivers assuming low or high levels of technological progress.

Figure 3-28. Sensitivity analysis of breakthrough technology impacts on stack costs in the 5 kW direct hydrogen PEM fuel cell system (100,000 units).



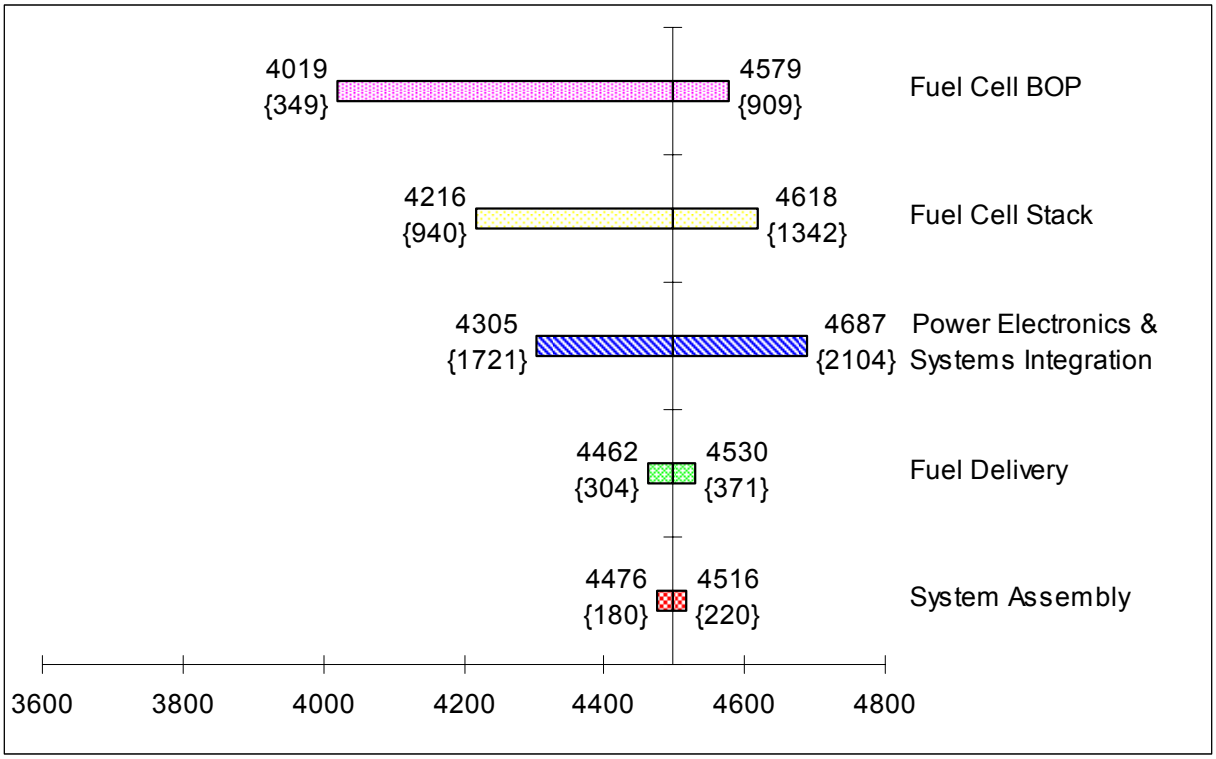
X-axis is cost ($) of the fuel cell stack. Numbers in brackets are the values of the major cost drivers assuming low or high levels of technological progress.

Figure 3-29. Sensitivity analysis of breakthrough technology impacts on stack costs in the 50 kW propane reformer PEM fuel cell system (100,000 units).

Reduced membrane costs are also a high leverage factor for both types of fuel cells. The low cost membrane in the analysis is assumed to be a PBI membrane that can operate at high temperatures. There are numerous interactions caused by the use of PBI membrane that may impact both other stack costs as well as other system costs beyond the stack. Power density may be lower, which may increase costs. However, MEA system durability may be higher than the baseline. Higher temperature may allow cheaper, less pure hydrogen reformate to be used and may reduce water management costs. These interactions will be discussed below in the examination of potential impacts of technological progress on engineering costs.

3.6.2 Analysis of Fuel Cell Subsystem Cost Sensitivity to Technology Breakthroughs

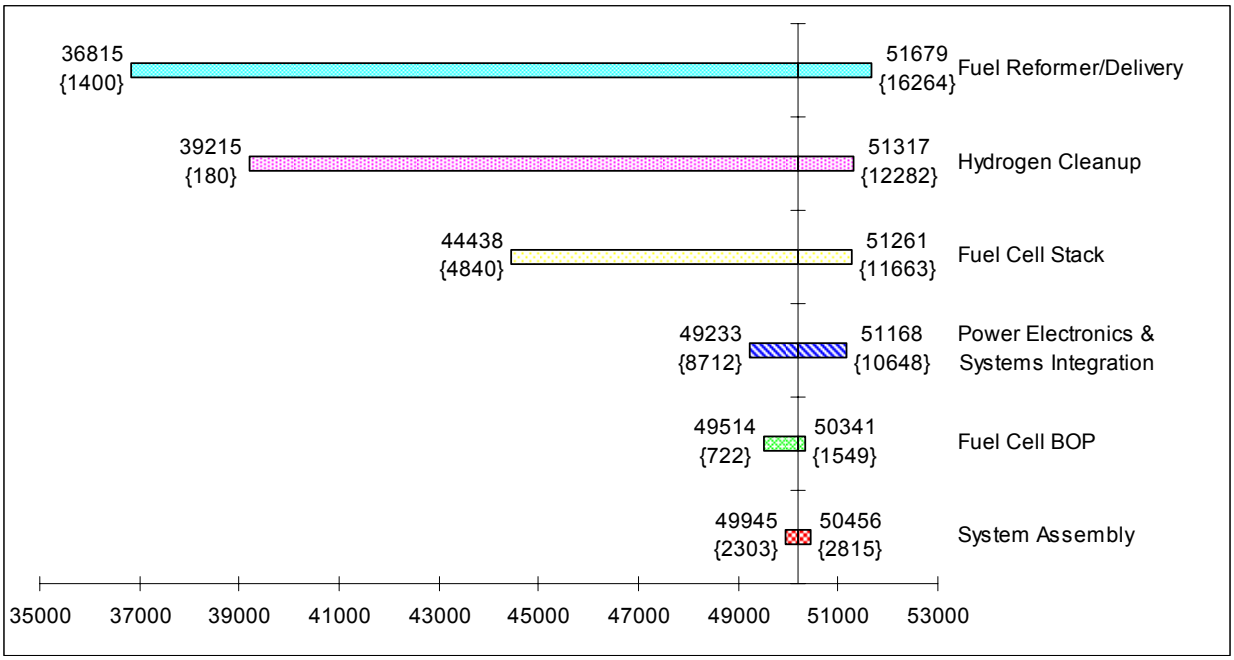
Results from the second level of analysis, the impact of technology on the engineering cost of the system, are presented in this section. The potential impacts of one or more major technology breakthroughs within a subsystem were combined with annual production volumes of 100,000 units to evaluate the impact of technology-driven fuel cell subsystem cost reductions on overall system costs (Figure 3-30). Some in-stack tradeoffs were assumed in selecting the best case figures, so, for example, the fuel cell stack value in the system analysis is not quite as low as the best case values in Figures 3-28 and 3-29.



X-axis is the cost ($) of the fuel cell system. Numbers in brackets are the costs ($) of the major subsystems, assuming low or high levels of technological progress.

Figure 3-30. Sensitivity analysis of breakthrough technology impacts on subsystem costs: 5 kW direct hydrogen PEM fuel cell system (100,000 units).

Figure 3-31 shows the impacts of breakthrough technologies on subsystem costs for the 50 kW propane reformer PEM fuel cell system. Lower reformer costs, lower hydrogen cleanup costs, and lower fuel cell stack costs provide the highest opportunities for system cost reductions. Use of high-temperature membranes is a technology with potential for broad cost leverage across all three of these areas. In addition to the lower cost of the membrane itself, the high temperature also prevents carbon monoxide poisoning of the anode catalysts, thereby eliminating most of the costs of the hydrogen cleanup system. The fuel cell stack costs could also be reduced through a combination of higher power density, elimination of precious metals, breakthrough cost reductions in GDL's, and breakthroughs in fuel cell subsystem manufacturing. Substantial reductions in reformer costs have the highest impact on system costs for this model.



Axis is the cost ($) of the fuel cell system. Numbers in brackets are the costs ($) of the major subsystems, assuming low or high levels of technological progress.

Figure 3-31. Sensitivity analysis of breakthrough technology impacts on subsystem costs: 50 kW propane reformer PEM fuel cell system (100,000 units).

3.6.3 Combined Conclusions from Lifecycle and Technology Impact Analysis

The most important driver for lowering lifecycle costs of both the backup power and baseload PEM fuel cells is increasing durability. For baseload systems, increased durability is also a necessary condition to be able to enter most markets. The fuel cell cost is the second most powerful lifecycle cost driver for both systems. The fuel cell stack is a major cost of both the 5 kW and 50 kW PEM fuel cell systems. Power density and catalyst costs are the major cost drivers for stack costs in both systems. Tradeoffs between these two cost drivers must be evaluated for particular design objectives to determine which approach, catalyst cost reduction or power density improvement, is likely to have the greater value. Due to the complex tradeoffs between technologies selected and design decisions, a significant opportunity exists to better integrate and optimize the fuel cell system as a whole.

Fuel cell efficiency is important for reducing the lifecycle costs of the 50 kW propane reformer PEM fuel cell system by lowering the amount of fuel required. Because the 50 kW PEM fuel cell system uses a steam reformer and palladium membrane separator, the engineering cost of the 50 kW propane reformer PEM fuel cell system can most significantly be impacted by cost reductions in the reformer, hydrogen cleanup, and fuel cell stacks. An inexpensive reformer that can provide high-purity hydrogen to the fuel cell, or a fuel cell that can operate on dirty reformate, present two alternative approaches for substantially lowering the cost of a 50 kW system propane reformer PEM fuel cell.

The lifecycle cost analysis indicated that the NPV of PEM fuel cells for backup power applications is competitive with that of batteries supplemented by diesel generators.

4 OVERALL CONCLUSIONS

This report includes a market assessment of the potential early adopters of stationary PEM fuel cells, the development of economic models to predict the cost breakdown of a fuel cell system and the associated lifecycle costs for two specific applications, and the development of a methodology for assessing the relative impact of technology innovations and breakthroughs on reducing the costs of PEM fuel cell systems. The economic and technology assessment models have been used to examine the attractiveness of a 5 kW direct hydrogen PEM fuel cell system used for backup power applications, and of a 50 kW propane reformer PEM fuel cell system used for grid independent applications.

4.1 SIGNIFICANT FINDINGS FROM MARKET ANALYSIS

In the near-term, it will be critical for PEM fuel cells to find their way into early adopter markets in order to demonstrate performance and build consumer confidence in the technology. Most early adopter applications of PEM fuel cells will be for backup power. Backup power users in early adopter market segments will place greater emphasis on reliability than on other factors, including capital cost, operating efficiency, and total lifetime of the PEM fuel cell. The current system size of PEM fuel cells (less than 250 kW) is compatible with backup power systems, but early adopters will also include some organizations interested in peak-load shaving to reduce electricity costs. Three potentially attractive target market segments for backup power (and possibly grid parallel) applications include the telecommunications and financial services sectors, and to a lesser extent the hotel sector.

PEM fuel cells in the 1 kW to 250 kW range have the potential to penetrate these market niches if they are able to meet the baseline user requirements. For early adopter market segments, PEM fuel cells must address the factors that matter most to users in those market segments. For the telecommunications sector, those factors are reliability, capital and installation costs, and ease of use. For the financial services sector, those factors are reliability, capital and installation costs, safety/perceived risk, and durability. For the hotel sector, those factors include capital and installation costs, efficiency, and to a lesser extent, reliability.

However, in order for PEM fuel cells to move beyond early adopter markets and achieve higher levels of market penetration, they must address a broader set of factors thought to be driving their commercialization. Among the most important of these are:

- High reliability relative to alternatives,
- Competitive capital cost,
- Competitive lifecycle costs of system or low cost of generated electricity,
- Adequate durability and lifetime relative to alternatives,
- Availability of incentives to reduce perceived risks,
- Demonstration projects to boost consumer confidence, and
- Availability of fuel and supporting infrastructure.

4.2 SIGNIFICANT FINDINGS FROM ECONOMIC ANALYSIS

The most important parameter for lowering lifecycle costs of the baseload PEM fuel cell system is increasing durability. For baseload systems, increased durability is also a necessary condition to be able to enter most markets. Even for the backup power market, where reliability is the key requirement, the most important parameter for lowering the lifecycle cost is to increase the service life of the PEM fuel cell.

The fuel cell capital cost is the second most important parameter for lowering the lifecycle cost for both the 5 kW and 50 kW PEM fuel cell systems. Power density and catalyst costs are the major cost drivers for stack costs in both systems. The power density has a multiplier impact because it affects how much active membrane area is needed in the fuel cell. The catalyst cost is determined by how much platinum is needed in the fuel cell or the cost of non-precious metal alternatives. Tradeoffs between these two cost drivers must be evaluated for particular design objectives to determine which approach, catalyst cost reduction, power density improvement, or some combination of the two, is likely to have the greatest value.

Fuel cell efficiency is important for reducing the lifecycle costs of the 50 kW baseload system by lowering the amount of fuel required. For backup systems, with limited operating time, efficiency has little or no importance.

In this study, a palladium separator fuel reformer system was selected in order to provide high-purity hydrogen to the fuel cell. Use of pure hydrogen rather than dirty reformate reduces problems and cost in the MEA. However, the cost of electricity produced by the system, even in high volumes and assuming substantial technology breakthroughs, is high. An alternative approach is to use an inexpensive reformer that yields dirty reformate to a 50 kW PEM fuel cell system that can tolerate CO and other impurities.

Systems design engineering is also likely to substantially reduce the cost of the PEM fuel cell systems through simplification, integration and optimization. Because of the complex tradeoffs among technologies selected and design objectives, it is likely that manufacturers of fuel cells will optimize systems independently as a competitive strategy to meet customer requirements. In many cases specific solutions may not be technically transferable to alternate designs or may be proprietary. An important exception is a complete reconceptualization of stack materials and manufacturing methods that could have value across all types of fuel cell applications.

For the 5 kW backup power PEM fuel cell system, the NPV of the fuel cell is superior to batteries supplemented by diesel generators. The major barrier to adoption is the lack of convincing data from field applications showing that PEM fuel cells can achieve 99.999% reliability. The perceived risk of purchasing PEM fuel cells for applications where reliability is of strategic importance to the company remains a barrier. To overcome this barrier, a history of high reliability in field units is required. As confidence in reliability is achieved, effective penetration of backup power markets is likely.

EERE's encouragement of R&D is needed to move critical technologies forward. Addressing the challenges necessary for PEM fuel cells to penetrate stationary markets more quickly is of vital importance to maintaining interest in further R&D by the private sector. It is likely that

many breakthroughs that are important for stationary applications will enable developments required for future automotive applications of fuel cells.

APPENDIX A:

SURVEY FORM ON MARKET REQUIREMENTS

SURVEY FORM ON MARKET REQUIREMENTS

Scope of the Assessment:

Battelle is currently conducting a project for U.S. Department of Energy (DOE) to analyze the economic, technology, and market drivers required to support the commercialization of fuel cells. The project is focused specifically on Proton Exchange Membrane (PEM) fuel cells for stationary applications.

As part of this project, Battelle is surveying companies in a several potential "early adopter" market segments, including telecommunications, financial services, and hotels. This survey is designed to help the DOE better understand how current energy requirements are being met and what the critical minimum performance requirements are for companies in each of these market segments. In essence, how would a PEM fuel cell have to perform for companies in your market area to adopt this technology? The Department of Energy will use the information collected through this project to help direct their research and technology development efforts and funding decisions.

Who Must Complete this Survey?
This Questionnaire is designed to obtain energy usage requirements, energy or facilities managers should complete the information requested in this survey.

Please Return Completed Forms to:
XXXXX

Thank you for your response.

1. COMPANY INFORMATION					
Name of Organization:					
Address:					
City:		State:		Zip:	
Name of Contact:					
Job Title:		Phone:		Fax:	
E-mail:		Website:			
Primary Business of Your Organization					
Company Size (by employees):	☐ Small (< 500)		☐ Medium (500-3000)		☐ Large (> 3000)

2. GENERAL QUESTIONS
Does your company take proactive actions to use manage its energy use in an efficient way? (e.g. monitor energy savings, adopt energy efficient technologies/equipment) ☐ Yes ☐ No
How disruptive is a power outage to your business operations (in terms if financial impact)? ☐ High ☐ Medium ☐ Low
How many outages does a typical facility experience in a year? per year
Can you identify the typical cause of a power outage?
How long do these outages typically last? ☐ < 5 seconds ☐ < 1 minute ☐ 1-5 minutes ☐ 5-25 minutes ☐ 25-60 minutes ☐ Other _____minutes

3. HOW ARE YOUR STATIONARY ENERGY REQUIREMENTS CURRENTLY BEING MET? (*Please check the appropriate boxes where applicable*):		
☐ Grid Electricity ☐ On-site Generation ☐ Backup power		
How much electricity does your organization consume?	kW per day	kW per year
How much do you typically pay of your electricity? ☐ > 25 cents kWh ☐ 16-25 cents kWh ☐ 10-15 cents kWh ☐ < 10 cents kWh		
Has the price of electricity changed in the past year?	☐ Yes	☐ No
If yes, by how much? ☐ > 5% ☐ > 15% ☐ > 30%		

3 A. IS THERE ANY ADDITIONAL ON-SITE GENERATION OF ELECTRICITY? ☐ **YES** ☐ **NO** ***(If no, skip to question 3B)***	
Is there any additional on-site generation of electricity for **prime power** needs? ☐ Yes ☐ No	Is there any additional on-site generation of electricity for **combined heat and power** needs ☐ Yes ☐ No
How is this electricity generated? ☐ Generators ☐ Renewables ☐ Gas Turbines	How is this heat and power generated? ☐ Generators ☐ Microturbines ☐ Combustion turbines
What is this electricity generated typically used for?	What is this electricity generated typically used for?
Can you estimate the amount of electricity produced on-site? _____ kW per day _____ kW per year	Can you estimate the amount of electricity produced on-site? _____ kW per day _____ kW per year Can you estimate the amount of heat produced on-site? _____ kW per day _____ kW per year
Can you estimate the cost of electricity produced on-site? _____ $/kW	Can you estimate the cost of electricity and heat produced on-site? _____ $/kW
Is this electricity fed back to the grid? ☐ Yes ☐ No	
Is the current level of on-site power generation expected to sustain you over the next 3 years? ☐ Yes ☐ No	

3 B. DO YOU HAVE ANY BACKUP POWER REQUIREMENTS? ☐ **YES** ☐ **NO** ***(IF NO, SKIP TO QUESTION 4)***	
If yes, please identify facility requiring backup and typical backup requirements (for example, controlled environmental hut, repeater stations)	
Facility	Backup Time Required
☐	☐ <15 minutes; ☐15-30 minutes; ☐ 30-60 minutes; ☐ 1-3 hours; ☐ 3-8 hours; Other: _____
☐	☐ <15 minutes; ☐15-30 minutes; ☐ 30-60 minutes; ☐ 1-3 hours; ☐ 3-8 hours; Other: _____
☐	☐ <15 minutes; ☐15-30 minutes; ☐ 30-60 minutes; ☐ 1-3 hours; ☐ 3-8 hours; Other: _____
☐	☐ <15 minutes; ☐15-30 minutes; ☐ 30-60 minutes; ☐ 1-3 hours; ☐ 3-8 hours; Other: _____
☐	☐ <15 minutes; ☐15-30 minutes; ☐ 30-60 minutes; ☐ 1-3 hours; ☐ 3-8 hours; Other: _____

4. FROM THE LIST BELOW, PLEASE IDENTIFY FACTORS THAT YOU BELIEVE WILL DRIVE THE ADOPTION OF NEW ENERGY TECHNOLOGIES IN YOUR MARKET SECTOR AS COMPARED TO MATURE DISTRIBUTED GENERATION TECHNOLOGIES LIKE GENERATORS.

(For each of the factors identified, rate their importance on a Scale of 1 To 5, 1 "Being Not Important" and 5 "Being Very Important" to Businesses in your Market Sector.)

Critical Decision Factors	**1**	**2**	**3**	**4**	**5**
☐ Size of the unit	☐	☐	☐	☐	☐
☐ Capital Cost of the System	☐	☐	☐	☐	☐
☐ Cost of Installation	☐	☐	☐	☐	☐
☐ Reliability	☐	☐	☐	☐	☐
☐ Total lifetime	☐	☐	☐	☐	☐
☐ Efficiency	☐	☐	☐	☐	☐
☐ Durability	☐	☐	☐	☐	☐
☐ Low emissions	☐	☐	☐	☐	☐
☐ Ease of use	☐	☐	☐	☐	☐
☐ Scalability	☐	☐	☐	☐	☐
☐ Low perceived safety risk	☐	☐	☐	☐	☐
☐ Availability of incentives	☐	☐	☐	☐	☐
☐ Environmental regulations (e.g. emissions standards)	☐	☐	☐	☐	☐
☐ Well articulated codes and standards (e.g. for interconnection etc)	☐	☐	☐	☐	☐
☐ Low disposal cost/high recyclability	☐	☐	☐	☐	☐
☐ Other: _____	☐	☐	☐	☐	☐
☐ *Other:* _____	☐	☐	☐	☐	☐

5. WHAT ARE YOUR MINIMUM USER REQUIREMENTS FOR A NEW ENERGY TECHNOLOGY? MINIMUM USER REQUIREMENTS SHOULD REFLECT THE LOWEST ACCEPTABLE STANDARD THAT A PEM FUEL CELL WOULD HAVE TO MEET IN ORDER TO BE ADOPTED FOR BACKUP, PRIME POWER OR COMBINED HEAT AND POWER APPLICATIONS IN YOUR MARKET AREA.

(This may not necessarily be the same as your current performance obtained from a mature technology, but the minimum standards you would consider before evaluating a new technology further.)

Energy System Parameter	**User Requirements for Backup Power**	**User Requirements for Prime Power**	**User Requirements for Combined Heat and Power**
Specify type of facility that would apply in each area			
Size	☐ < 5 kW ☐ 5-25 kW ☐ 25-50 kW ☐ 50-150 kW ☐ 150-250 kW	☐ < 5 kW ☐ 5-25 kW ☐ 25-50 kW ☐ 50-150 kW ☐ 150-250 kW	☐ < 5 kW ☐ 5-25 kW ☐ 25-50 kW ☐ 50-150 kW ☐ 150-250 kW
Total Capital Cost of System *(does not include installation)*	☐ < 300 $/kW ☐ 300-600 $/kW ☐ 600-1000 $/kW ☐ 1000-2000 $/kW ☐ 2000-3000 $/kW	☐ < 300 $/kW ☐ 300-600 $/kW ☐ 600-1000 $/kW ☐ 1000-2000 $/kW ☐ 2000-3000 $/kW	☐ < 300 $/kW ☐ 300-600 $/kW ☐ 600-1000 $/kW ☐ 1000-2000 $/kW ☐ 2000-3000 $/kW
Operations and Maintenance Costs	☐ <3 C/kWh ☐ 3-5 C/kWh ☐ 5-7 C/kWH ☐ 7-12 C/kWH ☐ Other:_____	☐ <3 C/kWh ☐ 3-5 C/kWh ☐ 5-7 C/kWH ☐ 7-12 C/kWH ☐ Other:_____	☐ <3 C/kWh ☐ 3-5 C/kWh ☐ 5-7 C/kWH ☐ 7-12 C/kWH ☐ Other:_____
Cost of Installation	☐ < 300 $ ☐ 300-1000 $ ☐ 1000-2000 $ ☐ 2000-3000 $ ☐ 3000-4000 $	☐ < 300 $ ☐ 300-1000 $ ☐ 1000-2000 $ ☐ 2000-3000 $ ☐ 3000-4000 $	☐ < 300 $ ☐ 300-1000 $ ☐ 1000-2000 $ ☐ 2000-3000 $ ☐ 3000-4000 $

5. WHAT ARE YOUR MINIMUM USER REQUIREMENTS FOR A NEW ENERGY TECHNOLOGY? MINIMUM USER REQUIREMENTS SHOULD REFLECT THE LOWEST ACCEPTABLE STANDARD THAT A PEM FUEL CELL WOULD HAVE TO MEET IN ORDER TO BE ADOPTED FOR BACKUP, PRIME POWER OR COMBINED HEAT AND POWER APPLICATIONS IN YOUR MARKET AREA. ***(This may not necessarily be the same as your current performance obtained from a mature technology, but the minimum standards you would consider before evaluating a new technology further.)***			
Reliability	☐ 99% - 3.7 days/yr ☐ 99.9 % - 9 hr/yr ☐ 99.99% - 53 min/yr ☐ 99.999% - 5 min/yr ☐ 99.9999% - 32 sec/yr ☐ 99.99999% - 3sec/yr	☐ 99% - 3.7 days/yr ☐ 99.9 % - 9 hr/yr ☐ 99.99% - 53 min/yr ☐ 99.999% - 5 min/yr ☐ 99.9999% - 32 sec/yr ☐ 99.99999% - 3sec/yr	☐ 99% - 3.7 days/yr ☐ 99.9 % - 9 hr/yr ☐ 99.99% - 53 min/yr ☐ 99.999% - 5 min/yr ☐ 99.9999% - 32 sec/yr ☐ 99.99999% - 3sec/yr
Total Lifetime (years)			
Footprint (L*B*W) (m^3)			
Efficiency (%/LHV)	☐ < 35% ☐ 35-45% ☐ 45-55% ☐ 55-65% ☐ > 65%	☐ < 35% ☐ 35-45% ☐ 45-55% ☐ 55-65% ☐ > 65%	☐ < 35% ☐ 35-45% ☐ 45-55% ☐ 55-65% ☐ > 65%
Typical Operating Conditions	☐ -35 - -15ºC ☐ -15 - 0ºC ☐ 0 - 15ºC ☐ 15 - 25ºC ☐ 25 - 40ºC	☐ -35 - -15ºC ☐ -15 - 0ºC ☐ 0 - 15ºC ☐ 15 - 25ºC ☐ 25 - 40ºC	☐ -35 - -15ºC ☐ -15 - 0ºC ☐ 0 - 15ºC ☐ 15 - 25ºC ☐ 25 - 40ºC
Emissions	☐ At Regulatory Threshold ☐ Well Below Regulatory Threshold	☐ At Regulatory Threshold ☐ Well Below Regulatory Threshold	☐ At Regulatory Threshold ☐ Well Below Regulatory Threshold

APPENDIX B:

FINANCIAL SERVICES SECTOR MARKET SUMMARY

FINANCIAL SERVICES SECTOR MARKET SUMMARY

Industry Overview

The financial services sector was one of three initial sectors analyzed by the Battelle team to better understand user requirements for PEM fuel cell systems. This market segment was selected for analysis because of:

- The potential financial impact of power loss;
- Regulatory drivers, which require financial institutions to resume business "crucial to the national economy" within 24 hours of any disaster;
- The market size for backup and potentially grid parallel applications, and;
- The pre-existing application of fuel cells in at least one bank data center (First National Bank of Omaha).

Industry Size and Growth

The financial services sector is comprised of three major subsectors: (1) banking, (2) insurance, and (3) securities, commodities, and other investments. Banking is the largest sector within the financial services industry, with a GDP of $375 billion in 2002, followed by insurance ($249 billion), and securities, commodities, and other investments ($180 billion). Together, the GDP of financial services was $804 billion in 2002, contributing 7.7 percent to the GDP. As illustrated in Tables B-1 and B-2 below, financial services industry growth has outpaced overall GDP and industry revenue represented a slightly larger share of GDP in 2002 than it did in 1998.

Table B-1. Gross Domestic Product of the Financial Services Industry, 1998-2002 ($ billions)[88]

	1998	1999	2000	2001	2002
Total GDP, $	**8,747.00**	**9,268.40**	**9,817.00**	**10,100.80**	**10,480.80**
Industry percent of total GDP	7.3%	7.3%	7.5%	7.6%	7.7%
Total financial services industry, $	641.10	679.80	740.50	770.10	804.00
Federal Reserve banks, credit intermediation and related activities	277.7	308	319	352.3	374.8
Securities, commodity contracts and investments	134.1	139.9	167.7	164.6	162.6
Funds, trusts and other financial vehicles	11.9	15	15.5	17.9	17.9
Insurance carriers and related activities	217.4	216.9	238.3	235.3	248.7

[88] U.S. Department of Commerce, Bureau of Economic Analysis. 2005. Homepage. Accessed May 12, 2005. Available at http://www.bea.doc.gov/.

Table B-2. Financial services vs. total U.S. gross domestic product growth, 1998-2002 ($ billions)[89]

Year	Total U.S. gross domestic product	Percent change from prior year	Finance and Insurance	Percent change from prior year
1998	$8,747.00	N/A	$ 641.1	N/A
1999	$9,268.40	6.0%	$679.80	6.0%
2000	$9,817.00	5.9%	$740.50	8.9%
2001	$10,100.80	2.8%	$770.10	4.0%
2002	$10,480.80	3.8%	$804.00	4.4%

The financial services sector, in total, operates more than 180,000 buildings in the United States.[90] According to Dun and Bradstreet,[91] the numbers of businesses in the three major financial services subsectors are:

- Banking and Supporting Businesses: 108,667
- Security and Commodity Exchanges and Supporting Businesses: 40,705
- Insurance Agents and Supporting Businesses: 197,054.

Relevant Industry Trends

IT Spending: Information technology (IT) spending in the financial services industry has increased dramatically over the past several years. According to Celent Communications,[92] total internal IT by banks is expected to grow from $592 million in 2002 to $1.0 billion in 2004. Growth in IT infrastructure brings with it an increase in power densities for data centers (from 30 to over 100 watts per square footage). This trend suggests a corresponding need for backup of critical IT systems and a growth in the prime power requirements of this sector, including possible opportunities for peak-load shaving.

Off-shoring: Another trend in this industry worth noting is off-shoring. Some financial institutions are using low-cost workers overseas to run their call centers. While these facilities will still require grid parallel and backup power sources, more and more of these facilities may be located in other countries.

Mergers and Acquisitions: The industry has seen a number of mergers and acquisitions in recent years, in both the banking and insurance sectors, and this trend is not expected to slow. In the banking sector, a number of "superbanks" are emerging with a major regional, national, or

[89] See reference 1.
[90] Personal communication between Kathya Mahadevan (Battelle) and Jerry Jackson (MAISY Consulting). May 11, 2005.
[91] Dun and Bradstreet. 2005. Zapdata Industry Reports. Accessed February 12, 2005. Available at http://www.zapdata.com.
[92] Celent Communications. 2005. Financial Services Fact Book. Accessed May 12, 2005. Available at http://www.financialservicesfacts.org/financial2/technology/it/.

international presence.[93] This may increase the demand for critical regional- and enterprise-scale facilities and data centers, with corresponding backup requirements.

Branch Banking Growth: While consolidation in commercial banking has substantially reduced the number of these institutions, it has not reduced the number of commercial bank branches and ATMs.[94] Banks are not only pouring capital into online banking services but are growing the number of branch locations as customers want their services to alternative locations (e.g., supermarkets).[Table B-3][95]

Table B-3. Number of banking offices by type of bank, 1990-2003[96]

All banking offices	96,951	98,468	97,766	98,640	98,394	99,079
Commercial banks	62,346	71,664	71,784	73,027	73,454	74,518
Number of banks	12,329	8,563	8,297	8,062	7,870	7,752
Number of branches	50,017	63,101	63,487	64,965	65,584	66,766
Savings institutions	21,630	14,534	14,077	14,094	13,785	13,779
Number of banks	2,815	1,642	1,589	1,535	1,467	1,413
Number of branches	18,815	12,892	12,488	12,559	12,318	12,366
Credit unions	10,160	10,628	10,316	9,984	9,688	9,369

Measures to Protect Critical Financial Infrastructure: Recent federal government requirements are also putting a greater emphasis on backup power systems in the financial services sector. Requirements have been established for "core clearing and settlement organizations and firms that play significant roles in critical financial markets" to help protect the nation's financial system from the risks of a wide-scale disruption and reduce the potential that key market participants will present systemic risk to one or more critical markets. These requirements include testing of backup equipment and establishing more aggressive objectives for recovery time in the event of a power failure (for critical institutions this is within the business day on which the disruption occurs).[97]

Current Energy Use by Market Sector

Energy Consumption

The financial services sector is classified as a commercial sector user by the electric utility industry. No specific information was available on financial services sector consumption and usage patterns from the Energy Information Administration (EIA). Information can be gleaned

[93] Plunkett Research. 2004. Plunkett's Financial Services Industry Almanac. Major trends in the Financial Services Industry.
[94] Insurance Information Institute. 2005. Financial Services Fact Book. Accessed May 10, 2005. Available at http://www.financialservicesfacts.org/financial2/banking/allsectors/.
[95] See reference 94.
[96] Federal Deposit Insurance Corporation, National Credit Union Administration. 2005. Homepage. Accessed May 12, 2005. Available at http://www.fdic.gov.
[97] U.S. Securities and Exchange Commission. 2003. Interagency Paper on Sound Practices to Strengthen the Resilience of the U.S. Financial System. Accessed May 9, 2005. Available at http://www.sec.gov/news/studies/34-47638.htm.

from EIA's Commercial Building Energy Consumption Survey, where banks and other financial institutions are classified as office buildings. The average size of an office building is approximately 16,300 sq ft, and 739,000 office building consume a total of approximately 678 billion kWh.[98] Of this, approximately 180,000 buildings are owned and operated by various arms of the financial sector.

Current Mode of Operation

Nearly all financial services institutions rely on backup power for critical systems to ensure business continuity in the event of a power outage. According to a study by the Meta Group, downtime can cost the financial services industry $1.4 million of lost revenue per hour and the banking industry $996,000,[99] providing a strong impetus for high quality and reliable power.

A single financial institution may operate several thousand facilities including retail branch offices, ATM sites, headquarters, regional offices, operations centers, and data centers. Currently, the industry relies on UPS systems in many of its bank facilities and UPS/generator systems at critical sites. The critical sites where longer-lasting backup power systems are deployed typically include headquarters, data centers, and critical operations centers (e.g., call centers and check processing centers).

No data were available on current grid parallel and CHP applications at the industry level; the experience of the survey participants is presented in the next section.

Analysis of Survey Results: Market Requirements for PEM Fuel Cells

Survey Participants

Nine financial services companies participated in the survey and follow-up interviews out of twenty-one financial services companies that were invited to participate. Respondents included:

- KeyBank National Association
- Wells Fargo
- National City
- Fifth Third Bancorp
- Merrill Lynch
- HomeStreet Bank
- Linsco Private Ledger
- Washington Mutual
- LaSalle Bank Corporation

Two of the participating institutions are medium-sized organizations (500-3000 employees) and the other seven are large organizations, each with over 3000 employees. All but one of the

[98] See reference 29.
[99] See reference 16.

participating companies stated that they proactively manage energy use (e.g., monitor energy savings, adopt energy efficient technologies).

The survey did not explicitly ask about energy management outsourcing, but several companies indicated during follow-up discussions that either all real estate management or certain aspects of energy management (e.g., generator maintenance) were outsourced to third parties. As a result, these companies would likely play an important role in decisions to adopt alternatives to the current energy technologies.

Power Outages

Interviewees were asked how disruptive a power outage would be to their business operations in terms of financial impact. All companies indicated that an outage would cause a "high" impact. Five of the participating companies stated that they currently experience between *zero and one* outage per year. Three institutions experience more frequent outages (*5 to 15* per year), and a third estimates that the sum of their facilities experience *more than 500* outages per year, although the majority of these are blips lasting for less than 10 seconds. Most outages were attributed to utility disruptions from inclement weather or voltage sags.

Grid Parallel (Peak Shaving or Baseload Power)

All interviewees meet their baseload power requirements through the grid. None of the participants produce electricity on-site for baseload power or peak-load shaving. The average price paid for grid electricity in less than 10 cents/kWh for seven of the companies surveyed. Two pay 10 to 15 cents/kWh and one company pays >25 cents/kWh. The latter was the only company whose grid electricity cost grew by more than 5% in the past year.

Backup Power

Eight of the companies interviewed use combined UPS/generator systems, and one is using both generators and combustion turbines for backup power. Just one company interviewed – a medium sized company – relies on only a UPS system, which allows the data center to shut down "gracefully" over a 10 to 15 minute period. The interviewee from this company indicated that they would prefer to have a longer-running backup power source; however, the property owner will not permit installation of a generator because they are located in a high-rise in a heavily populated urban area. Currently, this company relies on a redundant data room in another city to provide support during an emergency power outage.

During follow-up interviews some respondents elaborated on generator size and load requirements. Size of generators currently used by these financial services institutions ranged from 30 kW to 2000 kW.

The backup time required depends on system criticality to the business. Main data centers are the heart of a bank's business operations. Responses for minimum backup time for main data centers required range from 8-168 hours (up to 7 days). Three respondents said they do not have a specific backup time requirement for their critical facilities; they need the backup power source

continuously until the primary power source come back online and have a strategy to the refill the diesel tanks when the fuel reaches a pre-determined level.

One company interviewed with over 3000 facilities uses a tiered approach for definition of critical systems for backup. Tier III environments include enterprise data centers and call centers. These are large regional centers that are of the highest importance as a failure would result in an enterprise-wide impact. Tier II environments include data centers, call centers, and major administrative sites that may have regional importance but would not necessarily have an enterprise-wide impact if they failed. Finally, Tier I environments include smaller data centers, call centers, and administrative operations. Tier III and II environments rely on UPS and generator systems, while Tier I environments rely only on UPS systems. This company has a total of 96 generators at critical sites (Tier III and some Tier II) with individual generator capacity for these facilities ranging from 20 to 1800 kW. The most power intensive sites have multiple generators providing up to 4500 kW of backup power.

Another company with over 1200 facilities relies on 20 generators to backup 14 critical sites. The total generator capacity ranges from 30 to 4000 kW for these facilities. This company has diesel fuel tanks that provide a minimum of 15 hours of run time and up to 120 hours.

A third company with over 5000 facilities has over 50 sites with backup power requirements. Generator size ranges from 500 to 2000 kW for its different facilities. This company commented that as the power density in data centers increases (its new data centers are designed for 110 watts per square foot) they want fewer and larger generators. The company is building a new data center with ten 2750 kW generators to meet these increasing load requirements.

A fourth company surveyed with several hundred facilities relies on generators in 8 locations. One facility that houses the company's data centers have seven 1200 kW diesel generators installed for backup power. A service center with critical systems is also backed up with a 960 kW and a 1200 kW generator. Smaller generators (about 80 kW) are utilized for emergency power (e.g., elevators, sump pumps, emergency lights) in six of its large office buildings.

Size: Most survey participants indicated that they would only consider a fuel cell in the 150-250 kW range for backup and grid parallel power. Just one company indicated that they would consider a fuel cell for backup power in the 25-50 kW range, and a two would consider a fuel cell in the 50-150 kW range for backup power. None indicated that a 5 kW fuel cell would meet minimum user requirements for backup power or grid parallel power. In light of the output of the generators currently used for backup power by these financial institutions, a 1000 kW fuel cell would seem to be better aligned with user needs.

Total capital cost: Three survey participants stated they would pay less than $300 per kW for a backup power system, citing that is what they currently pay for backup generators. Two indicated that they would pay $2000-3000 per kW, and one company each indicated a willingness to pay $300-600 per kW, $600-1000 per kW, and $1000-2000 per kW for a backup system. Grid parallel power requirements ranged from $300-2000 per kW as well, with no one capital cost point being identified more than others.

Installation cost: Five survey respondents indicated that they would pay $3000 to 4000 for fuel cell installation for backup power applications, and three indicated they would pay that much for grid parallel power installation. One person commented that because this was a one-time expense there was a willingness to pay more. One company indicated a willingness to pay $1000 to 2000, another would pay $300 to 1000, and a third would pay <$300 for backup power installation.

Operations & Maintenance (O&M) Costs: Five companies indicated a willingness to pay $0.07 to 0.12 per kWh for backup power O&M. One company each responded that they would pay $0.05 to 0.07 per kWh, $0.03 to 0.05 per kWh, and <$0.03 per kWh. There may be a greater willingness to pay more for O&M because of the relatively high cost and effort of maintaining generators. Most companies interviewed have their generators checked monthly, and one even does so weekly, prompted by the recent East Coast blackout of 2003. In a follow-up interview with one respondent, the interviewee said that his company pays $9000 per year to have two 1000 kW generators serviced monthly by a third party. For grid parallel power just two people responded: one would pay $0.05 to 0.07 per kWh and one $0.07 to 0.12 per kWh.

Lifetime: Two respondents required a minimum lifetime of 20 years and two required a minimum lifetime of 25 years for a PEM fuel cell in backup applications. However, answers varied widely with other responses including 5, 10, 15, and 30 years. For grid parallel power, two respondents required a 20-year lifetime; others required 8, 15, and 25 years.

Reliability: Four survey participants indicated that seven 9s reliability (i.e., 3 seconds per year) would be the minimum requirement for a new backup energy technology. One interviewee pointed out that because his bank does data switching for other organizations (e.g., a transaction in a department store gets routed through the bank data center) the consequences of unanticipated downtime would have an enormous rippling affect. One respondent required six 9s of reliability (32 seconds per year downtime), two others required five 9s (5 minutes per year downtime), and another stated that just four 9s (53 minutes per year) would be acceptable. For grid parallel power, answers ranged widely from three 9s to seven 9s. The justification for three 9s performance was that it had to be at least as good as the grid.

Footprint: While few respondents provided specific maximum footprint requirements, in general it was considered important that the fuel cell take up no more space than a combined UPS and generator system. One company specified a maximum footprint of 9 m^3, one of 240 m^3 and another required no more than 1000 m^3. Requirements vary by location (i.e. a New York City data center has greater space constraints than one in Nebraska). Answers did not vary much for grid parallel power space requirements.

Typical Operation Conditions: Four companies identified typical operating conditions for backup power sources as 15 to 25 ºC. One described typical operation conditions as -15 to 0 ºC, two as 0 to 15 ºC and another as 25 to 40 ºC. Conditions were identical for grid parallel power.

Efficiency: For backup power, four companies would require greater than 65% efficiency for a new energy technology and three others expect at least 55 to 65% efficiency. Two companies did not respond, possibly suggesting that efficiency is not a critical parameter for backup power.

For grid parallel power, two indicated that efficiency would need to exceed 65%, while another required efficiency between 55 and 65%.

Emissions: Six respondents described their emissions requirements for backup power as "meeting the regulatory threshold," while just three require that their backup power source be "well below the regulatory threshold." Because emissions requirements vary by location, user requirements will still vary significantly. One company commented that his company gets fined every time they turn on their generator, suggesting a lower emission alternative would be attractive even though they don't have an interest in going beyond the regulatory requirements. Two of the respondents not concerned with exceeding emissions regulatory requirements for backup power were interested in achieving emissions well below the threshold for grid parallel power, noting that they use backup so infrequently it is not an issue.

Willingness to Adopt PEM Fuel Cells

During follow-up interviews, the respondents were asked whether their company would seriously consider a PEM fuel cell as a backup or grid parallel power source. All said they would consider PEM fuel cells as an alternative source of backup power, if the technology met their user requirements. Four interviewees indicated that if reliability were better than the current technology, their company might pay more. One interviewee stated that his company would want to be a leader in this area. Another interviewee thought his company could be persuaded with a payback analysis showing that the fuel cell is competitive with a generator system. For one company, a change in their backup power systems would have to be prompted by either an external driver (e.g., more frequent brownouts) or their current backup generators reaching the end of their useful life.

There was less interest in fuel cells for grid parallel power in this sector, probably due to the overall reliability and cost of the grid power. Three companies expressed interest in general grid parallel applications, two specifically for peak-load shaving and one in CHP applications to power chillers for their air conditioning systems more efficiently. One of these companies also said they would consider fuel cells for load stabilizing where grid power quality is poor.

Key Decision Factors

The financial services companies were asked to indicate what factors they believed would ultimately drive the adoption of new energy technologies in the financial services sector. Table B-4 summarizes the median response from the nine survey participants. *Reliability* received the highest median response, and *reliability, capital cost* and *total lifetime* received the highest mean responses. When survey participants were asked during follow-up interviews to identify the most important factor to potentially open the door for new energy technologies in this market sector, seven respondents again pointed to *reliability*. One said *reliability and cost* were equally important and another said *cost and size* were the most critical factors. One reason offered for why higher reliability would supersede capital cost as a decision factor was that banks and investment companies face substantial fines from the SEC if they are unable to stay online.

Table B-4. Decision factors driving adoption of new technologies in financial services sector.

Decision Factor	Company									Median	Mean
	1	2	3	4	5	6	7	8	9		
Reliability	5	5	5	5	5	5	5	5	5	5	5.0
Capital Cost	5	4	4	5	4	5	4	4	4	4	4.3
Total Lifetime	5	3	4	5	4	5	4	4	5	4	4.3
Safety/Perceived Risk	5	5	5	5	4	4	2	4	4	4	4.2
Cost of Installation	4	4	4	5	4	5	4	4	4	4	4.2
Efficiency	5	4	4	5	4	5	3	3	4	4	4.1
Scalability	5	4	4	3	4	5	3	3	3	4	3.8
Low Emissions	3	4	4	5	3	4	4	3	3	4	3.7
Ease of Use	5	3	5	3	4	4	2	3	4	4	3.7
Size of Unit	4	4	3	3	4	5	2	3	5	4	3.7
Code and Standards	4	2	2	5	4	1	3	5	5	4	3.4
Environmental Regulations	3	3	3	5	3	3	4	4	4	3	3.6
Disposal Cost/Recyclability	4	3	3	5	3	3	3	3	4	3	3.4
Availability of Incentives	1	3	3	3	3	4	2	3	4	3	2.9

APPENDIX C:

MARKET ANALYSIS:
TELECOOMUNICATIONS FOCUS GROUP MEETING MINUTES

MARKET ANALYSIS:
TELECOOMUNICATIONS FOCUS GROUP MEETING MINUTES

Application of PEM Fuel Cells in Telecommunications
Focus Group Discussion

Date: April 14, 2005

Location: Fort Lauderdale, Florida

Time: 5:00 – 7:00 pm

Agenda:

5:00 pm	Welcome and Introductions
5:15 pm	DOE Project Objectives and Purpose of Focus Group
5:30 pm	Discussion Questions
6:10 pm	Dinner and Brief Break
6:25 pm	Discussion Questions (continued)
7:20 pm	Discussion Summary and Wrap-up

Technique: General Brainstorming and Voting on Critical Drivers

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Notes from the Focus Group Discussion:

Kathleen Judd welcomed participants and thanked them for their support and time. Ms. Judd introduced herself as the facilitator and Ms. Mahadevan as the co-facilitator. Meeting was kicked off with brief introductions by participants. Ms. Mahadevan provided an overview of the DOE project indicating that Battelle is conducting an economic analysis of PEM fuel cells for stationary applications for the DOE. Ms. Mahadevan specified that results from the project will help the DOE to focus to its investments in PEM fuel cell R&D by providing an improved understanding of the energy requirements of key user groups (e.g., telecommunications), critical economic targets, and priority areas for technology improvement.

Ms. Judd emphasized the objective of the focus group was to obtain an improved understanding of the specific applications in telecommunications for which PEM Fuel Cells in the 1-250 kW range could be used and the conditions under which this would occur.

Discussion Question 1: What are the critical applications for supplementary power systems in the telecommunications sector?

Participants were asked to provide a list of the most critical sites for application of PEM fuel cells as backup power and prime power in telecommunications with corresponding sizes required to support the entire location. Table C-1 provides a listing of applications discussed.

Table C-1. Critical sites in telecommunications for application of PEM fuel cells.

Application	Size (kW)
Controlled Environmental Hut	20 – 50
Huts	20 – 200
Remote Cell Sites	20 – 200
Microwave Towers	20 – 200
Cell Sites	20 -100 (most sites 20 – 50)
Hub Sites	20 – 100 (3 - 10 for hub-equipment)
Enhancers Repeaters	20 – 30
Cabinet Sites	45 - 80
Outside Plant hut	< 2
Digital Loop Carrier	2 – 10
Fiber	2 -10
Private Branch Exchange (PBX)	2 – 10
Public Safety Answering Point (PSAP)	10 -100 (most systems 60 – 100)
Remote Radio Center	10 – 20
Portable Systems	10 – 100

Based on the economic impact from the loss of power, priority sites that require protection identified were hub sites, microwave transmitter sites and central office sites. Cell sites are considered less important than hub sites. For the wired-telecommunications market segment, sites that provide critical communications support like the public safety answering point (PSAP) are very important, as they are regulated by Government, to ensure public safety.

Focus group participants indicated that the primary source of power was the grid, with all sites having either batteries or generators or both as backup power. Several participants indicated that they had tested various technology alternatives including solar cells to charge batteries, flywheels, zinc air fuel cells, and aluminum air fuel cells. Participants indicated that microturbines were considered, but were not tested as the product was fairly expensive. One participant shared that for providing 12 kW of continuous power an 18 kW [3*6] microturbine system was quoted at $800,000. Participants indicated that first cost, functionality, and operation and maintenance costs were critical barriers for adoption of alternative technologies.

Discussion Question 2: What are the limitations and benefits of the current power systems used by telecommunications companies?

Participants indicated that they were fairly happy with batteries and generators, and indicated that these systems when engineered correctly could provide 99.9999% reliability. Participants also indicated that grid was very reliable and competitive even in remote locations. Limitations of backup power systems identified were high operation and maintenance costs, lower reliability in extreme weather, stringent EPA regulations which restricts use, increasing cost of fuels, fire hazard, safety problems in areas with high fault currents, leaking batteries, and hazardous material disposal. Participants identified environmental and safety issues as priority problems with current backup power systems.

Discussion Question 3: How do you evaluate new technologies for backup power? Who are the key influencers in the process?

In response to the above question, to facilitate adoption of new technologies, participants indicated that mean-time between failures (MTBF) would have to be demonstrated through accelerated life cycle testing. They identified reliability as critical requirement for technology adoption. Participants indicated that in the telecommunications industry, technologies were evaluated based on certifications or codes and standards obtained from Telecordia (Network Equipment Building System [NEBS] certification, Generic Requirements), Underwriters Laboratories (UL), American National Standards Institute (ANSI), and National Fire Protection Association (NFPA). The primary driver of new technologies in the telecommunications industry identified by participants was Telecordia, a R&D entity which develops requirements for the installation of various products including power systems.

Participants indicated that most telecommunications companies use generic requirements and other guidance documents developed by Telecordia for application of new products, siting of equipment, specifications for contractors, etc. For example, participants identified GR 78 developed by Telecordia as an important driver for application of new products. GR 78 was described as generic requirements for the physical design and manufacture of telecommunications products and equipment used in Local Exchange Carrier (LEC) networks and by network operators in the field. GR 78 requirements apply to design, engineering, manufacturing, and workmanship of the product. Participants suggested that having Generic Requirements for fuel cells would greatly increase adoption in telecommunications as buyers would be confident that the product meets all requirements and safety standards needed in telecommunications environments.

NEBS certification provided by Telecordia was also identified as critical for technology adoption. Participants described that Telcordia developed NEBS criteria are used to evaluate the ability of a product to operate as intended under electrical and physical environmental stresses, such as electromagnetic interference, high and low temperatures, and earthquake and vibration conditions. NEBS criteria are also used to assure that equipment does not pose a threat to services or personnel, via analyses for fire resistance,
electrical safety, and grounding.

Participants suggested that DOE provide financial support to Telecordia to work with utilities, fuel cell companies and other stakeholders to develop necessary requirements for application of fuel cells in Telecommunications. It was also suggested that to drive new technology adoption the government provide tax credits and other incentives. To promote greater safety standards, participants also felt that codes and standards by the NFPA need to be written to support use of hydrogen at telecommunications sites as most locations carry high voltages and high electricity.

Discussion Question 4: What critical factors will drive the adoption of PEM Fuel Cells for telecommunications applications?

Participants suggested that fuel cells would enter the telecommunications market as replacements to generators and not as replacements to batteries. Provided the reliability of the product is proven, the first area of adoption was identified as situations where generators cannot be used because of environmental or noise restrictions, followed by remote locations. Participants indicated that they would run a fuel cell in parallel with the generator, until reliability was proven before actually moving into widespread application of the technology. Participants cautioned that the rate of new technology adoption in the telecommunications industry is extremely slow, and a **demonstrated track record** is necessary for accelerated adoption. Participants also indicated that involving Telecordia in field trials would promote adoption through development of appropriate requirements. Critical factors that will drive adoption of fuel cells in this market identified by participants include:

- Reliability,
- Lifetime,
- Durability,
- Competitive economics - Low capital and installation costs; Low operation and maintenance costs,
- Scalability,
- Ease of use,
- Plug and play (to reduce training costs),
- Small footprint,
- Ease of shutting down and isolating the system from power network,
- Fuel availability,
- Image that product is “greener”, and
- Education/Perception of the technology.

Participants also identified that total cost of ownership was an important driver as management personnel are typically involved in making purchase decisions. Participants suggested that a detailed economic analysis of the application of fuel cells at remote sites would be an important

consideration, as companies often spend up to $30-40 a gallon of fuel for generators at remote sites. Participants indicated that capital and installation costs, however, are more important in the decision-making process than operation and maintenance costs.

Voting

Participants were asked to prioritize three critical drivers for adoption by selecting their choices from the list provided above. Choices were made on post-it notes and submitted to the co-facilitator who tabulated the results (ReliOn did not participate in the prioritization process). Primary drivers identified were: **(1) Reliability, (2) Cost, and (3) Ease of Use**.

Participants were also asked to provide feedback on what the proposed role of the DOE and the government in general could be. Participants provided varied responses, including that the government should:

- Stay out of the adoption process,
- Provide guidance to promote adoption,
- Underwrite costs through incentives,
- Promote R&D,
- Fund Telecordia to write good practices, and
- Commit to reduce dependence on fossil fuel.

APPENDIX D:

TELECOMMUNICATIONS SECTOR MARKET SUMMARY

TELECOMMUNICATIONS SECTOR MARKET SUMMARY

Industry Overview

The telecommunications market sector was one of three initial sectors analyzed by the Battelle team to better understand user requirements for PEM fuel cell systems. This market segment was selected for analysis because of:

- The potential financial impact associated with a power loss;
- Market drivers, which compel telecommunications companies to resume business as soon as possible after any disaster in order to facilitate flow of communication;
- The market size for backup and potentially grid parallel applications, and;
- The pre-existing application of fuel cells in at least one telecommunications facility.

Industry Size and Growth

The telecommunications sector is comprised of two major subsectors: (1) wireless and (2) wireline. The Bureau of Economic Analysis does not separate telecommunications companies from other broadcasting companies. Together, the GDP of the broadcasting and telecommunications industry was $283 billion in 2003, contributing 2.6 percent to the GDP. As illustrated in Tables D-1 and D-2 below, broadcasting and telecommunications industry growth has remained relatively steady with overall GDP and industry revenue representing a slightly larger share of GDP in 2004 than it did in 1999.

Table D-1. Gross domestic product of the telecommunications industry, 1999-2004 ($ billions)[100]

	1999	2000	2001	2002	2003	2004
Gross domestic product, $	9,268.40	9,817	10,128	10,487	11,004	11,735
Broadcasting and Telecommunications percent of total GDP	2.7%	2.8%	2.8%	2.6%	2.6%	...
Information Industry, $	439.30	458.30	476.90	470.00	493.80	547.20
Broadcasting and telecommunications	253.8	271.3	283.2	272.8	283.0	...
Information and data processing services	36.7	37.7	41.5	44.7	48.6	...

[100] U.S. Department of Commerce, Bureau of Economic Analysis. 2005. Homepage. Accessed May 12, 2005. Available at http://www.bea.doc.gov/.

Table D-2. Broadcasting and telecommunications vs. total U.S. gross domestic product growth, 1999-2002 ($ billions).

Year	Total U.S. GDP	$ Change from prior year	Percentage change from prior year
1999	$9,268.40	---	---
2000	$9,817.00	$548.60	5.9%
2001	$10,128.00	$311.00	3.2%
2002	$10,487.00	$359.00	3.5%
2003	$11,004.00	$517.00	4.9%
2004	$11,735.00	$731.00	6.6%

*Calculated using numbers in table above.

Relevant Industry Trends[101]

The telecommunications industry is regrouping and recovering from the telecom bust. Some companies are consolidating and merging. Other companies have downsized in order to reduce costs, while more than a few have endured bankruptcy to wipe out massive amounts of debt. The Baby Bells are adapting to today's environment, which includes declines in local landlines, continued growth in cellular subscribers, and rapid adoption of broadband access to the Internet by homes and businesses. Meanwhile, traditional telecommunications providers face rapidly growing competition from VOIP (Voice Over Internet Protocol).

Many services companies are taking advantage of existing fiber optics systems to create new products and service offerings. Fiber to the home and fiber to the business are becoming realities. In particular, Verizon has launched very aggressive, long-term fiber to the premises projects.

The modest growth of telecommunications services revenue enjoyed by carriers worldwide during 2004 is predicted to continue in 2005. Three quarters of a trillion dollars flowed into the telecommunications industry during the tech bubble of the late 1990s, but after several brutal years watching telecommunications industry fortunes being driven downwards – with the attendant layoffs, bankruptcies, and even a few accounting scandals – in 2005 the telecommunications industry has turned the corner.

Current Mode of Operation

Nearly all telecommunications facilities rely on backup power for critical systems to ensure business continuity in the event of a power outage. Downtime can cost the telecommunication industry millions of dollars in lost revenue per hour providing a strong impetus for high quality and reliable power.

A single telecommunications company can offer both wireless and wireline products and services. As a result, telecommunications companies operate several thousand facilities including retail sales offices, cellular tower sites, data centers, regional offices, and operations centers. Currently, the industry relies on UPS systems and battery backups at many of its

[101] Plunkett Research. 2004. Telecommunications Industry Almanac.

facilities and battery/generator systems at various critical sites. The critical sites where longer-lasting backup power systems are deployed typically include headquarters, data centers, and critical operations centers.

No data were available on current grid parallel and CHP applications at the industry level; the experience of the survey participants is presented in the next section.

Analysis of Survey Results: Market Requirements for PEM Fuel Cells

Survey Participants

Six telecommunications companies have participated in the survey and follow-up interviews out of approximately 18 companies that were invited to contribute. Many of the companies contacted did not have ready access to specific energy usage information and did not know to whom it would be best to refer our request. Other potential respondents found the task of gathering information to be too daunting and opted out of responding. Still others were suspicious and displayed concern with giving away too much information. Respondents included:

- Verizon Wireline
- Verizon Wireless
- Sprint
- SBC
- Bell South
- Qwest.

All six of the participating institutions are large-sized organizations (>3000 employees) and all of the companies stated that they proactively manage energy use (e.g., monitor energy savings, adopt energy efficient technologies).

Power Outages

Interviewees were asked how disruptive a power outage would be to their business operations in terms of financial impact. Three companies indicated that an outage would cause a "high" impact. The remaining two companies responded "low," with one respondent clarifying his response by stating that the financial impact would be low but operationally the impact would be high, while the other respondent clarified by saying his company provided backup power to bridge any loss of AC. One of the participating companies stated that they currently experience between *zero and one* outage per year. Two institutions experience more frequent outages (*three* per year), and a fourth estimates that the sum of their facilities experience *hundreds* of outages per year. The fifth respondent indicated the number of outages *varies* per year but could not provide a range of estimates. Most outages were attributed to utility disruptions, frequently as a result of inclement weather.

Prime Power

Three interviewees meet their prime power requirements through the grid, one indicated the grid and backup power, and the fifth company indicated a combination of grid, on-site generation and

backup power. Two companies indicated the on-site generation of electricity for prime power needs. The average price paid for grid electricity in less than 10 cents/kWh for the three respondents who were able to answer the question on cost. Two companies indicated their grid electricity cost grew by less than 5% in the past year, while three indicated a growth of between 5 and 15%.

Backup Power

Two companies interviewed use generator systems, while the other companies were unresponsive to this question. During follow-up interviews some respondents elaborated on typical problems with sizing power plants, costs associated with operations and maintenance, and its costs. Type of backup and backup time required depend on system criticality to the business. Responses for minimum backup time for all facilities were primarily in the 3 to 8 hour range for batteries and 72 hours for generators.

Size:
Controlled Environmental Vaults. Survey participants indicated that they would consider a fuel cell in the <5 to 250 kW range for backup and prime power. Fuel cell size requirements varied across the various companies with no clear preference for either prime or backup power.
Repeater Stations/Huts. The required size range for these facilities was <5 to 150 kW for both prime and backup power, but again, there was no clear preferred size amongst all the company respondents.
Central offices. The required size range for these facilities was 25 to 150 kW for backup power, with 50 to 150 kW being the most frequent response. For prime power, the range and most frequent response was 150 to 250 kW.
Switching Stations. The required size range for these facilities was 25 to 250 kW for backup power and 150 to 250 kW for prime power, with no clearly preferred requirement for either prime or backup power.

Total capital cost:
Controlled Environmental Vaults. Survey participants indicated that the total capital costs ranged from <$300 to $2000 per kW for backup power with the most frequent response being <$300 per kW. For prime power the range of costs and most selected costs were both $600 to $1000 per kW.
Repeater Stations/Huts. Survey participants said they paid a range of <$300 to $2000 per kW for backup power with $600 to $1000 per kW being the most selected range. For prime power the respondents reported spending in the same <$300 to $2000 per kW range, but the responses varied so that there was no clearly preferred capital cost response.
Central offices. The required cost for backup power ranged from <$300 to $2000 per kW with <$300 per kW being the preferred response. For prime power, $600 to $1000 per kW was both the range and most preferred response.
Switching Stations. For switching stations the range of capital cost responses was $300 to $2000 per kW with no popular response. The range of costs for prime power was $300 to $2000 per kW with no one capital cost point being identified more than others.

Installation cost:
Controlled Environmental Vaults. Installation costs varied widely with survey participants indicating costs ranging from <$300 to $4000 for backup power with the most frequent response being $2000 to $3000. For prime power the range of costs was $2000 to $4000 with no preferred costs category.
Repeater Stations/Huts. Survey participants said they paid a range of <$300 to $2000 for backup power with $600 to $1000 being the most selected range. For prime power the respondents reported spending in the same <$300 to $2000 range with $1000 to $2000 being the clearly preferred installation cost response.
Central offices. The required cost for backup power ranged from $300 to $4000 with this same range being the preferred response. For prime power, $300 to $4000 was the reported range of responses with no clearly favored cost range reported.
Switching Stations. For switching stations the range of installation cost responses was $300 to $4000 with no popular response for either backup or prime power.

Operations & Maintenance (O&M) Costs:
Controlled Environmental Vaults. O&M costs varied among survey participants in a range from <0.03 to 0.12 cents per kWh for backup power with the most frequent response being <0.03 cents per kWh. For prime power the range and most popular response was <0.03 cents per kWh.
Repeater Stations/Huts. Reported O&M for this facility type ranged from <0.03 to 0.12 cents per kWh for backup power with the most frequent response again being <0.03 cents per kWh. For prime power the range was <0.03 to 0.12 cents per kWh with no favored response.
Central offices. For central offices, O&M costs responses ranged from <0.03 to 0.12 cents per KWh for backup power with the 0.07 to 0.12 cents per kWh range being the most frequent response noted. For prime power the range and most popular response was <0.03 cents per kWh.
Switching Stations. O&M costs for switching stations was consistently reported as being <0.03 cents per kWh for both prime and backup power.

Lifetime:
Controlled Environmental. Reported lifetime varied among respondents. For both backup and prime power, the reported range was from 5 to 20 years with 20 years being the most often reported lifetime.
Repeater Stations/Huts. Likewise, for both backup and prime power, the reported range was from 10 to 20 years with 20 years being the most often reported lifetime.
Central offices. For central offices, those that responded indicated a range of 18 to 20 years for backup power with a variety of responses pointing to no clear preference. For prime power, there was no range of values; 18 years was the most popular response.
Switching Stations. O&M costs for switching stations was consistently reported as being <0.03 cents per kWh for both prime and backup power.

Reliability:
Controlled Environmental. Reported reliability requirements for backup power varied among respondents from four 9s (53 minutes per year) to seven 9s with seven 9s being the most frequent response. For prime power, the reported range was from four 9s (53 minutes per year) to seven 9s with no clearly preferred response.

Repeater Stations/Huts. For repeater huts the range of responses was from four 9s (53 min/year) to seven 9s with six 9s being the most frequent response. For prime power, the reported range was from four 9s (53 minutes per year) to six 9s with six 9s again being the most frequent response

Central offices. For central offices in both prime and backup power applications, the reported range was from four 9s (53 minutes per year) to seven 9s with seven 9s being the preferred response.

Switching Stations. Reliability ranges and preferred responses for switching stations was consistently four 9s.

Footprint:

Few respondents provided specific maximum footprint requirements and there was no repeated response value among participants' answers. Those that did respond provided a variety of responses.

Controlled Environmental Vaults. Reported range of values included 8 m^3, varies by site, 1m^3 and 24 m^3 were responses for this facility type.

Repeater Stations/Huts. For repeater huts the range of responses was varies by site, 2 m^3, 16 m^3, 24 m^3.

Central offices. For central offices in both prime and backup power applications, the reported range was from 8 m^3 to 40 m^3.

Switching Stations. For switching stations, the variety of footprint responses included varies by site, from 147 m^3 to 40 m^3.

Typical Operation Conditions:

Controlled Environmental Vaults. Reported range for backup and prime power was -35 to 40 °C, with 25 to 40 °C the most reported.

Repeater Stations/Huts. Reported range for backup power was -35 to 40 °C, with 25 to 40 °C the most reported. For prime power the same -35 to 40 °C range was reported with no popular response.

Central offices. Reported range for backup and prime power was -35 to 40 °C, with 15 to 25 °C the most reported.

Switching Stations. For switching stations, both backup and prime power responses were in the -35 to 40 °C range with no clear popular response for either application.

Efficiency:

Controlled Environmental Vaults. Reported range for backup power was >55% with the same value being the most popular response. Prime power efficiency was reported with 55 to 65% range and the same 55 to 65% range was the most popular response.

Repeater Stations/Huts. Reported range for both backup and prime power was <35 to <65% with no single value being the most popular response in either application.

Central offices. Reported range for both backup and prime power was <35 to <65% with no single value being the most popular response in either application.

Switching Stations. Reported range for both backup and prime power efficiency requirements for switching stations was <35 - <65 with no single value being the most popular response in either application.

Emissions:
In all cases and all applications for all facilities, respondents reported emissions "at regulatory threshold." No respondent indicated "well below regulatory threshold."

Willingness to Adopt PEM Fuel Cells

During follow-up interviews, the respondents indicated they would consider PEM fuel cells as an alternative source of backup power, if the technology met their user requirements. One interviewee indicated that while his company did not currently have any fuel cells in place, they hoped to have some in place by year's end. Another respondent said that they had looked at a number of very large fuel cells (250 kW+) but said their operations were in states where electricity was cheap so fuel cell cost just could not compete at this time. A third respondent indicated his company has tested and is employing fuel cells, but that most new technologies were not considered reliable enough to adopt at this time. That said, the interviewee thought fuel cells would be the future of power supply. There was less interest in fuel cells for prime power in this sector, largely due to the overall reliability and inexpensive cost of the grid power. There was a definite interest in adopting PEM fuel cells for backup power provided they met the reliability requirements.

Key Decision Factors

The telecommunication companies were asked to indicate what factors they believed would ultimately drive the adoption of new energy technologies in the financial services sector. Respondents were asked to rate their importance on a scale from 1 to 5, with 1 being not important and 5 being very important to businesses in the telecommunications sector. Table D-3 below summarizes the median response from the five survey participants. *Reliability, Capital Cost,* and *Codes and Standards* received the highest median responses. *Cost of Maintenance* also received the highest ranking of 5, but it was also an added category provided by only one respondent where asked to note *Other* critical decision factors. A number of respondents had indicated during the follow-up interviews that the telecommunications industry had codes and standards to be followed as guidance, so that highly ranked factor was not a surprise. The highly ranked responses on *Reliability* and *Capital Cost* make logical sense and were also reinforced in the later follow-up interviews. When survey participants were asked during follow-up interviews to identify the most important factor to potentially open the door for new energy technologies in this market sector, most respondents again pointed to *reliability* and *cost*.

Table D-3. Decision factors driving adoption of new technologies in telecommunications sector.

Decision Factor	Company					Median	Mean
	1	2	3	4	5		
Size of Unit	4	4	5	3	5	4	4.2
Capital Cost	5	5	5	5	3	5	4.6
Cost of Installation	5	5	3	4	3	4	4
Reliability	5	5	5	4	5	5	4.8
Total Lifetime	5	4	4	4	5	4	4.4
Efficiency	5	3	3	4	5	4	4
Durability	5	4	4	4	5	4	4.4
Low Emissions	5	4	1	3	4	4	3.4
Ease of Use	5	3	4	4	4	4	4
Scalability	5	4	3	2	--	3.5	3.5
Safety/Perceived Risk	5	5	4	3	4	4	4.2
Availability of Incentives	5	4	1	1	--	2.5	2.75
Environmental Regulations	5	3	3	2	5	3	3.6
Codes and Standards	5	5	3	2	5	5	4
Disposal Cost/Recyclability	5	3	1	3	3	3	3
Other: Cost of Maintenance	--	5	--	--	--	5	5

APPENDIX E:

HOTEL MARKET SURVEY FINDINGS

HOTEL MARKET SURVEY FINDINGS

Industry Overview

The hotel sector was the third of three sectors initially analyzed by the Battelle team to better understand user requirements for PEM fuel cell systems. This market segment was selected for analysis for two primary reasons:

- Pre-existing application of fuel cells – A few fuel cell projects have been demonstrated in the hotel sector and several others are underway. In 2002, Starwood Hotels & Resorts deployed two molten carbonate fuel cells in grid parallel applications. IdaTech is currently partnering with Marriott International (with the support of a US DOE grant) to field test its 50 kW system in CHP applications. And, FuelCell Energy is partnering with Starwood to deploy 250 kW direct fuel cells in San Diego by the end of this year. This activity suggested that hotels might be willing early adopters.
- Market size and growth potential.

Industry Size and Growth

In 2000, there were 53,500 lodging properties in the U.S., generating $108.5 billion in sales each year.[102] This figure represents steady growth from a low point in the early 1990s through 2000, when the industry posted record pretax profits of $23 billion, up 9% from 1999 and double the level in 1996.[103] However, profits fell to $16.7 billion in 2001, reflecting the impact of the September 11 terrorist attacks on leisure travel in the United States. Profits of $17.2 billion were expected for 2002.[104]

Other indicators of lodging industry market power are occupancy rate and revenue per available room (RevPAR). The occupancy rate averaged 66.2% in 2001, a 7.5% drop from the previous year, and was expected to average 61.3% in 2002, which is lower than the rate in all but 14 of the previous 75 years.[105] RevPAR was forecast to decrease from $50.83 in 2001 to $49.68 in 2002; the industry high of $55 was reached in 2000.[106]

The hotel sector is included within the "Arts, entertainment, recreation, accommodation, and food services" industry. The GDP of the accommodation segment of that industry was $93.2 billion in 2003. As illustrated in Tables E-1 and E-2 below, growth in the accommodation industry, as well as the industry's contribution to total GDP, slowed significantly in 2001 but has since begun a slow recovery.

[102] See reference 49.
[103] See reference 1.
[104] See reference 49.
[105] Hanson, B. Quarterly Lodging Forecast Update. As cited in reference 49.
[106] See reference 49.

Table E-1. Gross domestic product of the accommodation industry, 1998-2003 ($ billions).

	1999	2000	2001	2002	2003	2004
Total Gross Domestic Product , $	8,747	9,268.40	9,817	10,128	10,487	11,004
Industry Percent of Total GDP	0.89%	0.91%	0.92%	0.86%	0.86%	0.85%
Total Accommodation Industry, $	78.07	84.30	90.67	87.49	90.48	93.21

Table E-2. Accommodation industry vs. total U.S. gross domestic product growth, 1998-2003 ($ billions).

Year	Total U.S. gross domestic product	Percent change from prior year	Accommodation	Percent change from prior year
1998	$ 8,747.00	N/A	$ 78.07	N/A
1999	$ 9,268.40	6.0%	$ 84.30	8.0%
2000	$ 9,817.00	5.9%	$ 90.67	7.6%
2001	$10,128.00	3.2%	$ 87.49	-3.5%
2002	$10,487.00	3.5%	$ 90.48	3.4%
2003	$11,004.00	4.9%	$ 93.21	3.0%

Relevant Industry Trends

New construction and remodeling/renovation activities may have an impact on energy use in the hotel sector. The hotel sector added 3.5 million new rooms between 1998 and 2000, approximately 1 million more than in the previous 20-year period. However, the slump experienced by the industry in 2001 put many new construction projects on hold. Approximately $127 billion were spent on hotel construction in 2002, down over 12% from the previous year.[107] Another trend that has emerged in the past two decades is the inclusion or expansion of spa facilities and fitness club space in both new and existing facilities. The percentage of hotels featuring fitness centers has risen from 36% in 1988 to 48% in 1998.[108]

Hotels have also begun to invest in features that appeal to technology-savvy travelers. Many hotels now provide high-speed internet access in all guest rooms. Some facilities feature even more technologically advanced amenities, such as a flat screen-computer and a printer/copier/fax machine in every guest room.[109]

Examples of renovation and remodeling activities include re-roofing, installation of new windows, and replacement of energy equipment.

[107] See reference 49.
[108] See reference 49.
[109] Parets, R. T. 2001. The Big Tech Bet. Lodging Magazine. As cited in reference 49.

Current Industry Energy Use

Energy Consumption

Centrally managed hotel chains spend approximately 8% of their annual operating budgets on energy, incurring an average annual energy bill of $97,300 per property. Of the total energy expenditure, an average of 63% is spent on electricity, while an average of 16% is spent on fuels.[110]

The most recent DOE figures indicate that buildings with the principal activity of lodging consumed 450 trillion Btu of energy in 1999. This figure represents 7.8% of total energy consumption by commercial buildings.[111] Among commercial building types, lodging facilities ranked third in (gross) intensity of energy use when ranked on a Btu-per-building basis but seventh when ranked on a Btu/ft^2 basis.[112]

Current Mode of Operation

The major electric loads supported by lodging facilities include heating, ventilation, and air conditioning (HVAC), lighting equipment, laundries, elevators, and food service operations.[113]

Many large hotel establishments use diesel generator sets to provide emergency backup power in case of power outages. Some use UPS's to provide computers and critical facility control systems, such as emergency lights and alarms, in outage situations. A survey of hotel energy managers indicated that a backup unit that could also serve as a peak-shaving device would be attractive to them.[114]

Analysis of Survey Results: Market Requirements for PEM Fuel Cells

Survey Participants

Eight hotels have participated in the survey out of approximately 40 hotels that were invited to contribute. Many of the hotels contacted did not have ready access to specific energy usage information and indicated the collection of that information would be a daunting task. This, along with the fact that many of the contacts had little knowledge of fuel cells, is believed to be a key factor in the low survey response rate for this sector.
Respondents included:

- Bally's Las Vegas
- The Wynn (Las Vegas)
- Choice Hotels International
- Carlson Hotels Worldwide
- Seattle Marriott
- Fairmont Hotels and Resorts Inc.

[110] The Hospitality Research Group of PKF Consulting, as cited in reference 49.
[111] See reference 29.
[112] See reference 49.
[113] See reference 49.
[114] See reference 49.

- Fairmont Hotel franchise in Scottsdale, AZ
- Fairmont Hotel franchise in Vancouver, BC, Canada.

An overview of each hotel is provided below. Because the majority of hotels surveyed are franchises, they may not provide a complete representation of the hotel industry.

Bally's: Parent is Caesars Entertainment: engaged, through subsidiaries, in the ownership, operation and development of gaming facilities.

The Wynn Las Vegas: The Wynn Las Vegas is a wholly-owned indirect subsidiary of the Wynn Resorts.

Choice Hotels International, Inc.: Choice is a hotel franchisor of lodging properties under the brand names Comfort Inn, Comfort Suites, Quality, Clarion, Sleep Inn, Econo Lodge, Rodeway Inn, MainStay Suites, Cambria Suites and Flag Hotels.

Carlson Hotels Worldwide: Hotel franchiser; parent company is Carlson Holdings.

Seattle Marriott: Franchise of Marriott International. Marriott is a worldwide operator and franchisor of hotels and related lodging facilities, an operator of senior living communities, and a provider of distribution services.

Fairmont Hotels & Resorts Inc.: Manages a global portfolio of luxury and first-class hotels and resorts. The properties are located in Canada, the United States, Mexico, Bermuda, Barbados and the United Arab Emirates.

As indicated, many of the hotels surveyed operate multiple facilities. In some cases, franchise hotels do not own the hotels under their brands and it is the owners' responsibility to build in accordance with design and construction standards, so a holistic view is difficult to provide. (Each franchise would need to be surveyed.)

Power Outages

Interviewees were asked how disruptive a power outage would be to their business operations in terms of financial impact. Six of the hotels that answered this question all indicated that that a power outage would result in a high impact, especially if it was for a long duration.

Backup Power

All of the hotels have backup power. However, one hotel pointed out that backup power requirements vary by type and location of hotel. For example a hotel in a major city will have an emergency generator to take care of basic emergency requirements. It is assumed power will be restored in a short time. In remote resort locations, such as Mexico, they would have 100% backup power available through generators.

Generally, diesel generators are used for backup power. One hotel has 7 diesel generators at 1,800 kW each. Another hotel has five diesel generators: four are 1000 kW, one is 500 kW. Yet

another hotel uses a 450 kW generator. Again, the size of the generator varies by location. One hotel indicated the minimum requirement for backup power (lowest possible acceptable standard) is to support life safety systems, fire services, emergency lighting, information technology systems, refrigeration systems, and ventilation systems.

Six of the hotels also use batteries or a UPS. (Two of the hotels surveyed did not answer this question.)

The sense gained from discussions is that the backup power systems currently used are adequate for the most part, with UPS used for critical systems (life safety systems/emergency). However, one respondent indicated it would be good to have sufficient backup power to run the critical systems in addition to a kitchen, a few refrigerators, one freezer, and one large meeting room for a period of 72 hours.

Size: Survey participants indicated that a fuel cell would need to be in the 150 to 250 kW range for backup power. One respondent indicated the same requirements for prime and CHP.

Total capital cost: Only one respondent answered this question indicating a requirement of $300 to 600 per kW.

Installation cost: The respondent that answered this question indicated that installation cost for backup power would need to be $2,000 to $3,000.

Operations & Maintenance (O&M) Costs: Two respondents answered this question. One indicated that O&M cost for backup power would need to be $0.05 to 0.07 per kWh while the two other respondents indicated that less than $0.03 per kWh would be required.

Lifetime: Two respondents required a minimum lifetime of 10 years for a fuel cell used for backup power, with one requiring 20 years for prime power and another 15 years. Another required 20 years for backup power.

Reliability: One survey participant indicated that seven 9s reliability (i.e., 3 seconds per year) would be the minimum requirement for a new backup energy technology and five 9s reliability (i.e., 5 minutes per year downtime) for prime and CHP. One of the respondents required five 9s of reliability for backup power and another required four 9s of reliability.

Footprint: One company specified a maximum footprint of 125 cubic feet (3.54 m^3), while two others required a maximum of 100 to 200 square feet and 200 to 300 square feet for backup, prime, and CHP applications, respectively.

Typical Operation Conditions: One hotel described typical operation conditions as 25 to 40 ºC for backup, prime and CHP applications, while another required 15 to 25 °C.
Emissions: Two hotels required their backup power source be "well below the regulatory threshold."

Willingness to Adopt PEM Fuel Cells

Respondents were asked whether their company would seriously consider a PEM fuel cell as a backup or prime power source. Four said they might consider PEM fuel cells as an alternative power source. One hotel specifically stated they would not have an appetite for anything new unless it was clearly beneficial to their bottom line at the construction stage and probably would not necessarily embrace a higher initial cost for a longer life or lower operating cost. Many of the design and construction practices in the extended stay and select brand hotels follow the best practices of the residential home building industry.

Another hotel had an opportunity through Seattle City Light to install IR temperature sensors at a total cost of $300,000 with a $150,000 rebate. It was projected that the savings would be $30,000 per year and yet management was unwilling to participate. Similarly, another hotel was willing to invest $30M to put in a 30 megawatt cogeneration system with a 12-year payoff, but when the power company negotiated lower rates, the project was dropped. One interviewee explained they have heard of fuel cell systems but understand that at this point they are still more expensive to purchase and operate. They believe the best scenario would be to use it for base loading and heating/absorption cooling, but in area where rates are high and the current supply is not reliable. This may provide an indication of the likelihood of early adoption of fuel cells in the hotel industry.

Key Decision Factors

The hotels were asked to indicate what factors they believed would ultimately drive the adoption of new energy technologies in their sector. Table E-3 below summarizes the mean response from the four survey participants who responded to this question. *Capital Cost, Cost of Installation,* and *Efficiency* had the highest mean responses.

Table E-3. Decision factors driving adoption of new technologies in the hotel industry.

Decision Factor	Company				Median	Mean
	1	2	3	4		
Capital Cost	5	5	5	5	5	5.0
Cost of Installation	5	5	5	5	5	5.0
Efficiency	5	5	5	5	5	5.0
Reliability	5	5	4	5	5	4.8
Total Lifetime	5	5	4	4	4.5	4.5
Low Emissions	4	5	5	4	4.5	4.5
Scalability	5	5	4	4	4.5	4.5
Environmental Regulations	4	5	5	4	4.5	4.5
Safety/Perceived Risk	4	5	4	5	4.5	4.5
Ease of Use	4	5	4	5	4.5	4.5
Availability of Incentives	3	5	5	4	4.5	4.3
Code and Standards	3	5	4	5	4.5	4.3
Disposal Cost/Recyclability	3	5	4	4	4	4.0
Size of Unit	4	5	2	4	4	3.8

APPENDIX F:

ENGINEERING COST ANALYSIS – ASSUMPTIONS AND COMPONENT CLASSIFICATION SYSTEM (CCS)

ENGINEERING COST ANALYSIS – ASSUMPTIONS AND COMPONENT CLASSIFICATION SYSTEM (CCS)

Each component within the PEM fuel system was given a CCS number corresponding to a primary and secondary driver of manufacturing processes that are applicable.

- The primary drivers of manufacturing processes are
  - Function of Output Power or
  - Function of Production Volume.

- The secondary drivers of manufacturing processes are
  - Fuel Cell Unique or
  - Non-Fuel Cell Unique.

The following nomenclature was used as the baseline classification system:

- CCS 1 Function of Output Power – Fuel Cell Unique
  - Example: MEA, Fuel Cell Stack, Membrane Separator

- CCS 2 Function of Output Power – Non-Fuel Cell Unique
  - Example: Steam Reformer, Heat Exchanger, Water Mgmt System

- CCS 3 Function of Production Volume – Fuel Cell Unique
  - Example: Specific performance characteristics (pumps, sensors)

- CCS 4 Function of Production Volume – Non-Fuel Cell Unique
  - Example: Housings, Radiators, Blowers, Controls

- CCS 5 Function of Production Volume – Commodities
  - Example: Misc, Components, Valves, Piping, Safety Sensors

Components were designated CCS 1 through 5 based on literature review and general engineering knowledge based on hands-on product development, and interviews with manufacturers, component makers and researchers. Each CCS designation corresponds to a specific scaling factor also developed via literature review and hands-on product development experience as a calculated function of estimated/actual single-component costing (Table F-1).

Table F-1. Scaling factors as a % of single component costing.

Annual Production Volume	CCS 1	CCS 2	CCS 3	CCS 4	CCS 5
1,000	0.84	0.23	0.23	0.44	0.53
10,000	0.48	0.17	0.18	0.31	0.40
100,000	0.46	0.15	0.16	0.27	0.35
500,000	0.43	0.13	0.13	0.20	0.25

The following graphs (Figures F-1 to F-5) depict each Component Classification on a logarithmic scale of units of production versus Scaling Factors as a function of single component costing.

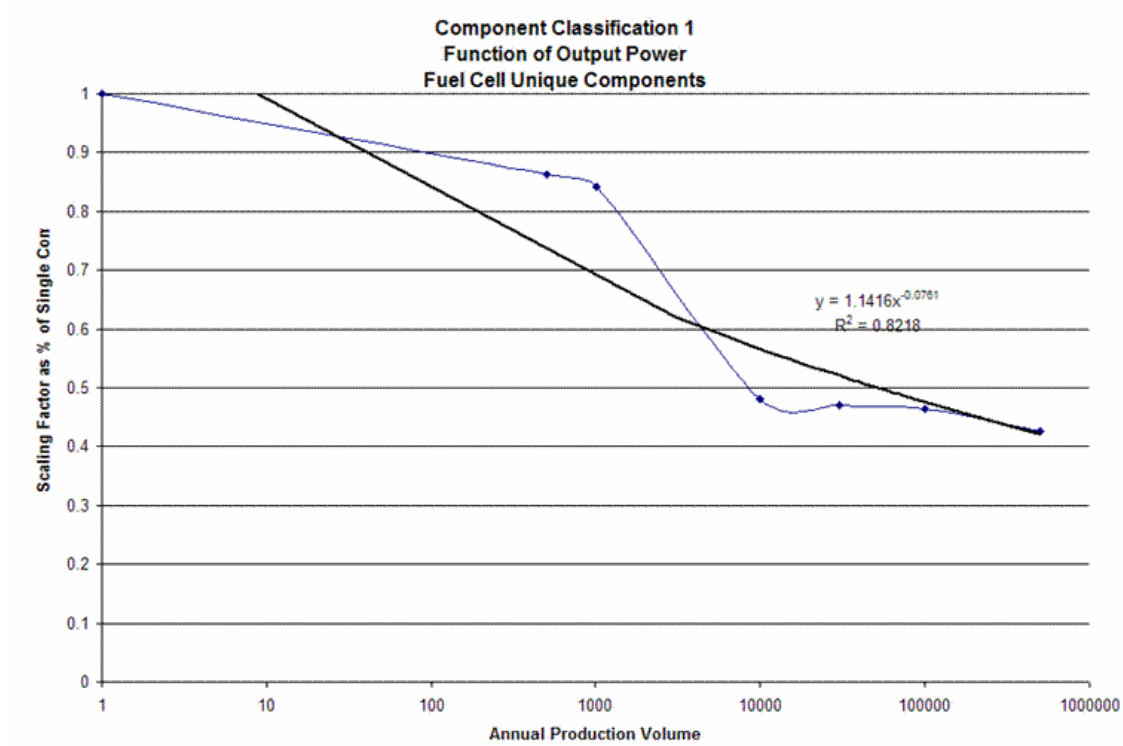

Figure F-1. Component classification 1, fuel cell unique components - function of output power.

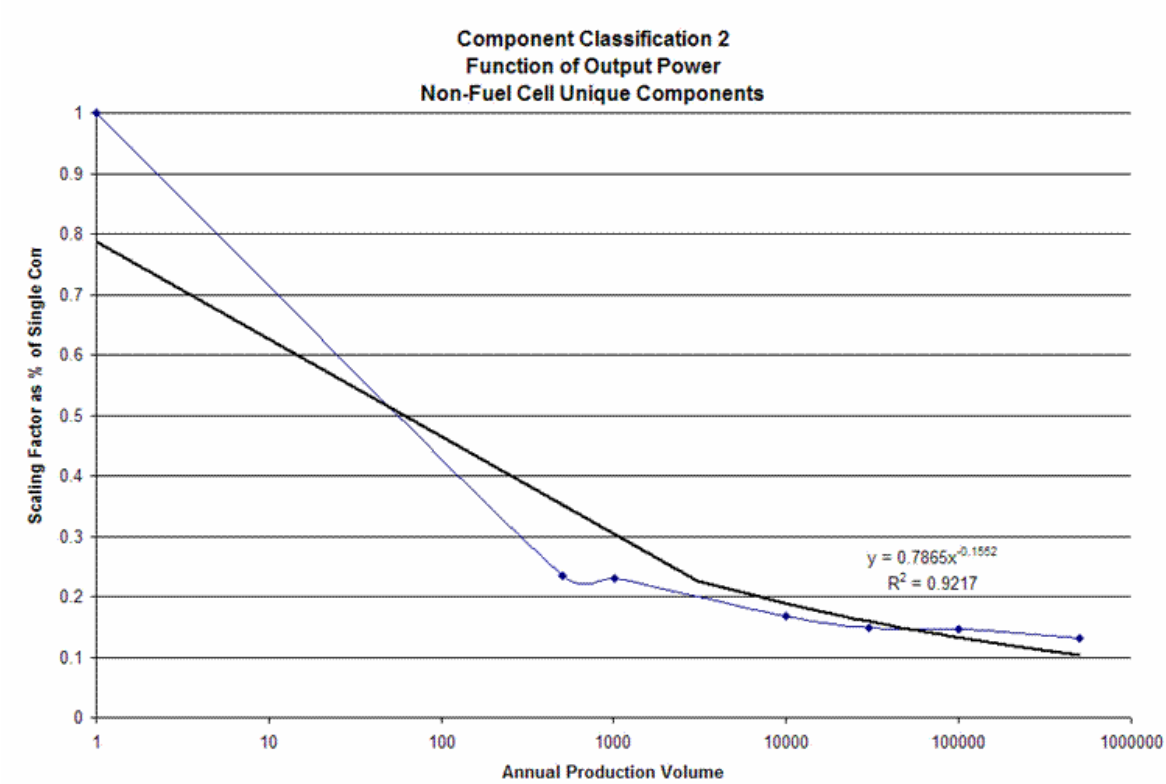

Figure F-2. Component classification 2, non-fuel cell unique components– function of output power.

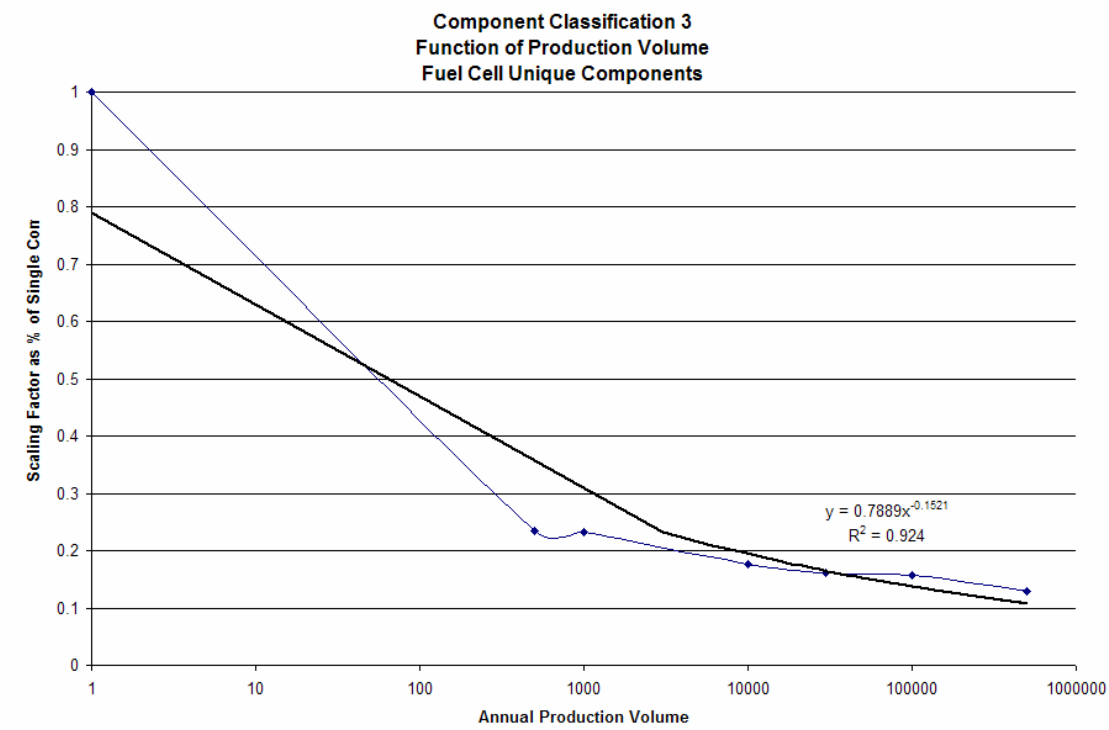

Figure F-3. Component classification 3, fuel cell unique components – function of production volume.

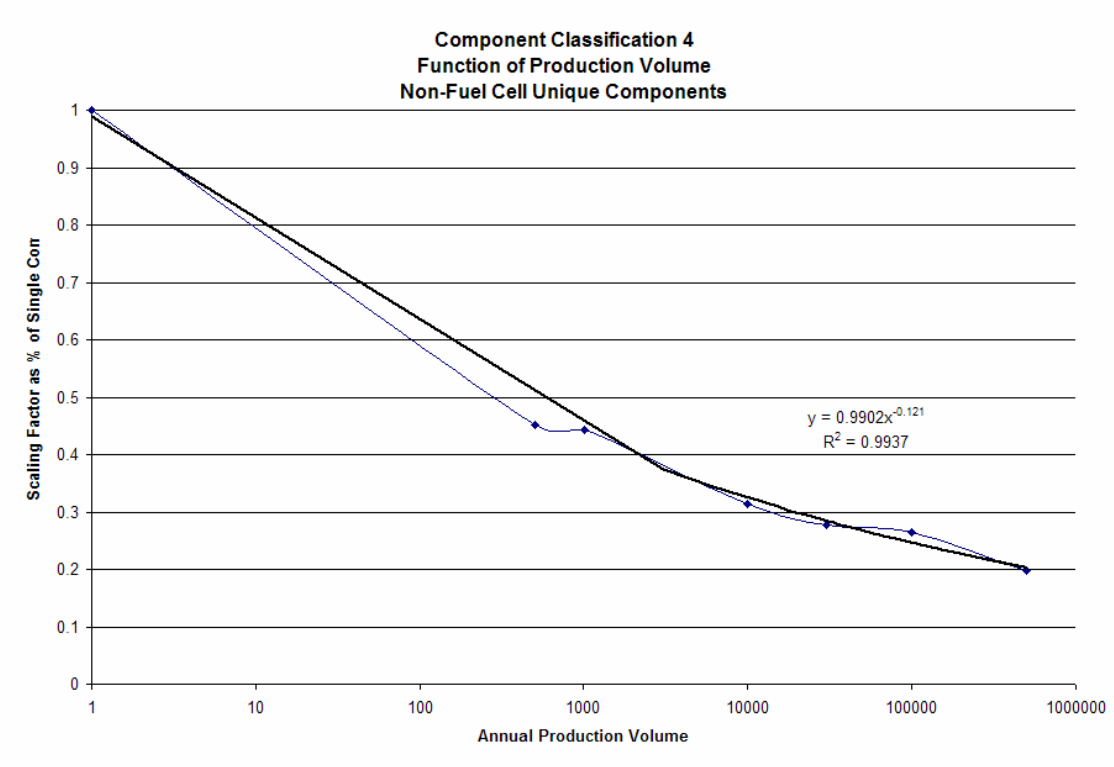

Figure F-4. Component classification 4, non-fuel cell unique components - function of production volume.

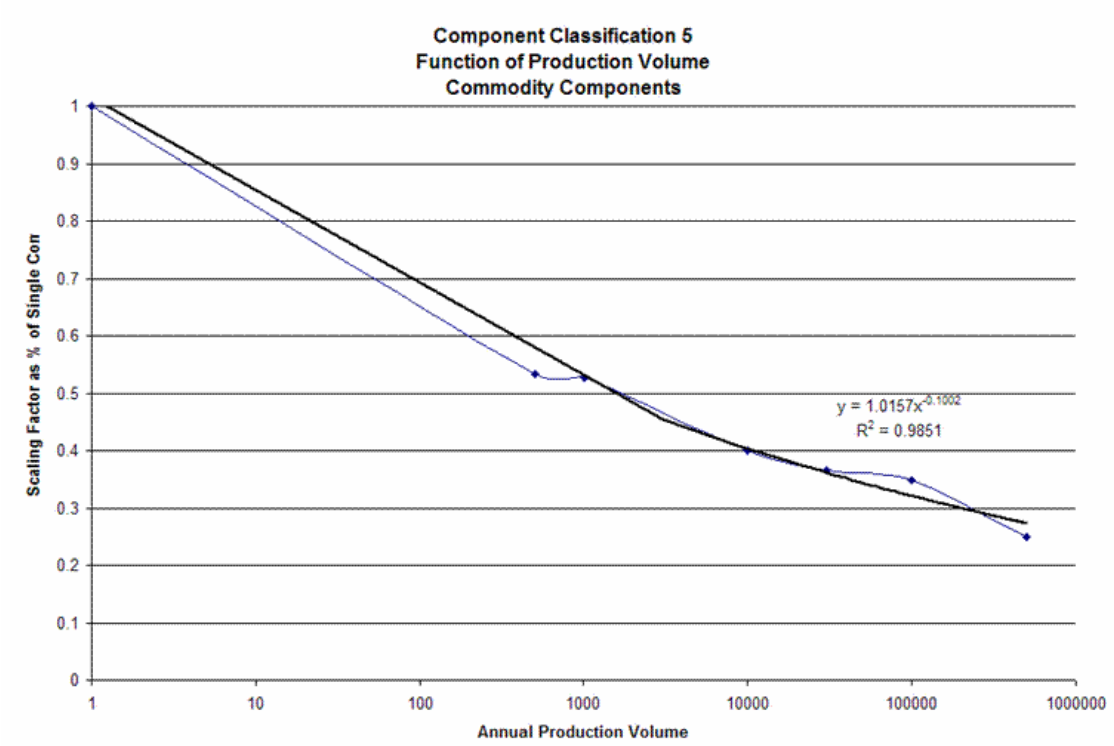

Figure F-5. Component classification 5, function of production volume – commodity components.

F.1 Definitions Of Subsystems And Components

The four major subsystems defined for both of the fuel cell systems (propane reformer and direct hydrogen) are as follows:

1. Hydrogen Delivery – 99.99% hydrogen is delivered to the fuel cell for both systems. Source of hydrogen is assumed to be K cylinders of ultra pure hydrogen (UPH) for the 5 kW direct hydrogen system while the 50 kW reformer based system includes a propane fueled steam reformer with palladium membrane separator for hydrogen cleanup.

2. Fuel Cell System – PEM fuel cell. Fuel cell may run dead ended with a timed purge to remove excess water and unreactive gases. The fuel cell stack is assumed to incorporate hydrogen recirculation for water management and less frequent purging.

3. Power Electronics & System Integration – Electronic controls and 90% efficient conversion of DC electrical power from the fuel cell to AC.

4. System Assembly – The fuel cell, hydrogen delivery, and power electronics are manufactured as individual subsystems. These are electrically and mechanically joined together and inspected.

F.1.1 Hydrogen Delivery System

The Hydrogen Delivery System for the reformer based system is divided into five additional subsystems. Details of these subsystems and several of the ancillary components are shown below:

1. Fuel Delivery System – delivers up to 12 kg/hr liquid propane at 250 psi to the steam reformer.
    a. The fuel pump with its associated electric drive motor provides the high differential pressure required by the system. The propane is assumed to be stored at approximately 50 psi and filtered with a 10 micron filter before going to the pump. The pump is assumed to be a stainless steel positive displacement gear pump with variable speed.
    b. A flow meter is used to monitor the flow of propane and help ensure that the appropriate steam to carbon ratio is maintained.

2. Water Delivery System – delivers up to 45 kg/hr water at 300 psi to the vaporizer in the reformer system.
    a. The water pump with its associated electric drive motor provides the high differential pressure required by the system. The water is recovered in the system from the exhaust of the reformer and the water produced in the fuel cell. It is filtered through a 10 micron filter before entering the pump. The pump is assumed to be a stainless steel positive displacement gear pump with variable speed.
    b. A flow meter is used to monitor the flow of water and ensure that the appropriate steam to carbon ratio is maintained.

3. Main Coolant Management System – provides the necessary cooling of the hydrogen out of the separator, the power electronics, the condenser, and the fuel cell stack.
    a. The condenser is sized to recover the water in the exhaust from the fuel cell and the reformer. The heat duty is assumed to be 120 kW. The condenser is assumed to be a tube and shell design.
    b. The main coolant pump with its associated electric drive motor provides the necessary flow for the coolant (likely to be propylene glycol and water mix) through the coolant loop. The pump is assumed to be a thermoplastic centrifugal pump rated for up to 75 °C.
    c. The radiator is sized to reject 120 kW of heat with ambient air as high as 40 °C. The radiator is a liquid/gas heat exchanger with fans providing the air flow.
    d. The fuel cell stack is cooled with DI water by means of a separate coolant pump. The heat from the DI loop is removed via a heat exchanger with the main coolant loop.

4. Steam Reformer – converts the propane and water into hydrogen rich reformate to be delivered to the membrane separator. Heat for the reaction is supplied by burning the retentate (after hydrogen extraction) delivered from the membrane separator.
    a. The inputs to the steam reformer are the fuel (liquid propane) and water.
    b. The reformate stream out of the steam reformer is composed of approximately
       – 45% [H_2] – 35% [H_2O] – 10% [CO]
       – 8% [CO_2] – 2% [CH_4]
    c. The fuel reforming process operates at temperatures as high as 900°C. The reformer burns fuel from the retentate stream and air in a catalytic combustor to achieve these temperatures. The combustion blower is sized to provide 2800 SLPM air flow with a pressure drop of approximately 2 psi for this process.

5. Hydrogen Cleanup – the palladium membrane separator is sized to achieve 75% recovery of the hydrogen in the reformate stream.
    a. The palladium membrane provides permeate (99.99% hydrogen and less than 10 ppm CO) to the fuel cell. A pressure regulator maintains the pressure of the hydrogen to the fuel cell between 2 and 10 psi. The flow rate of hydrogen to the fuel cell is approximately 750 SLPM for 50 kW. The permeate stream is cooled by a heat exchanger sized to provide hydrogen at approximately 55°C to the fuel cell.
    b. The retentate (remaining hydrogen and other gases) is sent back to the reformer for combustion to provide heat for the endothermic reforming reaction. The palladium membrane separator operates at approximately 350°C and 250 psi.

Individual components in the hydrogen delivery system and their corresponding CCS numbers are presented in tables F2 to F6.

Table F-2. Fuel delivery subsystem individual components and corresponding CCS number.

Fuel Delivery Systems	CCS Number
Fuel Tank	4
Level Sensor	5
Fuel Tank Petcock	5
In-line Fuel Filter	5
Fuel Shut-off Valve	5
High Pressure, Low Flow Fuel Pump	3
Flow Meter	4
Fuel Check Valve	5
Assembly, Fuel Mgmt System	

Table F-3. Water delivery subsystem individual components and corresponding CCS number.

Water Delivery Systems	CCS Number
Water Tank	4
Level Sensor	5
Water Filter	5
Water Filter Holder	5
High Pressure, Low Flow, DI Water Pump	3
Flow Meter	4
Water Check Valve	5
Assembly, Water Delivery System	

Table F-4. Main coolant management subsystem individual components and corresponding CCS number.

Main Coolant Management Systems	CCS Number
Condenser	4
Hydrogen Cooler	2
Main Coolant Pump	5
Radiator	5
Radiator Fans	5
Radiator Assembly Components	3
Re-Circulation Drain Valve	4
Exhaust	5
Assembly, Water Mgmt System	

Table F-5. Steam reformer subsystem individual components and corresponding CCS number.

Steam Reformer Subsystem	CCS Number
Retentate Pressure Regulator	4
Retentate Throttle Valve	4
Retentate Relief Valve	5
Reformate Recuperator	1
Reformer w/ Integrated Reactor	1
Combustor	2
Combustor Air Filter	4
Thermocouple, Reformer	5
Thermocouple, Combustor	5
Fuel / Air Mixer	2
Thermocouple, Fuel / Air Mixer	5
Vaporizer	2
Air Recuperator	2
Thermocouple, Air Recuperator	5
Combustor Blower	3
Resistance Electric Preheater/Starter	5
Fuel / Steam Mixer	4
Insulation	5
Assembly, Steam Reformer	

Table F-6. Hydrogen cleanup subsystem individual components and corresponding CCS number.

Hydrogen Cleanup	CCS Number
Palladium Membrane Separator	1
Membrane Pressure Transducer	5
Membrane Preheater	5
Assembly, Hydrogen Cleanup	

F.1.2 Steam Reformer Manufacturing Assumptions

A Design for Manufacture and Assembly (DFMA) Analysis was conducted using Boothroyd Dewhurst® DFMA software and the additional software module DFM Concurrent Costing® to provide actual and simulated manufacturing data based on modeling information.

DFMA modeling was developed for the following five specific components within the steam reformer subsystem:

- Reformer with Integrated Reactor,
- Combustor,
- Fuel/Air Mixer,
- Vaporizer, and
- Air Recuperator.

Each above element of the steam reformer assumed a construction using sheet architecture design consistent with high-volume manufacturing processes such as photochemical etching, metal stamping for shim formation, and an existing bonding process such as diffusion bonding or brazing (if applicable) for reactor formation.

Material selection for the DFMA analysis of the major components of the steam reformer system was based on the working temperature and pressure requirements for the above elements of the Steam Reformer system. Hastelloy was selected as the high-temperature resistant alloy equivalent to be an estimated 10x more expensive than standard grade stainless steels within the DFM® Concurrent Costing model. Alternatively, 316L stainless steels were selected for the vaporizer and air recuperator subsystems as appropriate for the working temperature and pressure requirements.

F.1.3 Fuel Cell System

The Fuel Cell System is divided into 5 major subsystems:

1. Fuel Cell Stack,
2. Fuel Cell Stack Water Recovery System,
3. Anode Side Support Hardware,
4. Cathode Side Support Hardware, and
5. Cooling System.

The Fuel Cell Stack is composed of the MEA purchased as a fully assembled unit from a designated manufacturer (outlined) components, plus additional required components (Table F-7). The fuel cell subsystem and their individual components and corresponding CCS numbers are presented in tables F-7 to F13.

Table F-7. Membrane electrode assembly individual components and corresponding CCS number.

Membrane Electrode Assembly	CCS Number
Ion Exchange Membrane	1
Membrane Substrate	1
Gas Diffusion Layer	1
Catalyst Layer (Anode & Cathode)	1
Gasket/Seals	1
Bipolar plates	1
Tie Rods	1
Insulators	1
End Plates	1
Current Collectors	1
Stack Housing	1
Stack Voltage Monitor	4
Assembly, Fuel Cell Stack	

Table F-8. Fuel cell stack water recovery subsystem individual components and corresponding CCS number.

Fuel Cell Stack Water Recovery System	CCS Number
Condenser	2
Radiator	5
Assembly, Fuel Cell Stack Water Recovery System	

Table F-9. Anode side support subsystem individual components and corresponding CCS number.

Anode Side Support Hardware	CCS NUMBER
Hydrogen Pressure Regulator	5
Hydrogen Shut-off Valve	5
Diaphragm Recirculation Pump	4
Recirculation Pump Assembly Components	4
Water Trap System	5
Recirculation Drain Valve	5
Anode Pressure Relief Valve	5
Purge Valve	5
Assembly, Anode Side Support Hardware	

Table F-10. Cathode side support subsystem individual components and corresponding CCS number.

Cathode Side Support Hardware	CCS Number
Fuel Cell Cathode Humidifier	2
Check Valve	5
Cathode Air Blower	4
Cathode Air Filter	3
Assembly, Cathode Side Support Hardware	

Table F-11. Cooling subsystem individual components and corresponding CCS number.

Cooling Subsystem	CCS NUMBER
DI Coolant Pump	4
DI Filter	5
DI Coolant Relief Valve	5
Coolant Port Adaptor	5
Radiator	5
Heat Exchanger	2
Flow Restrictor	5
Assembly, Cooling System	

Table F-12. Power electronics subsystem individual components and corresponding CCS number.

Power Electronics	CCS Number
Master Controller	4
Pre-heater Relay Control	5
Blower Interface	4
Buss Bar	5
Power Module Bracket	5
Cold Plate	5
Power Module	4
Inverter, DC to AC	3
Connection Box	5
Voltage and Current Sensor	5
Assembly, Power Electronics System	

Table F-13. System integration subsystem individual components and corresponding CCS number.

Systems Integration	CCS Number
Frame Structure	4
Levelers	5
User Interface Module	4
CO/H2 Censor	4
H2 Flame Sensor/Arrestor	4
H2 Relief Valve	5
Hour Meter	4
Auxiliary Battery	4
Miscellaneous Piping, Fasteners, Etc.	5
Assembly, Systems Integration Systems	

F.2 Subassembly Cost Predictors

Estimated assembly costs of the individual subassemblies described in the above section F-1 were predicted as a function of the number of components assembled and complexity of those individual components. Factors was applied as a percentage of the overall total subassembly cost to predict assembly costs (Table F-14).

Table F-14. Assembly costs as a percentage of the overall assembly costs.

	1000	10,000	100,000
Subassembly Cost Predictor	5 %	4 %	2.5%

F.2.1 System Assembly Progress Curve

The overall system assembly process was decomposed into the following steps of major subassemblies as a logical sequence of the assembly steps to be followed:

- Sub Assembly 1: Hydrogen Delivery + Fuel Cell System
- Sub Assembly 2: Sub Assembly 1 + Power Electronics/System Integration
- Final Assembly

The next step in estimating overall system assembly costs was the assumption of uniquely defined "progress curve." These progress curves follow the transition of unit manufacturing costs from low, medium, to high-volume production as a function of two major predictors of lower manufacturing cost: the experience curve effect and economies of scale.

The experience curve effect quantifies the relationship between experience and efficiency, and in general states that the more times a task is performed the greater the efficiency, i.e., the lower the cost of completion. The National Aeronautics and Space Administration (NASA) has calculated, by statistical analysis, actual cost data for similar products and has provided in the public domain the following experience curves.

- Aerospace 85%
- Shipbuilding 80-85%
- Complex machine tools for new models 75-85%
- Repetitive electronics manufacturing 90-95%
- Repetitive machining or punch-press operations 90-95%
- Repetitive electrical operations 75-85%
- Repetitive welding operations 90%
- Raw materials 93-96%
- Purchased Parts 85-88%.

This first iteration of progress curves was designed based solely on the standard experience curve effects as provided for an industry of similar level of complexity. The aerospace industry was selected as the comparable level to the fuel cell industry in assembly complexity, and was therefore selected to be at an 85% experience curve. The resulting impact of the 85% "progress curve" predicts an estimated direct cost a unit of production will decreased by a predicted percentage, in this case 100-85 or 15% of the original level, each time the level of production quantity is doubled.

APPENDIX G:

ECONOMIC ANALYSIS:
BATTELLE EXPERT FOCUS GROUP MINUTES

ECONOMIC ANALYSIS:
BATTELLE EXPERT FOCUS GROUP MINUTES

First Expert Focus Group on Technology Analysis of the Stationary PEM Fuel Cell System

Date:	Monday, February 28, 2005
Location:	Woods Room, Battelle, Columbus, Ohio
Topic Question:	"What specific areas and types of technological progress could substantially reduce the cost of stationary PEM fuel cells?"
Method:	Brainstorming and Nominal Group Technique
Battelle Experts:	Jeffery Myers Paul George Vince Contini Holly Stein Brad Glenn Jim Saunders Bhima Vijayendran Jay Sayre
PEM Fuel Cell Project Participants:	Harry Stone Darrell Paul Kathya Mahadevan
Facilitator:	Stephen M. Millett

Responses Generated in Response to the Topic Question

1. Typical Components and Costs of Various Subsystems of PEM Fuel Cells

To answer the first part of the topic question, participants were asked to provide input to (1) typical subsystems of a PEM fuel cell and their components, (2) cost of the subsystem and its components, and (3) high cost areas within PEM fuel cells.

Drawing from Battelle's experience with development and demonstration of the fuel cell auxiliary power unit in the Bradley fighting vehicle, participants discussed the above questions relative to a membrane separator based reformer PEM fuel cell system. Schematics of fuel cell systems integrated by Battelle were used to facilitate the discussion on importance of components to cost and performance of fuel cell systems.

Participants discussed the impact of fuel quality on the engineering cost of a PEM fuel cell and identified three types of fuel cell systems - direct hydrogen, natural gas and propane based systems as standard systems that should be further evaluated for stationary applications. Participants suggested that steam reformers were more efficient, cost effective, and produced purer hydrogen streams than conventional partial oxidation or autothermal reformers.

Participants also indicated that significant commercial advances have been made to commercial steam reformers for distributed generation including the elimination of water gas shift reactors. Figure G-1 below shows a block diagram of a conventional steam reforming system, consisting of a high temperature shift (HTS), low temperature shift (LTS) and a preferential partial oxidizer. The block diagram below shows the relative size of the units in a typical commercial system.

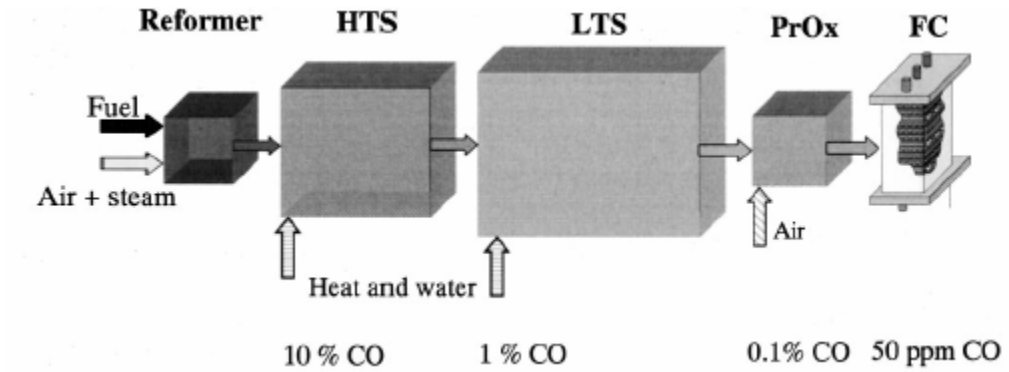

Figure G-1. Block diagram of a conventional steam reforming system.[115]

Participants discussed various ways of classifying PEM fuel cell subsystems and their components, and a consensus was reached to classify the subsystem into the following categories for all types PEM fuel cells: (1) fuel delivery system which includes fuel management systems and fuel processor (if applicable), (2) fuel cell including stack and components associated with air and water management, (3) balance of plant specifically power electronics and system integration, and (4) system assembly and installation. Participants further discussed typical

[115] Lakshmanan, B., W. Huang, J.W. Weidner. 2002. Electrochemical filtering of CO from fuel cell reformate. Electrochem, 5(12) A267-A270.

components within these various subsystems and Figure G-2 shows a schematic of the subsystems and their components identified by the participants for a typical membrane separator steam reformer based fuel cell system.

Discussions regarding cost were kept at a fairly high-level due to time constraints. Participants indicated that the commonly cited rule of thumb for fuel cell cost breakdown - 1/3 fuel processor, 1/3 fuel cell system and 1/3 balance of plant including power electronics and system assembly, was still valid, due to the limited economies of scale. They indicated that significant detail should be paid to scaling factors for their impact of costs of various components at higher production volumes. Scaling factors would differ significantly between various components and could be a function of output power, production volume, custom manufacturing unique to a fuel cells, custom manufacturing not unique to a fuel cell, and availability of components as a commodity. In addition to fuel cell system costs, for stationary application installation costs were identified as significant cost.

The participants identified the following areas of a reformer based PEM fuel cell, as specific opportunities where technological progress could affect cost of the entire system:

- Fuel Delivery System – Water-Gas Shift Reactors, Membrane Separator; Pumps For Fuel Delivery
- Stack – Electrolyte Membrane; Platinum; Bipolar Plates; Seals; Labor For Fabrication Of Stack
- Sensors – Specifically Gas Sensors
- Power Electronics

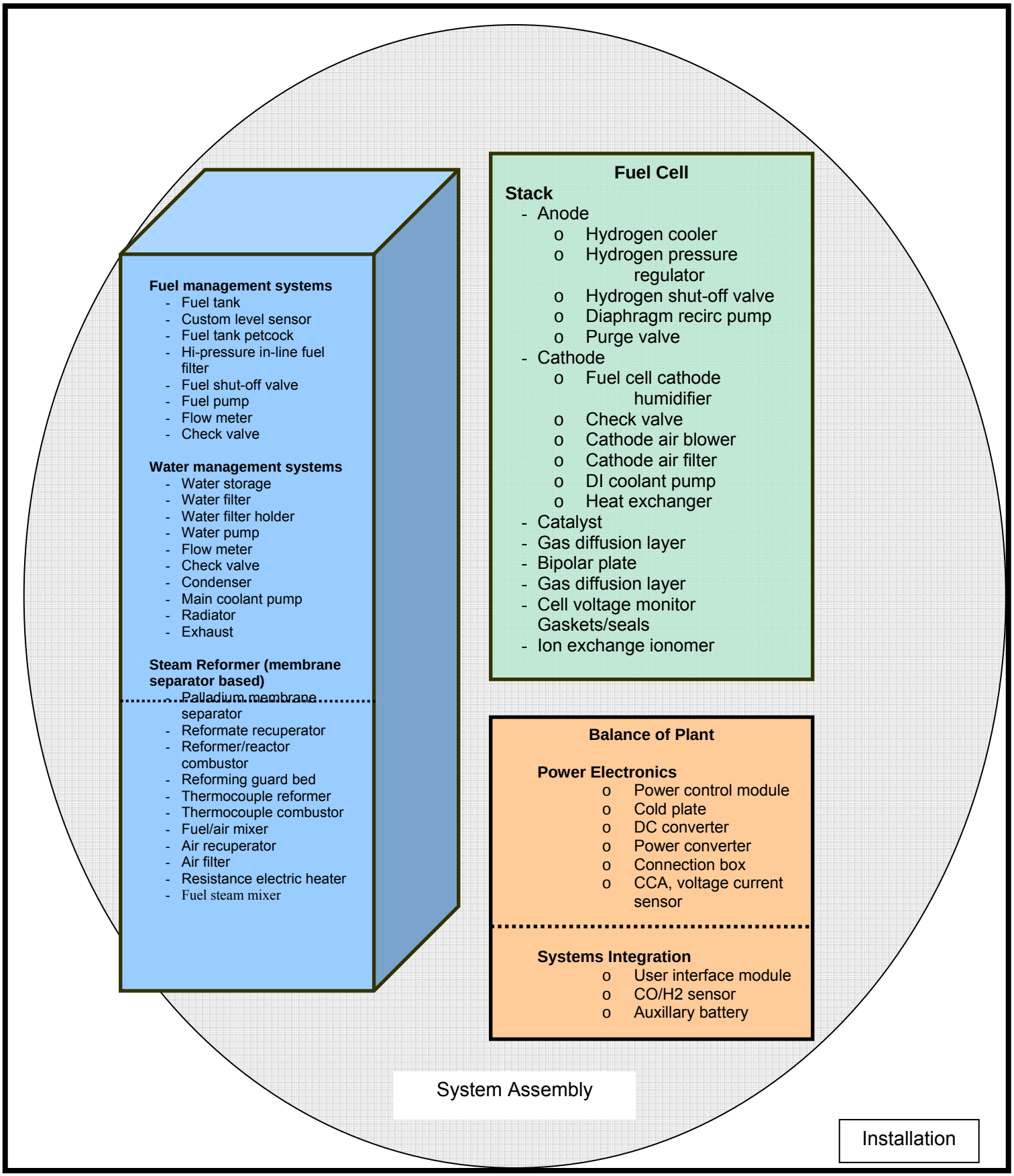

Figure G-2. Schematic of fuel cell subsystems and their components.

2. Types of Technological Progress that Could Affect the Cost of PEM Fuel Cells

To answer the second part of the topic question, participants provided the following list of 32 areas of technological progress that could significantly affect cost. Many of these areas are currently funded by the EERE. This initial listing of technological progress serves as a starting point for further examination of possible breakthrough technologies that could impact cost and other areas of R&D.

1. Cost competitive fuel cell membrane alternatives. [Cost Impact: Fuel cell]
2. Discover alternatives to precious metals for electrodes and reduce platinum loading to reduce material costs. [Cost Impact: Fuel cell]
3. Develop less expensive, including non-precious metal membrane separators. [Cost Impact: Fuel delivery system]
4. Low cost, non-corroding bipolar plate technology [Cost Impact: Fuel cell]
5. Breakthrough in pumps for fuel and water delivery; limited choices in state of the art pumps used in fuel cells. [Cost Impact: Fuel delivery and fuel cell]
6. Alternative low cost cell/stack fabrication techniques such as screen printing and other mass production methods would improve quality control and reliability. [Cost Impact: Fuel cell]
7. Improve MEA manufacturing and fabrication techniques; for example, how to apply the catalyst more effectively and achieve a higher quality using innovative coating methods. [Cost Impact: Fuel cell]
8. Improved membrane hydration controls, including but not limited to high temperature, low humidity membranes, and membranes with increased durability [Cost Impact: Fuel cell]
9. Stacks that can tolerate impurities, including carbon monoxide and sulfur; for example, this could include simplified reforming and fuel management inside the cells, such as dynamic electrodes. [Cost Impact: Fuel cell]
10. In-cell water management including efficient and effective anode recirculation schemes. [Cost Impact: Fuel cell]
11. Automated assembly for the whole system, including design for manufacture and assembly. [Cost Impact: Total cost of PEM fuel cell system]
12. Develop better method for managing steam-to-carbon ratio would reduce the number of parts currently used. This could include the development of a steam-to-carbon sensor. [Cost Impact: Fuel delivery system]
13. Recuperative humidification techniques for fuel cell cathode or anode, including recycling the water and passive humidification. [Cost Impact: Fuel cell]
14. Hydrogen storage for stationary applications. [Cost Impact: Fuel delivery system]

15. Improve power density which would reduce stack volume and cell area. [Cost Impact: Fuel cell]g

16. Improve stack reliability and durability including resistance to fuel crossover/short circuiting, efficient anode recirculation schemes for effective fuel utilization, improved mechanical properties, and longer life times. [Cost Impact: Fuel cell]

17. System simplification and system integration; for example, one blower for cell and fuel processor. [Cost Impact: Total cost of PEM fuel cell system]

18. Improve manufacturing techniques for the fuel processor, especially for steam reforming. [Cost Impact: Fuel delivery system]

19. Develop alternative gaskets/group designs and use advance sealant technologies in the membrane separator and the MEA, which would increase reliability and durability. [Cost Impact: Fuel cell]

20. Improve efficiencies through new materials, heat exchanges, thermal management, and thermal flow. [Cost Impact: Total cost of PEM fuel cell system]

21. CHP -- use waste heat for practical purposes and improve efficiency of the system. [Cost Impact: System assembly and installation]

22. Durability improvements through accelerated lifecycle testing and gaining an understanding of mechanistic parameters that affect the system, development of diagnostic tools that not only determine the heath of the stack/system, but recommend corrective actions that will alleviate premature failures. [Cost Impact: Total cost of PEM fuel cell system]

23. Equipment standards through uniform specifications. [Cost Impact: Total cost of PEM fuel cell system]

24. Improvement in sensor technology for pressure, humidity, hydrogen, carbon monoxide, steam-to-carbon ratio sensors, which will increase system reliability and efficiency. [Cost Impact: Total cost of PEM fuel cell]

25. Improve sulfur management. [Cost Impact: Fuel delivery and fuel cell]

26. Design for repair and reassembly. This is similar to designing for manufacturability but focusing on field serviceability. [Cost Impact: Total cost of PEM fuel cell system]

27. Advances in fuel supply storage, fuel quality, operating pressures. [Cost Impact: Fuel delivery system]

28. Plug and play installation. Designing systems with ease of repair in mind. This would include “hot” swappable stacks as well as other components which would increase system reliability and durability [Cost Impact: Total cost of PEM fuel cell system]

29. Recovery of catalyst through regeneration and other recycling programs that would recapture the precious metals at the end of the fuel cell’s life cycle [Cost Impact: Fuel cell]

30. Disposal – recycling of the whole system and its components. [Cost Impact: Total cost of PEM fuel cell system]

31. Modularity – scalability: the ability to put systems together easily for larger kW capacity. [Cost Impact: Total cost of PEM fuel cell system]

32. Power electronics and management – regulate voltage and quality. [Cost Impact: Total cost of PEM fuel cell system]

Voting

Eight participants voted (votes of project personnel are excluded below), each participant selected eight types of technology progress that could significantly impact cost from the master list that he/she thought were the most responsive to the topic question (types of technological progress could substantially reduce the cost of stationary PEM fuel cells). Each participant assigned to each of the eight selected drivers a point value ranging from eight points, high, to one point, low. The maximum number of votes that a driver could receive was 8 (one from each participant), and the maximum number of points that a driver could receive was 64 (8 X 8).

Table G-1. Rankings of technology drivers by Battelle expert focus group participants.

#	DRIVER	VOTES WITH POINT VALUES	VOTES/ POINTS	RANK*
1	**Cost competitive fuel cell membrane alternatives.**	**7,7,7,7,5,2**	**6/35**	**2**
2	**Discover alternatives to precious metals for electrodes and reduce platinum loading to reduce material costs.**	**8,8,1,4,4,6,6**	**7/37**	**1**
3	Develop less expensive, including non-precious metal membrane separators.	4,8	2/12	-
4	Low cost, non-corroding bipolar plate technology	4,2,2	3/8	-
5	Breakthrough in pumps for fuel and water delivery; limited choices in state of the art pumps used in fuel cells.	1,2	2/3	-
6	Alternative low cost cell/stack fabrication techniques such as screen printing and other mass production methods would improve quality control and reliability.	3,5	2/8	-
7	**Improve MEA manufacturing and fabrication techniques; for example, how to apply the catalyst more effectively and achieve a higher quality using innovative coating methods.**	**6,5,7,4,4**	**5/26**	**5**
8	**Improved membrane hydration controls, including but not limited to high temperature, low humidity membranes, and membranes with increased durability.**	**4,2,1,8,5,6**	**6/26**	**4**
9	**Stacks that can tolerate impurities, including carbon monoxide and sulfur; for example, this could include simplified reforming and fuel management inside the cells, such as dynamic electrodes.**	**6,8,5,8**	**4/27**	**3**
10	**In-cell water management including efficient and effective anode recirculation schemes.**	**3,4,6**	**3/13**	**8**

#	DRIVER	VOTES WITH POINT VALUES	VOTES/ POINTS	RANK*
11	Automated assembly for the whole system, including design for manufacture and assembly.	2	1/2	-
12	Develop better method for managing steam-to-carbon ratio would reduce the number of parts currently used. This could include the development of a steam-to-carbon sensor.	-	-	-
13	Recuperative humidification techniques for fuel cell cathode or anode, including recycling the water and passive humidification.	5,3,2	3/10	-
14	Hydrogen storage for stationary applications.	2	1/2	-
15	Improve power density which would reduce stack volume and cell area.	6	1/6	-
16	Improve stack reliability including resistance to fuel crossover/short circuiting, improved mechanical properties, and longer life times.	3,4	2/7	-
17	**System simplification and system integration; for example, one blower for cell and fuel processor.**	**8,6**	**2/14**	**7**
18	Improve manufacturing techniques for the fuel processor, especially for steam reforming.	3	1/3	-
19	Develop alternative gaskets/group designs and use advance sealant technologies in the membrane separator and the MEA, which would increase reliability and durability.	-	-	-
20	Improve efficiencies through new materials, heat exchanges, thermal management, and thermal flow.	-	-	-
21	Combined heat and power (CHP) -- use waste heat for practical purposes and improve efficiency of the system.	-	-	-
22	**Durability improvements through accelerated lifecycle testing and gaining an understanding of mechanistic parameters that affect the system, development of diagnostic tools that not only determine the heath of the stack/system, but recommend corrective actions that will alleviate premature failures.**	**2,1,6,2,5**	**4/16**	**6**
23	Equipment standards through uniform specifications.	1	1/1	-
24	Improvement in sensor technology for pressure, humidity, hydrogen, carbon monoxide, steam-to-carbon ratio sensors, which will increase system reliability and efficiency.	1,6,1	3/8	-
25	Improve sulfur management.	2,6	2/8	-
26	Design for repair and reassembly. This is similar to designing for manufacturability but focusing on field serviceability.	-	-	-
27	Advances in fuel supply storage, fuel quality, operating pressures.	7	1/7	-
28	Plug and play installation. Designing systems with ease of repair in mind. This would include “hot” swappable stacks as well as other components which would increase system .reliability and durability/	-	-	-
29	Recovery of catalyst through regeneration and other	-	-	-

#	DRIVER	VOTES WITH POINT VALUES	VOTES/ POINTS	RANK*
	recycling programs that would recapture the precious metals at the end of the fuel cell's life cycle.			
30	Disposal – recycling of the whole system and its components.	-	-	-
31	Modularity – scalability: the ability to put systems together easily for larger kW capacity.	3	1/3	-
32	Power electronics and management – regulate voltage and quality.	5,5	2/10	-

*Ranking is based on total points, number of votes, and number of 8's, in that order of importance.

Top 8 Ranked Technology Drivers

1. Discover alternatives to precious metals for electrodes and reduce platinum loading to reduce material costs. (technological progress #2 with 7 votes and 37 points) [Cost Impact: Fuel cell]

2. Cost competitive fuel cell membrane alternatives. (technological progress #1, with 6 votes and 35 points) [Cost Impact: Fuel cell]
3. Stacks that can tolerate impurities, including carbon monoxide and sulfur; for example, this could include simplified reforming and fuel management inside the cells, such as dynamic electrodes. (technological progress # 9, with 4 votes and 27 points) [Cost Impact: Fuel cell]

4. Improved membrane hydration controls, including but not limited to high temperature, low humidity membranes, and membranes with increased durability. (technological progress # 8, with 6 votes and 26 points) [Cost Impact: Fuel cell]

5. Improve MEA manufacturing and fabrication techniques; for example, how to apply the catalyst more effectively and achieve a higher quality using innovative coating methods. (technological progress # 7, with 5 votes and 26 points)

6. Durability improvements through accelerated lifecycle testing and gaining an understanding of mechanistic parameters that affect the system, development of diagnostic tools that not only determine the heath of the stack/system, but recommend corrective actions that will alleviate premature failures. (technological progress #22, with 4 votes and 16 points) [Cost Impact: Total cost of PEM fuel cell]

7. System simplification and system integration; for example, one blower for cell and fuel processor. (technological progress #17, with 2 votes and 14 points) [Cost Impact: Total cost of PEM fuel cell]

8. In-cell water management including efficient and effective anode recirculation schemes. (technological progress #10 with 3 votes and 13 points) [Cost Impact: Fuel cell]

Principal Themes

1. Increased durability through technological improvements in
   - MEA (1*[116], 2*, 3, 4, 8*, 16, 19, 20)
   - water management (5, 9, 8*, 10*, 13, 24)
   - impurity tolerance (5, 9*,12, 16, 24, 25)
   - life cycle testing (22*)

2. Improvements in systems simplification and integration (drivers 5, 12, 15, 17*, 24, 28, 31, 32)

3. Improvements in manufacturing and fabrication of specific components and the entire system (drivers 4, 6, 7*, 11, 18, 26)

[116] Driver ranked in the top 8 ranked technological drivers

APPENDIX H:

ECONOMIC ANALYSIS:
INDUSTRY STAKEHOLDER EXPERT FOCUS GROUP MINUTES

ECONOMIC ANALYSIS:
INDUSTRY STAKEHOLDER EXPERT FOCUS GROUP MINUTES

First Economic Analysis Workshop on Stationary PEM Fuel Cell Systems

Date: April 21, 2005, 8:00 am - 3:00 pm

Place: Wyndham Bourbon Orleans, New Orleans, Louisiana

Agenda:

8:00 – 8:30 am	Welcome, Opening Remarks, and Introductions
8:30 – 9:00 am	General Discussion: Cost Drivers in PEM Fuel Cell Systems
9:00 - 10:30 am	Briefing on Battelle's Cost Analysis of Stationary PEM Systems
10:30 – 10:45 am	Break and Networking
10:45 – 12:00 pm	Facilitated Discussion of PEM Fuel Cell Cost Analysis
12:00- 12:45 pm	Lunch
12:45 – 2:30 pm	Expert focus group on the topic questions "What innovations could substantially reduce the cost of stationary fuel cells in the U.S?"
2:30 – 3:30 pm	Next Steps and Closing Remarks

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Recommended Revisions to Cost Analysis:

1. **Comment 1: Definitions of 5 and 50 kW PEM fuel cells**. The workshop participants suggested that PEM fuel cell system design parameters should be tied to a specific application in order to make the analysis realistic.

   Response: Battelle will design the 5 kW PEMFC system to be applicable as a backup power application, and the 50 kW PEMFC system to be applicable as a base load, grid independent system.

2. **Comment 2: Details of Cost Breakdown.** The workshop group requested that Battelle supply supporting details concerning the cost breakdowns presented on April 21. For instance, the group wanted to know the current manufacturing process that were built into the cost estimates for each of the components. In addition, the group wanted information on the number of MEAs and other system parameters assumed for both the 5 and 50 kW systems.

   Response: Battelle will provide additional information as deemed applicable to the scope of the study and will send it out for review to the group by May 4, 2005.

3. **Comment 3: Specific comments on cost analysis.** Participants at meeting suggested revisions to cost of the following components 1) bi-polar plates 2) gasketing 3) platinum loading 4) power density 5) power degradation and 6) packaged MEA costs.

   Response: Battelle will review and revise costs after gathering further detail from manufacturers of various components.

Topic Question Discussion:

Topic Question: "What innovations could substantially reduce the cost of stationary fuel cells in the U.S?"

Method: Modified Nominal Group Technique: three rounds of round-robin generation of ideas in response to the topic question and each of 16 participants voted on five choices from the master list as being "the most important". Battelle project team did not participate in the voting.

Results:

1. Non-palladium based membrane separator [Cost Impact: Hydrogen Delivery System]
2. Non-platinum catalyst [Cost Impact: Fuel Cell Subsystem]
3. Completely new stack architecture – semi-conductor fabrication process like a semi-conductor chip architecture for stack [Cost Impact: Fuel Cell Subsystem]
4. High CO tolerant non-ruthenium catalyst [Cost Impact: Fuel Cell Subsystem]

5. Self control systems and diagnostics to minimize balance of plant and controls [Cost Impact: Power Electronics and System Integration]

6. Automated and standardized sub-assembly (like automobiles) [Cost Impact: Total Fuel Cell System]

7. Efficient internal water management [Cost Impact: Fuel Cell Subsystem]

8. Robust MEA which can tolerate multiple conditions and impurities [Cost Impact: Fuel Cell Subsystem and Hydrogen Delivery System]

9. Methods to reduce catalyst loadings on MEA [Cost Impact: Fuel Cell Subsystem]

10. "Zero" call back system for increased reliability and where no unscheduled maintenance is required [Cost Impact: Total Fuel Cell System]

11. Standardized installation and grid interconnect [Cost Impact: Installation Costs]

12. Improved tolerance of fuel and air impurities in the stack (CO, sulfate, etc) [Cost Impact: Fuel Cell Subsystem and Hydrogen Delivery System]

13. No water needed within the stack. This is a hypothetical membrane of the future [Cost Impact: Fuel Cell Subsystem]

14. Optimize the design and manufacture process of the stack to improve reliability and durability [Cost Impact: Total Fuel Cell System]

15. High temperature, good performance, long-lasting membrane [Cost Impact: Fuel Cell Subsystem and Hydrogen Delivery System]

16. Direct manufacturing of a modular housing and balance of plant [Cost Impact: Total Fuel Cell System]

17. Cheap plates like aluminum [Cost Impact: Fuel Cell Subsystem]

18. Integrated reforming system [Cost Impact: Total Hydrogen Delivery System]

19. Direct fuel cells, which are more durable and perform better than a direct methanol fuel cell [Cost Impact: Total Fuel Cell System]

20. Government is an adopter, and buys or supports buying of fuel cells and focused on specific application [Cost Impact: Total Fuel Cell System]

21. Higher performance systems – more active catalysts and higher conductivity membrane [Cost Impact: Total Fuel Cell System]

22. Open architecture (like PC's), i.e. a system design/architecture that uses non-proprietary standards allowing flexibility in access and scalability [Cost Impact: Total Fuel Cell System]

23. Reduce Gas Diffusion Layer costs [Cost Impact: Fuel Cell Subsystem]

24. Low cost, high density hydrogen storage [Cost Impact: Total Fuel Cell System]

25. High efficiency, low emissions (clean) hydrogen production [Cost Impact: Total Fuel Cell System]

26. Improve operation controls to optimize power efficiency and durability in up and down (on/off) manner to bring to full power [Cost Impact: Total Fuel Cell System]

27. Engineered plastics throughout the fuel cells (fuel cell as plastic) [Cost Impact: Total Fuel Cell System]

28. Intelligent diagnostic system [Cost Impact: Total Fuel Cell System]

29. Low-cost, real time, robust gas chromatograph sensor on a chip [Cost Impact: Total Fuel Cell System]

30. Cheap seals and gaskets [Cost Impact: Fuel Cell Subsystem]

31. SECA like technology development, that has a market focus and specific criteria for development [Cost Impact: Total Fuel Cell System]

32. High efficiency, low cost regenerative systems for when the unit is down (off) [Cost Impact: Total Fuel Cell System]

33. Self healing membranes [Cost Impact: Fuel Cell Subsystem]

34. Cheaper, better hydrogen cleanup systems [Cost Impact: Hydrogen Delivery System and Fuel Cell Subsystem]

35. Regulatory pressure to improve the attractiveness of fuel cells [Cost Impact: Total Fuel Cell System]

36. More customers [Cost Impact: Total Fuel Cell System]

37. High power, high density power electronics [Cost Impact: Power Electronics and System Integration]

38. Smaller, faster reformers [Cost Impact: Hydrogen Delivery System]

Voting:

Sixteen participants voted (votes of project personnel excluded below), each participant selected five types of technological progress that could significantly impact cost from the master list that he/she thought were the most responsive to the topic question above. Each participant assigned to each of the five selected technology opportunities a point value ranging from eight points, high, to one point, low. The maximum number of votes that a driver could receive was 8 (one from each participant), and the maximum number of points that a driver could receive was 80 (16 X 5).

Table H-1. Rankings of technology drivers by industry stakeholder expert focus group participants.

#	DRIVER	VOTES WITH POINT VALUES	VOTES/ POINTS	RANK*
1	Non-palladium based membrane separator	3	1/3	
2	**Non-platinum catalyst [1]**	**5,4,5,3,5,4**	**6/26**	**1**
3	Completely new stack architecture – semi-conductor fabrication process like a semi-conductor chip architecture for stack	3,5,1	3/9	
4	**High carbon monoxide (CO) tolerant non-ruthenium catalyst [2]**	**5,4,1,2,5**	**5/17**	**2**
5	**Self control systems and diagnostics to minimize balance of plant and controls [4]**	**3,5,2,4**	**4/14**	**4**
6	Automated and standardized sub-assembly (like automobiles)	3,2	2/5	
7	Efficient internal water management	-	-	-
8	Robust MEA which can tolerate multiple conditions and impurities	1,3	2/4	-
9	Methods to reduce catalyst loadings on MEA	1,5	2/6	-
10	"Zero" call back system for increased reliability and where no unscheduled maintenance is required	4,3	2/7	-
11	Standardized installation and grid interconnect	2,2,4,1	4/9	-
12	Improved tolerance of fuel and air impurities in the stack (CO, sulfate, etc)	5	1/5	-
13	No water needed within the stack	1,4,3	3/8	-
14	Optimize the design and manufacture process of the stack to improve reliability and durability	2,3,2	3/7	-
15	**High temperature, good performance, long-lasting membrane [3]**	**4,5,4,3**	**4/16**	**3**
16	Direct manufacturing of a modular housing and balance of plant	5	1/5	-
17	Cheap plates like aluminum	3,2,1,2	4/8	-
18	Integrated reforming system	3	1/3	-
19	Direct fuel cells, which are more durable and perform better than a direct methanol fuel cell [7]	1,4,5	3/10	-
20	Government is an adopter, and buys or supports buying of fuel cells and focused on specific application [6]	5,2,4	3/11	-
21	**Higher performance systems – more active catalysts and higher conductivity membrane [5]**	**2,5,4,2**	**4/13**	**5**
22	Open architecture (like PC's)	4,2,3	3/9	-
23	Reduce Gas Diffusion Layer costs	4	1/4	-
24	Low cost, high density hydrogen storage	1	1/1	-
25	High efficiency, low emissions (clean) hydrogen production	1,3	2/4	-
26	Improve operation controls to optimize power efficiency and durability in up and down (on/off) manner	4	1/4	-
27	Engineered plastics throughout the fuel cells (fuel cell as plastic)	3,3	2/6	-
28	Intelligent diagnostic system			-
29	Low-cost, real time, robust gas chromatograph sensor	5	1/5	-

#	DRIVER	VOTES WITH POINT VALUES	VOTES/ POINTS	RANK*
	on a chip			
30	Cheap seals and gaskets	5	1/5	-
31	SECA like technology development, that has a market focus and specific criteria for development	4,1,2	3/7	-
32	High efficiency, low cost regenerative systems for when the unit is down (off)	1	1/1	-
33	Self healing membranes			-
34	Cheaper, better hydrogen cleanup systems	2,1	2/3	-
35	Regulatory pressure to improve the attractiveness of fuel cells	1,2	2/3	-
36	More customers	-	-	-
37	High power, high density power electronics	-	-	-
38	Smaller, faster reformers	1	1/1	-

*Ranking is based on total points, number of votes, and number of 8's, in that order of importance.

Top 5 Ranked Technology Drivers:

1. Non-platinum catalyst [1] (technological progress #2 with 6 votes and 27 points) [Cost Impact: Fuel Cell Subsystem]

2. High carbon monoxide (CO) tolerant non-ruthenium catalyst (technological progress # 4 with 5 votes and 17 points) [Cost Impact: Hydrogen Delivery System]

3. High temperature, good performance, long-lasting membrane (technological progress #15 with 4 votes and 16 points) [Cost Impact: Fuel Cell Subsystem and Hydrogen Delivery System]

4. Self control systems and diagnostics to minimize balance of plant and controls (technological progress #5 with 4 votes and 14 points) [Cost Impact: Power Electronics and System Integration]

5. Higher performance systems – more active catalysts and higher conductivity membrane (technological progress #21 with 4 votes and 13 points) [Cost Impact: Total Fuel Cell System]

Principal Themes for Opportunities for Cost Reduction:

1. Improvements in the Fuel Cell Subsystem, and specifically the MEA with focus on
   a. Catalysts (2*, 9, 21*,4*)
   b. Membranes (15*,21*,33)
   c. Improved stack tolerance to impurities (8,12)
   d. Internal water management (7, 13)

2. Improvements in power electronics to minimize balance of plant and controls (5*, 10, 26, 28, 29, 37)

3. Technological improvements in hydrogen delivery to stationary fuel cells through development of
   a. Hydrogen storage (24)
   b. High efficiency and low impact hydrogen production (25)
   c. Hydrogen cleanup systems (34)
   d. Small reformers (38)

4. Improvements in architecture, manufacture and integration of Subsystems and the whole fuel cell unit with optimization for reliability and durability (6 ,14, 22)

Appendix D: Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets

Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets

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Battelle
The Business of Innovation

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TABLE OF CONTENTS

1.0 INTRODUCTION 1

1.1 Marketing Research Design 2
1.1.1 Phase 1 Research 2
1.1.2 Phase 2 Research 3

1.2 Methodology 3
1.2.1 Secondary Research 3
1.2.2 Surveys and Interviews 4
1.2.3 Market Research Data Analysis 7
1.2.4 Lifecycle Cost Analysis 8
1.2.5 Market Adoption Modeling 9

2.0 ANALYSIS OF PRE-AUTOMOTIVE MARKETS TO 2015 12

2.1 Pre-Automotive Applications and Markets for PEM Fuel Cells 12
2.1.1 Potential Pre-Automotive Applications 12
2.1.2 Likely Pre-Automotive Markets for PEM Fuel Cells to 2015 13

2.2 Analysis of Pre-Automotive Backup Power Markets for PEM Fuel Cells 15
2.2.1 Analysis of Individual Backup Power Market Segments 15
2.2.1.1 Commercial Backup Power Market Segment Analysis 17
2.2.1.2 Institutional Backup Power Market Segment Analysis 22
2.2.1.3 Industrial Backup Power Market Segment Analysis 25
2.2.1.4 Government Backup Power Market Segment Analysis 28
2.2.2 Composite Analysis of Trends in Backup Power Markets 33
2.2.2.1 Survey Participant Profile 33
2.2.2.2 Frequency and Duration of Outages 33
2.2.2.3 Current Backup Power Systems 35
2.2.2.4 Satisfaction with Current Systems 35
2.2.2.5 Purchase Decision Factors 37
2.2.2.6 Trends and Potential for Backup Power Applications 37

2.3 Analysis of Specialty Vehicle Markets 38
2.3.1 Analyses of Individual Specialty Vehicle Market Segments Based on User and Integrator Responses 38
2.3.2 Composite Analysis of Trends in Specialty Vehicle Markets Based on User Responses and Manufacturer Responses 43
2.3.2.1 Specialty Vehicle User Responses 43
2.3.2.2 Specialty Vehicle Manufacturer Responses 46

2.4 Analysis of Most Promising Near-term and Mid-term Pre-Automotive Markets 47

3.0 MARKET OPPORTUNITY ASSESSMENT OF THREE NEAR-TERM PRE-AUTOMOTIVE MARKETS 49

3.1 PEM Fuel Cells in Backup Power Applications in State and Local Emergency Response Agencies 49
3.1.1 Market Attributes 49
3.1.1.1 Market Segment Description 49

3.1.1.2 Market Size ... 51
3.1.1.3 Market Trends ... 53
3.1.2 Market Segment Analysis ... 54
3.1.2.1 Phase 1 Analysis ... 54
3.1.2.2 Phase 2 Analysis ... 58
3.1.2.3 Market Research Summary Analysis ... 63
3.1.3 Cost Analysis of PEM Fuel Cells ... 64
3.1.3.1 Lifecycle Cost Analysis Assumptions by Scenario ... 65
3.1.3.2 Lifecycle Cost Analysis Results by Scenario ... 68
3.1.3.3 Lifecycle Cost Summary ... 71
3.1.4 Sensitivity Analysis ... 72
3.1.4.1 Sensitivity Analysis Modeling Analysis Methodology ... 72
3.1.4.2 Sensitivity Analysis Results ... 73
3.1.5 Market Penetration Analysis ... 74
3.1.5.1 Market Penetration Assumptions ... 74
3.1.5.2 Market Penetration Results ... 75
3.1.6 Value Proposition for PEM Fuel Cells ... 79

3.2 PEM Fuel Cells in Forklifts at High Throughput Distribution Centers ... 80
3.2.1 Market Attributes ... 80
3.2.1.1 Market Segment Description ... 80
3.2.1.2 Market Size ... 83
3.2.1.3 Market Trends ... 86
3.2.2 Market Segment Analysis ... 88
3.2.2.1 Manufacturer Response Analysis ... 88
3.2.2.2 User Response Analysis ... 90
3.2.2.3 Market Research Summary ... 94
3.2.3 Lifecycle Cost Analysis ... 96
3.2.3.1 Lifecycle Cost Assumptions by Scenario ... 96
3.2.3.2 Lifecycle Cost Results by Scenario ... 97
3.2.3.3 Lifecycle Cost Summary ... 99
3.2.4 Sensitivity Analysis ... 99
3.2.4.1 Sensitivity Analysis Modeling Methodology ... 99
3.2.4.2 Sensitivity Analysis Results ... 100
3.2.5 Market Penetration Analysis ... 100
3.2.5.1 Market Penetration Assumptions ... 100
3.2.5.2 Market Penetration Results ... 101
3.2.6 Value Proposition for PEM Fuel Cell-Powered Forklifts ... 105

3.3 PEM Fuel Cells in Airport Ground Support Equipment (GSE) ... 107
3.3.1 Market Attributes ... 107
3.3.1.1 Market Segment Description ... 107
3.3.1.2 Market Size ... 109
3.3.1.3 Market Trends ... 112
3.3.2 Market Segment Analysis ... 115
3.3.2.1 Manufacturer Response Analysis ... 115
3.3.2.2 Ground Support Equipment User Response Analysis ... 116
3.3.2.3 Market Research Summary Analysis ... 122

3.3.3 Lifecycle Cost Analysis 124
3.3.3.1 Lifecycle Cost Analysis Assumptions by Scenario 124
3.3.3.2 Lifecycle Cost Results by Scenario 127
3.3.3.3 Lifecycle Cost Summary 130
3.3.4 Sensitivity Analysis 130
3.3.4.1 Sensitivity Analysis Modeling Methodology 130
3.3.4.2 Sensitivity Analysis Results 131
3.3.5 Market Penetration Analysis 131
3.3.5.1 Market Adoption Assumptions 131
3.3.5.2 Market Penetration Results 132
3.3.6 Value Proposition for PEM Fuel Cells in Baggage Tractors 136

4.0 SUMMARY OF FINDINGS AND CONCLUSIONS 139

APPENDIX A: Survey Instruments for Analysis of Pre-automotive Markets 141

APPENDIX B: Complete List of Respondents and Level of Participation 175

APPENDIX C: Summary Research for Market Segments Analyzed 190

LIST OF FIGURES

Figure 1-1. Battelle Marketing Research Approach. 2

Figure 1-2. Financial Input Screen to the Modified H2A Model. 9

Figure 1-3. Adopter Categories Reflecting Time of Adoptions where $\bar{x}$ is the Mean Time of Adoption and SD is the Standard Deviation. 10

Figure 1-4. Logistic Curve of Cumulative Adopters and Normal Curve of New (Incremental) Adopters Generated by Bass Innovation Diffusion Model. 11

Figure 2-1. Number of Outages Experienced in the Past 12 Months. 34

Figure 2-2. Duration of Outages Experienced in the Last 12 Months. 34

Figure 2-3. Current Sources of Backup Power. 35

Figure 2-4. Factors of Concern with Current Backup Systems. 36

Figure 2-5. User Satisfaction with Various Backup Power System Characteristics. 36

Figure 2-6. Importance of Various Factors in Selecting a Backup Power System. 37

Figure 2-7. User Satisfaction with Specialty Vehicle Characteristics. 44

Figure 2-8. Importance of Various Characteristics When Selecting a Specialty Vehicle. 45

Figure 3-1. Number of Outages Experienced by Survey Respondents in the Past 12 Months (n=13). 55

Figure 3-2. Size of Backup Power Systems in Use (n=15). 56

Figure 3-3. Decision Factors Identified as Very Important in Evaluating Backup Power Systems (n=11). 60

Figure 3-4. Factors that Most Influence Backup Power System Purchase Decisions (n=10). 61

Figure 3-5. Characteristics of Current Systems that Users Identified as Very Good (n=11). 62

Figure 3-6. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell Backup Power System. 73

Figure 3-7. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Base Case. 76

Figure 3-8. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Base Case. 76

Figure 3-9. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Communication Case. 77

Figure 3-10. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Communication Case. 77

Figure 3-11. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Subsidy Case. 78

Figure 3-12. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Subsidy Case. 78

Figure 3-13. Factors That Most Influence Purchase Decisions (n=13). 93

Figure 3-14. Characteristics of Current Systems That Users Identified as Very Good (n=13). 94

Figure 3-15. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell-Powered Pallet Forklift. 100

Figure 3-16. Adoptions of PEM Fuel Cell-Powered Forklifts in the Base Case. 102

Figure 3-17. Sales of PEM Fuel Cell-Powered Forklifts in the Base Case. 102

Figure 3-18. Adoptions of PEM Fuel Cell-Powered Forklifts in the Communication Case... 103

Figure 3-19. Sales of PEM Fuel Cell-Powered Forklifts in the Communication Case. 103

Figure 3-20. Adoptions of PEM Fuel Cell Forklifts in the Subsidy Case. 104

Figure 3-21. Sales of PEM Fuel Cell Forklifts in the Subsidy Case. 104

Figure 3-22. Specialty Vehicle Purchase Decision Factors Identified as Very Important (n=7). 120

Figure 3-23. Characteristics of Current Systems that Users Identified as Very Good (n=7). 121

Figure 3-24. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell-Powered Baggage Tractor. 131

Figure 3-25. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Base Case. 134

Figure 3-26. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Base Case. 134

Figure 3-27. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Communication Case. 135

Figure 3-28. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Communication Case. 135

Figure 3-29. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Subsidy Case. 136

Figure 3-30. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Subsidy Case. 136

LIST OF TABLES

Table 2-1. Pre-Automotive Applications and Markets Analyzed. 14

Table 2-2. Total Number and Size of Respondents for Backup Power Market Segments. ... 16

Table 2-3. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Commercial Market Segments..... 18

Table 2-4. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Institutional Market Segments. 23

Table 2-5. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Industrial Market Segments. 26

Table 2-6. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Government Market Segments. 29

Table 2-7. Number of Respondents to Phase 1 and Phase 2 Surveys by Size of Organization..... 33

Table 2-8. Total Number of Respondents and Size of Organizations Surveyed for Specialty Vehicles..... 39

Table 2-9. Specialty Vehicle Market: User and Integrator Analysis Data..... 40

Table 2-10. Most Promising Near-term and Mid-term Markets. 47

Table 3-1. SIC and NAICS Codes Relevant to State and Local Departments of Emergency Response. 50

Table 3-2. Number of Emergency Response-Related Organizations..... 52

Table 3.3. Lifecycle Cost Analysis Assumptions by Scenario. 67

Table 3-4. Scenario 1: 5 kW for 52 hours - NPV of PEM Fuel Cells and Battery-Generator System over 15-Year Analysis Period with a 3-Year and 5-Year Battery Replacement Schedule 69

Table 3-5. Scenario 2: 5 kW for 176 hours - NPV of PEM Fuel Cells and Battery-Generator System over 15-Year Analysis Period with a 3-Year and 5-Year Battery Replacement Schedule. 70

Table 3-6. Scenario 3: 3 kW for 72 hours - NPV of PEM Fuel Cells, Battery-Generator System, and Generator-Only System over 15-Year Analysis Period with a 5-Year Battery Replacement Schedule. 71

Table 3-7. Scenario 3: 2 kW for 8 hours - NPV of PEM Fuel Cells and Battery-Only System over 15-Year Analysis Period with a 5-Year Battery Replacement Schedule..... 71

Table 3-8. Comparison of NPV for Total Cost of System: 8-Hour, 52-Hour, 72-Hour, and 176-Hour Runtime Scenarios..... 72

Table 3-9. Cost Assumptions for PEM Fuel Cell Backup Power Sensitivity Analysis: +/-10% Base Assumption. 73

Table 3-10. Assumptions for PEM Fuel Cell Adoption for Backup Power Applications at Emergency Response Radio Towers. 75

Table 3-11. Summary of PEM Fuel Cell Penetration Assuming Alternative Cases..... 79

Table 3-12. SIC and NAICS Codes for Forklift Manufacturing..... 80

Table 3-13. Number of Companies Potentially Involved in Forklift Manufacturing. 83

Table 3-14. Material Handling Equipment Demand by End-User Market to 2013 in Millions of Dollars. 84

Table 3-15. Manufacturers' Shipments of Forklift Equipment in the United States in Millions of Dollars. 85

Table 3-16. U.S. Factory Shipments of Class 1, 2, 3, 4, and 5 Forklifts..... 85

Table 3-17. Total Population of ICE Forklift Trucks in the United States in 1996..... 86

Table 3-18. Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts..... 97

Table 3-19. Scenario 1: Lifecycle Cost Comparison of PEM Fuel Cell- and Battery-Powered Pallet Trucks. 98

Table 3-20. Scenario 2: Lifecycle Cost Comparison of PEM Fuel Cell- and Sit-down Battery-Powered Trucks. 98

Table 3-21. Cost Assumptions for PEM Fuel Cell-Powered Forklift Sensitivity Analysis..... 99

Table 3-22. Assumptions for PEM Fuel Cell-Powered Forklift Adoption in Distribution Centers and Warehouses..... 101

Table 3-23. Summary of Sales and Market Share for Alternative Market Adoption Cases for PEM Fuel Cell-Powered Forklifts. 105

Table 3-24. SIC and NAICS Codes for Ground Support Tractor Manufacturing. 107

Table 3-25. Number of Companies Potentially Involved in Airport Tug Manufacturing - Industry: Industrial Trucks and Tractors (SIC Code 3537). 109

Table 3-26. Number of Potential Adopters of Airport Tugs 110

Table 3-27. Estimated U.S. Ground Support Tractor Population by Power Source, 1999. ... 111

Table 3-28. Total Population of ICE-Powered Ground Support Equipment in the United States in 1998 and 2000..... 112

Table 3-29. Scenario 1: Cost Assumptions for Net Present Value Analysis of Baggage Tractors for 6 Hours per Day Runtime. 125

Table 3-30. Scenario 2: Cost Assumptions for NPV Analysis of Baggage Tractors for 18 Hours per Day Operation with Battery Change-outs. 126

Table 3-31. Scenario 3: Cost Assumptions for NPV Analysis of Baggage Tractors for 18 Hours per Day Operation with Fast Charging. 127

Table 3-32. Scenario 1: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel-, and Battery-Powered Baggage Tractors for 6 Hours of Runtime..... 128

Table 3-33. Scenario 2: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel- and Battery-Powered Baggage Tractors for 18 Hours of Runtime with Battery Change-outs 129

Table 3-34. Scenario 3: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel- and Battery-Powered Baggage Tractors for 18 Hours of Runtime with Fast Charging 129

Table 3-35. Cost Assumptions for PEM Fuel Cell-Powered Baggage Tractor Sensitivity Analysis: Base Assumption +/- 10%. 130

Table 3-36. Assumptions for PEM Fuel Cell-Powered Baggage Tractor Adoption in Airports 132

Table 3-37. Summary of Sales and Market Share for Alternative Market Adoption Cases for PEM Fuel Cell-Powered Baggage Tractor Adoption in Airports. 133

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE)[1] is working on the development of direct hydrogen proton exchange membrane (PEM, also referred to as polymer electrolyte membrane) fuel cell vehicles. The DOE realizes that the pathway to direct hydrogen PEM fuel cells (hereafter referred to as PEM fuel cells) in vehicles will likely include the introduction of PEM fuel cells in near-term markets with fewer technical challenges than automobiles. The DOE also recognizes that fuel cell companies and component developers need to increase fuel cell sales in the coming years in order to support the continued research and development (R&D) required for technological advancements in automotive applications, and to sustain the interest of investors in their companies. In order to facilitate growth of the PEM fuel cell industry, build a supplier base for future automotive markets, and develop robust products, the DOE is focused on identifying near-term market opportunities for PEM fuel cells in pre-automotive applications.

The DOE commissioned Battelle to identify likely near-term pre-automotive markets for PEM fuel cells in the 1 kilowatt (kW) to 250 kW range.[2] Near-term pre-automotive markets will be those segments in which PEM fuel cells can be demonstrated successfully by 2008 in the United States. However, Department of Defense (DoD) applications for PEM fuel cells were excluded from the scope of work.

The research presented in this report identifies and characterizes near-term and mid-term markets in which PEM fuel cells can be successful. This report also assesses the market opportunity for PEM fuel cells in three near-term pre-automotive markets, including state and local emergency response agencies, forklifts in warehousing and distribution centers, and airport ground support equipment markets. Specific goals of this project were to:

- Identify and segment markets and applications for 1 to 250 kW PEM fuel cells in the near-term (2008) and mid-term (2012)
- Develop an understanding of technology and market factors, including user requirements, that will drive the adoption of PEM fuel cells in these markets and applications to 2015
- Determine the cost and quality of PEM fuel cell products that will be commercially available by 2008
- Modify the DOE's hydrogen analysis model (H2A model) to allow lifecycle cost analysis of electricity production from PEM fuel cells and competing electricity generation technologies
- Analyze and compare performance and lifecycle cost of existing PEM fuel cells and competing technologies in three near-term markets
- Estimate rates of market penetration in the three near-term markets.

This report is organized into four sections: Section 1.0 provides information on the scope of work and the methodology adopted; Section 2.0 analyzes trends from market research data in pre-automotive markets and applications to 2015; Section 3.0 analyzes the market opportunity

[1] The DOE in this report refers to the Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen Fuel Cells and Infrastructure Technologies Program.

[2] The scope of the study was limited to direct hydrogen PEM fuel cells to support the identification of transitional markets for direct hydrogen PEM fuel cells in automotive applications. The absence of information on direct methanol fuel cells and reformer based PEM fuel cells and applications in this study should not be interpreted in any way as an implied statement about those markets. Rather, DOE focused the scope based on assumptions about the pathway to the long-term objective of a successful PEM fuel cell automotive industry.

for PEM fuel cell in three near-term markets, and Section 4.0 presents a project summary and conclusions.

1.1 Marketing Research Design

Battelle's research approach, outlined in Figure 1-1, uses a two-phase exploratory research process, supplemented by modeling of lifecycle costs of PEM fuel cells and competing technologies, in order to identify those markets in which PEM fuel cells offer value and better performance in areas that are valued most by the market.

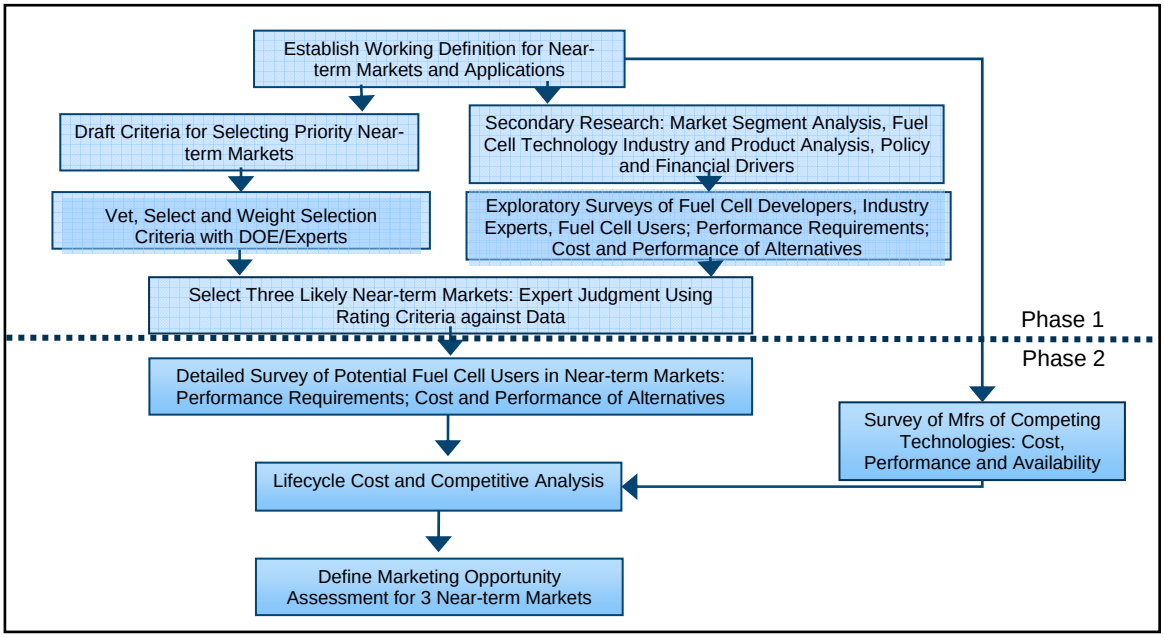


Figure 1-1. Battelle Marketing Research Approach.

1.1.1 Phase 1 Research

In the first phase, secondary research and exploratory primary research were used to establish a working definition of pre-automotive applications and markets. The definition and the approach to identifying near-term markets were discussed with the DOE. This phase resulted in broad guidance as to which applications would be evaluated to determine the potential for PEM fuel cells. Secondary research and primary research, including surveys and interviews, were used to profile and characterize the pre-automotive market segments. A total of 36 pre-automotive market segments were identified for further evaluation in backup power and specialty vehicle applications.

To prioritize near-term opportunities for PEM fuel cells, the following rating criteria were developed with input from DOE and industry. These rating criteria were applied to the findings from Phase 1 research on the 36 market segments to identify and select three markets for detailed analysis. Primary criteria were:

- PEM fuel cells offer unique value to market segment not met by competing technologies
- The product characteristics and potential benefits of PEM fuel cell product characteristics and their potential benefits fit user requirements (high priority needs)

- Market size and growth potential of the market segment are sufficient to ensure current and continued fuel cell adoption
- Cost of reaching the market, including product development and marketing, is reasonable
- PEM fuel cell products are available for immediate application, or will be available over the short-term.

1.1.2 Phase 2 Research

The second phase of research involved detailed analyses to determine the value proposition of PEM fuel cells in the three near-term markets including state and local departments of emergency response, forklifts in warehousing and distribution centers, and ground support equipment at airports. Analyses included an identification of user requirements for PEM fuel cells, a comparison of the lifecycle costs of PEM fuel cells against competing alternatives, and a determination of market penetration for PEM fuel cells.

Market research was utilized to develop user requirements for PEM fuel cells in the three near-term markets. Secondary sources, surveys, and follow-up telephone interviews were used to assess the ability of PEM fuel cells to meet market requirements by 2008.

A comparative lifecycle cost analysis was performed by modifying the H2A model[3] to compare cash flow and net present value (NPV) of costs using PEM fuel cells and current competing technologies. Cost data for PEM fuel cells and competing technologies collected through secondary and primary research were used to populate the modified H2A model in order to analyze lifecycle costs in the three near-term market segments.

Innovation diffusion models were used to estimate the rate of market penetration over time under alternative assumptions of government interventions. The Bass mixed-influence innovation diffusion model is the most widely used theoretical model in marketing today.[4] The Bass model was used to forecast market adoption rates based on factors such as the strength of government subsidies, mass communications (e.g., government documents, face-to-face discussions regarding experiences with a technology), and various degrees of government intervention.

1.2 Methodology

1.2.1 Secondary Research

Peer reviewed journal articles, magazine articles, and market research reports were reviewed to support market data collection. Findings from Battelle's previous work were also used to inform this analysis.[5]

To guide the definition of near-term and mid-term market segments and applications on the pathway to automotive PEM fuel cell markets, information was reviewed to identify:

- Potential near-term applications and markets for direct hydrogen PEM fuel cells
- Availability, cost, and performance of direct hydrogen PEM fuel cell products

[3] DOE H2A Production Analysis. Available at http://www.hydrogen.energy.gov/h2a_production.html [Accessed September 2006].
[4] Rogers, E. M. 2003. Diffusion of Innovations. New York, Free Press.
[5] Battelle. 2006. Economics of Stationary PEM Fuel Cell Systems. For the Department of Energy, DOE Contract No. DE-FC36-03GO13110.

- Financial performance and general trends in the fuel cell industry
- Investment trends in hydrogen and PEM fuel cell technology
- Current and planned demonstration of direct hydrogen PEM fuel cell products
- Policy drivers for hydrogen and fuel cell technologies
- Institutional and market barriers to adoption of PEM fuel cells in the near-term.

Once these market segments were identified, secondary research was conducted to help assess:

- Specific uses for direct hydrogen PEM fuel cells within market segments
- Market segments that may be early adopters of direct hydrogen PEM fuel cells and the value proposition that would lead to early adoption
- Cost and performance requirements for PEM fuel cells in each market segment
- Companies with products into which direct hydrogen PEM fuel cells can be readily integrated
- Key drivers for the adoption of hydrogen PEM fuel cells
- Size of the market segment and growth potential.

A literature review was conducted to collect data required for a competitive analysis of PEM fuel cells and alternative technologies. Specifically, this information was used to identify:

- Characteristics of competing technologies
- Advantages and disadvantages of competing technologies
- Current and projected market applications and segments for competing technologies
- Performance of competing technologies
- Capital cost, cost of operation and maintenance, and salvage value or disposal costs for competing technologies
- Current and projected market share for competing technologies
- User satisfaction with competing technologies
- Potential technology improvements and other changes in competing technology industries
- Key drivers for competing technology adoption.

1.2.2 Surveys and Interviews

The primary research data necessary to identify PEM fuel cell markets likely to develop by 2015 and to further identify near-term markets with a high likelihood of commercial success were obtained through exploratory interviews and/or surveys with Battelle and Pacific Northwest National Laboratory (PNNL) subject matter experts, fuel cell technology developers, venture capital investors, current and/or candidate fuel cells users, and current and/or candidate specialty vehicle manufacturers (thought to be potential integrators of PEM fuel cells in their systems). A judgment sample[6] was selected from each of the aforementioned categories and interviewed.

Users were identified through internet research and review of industry databases like Hoovers and Dun and Bradstreet. Fuel cell developers, venture capital investors, and specialty vehicle manufacturers were identified from information in industry publications, market research reports,

[6] A judgment sample is a non-probability sample that is often called a purposive sample because the sample elements are handpicked to serve the research purpose.

and internet research. PEM fuel cell manufacturers and component developers were surveyed through the U.S. Fuel Cell Council.

For each market identified, current and/or candidate fuel cell technology integrators and current and/or candidate users were contacted to gather data on applications for PEM fuel cells, the current mode of use, satisfaction with current mode of use, and interest in alternatives. The exploratory research and analysis in the first phase was primarily qualitative.

A survey instrument was developed to elicit information from users in the specific market segments. Separate surveys were prepared for each application researched. The questions were developed by Battelle staff experienced with survey design and primary research methods. All surveys were pre-tested, after which refinements were made. The survey instruments used can be found in Appendix A.

A consistent approach was developed and followed for surveys and interviews. Persons implementing primary data collection were trained in using the survey instrument and interview protocol. Preliminary contact was established via an introductory telephone call and/or e-mail with details of the project and the requested information. Participants were provided with three options for response, including e-mail, fax, or telephone. If the questions were out of the respondent's scope of work, contact information for an alternate and more suitable candidate within the same organization was requested. If the respondent was knowledgeable about industry trends, in some cases short interviews were conducted to gather general trend information. If certain questions were left unanswered or incomplete, short follow-up calls and/or e-mails were used to attempt to fill the data gaps.

Precise notes were taken during telephone calls. Information received through the exploratory surveys via e-mail, fax, and telephone was input into an Access database by the persons implementing the survey. Quality assurance was conducted by a designated staff person. The staff person reviewed 10% of the completed forms against the data input into the Access database. The opportunity for response bias was minimized by limiting the number of open-ended questions subject to recording error from interviewer interpretation.

Specific data collected during the first phase is described below.

Battelle and PNNL Experts

Battelle and PNNL staff members with fuel cell experience were interviewed to identify:

- Likely PEM fuel cell markets to 2015 and likely near-term markets by 2008
- Market barriers to adoption of PEM fuel cells
- Potential early adopters of PEM fuel cells
- Strategies that DOE may employ to facilitate the critical market pathway to automotive hydrogen fuel cells.

Fuel Cell Manufacturers and Component Developers

Fuel cell technology manufacturers and component developers were contacted for input on:

- Current and projected status of commercially available PEM fuel cell technology
- Current and projected cost and performance of PEM fuel cell technology
- Near-term and mid-term markets of interest to PEM fuel cell companies

- Current and planned demonstrations for PEM fuel cells
- Strategies that DOE may employ to facilitate the critical market pathway to automotive hydrogen fuel cells.

Venture Capital Investors

Venture capital firms with energy technology portfolios participated in telephone interviews to help assess:

- Current status of the fuel cell industry and PEM fuel cell products
- Level of interest in PEM fuel cell technology
- Key areas of government support
- Requirements for successful commercialization.

Current and/or Candidate Fuel Cell Users

For the 36 market segments identified, users were contacted for information on:

- Classification data for respondents (industry, size, related SIC code)
- Frequency and impact of power system failure related to potential PEM fuel cell applications
- Specific potential uses for PEM fuel cells within the market segment
- Size (kW) and type of power system currently in use in potential PEM fuel cell applications
- Perceptions of cost of purchase, operation, maintenance, ease of use, and expected life of current systems
- Frequency of procurement of current systems
- Level and causes of dissatisfaction with current or alternative systems
- Awareness of PEM fuel cells
- Attitude toward PEM fuel cells
- Factors that would drive adoption of PEM fuel cells in the target applications.

Current and/or Candidate Fuel Cell Integrators

Specialty vehicle manufacturers were surveyed or interviewed in each specialty vehicle market to identify:

- Potential applications and markets for PEM fuel cells
- Technical requirements for integration of PEM fuel cells
- Typical operational requirements of end-user markets
- Value proposition of PEM fuel cells as a source of continuous power
- Potential barriers to the adoption of PEM fuel cells.

In Phase 2, primary data were obtained from current and/or candidate fuel cell users in the three near-term markets through surveys and interviews. The survey instrument used for the exploratory research was modified slightly to incorporate questions required to support the comparative economic analysis. The survey was pre-tested and refined. Questions in the survey were designed to elicit qualitative and quantitative information. The survey instruments can be found in Appendix A. All data obtained through surveys and interviews from both phases were input to an Access database to facilitate analysis and presentation of results. Specific data that were collected for each of the three near-term markets are:

- Frequency and duration of power outages
- Priority applications for PEM fuel cells

- Equipment used, its characteristics (e.g., power output) and specific operating conditions (e.g., hours of operation per day/quarter)
- Key factors driving the adoption of new energy technologies, including durability, lifetime, capital cost, operation and maintenance cost, emissions, and typical operating conditions of new energy technologies
- User perceptions regarding use of hydrogen
- Cost and performance of current mode of operation
- Factors driving the adoption of direct hydrogen PEM fuel cell technology in the target market segment
- Capital equipment financing and decision approaches
- Other information to inform development of strategies to facilitate PEM fuel cell technology adoption.

1.2.3 Market Research Data Analysis

Responses from current and/or candidate fuel cell users provided data that enabled development of detailed descriptions of each market segment and differences among market segments and behaviors of users in various markets. The data were input to an Access database that enabled the data to be queried.

Within the backup power market segments, data were tabulated or cross-tabulated based on the type of business to identify:

- How is backup power provided?
- What is the size of backup power systems?
- What are the durations and impacts of these outages?
- How disruptive are power outages?
- What is the number of backup power units per facility and across facilities, and what are potential opportunities for future procurement of new systems?
- How satisfied are organizations with their backup power technologies?
- What are the specific concerns regarding backup power systems?
- What are the most critical factors for selecting a backup power system?
- What are the perceptions of PEM fuel cells as backup power and the use of hydrogen as a fuel source?
- What factors would drive the adoption of PEM fuel cells?
- How are capital purchase decisions made? Are those not concerned with capital cost more concerned with return on investment, payback period, or other factors?

Across backup power market segments, data were cross-tabulated to identify:

- For each market segment, what are the frequency, duration, and impacts of power outages?
- What factors are considered by each market segment when purchasing backup power systems?
- Do certain market segments show larger market size and higher growth potential for backup power systems?
- Are certain market segments more familiar with PEM fuel cells than others?
- What factors are considered by each market segment when purchasing PEM fuel cells?
- Do market segments differ in capital purchase decision-making?

- Are certain market segments more concerned about incentives when making purchasing decisions?

Within specialty vehicle market segments, data were tabulated and cross-tabulated to identify the following:

- How is power for the specialty vehicles provided?
- What is the size of power systems?
- How often does the current power system fail to operate?
- What is the lifespan of the current power system?
- How much maintenance (frequency and duration) is required for the power system?
- How satisfied are organizations with their power technologies?
- If dissatisfied, what are the specific concerns regarding power systems?
- What are the most critical factors for selecting a power system?
- What are the perceptions of PEM fuel cells as a power system for specialty vehicles and the use of hydrogen as a fuel source?
- What factors would drive the adoption of PEM fuel cells as a power system for specialty vehicles?
- How are capital purchase decisions made? Other than capital costs, are capital decisions concerned with return on investment, payback period, or other factors?
- How would incentives impact the decision to adopt PEM fuel cells?

Across specialty vehicle market segments, data were cross-tabulated to identify the following:

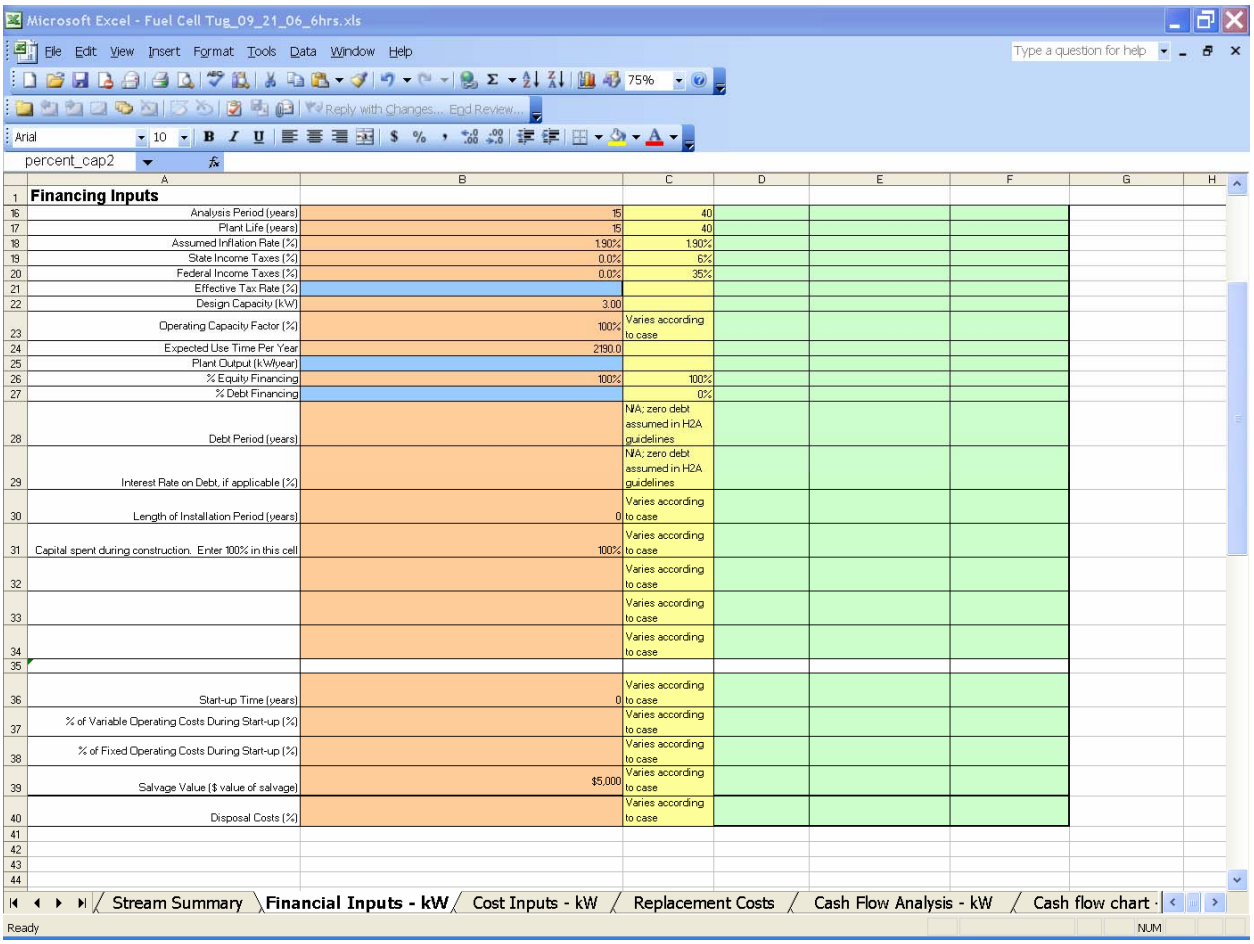
- For each market segment, what is the level of dissatisfaction with current power systems for specialty vehicles?
- For each market segment, what factors drive the selection of power systems for specialty vehicles?
- Do certain market segments show larger market size and higher growth potential for PEM fuel cell systems?
- Are certain market segments more familiar with PEM fuel cells than others?
- For each market segment, what factors would influence the purchase of PEM fuel cells for specialty vehicle applications?
- How are capital purchase decisions made in each market?
- Are certain market segments more concerned about incentives when making purchasing decisions?

1.2.4 Lifecycle Cost Analysis

Secondary and primary research was used to populate the modified H2A model. The modified H2A model shows explicit assumptions, allows comparison of the costs to own and operate the alternate energy systems, and provides sensitivity analysis to various assumptions. The financial input screen to the H2A model is presented in Figure 1-2 as an example. Current PEM fuel cell costs and current costs of competing energy generation or storage technologies were used in the lifecycle analysis.

Through surveys and interviews with PEM fuel cell manufacturers, fuel cell installation engineering companies, and hydrogen suppliers, PEM fuel cell system costs, installation costs, hydrogen fuel costs, salvage value, and other operation and maintenance costs were gathered.

Secondary research was performed to gather information on characteristics, applications, benefits, and growth of electricity generation and storage technologies that will compete with PEM fuel cells in the selected near-term markets. Short surveys were implemented with manufacturers to gather quantitative information on the performance and cost of competing technologies. Information gathered by Battelle for batteries and generators in fiscal year 2005 was reviewed for completeness and updated as necessary through contact with manufacturers and technology developers.



	A	B	C
1	**Financing Inputs**		
16	Analysis Period (years)	15	40
17	Plant Life (years)	15	40
18	Assumed Inflation Rate (%)	1.90%	1.90%
19	State Income Taxes (%)	0.0%	6%
20	Federal Income Taxes (%)	0.0%	35%
21	Effective Tax Rate (%)		
22	Design Capacity (kW)	3.00	
23	Operating Capacity Factor (%)	100%	Varies according to case
24	Expected Use Time Per Year	2190.0	
25	Plant Output (kW/year)		
26	% Equity Financing	100%	100%
27	% Debt Financing		0%
28	Debt Period (years)		N/A; zero debt assumed in H2A guidelines
29	Interest Rate on Debt, if applicable (%)		N/A; zero debt assumed in H2A guidelines
30	Length of Installation Period (years)	0	Varies according to case
31	Capital spent during construction. Enter 100% in this cell	100%	Varies according to case
32			Varies according to case
33			Varies according to case
34			Varies according to case
35			
36	Start-up Time (years)	0	Varies according to case
37	% of Variable Operating Costs During Start-up (%)		Varies according to case
38	% of Fixed Operating Costs During Start-up (%)		Varies according to case
39	Salvage Value ($ value of salvage)	$5,000	Varies according to case
40	Disposal Costs (%)		Varies according to case

Figure 1-2. Financial Input Screen to the Modified H2A Model.

1.2.5 Market Adoption Modeling

For the three near-term market segments selected in the previous tasks, market adoption rates were estimated using a Bass innovation diffusion modeling approach.[7] The Bass innovation diffusion model is a three-parameter model for calculating the number of new adopters at a given time, *t*, and cumulative adoptions (X).[8] The parameters include the total potential adopters, m; a coefficient of innovation, p; and a coefficient of imitation, q. The parameter m is an estimate of the number of potential adopters at a given point in time. The parameter p reflects innovators that make their initial purchase without influence from the number of others who have

[7] Bass, F. M. 1969. A New Product Growth for Model Consumer Durables. Management Science 15(5): 215-227.
[8] Rogers, E. M. 2003. Diffusion of Innovations. New York, Free Press.

purchased. Innovators are important early in a product lifecycle, but their importance diminishes with time. Figure 1-3 shows the innovators in comparison with other early adopters of technology. The buying decisions of innovators are informed by sources external to the industry networks. The parameter *q* reflects purchases by other categories of adopters that rely on communications within their industry networks to inform their purchase decisions.

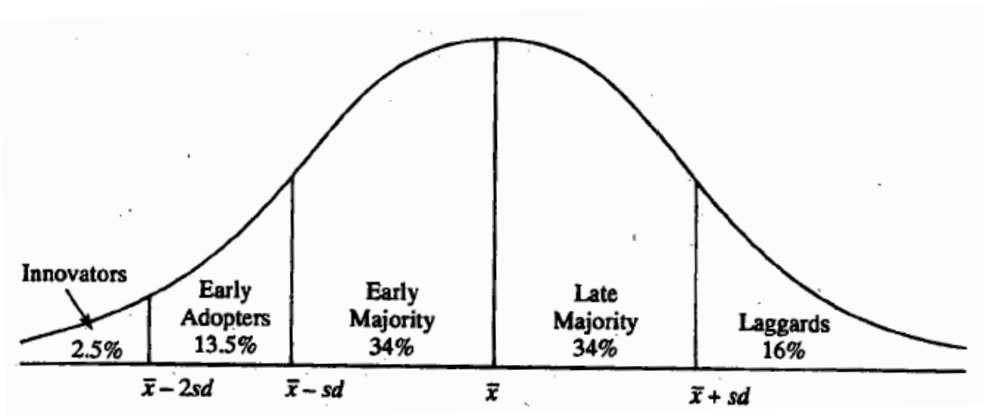


Figure 1-3. Adopter Categories Reflecting Time of Adoptions where $\bar{x}$ is the Mean Time of Adoption and SD is the Standard Deviation.[9]

The basic formula of the Bass model is[10]:

$$x(t) = p + q[(X(t-1)/m][m - X(t-1)]$$

As shown in Figure 1-4, the number of incremental (new) adopters is normally distributed over time, generating a bell-shaped curve. The number of cumulative adopters generates a logistic (S-shaped) curve.

The Bass innovation diffusion model has been demonstrated successfully to forecast product sales corresponding to empirical results. Where historical data are lacking, parameters can be estimated by using the history of analogous products and expert judgments.[11] It is recommended that environmental context, buyer behavior, market structure, marketing mix strategies, and product characteristics be considered in the selection of analogies.[12]

The approach used here combines the selection of analogies with a subsequent revision of parameters based on expert judgment. The initial analogies will consider the factors recommended by Thomas based on the survey findings.[13] Factors considered include, for example, how much relative advantage PEM fuel cell products provide compared to competing

[9] Rogers, E. M. 2003. Diffusion of Innovations. New York, Free Press.
[10] Lilien, G., A. Rangaswamy, and C.V.D. Bulte. 2000. Diffusion Models: Managerial Applications and Software in New Product Diffusion Models. International Series in Quantitative Marketing, 9. Kluwer Academic Publishers, p. 295-336.
[11] Mahajan, V. and R. A. Peterson. 1985. Models for Innovation Diffusion. Newbury Park, CA, Sage Publications.
[12] Thomas, R. J. 1985. Estimating Market Growth for New Products: an Analogical Diffusion Models Approach. Journal of Product Innovation Management 2: 35-47.
[13] Thomas, R. J. 1985. Estimating Market Growth for New Products: an Analogical Diffusion Models Approach. Journal of Product Innovation Management 2: 35-47.

technologies and factors that may influence buying decisions. Assumptions leading to the selection of analogies were inferred from the survey findings for the three selected markets.

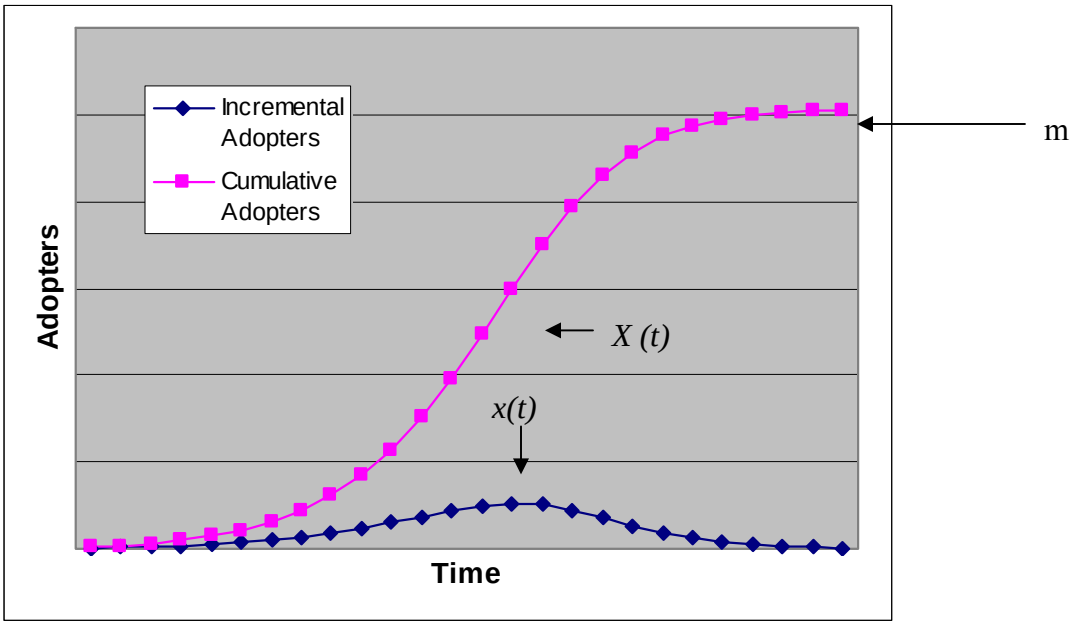


Figure 1-4. Logistic Curve of Cumulative Adopters and Normal Curve of New (Incremental) Adopters Generated by Bass Innovation Diffusion Model.

For each near-term pre-automotive market, three different cases were evaluated:

- The base case assumes that the adoption of PEM fuel cells in a market is typical for industrial products. The parameters used in the model reflect an average industrial level of innovation and imitation and generate a market penetration curve comparable to that for the adoption of the cellular telephone.
- The communication case assumes a higher than average level of innovation (50% higher *p*-value than the base case) as a result of effective communications and education by government or others outside of the target market.
- The subsidy case assumes that communications are supplemented by subsidies that lower the cost of purchasing a system. While the precise relationship between subsidy and purchasing is not known, a $1,000 per kW one-time subsidy for PEM fuel cell[14] systems for 3 to 5 years was assumed, and the corresponding cost to provide the subsidy was calculated as a point of reference.

[14] Under the Energy Policy Act (EPAct) 2005, fuel cells receive a 30% tax credit that is capped at $1,000 per kW of generating capacity.

2.0 ANALYSIS OF PRE-AUTOMOTIVE MARKETS TO 2015

2.1 Pre-Automotive Applications and Markets for PEM Fuel Cells

For the purposes of this study, pre-automotive applications and markets for PEM fuel cells are defined as those opportunities that will support the development of technology and the industry necessary for the commercialization of automotive PEM fuel cells by 2015. Pre-automotive markets for PEM fuel cells utilize components and underlying technologies similar to automotive PEM fuel cells. They include applications that have some operational characteristics similar to automotive PEM fuel cells. These might include frequent cycling, the ability to quickly respond to requests for power. Pre-automotive markets can also include markets with early adopters for stationary applications. While stationary applications have different operational characteristics than automotive applications, it is anticipated that increased demand from these markets will decrease the cost of components, help to maintain investor interest, and facilitate the development of a supplier base of PEM fuel cell technology.

2.1.1 Potential Pre-Automotive Applications

Five potential pre-automotive applications of PEM fuel cells were identified. Characteristics of these applications, some example markets, and potential advantages that PEM fuel cells may offer in these applications are described below:

- **Backup Power** – PEM fuel cells can provide standby or emergency power to ensure uninterrupted service. PEM fuel cells could be used to provide electricity that meets standard backup requirements (e.g., in blackout conditions), as well as high quality backup power requirements for industries such as financial services and telecommunications, which are willing to pay more to secure reliable service. In backup applications, efficiency is not as critical as reliability and availability of the system. PEM fuel cells in these applications provide longer runtimes than batteries. PEM fuel cells also have low operations and maintenance requirements, and have no emissions as compared to generators.

- **Grid Independent Power** – PEM fuel cells can provide continuous, stand-alone power to operations that are not connected to the grid. The fuel cell may operate on direct hydrogen from chemical processes or hydrogen supplied in canisters or tanks. For example, a fuel cell might support all the energy needs for a building at a chemical plant using hydrogen generated from the plant's production process. Power sources selected for these applications typically have high reliability, fuel availability, high efficiency, and low maintenance costs. Costs may be less important for grid independent applications than for on-grid applications. Units are expected to run for a long time, typically over 6,000 hours per year.[15] The power source is also expected to have good load-following characteristics as it is the sole source of power.

- **Specialty Vehicles –** PEM fuel cells can provide complete power for specialized equipment and vehicles such as forklifts, industrial movers, and motorized scooters, in

[15] Resource Dynamics Corporation. 2004. Distributed Generation Sourcebook.

lieu of batteries or internal combustion engines (ICEs). These applications operate in indoor and outdoor environments and are used typically to transport people or goods. PEM fuel cells in these applications are typically less than 100 kW and are expected to operate between 2,000 and 5,000 hours per year. Many specialty vehicles are expected to have long runtimes, low emissions, and easy start-up.

- **Portable Power** – PEM fuel cells can provide continuous power to meet the complete energy needs of small electronic products. PEM fuel cells may provide a substitute for conventional batteries in products such as portable phones, cameras, computers, and security devices. Product power requirements are typically less than 1 kW and are expected to operate approximately 1,000 to 5,000 hours per year.[16] Energy density, efficiency, and hydrogen storage are critical in portable applications.

- **Auxiliary Power –** PEM fuel cells can provide an alternate source of power serving specific requirements in portable, mobile on-road transportation, and off-road transportation applications. For example, they can provide electrical power to trucks, locomotives, airplanes, boats, or military vehicles when the main ICE is not operating, enabling cooling, lighting, or other auxiliary power needs to be met. PEM fuel cells for these applications can range in size from 3 to 30 kW and are expected to operate over their lifetime between 20,000 and 35,000 hours.

2.1.2 Likely Pre-Automotive Markets for PEM Fuel Cells to 2015

Based on a review of information on products in the marketplace, interviews with experts, fuel cell manufacturers, and industry stakeholders, the most promising near-term opportunities (by 2008) for PEM fuel cells operating on direct hydrogen are in specialty vehicle applications, backup power applications, and to a limited extent, in auxiliary power and portable power applications. Due to scope of the project, this report focuses on prioritizing and analyzing near-term pre-automotive markets for backup power and specialty vehicle applications.[17]

The application and development of PEM fuel cells for specialty vehicles are expected to significantly advance the development of automotive fuel cells and serve as an early market for hydrogen. Backup power applications and markets will impact the development of a supplier base by getting PEM fuel cell technology into the market and in the hands of early adopters. It is anticipated that portable power and auxiliary power applications will also develop for PEM fuel cells.

The benefit segmentation method[18] was adopted for the purpose of analyzing the applicability of PEM fuel cells to these markets. PEM fuel cell technology and its unique benefits, identified by reviewing product and application information, were matched with specific user requirements in various markets. For example, PEM fuel cells have the potential to offer customers specific benefits such as reliability, power quality, extended runtime, scalability, ease of use

[16] DOE. 2005. Multi-Year Research, Development and Demonstration Plan: Planned Program Activities for 2003-2010. Available at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp [Accessed September 2006].
[17] The scope of the project includes PEM fuel cells between 1 kW and 250 kW only and excludes Department of Defense applications.
[18] Cooper, R. 2001. Winning at New Products. Cambridge, MA, Perseus Publishing.

(plug-and-play modules), and distributed power. Extended runtime and distributed power are key decision factors for users such as telecommunications companies that operate relay towers.

Using the benefit segmentation method, the telecommunications market was defined as a unique market segment that desires a set of product benefits offered by PEM fuel cell technology. Complete market segmentation was performed using this approach for backup power and specialty vehicle markets. Through secondary and primary research, 36 market segments were identified as potential markets for PEM fuel cells to 2015 in backup power and specialty vehicle applications (Table 2-1) based on the need for lower emissions, longer runtimes, lower operation and maintenance costs, and ease of use. Of these 36 market segments, 24 are backup power market segments in the commercial, industrial, institutional, and government market sectors. Twelve market segments are specialty vehicle markets.

Table 2-1. Pre-Automotive Applications and Markets Analyzed.

Backup Power Markets				Specialty Vehicle Markets*
Non-Government Markets			Government Markets	
Commercial Markets Telecom Finance Data centers Grocery stores Casinos Hotels Ski parks Amusement parks Railways Mining	Institutional Markets Water treatment Wastewater treatment Healthcare Airports Electric utilities	Industrial Markets Chemical manufacturing Oil and gas – refineries Pharmaceuticals Metals processing and refining Computer and electronic products Transportation manufacturing Food manufacturing	Federal Agencies** National Aeronautics and Space Administration (NASA) Nuclear Regulatory Commission (NRC) Department of Transportation (DOT) – Federal Aviation Administration (FAA) Department of Homeland Security (DHS) – United States Coast Guard (USCG) National Oceanic and Atmospheric Administration (NOAA) – National Weather Service (NWS) DOE Environmental Protection Agency (EPA) General Services Administration (GSA) National Park Service (NPS) Department of Interior (DOI) United States Postal Service (USPS) United States Department of Agriculture (USDA) State Agencies** State and local emergency response agencies	Forklifts Automatic guide vehicles Mining vehicles Airport ground support equipment Golf carts Turf maintenance vehicles Commercial sweepers Ice resurfacers Wheelchairs Motorized bicycles/scooters Unmanned Undersea Vehicles (UUVs) Unmanned Aerial Vehicles (UAVs)

* Specialty vehicles include industrial and recreational transportation and mobility applications.
** Counted as single market segment comprised of multiple agencies

Secondary and primary research (section 1.2.2) was conducted to identify likely applications for PEM fuel cells, market attributes, market trends, and user requirements for adopting new technologies in each of these 36 market segments. For telecom, finance, and hotels, secondary and primary research conducted in fiscal year 2005 was reviewed to identify trends for backup power. A total of 136 survey responses and 87 interviews were completed in Phase 1 and Phase

2 research. Of these 136 surveys, 83 surveys were completed by backup power users; 24 surveys were completed by specialty vehicle manufacturers, and 29 were completed by specialty vehicle users. One golf cart manufacturer provided two responses to the survey from separate departments within the company. Both responses were combined and analyzed for this manufacturer. Three specialty vehicle users (one airline company, two retail companies) and four backup power users (four emergency response agencies) answered both Phase 1 and Phase 2 surveys. If a respondent participated in more than one survey, during analysis only one response was taken into account for questions appearing in both surveys. A complete listing of respondents and their level of participation can be found in Appendix B.

The following sections analyze the likely applications for PEM fuel cells, user requirements for adopting new technologies, satisfaction with current technologies, and interest in alternatives in the backup power and specialty vehicle markets.

2.2 Analysis of Pre-Automotive Backup Power Markets for PEM Fuel Cells

This section presents qualitative and quantitative analysis of the key trends, drivers, and requirements of users for backup power in commercial, institutional, industrial, and government markets. Analyses of trends in individual segments (section 2.2.1), as well as a composite analysis of trends across backup power markets (section 2.2.2) are presented in this section. Individual backup power segment reports can be found in Appendix C. Detailed analyses of the emergency response market segment can be found in section 3.0.

2.2.1 Analysis of Individual Backup Power Market Segments

Of the 36 market segments analyzed, 24 market segments were analyzed for their potential to adopt PEM fuel cells in backup power applications in the near-term (2008). Ten commercial market segments, five institutional market segments, seven industrial market segments, and two government market segments were analyzed.

This section presents Battelle's analysis of the trends in the individual backup power market segments as determined through surveys, interviews, and secondary research. For the telecom, finance, and hotel market segments, trends are reported based on information gathered in fiscal year 2005 and a review of more recent secondary information. Table 2-2 summarizes the number of survey respondents and interviewees for each market segment and the size of the survey respondents' organizations. A complete listing of survey respondents and interviewees for Phase 1 and Phase 2 research can be found in Appendix B.

Table 2-2. Total Number and Size of Respondents for Backup Power Market Segments.

Market Segment	Number of Survey Respondents	Number of Interviewees	Size of Survey Respondent's Organization~		
			Small	Medium	Large
Telecom*	6	16	-	-	6
Finance*	9	-	2	-	7
Data Centers	2	-	1	-	1
Grocery Stores	4	9	1	-	3
Casinos	1	2	1	-	
Hotels*	8	-	2	1	5
Ski Parks	1	1	-	-	1
Amusement Parks+	-	1	-	-	-
Railways	6	-	1	1	4
Mining	1	2	-	1	
Water Treatment	3	-	3	-	-
Wastewater Treatment	4	3	4	-	-
Healthcare	5	2	-	3	2
Airports	6	3	1	5	
Electric Utilities	2	5	-	-	2
Chemical Manufacturing	2	7	-	-	2
Oil and Gas - Refineries	2	-		1	1
Pharmaceuticals+	-	1	-	-	-
Metals Processing and Refining	4	-	3	-	1
Computer and Electronic Products	4	3	3	-	1
Transportation Manufacturing	2	8	1		1
Food Manufacturing+	-	-	-	-	-
NASA	1	1			1
Department of Interior (DOI)+					
United States Postal Service (USPS)+					
NRC+	-	1	-	-	-
DOT - FHWA+					
USDA+		1			
FAA*	1	-	-	-	1
USCG	1	1	-	-	1
NOAA - National Weather Service (NWS)	1	-	-	-	1
DOE	1	2	-	-	1
EPA	3	2	2	1	-
GSA+	-	1	-	-	-
NPS	1	2	-	-	1
State and Local Emergency Response	22	11	17	2	3
Total	103	85	42	15	46

~ Small is classified as 500 employees or less, medium is classified as 500 to 3000 employees, and large is over 3000 employees; *These market segments were analyzed in fiscal year 2005. Surveys implemented with these segments were similar to those implemented in Phase 1 research; + No surveys were received from these market segments. Analysis is based on secondary research and interviewee feedback only.

2.2.1.1 Commercial Backup Power Market Segment Analysis

Table 2-3 presents Battelle's analysis of the information gathered through secondary research and through surveys of users in ten commercial market segments. Limited information was available on the potential for backup power in amusement parks (only one interviewee); as a result, the information presented in Table 2-3 for this market segment is based primarily on secondary research.

Of the ten segments analyzed, telecom and data centers are most severely impacted by power outages. In the commercial market, long outages are very disruptive and can have significant economic impact. All the segments analyzed have some level of backup power. Casinos and large data centers often have redundant grid power lines in case of outages. Reliability was identified as one of the most critical factors when selecting backup power systems by all ten commercial segments. Fuel availability, start-up time, lifetime, and ease of use of the backup power system were also identified as very important factors when selecting backup power systems by users in this segment. Initial capital costs were cited as an important factor when selecting a backup power system by all commercial segments except the railways and grocery store segments.

Commercial users are satisfied with the performance of current backup power technologies. Of the ten segments analyzed, four – grocery stores, railways, telecom, and mining – identified concerns with their current mode of operation. Maintenance concerns were identified for generator systems by two segments. The telecom market segment indicated concerns over battery life, operations and maintenance requirements of generators, and fuel availability, particularly in remote locations. Alternative backup power technologies, including fuel cells, have been considered by the telecom, data center, grocery store, and railway market segments. Commercial users familiar with PEM fuel cells in the commercial market segment identified the high capital cost of PEM fuel cells as a significant barrier to adoption. Initial capital cost was identified as a decision factor for capital purchases by five of the ten commercial market segments including casinos, data centers, ski parks, amusement parks, and finance. Primary concerns for considering alternatives in the commercial market segments were environmental concerns, regulatory requirements, the need for low maintenance systems, and the need for extended backup power at remote locations. Government incentives were not identified as a primary driver for purchasing alternatives in the data center, amusement park, finance, and telecom market segments.

Based on technology-market fit analysis, near-term opportunities for PEM fuel cells exist in the telecom and railway market segments. Users in these segments are looking for backup power alternatives to support remote communications applications. Of the two segments, the telecom market sector is a more attractive market opportunity because users are less price sensitive than the railway market segment; it is also a larger market opportunity. However, a number of barriers will have to be addressed before PEM fuel cells will be widely accepted in the telecom market segment, including a lack of reliability data on the operation of PEM fuel cells for backup power in telecom applications, guidelines for installation and operation of hydrogen fuel in high power zones, and track record of other users adopting PEM fuel cells for backup power applications.

Table 2-3. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Commercial Market Segments*.

Market Segment	Casinos	Data Centers	Grocery Stores	Railways	Ski Parks	Amusement Parks	Hotels	Finance	Telecom	Mining
Applications	Surveillance, Emergency lighting and alarms, Sprinkler systems	Servers, Lighting, Air-conditioning, Data center-specific network switches, Telephone switching	Emergency lighting, Emergency medical system controllers, Point of sale registers, Refrigeration	Signals, Crossing guard mechanisms, Onsite communication, Emergency lighting	Lifts	Rides, Park services	Emergency lighting and alarm systems, Point of sale registers, Heating and ventilation systems, Refrigeration systems	Computer systems, Servers, Telecom systems, ATMs	Controlled environmental huts, Remote cell sites, Microwave towers, Cell sites, Hub sites, Enhancers, Repeaters, Cabinet sites, Outside plant huts, Digital loop carriers, Fiber, Private branch exchange, Public safety answering points, Remote radio centers, Portable systems, Central offices, Switching stations	Ventilation systems, Safety systems, Hoists, Communication devices, Emergency lighting and alarms, Mine pumps
Most Critical Applications	Surveillance, Emergency lighting and alarms	Servers	Refrigeration, Emergency lighting	All of the above	Lifts	Rides	Emergency lighting and alarm systems, Heating and ventilation systems, Refrigeration systems	All of the above	Hub sites, Microwave transmitter sites, Central offices	Pumps, Safety systems, Emergency lighting and alarms
Economic Impact and Other Impacts of Outages	High; Results in security breach and implementation of emergency management plans	High; Results in security breach, disruption of production, and distribution, implementation of emergency management plans	High; Results in economic loss through food spoilage, disruption in distribution, and implementation of emergency management plans	Medium; Dependent on location of outage; Impacts distribution, results in implementation of emergency management plans and potential loss of life	High; Results in implementation of emergency management plans and in customer dissatisfaction	Medium; Results in disruption of operations, implementation of emergency management plans, and in customer dissatisfaction	High; Results in disruption of operations, implementation of emergency management plans, and in customer dissatisfaction	High; Results in security breach, disruption of distribution, and implementation of emergency management plans	High; Results in security breach, disruption of production and distribution, and implementation of emergency management plans	High, Results in implementation of emergency management plans and disruption of production and distribution

Table 2-3. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Commercial Market Segments*.

Market Segment		Casinos	Data Centers	Grocery Stores	Railways	Ski Parks	Amusement Parks	Hotels	Finance	Telecom	Mining
Types and Typical Size of Backup Systems Used		UPS; 15 - 30 kW	UPS, Generators; < 5 kW, 15 - 250 kW, > 1,000 kW	UPS, Generators; 5 - 250 kW, > 2,000 kW for warehouses	Batteries, UPS, Generators; < 5 - 150 kW	Generators; Unknown	Generators; 50 - > 500 kW	UPS, Generators; < 5 kW, 150 - 250 kW	UPS, Generators; 50 - 250 kW, > 1,000 kW	Batteries, Generators; 2 - 200 kW	Generators; > 750 kW - 2 MW
User Requirements When Selecting a Backup System	**Reliability**	Very important	Very important	Very important	Very important	Very important	Very important	Very important	Very important	Very important	Very important
	Capital Cost	Very important	Very important	Important	Important	Very important	Very important	Very important	Very important	Very important	Important
	Lifetime	Very important	Very important	Important	Very important	Very important	Very important	Very important	Very important	Very important	Important
	Annual Operating Cost	Very important	Important	Important	Important	Very important	Very important	Very important	Data not available	Important	Not so important
	Emissions	Very important	Important	Important	Important	Very important	Very important	Very important	Important	Not so important	Very important
	Start-up Time	Very important	Very important	Important	Very important	Very important	Very important	Very important	Very important	Very important	Important
	Ease of Use	Very important	Very important	Important	Important	Very important	Very important	Very important	Important	Very important	Very important
	Fuel Availability	Very important	Very important	Very important	Important	Very important	Very important	Very important	Important	Very important	Very important
	Good Experience	Important	Important	Important	Very important	Very important	Very important	Very important	Important	Very important	Very important
Most Important User Requirements		Reliability	Reliability, Start-up time, Fuel availability	Reliability, Fuel availability	Reliability, Start-up time, Lifetime	Reliability, Start-up time, Emissions	Reliability, Capital cost	Capital cost, Operating cost, High efficiency	Reliability, Capital costs, Lifetime	Reliability, Capital costs, Ease of use	Reliability, Emissions, Ease of use
User Satisfaction with Current Technologies		Very satisfied	Very satisfied	Satisfied, with some concerns	Satisfied, with some concerns	Very satisfied	Very satisfied	Very satisfied	Very satisfied	Satisfied, with some concerns	Satisfied, with some concerns
User Concerns with Current Technologies		No concerns	No concerns	Maintenance of generators a concern, Emissions from generators a concern	Concerns about reliability at remote location, Inability to determine charge of battery systems	No concerns	No concerns	No concerns	No concerns	Battery lifetime, Fuel availability and operations and maintenance costs at remote locations a concern	Emissions from generators are a concern, Reliability concerns also exist

Table 2-3. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Commercial Market Segments*.

Market Segment	Casinos	Data Centers	Grocery Stores	Railways	Ski Parks	Amusement Parks	Hotels	Finance	Telecom	Mining
Performance Factors Users are Most Satisfied with – Current Technologies	Reliability, lifetime, Start-up time, Ease of use, Fuel availability	Reliability, Operations and maintenance costs, Lifetime, Annual operating cost, Emissions, Start-up time, Ease of use, Fuel availability	Lifetime, Annual operating cost, Ease of use, Fuel availability	Lifetime, Start-up time	Reliability, Operations and maintenance costs, Start-up time, Ease of use, Fuel availability	Data not available	Data not available	Data not available	Data not available	Ease of use, Operations and Maintenance costs, Fuel availability
Market Potential for Backup Power	Low	Medium to High	Medium to High – Geographically driven	High – Remote locations, subway stations	Low	Low	Low	Low	High – Remote locations	Medium to High
Interest in Alternatives for Backup Power	No interest	Limited interest	High interest	High interest	Limited interest	No interest	No interest	Limited interest	High interest	Limited interest
Awareness of PEM Fuel Cells for Backup Power	Limited to no awareness	Some level of awareness	High level of awareness	Some level of awareness	Limited to no awareness	Limited to no awareness	Limited to no awareness	Some level of awareness	High level of awareness	Some level of awareness
Key Decision Factors for Capital Purchases	Initial capital cost, Payback period, Return on investment	Initial capital cost, Business justification	Need for backup power, Return on investment, Payback period, Initial capital cost	Payback period, Initial capital cost, Return on investment	Initial capital cost, Payback period	Initial capital cost	Payback period, Return on investment, Initial capital cost	Initial capital cost, Payback period	Return on investment, Initial capital cost	Return on investment
Importance of Government Incentives in Purchasing	Important	Not so important	Very important	Important	Important	Not so important	Important	Not so important	Not so important	Important
Potential Opportunity for PEM Fuel Cells in the Near-term	Low	Low	Low	Medium	Low	Low	Low	Low	High	Low

Table 2-3. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Commercial Market Segments*.

Market Segment	Casinos	Data Centers	Grocery Stores	Railways	Ski Parks	Amusement Parks	Hotels	Finance	Telecom	Mining
Drivers for PEM Fuel Cell Adoption	No apparent drivers	No apparent drivers	Potential environmental concerns, Need for backup power to support long outages in coastal zones	Potential environmental concerns, Need for backup power in remote locations, Mandate to provide backup power in subways	Environmental concerns, Regulatory concerns	No apparent drivers	No apparent drivers	No apparent drivers	Need for backup power in remote locations with longer runtimes and lower operations and maintenance costs	Environmental concerns, Regulatory drivers that require mining companies to install backup power
Barriers to PEM Fuel Cell Adoption	Capital costs are a decision driver, Users are satisfied with current mode of operation, Limited interest in alternatives	Capital costs are a decision driver, Users are satisfied with current mode of operation, Limited interest in alternatives, Small size of PEM fuel cell products current available in the marketplace may limit application	Track record of others using PEM fuel cells is important, PEM fuel cell size may limit application, Market segment is sensitive to fuel costs	Backup power is dependent on need, Capital costs are a concern, Track records of others using PEM fuel cells is important	Capital costs are a decision driver, Users are satisfied with current mode of operation, Limited interest in alternatives	Capital costs are a decision driver, Users are satisfied with current mode of operation, Limited interest in alternatives	Users are satisfied with their current technologies, Looking for alternatives that have high efficiency and can support their CHP needs	Capital costs are a concern, Users are satisfied with current technologies, Limited interest in alternatives	Unknown reliability of PEM fuel cells, Track record of others using PEM fuel cells is important, Need Telecordia to set guidelines for PEM fuel cell installation	Current power size of PEM fuel cells may be a limitation

*Telecom, finance, and hotels were analyzed based on surveys conducted in fiscal year 2005; No primary information was available on user requirements for amusement parks.

2.2.1.2 Institutional Backup Power Market Segment Analysis

Five institutional market segments were analyzed for the potential for adoption of PEM fuel cells in backup power applications. Table 2-4 presents Battelle's analysis of the information gathered through surveys of users in these market segments and secondary research. For the number of respondents to surveys and the number of interviewees in each of these segments, see Table 2-2.

All institutional market segments analyzed use some level of backup power; and all appear to have some backup applications that are a good fit for PEM fuel cells in the near-term, including communications systems, supervisory control and data acquisition (SCADA) systems, telecom sites, and emergency lighting. In addition to UPS systems, batteries, and generators, large users in the healthcare, airports, and electric utility markets also have redundant power lines for backup. Of the five segments analyzed, healthcare, airports, and the electric utility markets are most severely impacted by outages. Extended outages appear to be very disruptive to all three of these segments.

Reliability, start-up time, fuel availability, ease of use, and good experience with this type of system in the past were identified as the most important factors when selecting a backup power system by institutional users in the five institutional market segments. However, when making a decision to purchase a system, all users in the various institutional market segments analyzed identified initial capital cost as an important consideration. Government incentives are considered important or very important by all institutional market segments, except healthcare. Of the five institutional segments, dissatisfaction with current technologies was noted only in the airport market segment. Primary concerns are emissions from generators and the large footprint of generators. While users in the water treatment and electric utility substation market segments identified some concerns with batteries and generators, users in these segments appear to be very satisfied with current technologies. High interest in alternatives to support critical energy requirements was identified in the airport and healthcare market segments. However, it appears that this interest is primarily to support large applications (e.g., facilities, equipment). Market research suggests that only the electric utility substation market has considered PEM fuel cells as alternatives. Some users surveyed in this market segment are testing PEM fuel cells for substation backup power; however, these users are yet to be convinced of the reliability of PEM fuel cells and are considering them for battery recharging applications.

Based on the technology-market fit analysis, near-term opportunities for PEM fuel cells exist for backup power support of communications systems, SCADA systems, and emergency lighting applications. However, it is likely that none of these market segments will be adopters in the near-term. No apparent drivers were identified for the adoption of PEM fuel cells in the near-term in these market segments. Most users appear to be concerned about capital cost and reliability of backup power systems. Those users familiar with PEM fuel cells are unconvinced of their reliability. Furthermore, users are also interested in good experience with the system in the past, which may limit early adoption. No unique value for PEM fuel cells could be determined.

Table 2-4. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Institutional Market Segments.

Market Segment		Healthcare	Airports	Wastewater Treatment	Water Treatment	Electric Utility Substations
Applications		Life support equipment, Critical life safety equipment, Communications systems, Blood bank refrigerators, Urgent care areas, Emergency lighting	Airfield lighting, Security systems, Life safety systems, Terminals - lighting and space heating and cooling, Ticket counters, Baggage systems, Fueling stations, Aircraft operations/tower, Emergency lighting, Communications centers, Emergency response stations, Electrical substations, Parking structures	Pumps, aeration blowers and mixers, Clarifier drivers, Digester blowers, Wastewater processing equipment, Traveling bridges	Plant emergency lights, SCADA systems, Communications systems, Computer operations, Water pump operations including low and high service pumps, Chemical feed systems, Mixers, Filters	Power control networks, Relay protection, Telecom sites
Most Critical Applications		Life support equipment, Critical life safety equipment	Life safety equipment, Airfield lighting, Communications centers, Security systems	All of the above	SCADA systems, Communications systems, Water pumps	All of the above
Economic Impact and Other Impacts of Outages		High; Results in implementation of emergency management plans, loss of life, and security breach	High; Results in security breach, flight delays impacting airline schedules across the country, and implementation of emergency management plans	High; Results in disruptions in production and distribution, loss of safe drinking water, and implementation of emergency management plans	High; Results in loss of safe drinking water, disruptions in production and distribution, and in extreme cases could result in lives lost where water is not available for fire protection	High; Results in implementation of emergency management plans and potential loss in distribution of power
Types and Typical Size of Backup Systems Used		Stand-by utility lines, UPS, Batteries, Generators; 5 kW - > 1,000 kW	UPS, Batteries, Generators, Stand-by utility lines; Sizes: 5kW - > 1 MW. For entire terminals > 4 MW; backup power systems on trailers ~350 kW	UPS, Generators; 5 - 30 kW, > 250 kW	UPS, Generators; 5 - 15 kW, > 250 kW	Batteries; Sizes: 15 - 30 kW, > 250 kW
User Requirements	**Reliability**	Very important	Very important	Very important	Very important	Very important
	Capital Cost	Important	Important	Important	Important	Important
	Lifetime	Important	Very important	Important	Important	Important
	Annual Operating cost	Important	Important	Important	Important	Very important
	Emissions	Important	Very important	Important	Important	Important
	Start-up Time	Very important	Very important	Very important	Very important	Very important
	Ease of Use	Very important	Very important	Very important	Very important	Very important
	Fuel Availability	Very important	Very important	Very important	Very important	Very important
	Good Experience with System in the Past	Very important	Very important	Very important	Very important	Very important

Table 2-4. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Institutional Market Segments.

Market Segment	Healthcare	Airports	Wastewater Treatment	Water Treatment	Electric Utility Substations
Most Important User Requirements	Reliability, Start-up time, Ease of use, Fuel availability	Reliability, Start-up time, Good experience in the past	Reliability, Start-up time, Fuel availability	Reliability, Start-up time, Good experience with system in the past	Reliability, Ease of use
User Satisfaction with Current Technologies	Very satisfied	Satisfied, with some concerns	Very satisfied	Very satisfied	Very satisfied
User Concerns with Current Technologies	No concerns	Cost of system, Emissions, Space occupied by facility backup power systems, Limited ability of UPS systems to support extended outages	No concerns	Transportability of generators	Corrosion of batteries, High maintenance requirements of batteries including room ventilation, Disposal requirements for batteries
Performance Factors Users are Most Satisfied with – Current Technologies	Reliability, Start-up time	Reliability, Fuel availability, Start-up time	Reliability, Annual operating costs, Start-up time, Fuel availability	Reliability, Start-up time	Reliability, capital cost, Operations and maintenance costs, Lifetime, Annual operating cost, Start-up time, Ease of use, Fuel availability
Market Growth Potential for Backup Power	Medium	Medium	Low	Low	Low
Interest in Alternatives for Backup Power	High interest	High interest	Limited interest	Limited interest	Limited interest
Awareness of PEM Fuel Cells for Backup Power	Some level of awareness	Limited awareness among users	Limited to no awareness	Limited to no awareness	High level of awareness
Key Decision Factors for Capital Purchases	Initial capital cost, Equipment reliability	Initial capital cost, Payback period, Return on investment	Initial capital costs, Payback period, Return on investment	Initial capital cost	Initial capital cost, Payback period, Dependent on availability of funds and need for backup power
Importance of Government Incentives in Purchasing	Not so important	Very important	Important	Important	Very important
Potential Opportunity for PEM Fuel Cells in the Near-term	Low	Low	Low	Low	Low
Drivers for PEM Fuel Cell Adoption for Backup Power	No apparent drivers	No apparent drivers	No apparent drivers	No apparent drivers	No apparent drivers
Barriers to PEM Fuel Cell Adoption	Users satisfied with current mode of operation, Limited interest in small sized alternatives, Unknown reliability of PEM fuel cells, Concerns about hydrogen siting with critical equipment	Users interested in large capacity backup power, Limited interest in alternatives for smaller applications, Unknown reliability and high capital costs of PEM fuel cells a concern	Users satisfied with current mode of operation, Limited interest in alternatives, Market is sensitive to capital costs, Users look for track record of others using similar system	Users satisfied with current mode of operation, Limited interest in alternatives, Market is sensitive to capital costs, Users look for track record of others using similar system	Users satisfied with current mode of operation, Limited interest in alternatives, Unknown reliability of PEM fuel cells a concern, Market is sensitive to capital costs

2.2.1.3 Industrial Backup Power Market Segment Analysis

Seven industrial market segments were analyzed to determine the market opportunity for PEM fuel cells in the near-term. This section reports on findings in just five of seven industrial market segments (Table 2-5), due to limited primary and secondary information on the pharmaceutical and food manufacturing market segments.

Secondary information reviewed on the pharmaceutical sector suggests that users are interested in alternatives to meet their carbon reduction goals; however, limited information was available on their interest in adopting backup power alternatives. As pharmaceutical manufacturing requires highly reliable grid power, it is expected that manufacturers would have redundant power sources including the grid, large generators, and UPS systems. It is likely that, in the near-term, opportunities for PEM fuel cells will be limited to those areas where UPS systems are applied. Little information was available on opportunities for backup power in the food manufacturing sector and user interest in alternative technologies. It can be anticipated that, like other manufacturing operations sensitive to power outages, backup power for communications and SCADA systems could be potential opportunities for PEM fuel cells. The secondary and primary information gathered to support analyses of the opportunities for PEM fuel cells in all seven industrial market segments is presented in Appendix C.

Due to limitations in the size and durability of PEM fuel cells, near-term applications in industrial segments may be limited to the support of communications systems, control systems, emergency lighting and alarm systems, and other life safety systems. Users in these market segments experience outages; however, outages are typically short (< 60 seconds). Longer, more severe outages are experienced typically during weather-related events. The economic impact of extended outages is severe in this sector; as a result, most operations have a high level of redundancy. Backup power is provided through additional support from the grid, large generators, and UPS systems.

Reliability, start-up time, ease of use, and fuel availability were identified by users as the most important factors when selecting a backup system. Initial capital cost was also identified as an important factor when evaluating new systems. Users appear to be fairly satisfied with their current mode of operation. Only users in the computer and electronics manufacturing sector identified some concerns with emissions from generators and operations and maintenance requirements for batteries.

The market growth potential for small backup power systems appears to be more promising in the oil and gas refinery segment and the metal processing and refining segment than in the other industrial segments, due to regulatory drivers. However, in these market segments, there has been limited to no interest in small backup power alternatives, including PEM fuel cells. No apparent drivers or value for PEM fuel cells for backup power in the near-term could be identified. The adoption of PEM fuel cells in these market segments will depend on the ability of PEM fuel cells to compete effectively with current alternatives in terms of reliability and capital cost.

Table 2-5. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Industrial Market Segments.

Market Segment		Chemical Manufacturing	Oil and Gas Refining	Computer and Electronic Products	Metals Processing and Mining	Transportation Equipment
Applications		Within process facilities - Control systems, Switchgear control power, Instruments, Vibration monitors, Motors, Computer systems, Emergency lighting	SCADA systems, Remote instrumentation support, Mainframe computing hardware, Emergency lighting, Corporate crisis management, Data center supporting corporate operations	Computer systems and servers, Emergency lighting, Exhaust fans, Light safety systems, SCADA systems	Process control systems, Automation and robotics control systems, Process lines	Emergency lighting, Servers, Process control for machining operations
Most Critical Applications		All of the above	SCADA systems	All of the above	All of the above	Process control for machining operations, Servers
Economic and Other Downtime Impacts		High; Critical equipment fitted with ride through for shorter interruptions; Longer disruption affects distribution and production; Results in implementation of emergency management plans	High; Any disruption is very disruptive; Results in disruptions in distribution and production and implementation of emergency management plans	High; Any type of interruption is very disruptive; Results in disruption of production and distribution and could potentially result in the implementation of emergency management plans	High; Results in equipment damage, safety concerns, and disruptions in production and distribution	Medium to High; Varies based on type of operation; Results in disruption of production and distribution
Types and Typical Size of Backup Systems Used		Batteries, UPS, Generators, Redundant feeds from electric utilities; Sizes unknown	Redundant feeds from electric utilities, Batteries, UPS, Generators; 2 kW - > 2,000 kW	UPS, Batteries, Generators; < 5kW - > 250 kW	UPS, Generators; 1 - 150 kW	UPS, Generators; < 5 kW - 500 kW
User Requirements	**Reliability**	Very important	Very important	Very important	Very important	Very important
	Capital Cost	Very important	Important	Very important	Important	Important
	Lifetime	Important	Important	Very important	Important	Very important
	Annual Operating Cost	Important	Important	Important	Important	Important
	Emissions	Very important	Very important	Important	Not so important	Important
	Start-up Time	Very important	Very important	Important	Very important	Very important
	Ease of Use	Very important	Important	Very important	Important	Very important
	Fuel Availability	Very important	Very important	Important	Important	Important
	Good Experience	Very important	Very important	Important	Important	Important
Most Important User Requirements		Reliability, Start-up time, Fuel Availability	Reliability, Start-up time	Reliability, Start-up time, Fuel availability	Reliability, Ease of use, Start-up time, Capital cost	Reliability, Start-up time, Capital cost

Table 2-5. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Industrial Market Segments.

Market Segment	Chemical Manufacturing	Oil and Gas Refining	Computer and Electronic Products	Metals Processing and Mining	Transportation Equipment
User Satisfaction with Current Technologies	Very satisfied	Very satisfied	Satisfied, with some concerns	Very satisfied	Very satisfied
User Concerns with Current Backup Power Technologies	No concerns	No concerns	UPS systems - Maintenance, Generators - Emissions	No concerns	No concerns
Performance Factors Users are Most Satisfied with – Current Technologies	Reliability, Start-up time, Fuel availability, Operations and maintenance costs	Reliability, Start-up time	Reliability, Capital costs, Annual operating costs, Emissions, Start-up time, Ease of use, Fuel availability	Start-up time, Fuel availability, Reliability, Ease of use	Lifetime of unit, Fuel availability
Market Potential for Backup Power	Low	Medium	Low	Medium	Low
Interest in Alternatives for Backup Power	No interest	No interest	Limited interest	Some interest	No interest
Awareness of PEM Fuel Cells for Backup Power	Limited awareness	Limited awareness	Limited awareness	No awareness	No awareness
Key Decision Factors for Capital Purchases	Return on investment, Initial capital cost	Return on investment	Return on investment, Initial capital costs, Payback period, and Need	Initial capital cost	Return on investment, Payback analysis
Importance of Government Incentives in Purchasing	Important	Important	Not so important	Not so important	Not so important
Potential Opportunity for PEM Fuel Cells in the Near-term	Low	Low	Low	Low	Low
Drivers for PEM Fuel Cell Adoption	No apparent drivers	No apparent drivers, To a limited extent mandates for backup power could drive interest in PEM fuel cells	Environmental concerns	Environmental concerns, Regulatory concerns	No apparent drivers
Barriers to PEM Fuel Cell Adoption	Users are satisfied with current technologies, Alternatives for small backup systems are of limited interest, Track record of others using PEM fuel cells is important, PEM fuel cells are limited by size and durability	Users are satisfied with current technologies, Users are looking for larger systems to fit their requirements, PEM fuel cells are limited by size and durability	Users appear to be fairly satisfied with current technologies, Limited interest in alternatives, PEM fuel cells are limited by size and durability	Limited interest in alternatives, Users are sensitive to capital costs, Users are fairly satisfied with current technologies	Limited interest in alternatives, Users appear to be fairly satisfied with current technologies

2.2.1.4 Government Backup Power Market Segment Analysis

Two government market segments were analyzed, including the federal market and state and local emergency response market, as potential adopters of PEM fuel cells. Twelve federal sub-markets were identified for further analysis, as secondary research indicated a need for backup power in these segments that PEM fuel cells may be able to meet. The DoD is currently developing PEM fuel cells for various applications and is a likely early adopter. Due to the diverse number of applications and their sensitive nature, limited primary and secondary research was conducted in this market segment. While research was conducted, limited primary and secondary information was available on five agencies, including DOI, USPS, NRC, USDA, and GSA. No formal surveys were conducted with these agencies; interviews were conducted with three federal agencies, including NRC, USDA, and GSA. An analysis of FAA requirements was based on responses received to the surveys conducted in fiscal year 2005 and on a more recent review of secondary research. Due to this general lack of information, the potential for PEM fuel cell adoption in backup power applications is presented in Table 2-6 for only seven of the twelve federal government sub-markets analyzed.

Market research identified various drivers to adopt PEM fuel cells, including the need for extended backup power, dissatisfaction with generators and batteries, and environmental concerns, in all eight government market segments. Primary backup applications for PEM fuel cells in the near-term include radio sites, communication systems, computer networks, and emergency lighting and alarms. All of the government markets presented in Table 2-6 have remote applications that could be supported by PEM fuel cells. The impacts of outages are most significant for emergency response agencies, NOAA, the FAA, and the USCG. Outages may result in implementation of emergency management plans and potential loss of life; therefore, it is critical for these users to ensure continuous power supply at all times. In some cases, agencies are mandated to have backup power due to the criticality of their operations. Backup power is primarily provided through generators, UPS systems, and batteries.

Primary concerns for users in the government market segments when selecting a backup power system, in order of importance, are: reliability, start-up time, lifetime, fuel availability, emissions, and good experience with the system in the past. There is some level of discontent among users in the emergency response market, NOAA, NPS, USCG, and FAA, with regard to their current mode of operation for backup power. Furthermore, there is interest in alternatives in all five market segments. However, since the NPS market has limited funds for facility upgrades and considers a variety of issues when making a purchasing decision, adoption by this market in the near-term is unlikely. When the technology-market fit is examined, PEM fuel cells could offer a unique value proposition for the emergency response, NOAA, USCG, and FAA markets in the near-term; potential benefits include longer runtimes as compared to batteries, lower emissions than generators, and remote operation and monitoring capabilities. It should be noted that in all four market segments, users are sensitive to initial capital costs and that incentives will be important to facilitate purchasing. It is likely that applications for PEM fuel cells at other federal agencies like EPA, NASA, and DOE will evolve as the capital costs of PEM fuel cells become more attractive.

Table 2-6. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Government Market Segments.

	State and Local Government	Federal Agencies						
Market Segment	**Emergency Response***	**NOAA (National Weather Service)**	**EPA (Facilities)**	**NASA (Facilities)**	**DOE (Facilities)**	**National Parks**	**USCG**	**FAA****
Applications	911 call centers, Dispatch telephones and computer systems, Radios, Wireless communications facilities and radio infrastructure, Security systems for jails, fire, police stations	Mission critical weather systems	Lab (includes critical analysis) equipment, Emergency operations center, Computer networks, Data centers, Emergency lighting and alarm systems	Research, operations, Data communications, Data storage	Life safety equipment, Emergency lights, Fire protection, Security, Servers and computers	Fire protection, Radio and telephone systems, Dispatch centers, Fire/rescue/law enforcement operations, Hospitality, Museums and curatorial centers, Wastewater treatment, Utility water systems, Administrative centers	Telecom systems – National distress system, Computers and servers, Navigation systems, Telephones	Air traffic control towers, Radio transmitter sites
Most Critical Applications	Remote radio sites, Dispatch radios, Computer aided systems, Telephones	All of the above	Computer networks, Critical analysis equipment	Research, Operations, Data communications	Life safety equipment	Fire protection, Radio and telephone systems, Dispatch centers, Fire/rescue/law enforcement operations, Wastewater treatment, Utility water systems	Security communication systems	Remote radio sites
Economic and Other Downtime Impacts	High; Long outages are very disruptive; Potential impacts are lives lost, security breach, and implementation of emergency management plans	High; Longer outages are very disruptive, Results in the implementation of emergency management plans and possibly in security breach	Medium to High; Outages can disrupt experiments, which may impact data	Medium to High; Impact is dependent on the type of operation supported; Results in disruptions in production and implementation of emergency management plans	Medium to High; Impact is dependent on the type of operation supported; Results in disruptions in production and can also result in implementation of emergency management plans	Low; Impact is dependent on where the outage occurs; Results in implementation of emergency management plans, loss of safe drinking water, and uncontrolled release of sewage	High; Impact is dependent on where the outage occurs; Can result in loss of life, implementation of emergency management plans, and release of sewage	High; Results in disruption of air traffic and implementation of emergency management plans

Table 2-6. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Government Market Segments.

		State and Local Government	Federal Agencies						
Market Segment		**Emergency Response***	**NOAA (National Weather Service)**	**EPA (Facilities)**	**NASA (Facilities)**	**DOE (Facilities)**	**National Parks**	**USCG**	**FAA****
Types and Typical Sizes of Backup Systems Used		Batteries, UPS, Generators; Radio sites: < 5 - 60 kW, Telecom equipment and computer aided dispatch: < 5 - 30 kW, Facility backup: > 1,000 kW	UPS; 5 - 30 kW	UPS, Generators; < 5 - 250 kW, Facility backup: > 1.2 MW	UPS, Generators; < 5 - 250 kW, Facility backup: > 1MW	UPS, Generators; < 5 - 250 kW, Facility backup: > 1 MW	Generators; 5 - 150 kW	UPS, Batteries, Generators; 5 - 250 kW	UPS, Generators; 0.5 - 150 kW
User Requirements	**Reliability**	Very important	Very important	Very important	Very important	Very important	Very important	Very important	Very important
	Capital Cost	Important	Very important	Very important	Very important	Important	Important	Very important	Important
	Lifetime	Important	Very important	Very important	Very important	Important	Very important	Very important	Very important
	Annual Operating Cost	Important	Very important	Important	Very important	Not so important	Important	Important	Very important
	Emissions	Important	Very important	Very important	Very important	Important	Very important	Very important	Important
	Start-up Time	Very important	Very important	Very important	Very important	Very important	Not so important	Very important	Very important
	Ease of Use	Important	Very important	Important	Very important	Very important	Important	Important	Very important
	Fuel Availability	Very important	Very important	Very important	Very important	Important	Important	Important	Very important
	Good Experience	Important	Very important	Important	Important	Very important	Very important	Important	Important
Most Important User Requirements		Reliability, Fuel availability, Start-up time, Ease of use	Reliability, Lifetime, Capital cost	Reliability, Lifetime	Reliability, Capital cost, Low annual operating cost, Ease of use	Reliability, Ease of use, Good experience with system in the past	Reliability, Low annual operating cost, Ease of use	Lifetime, Emissions, Start-up time	Reliability, Lifetime, Operations and maintenance costs
User Satisfaction with Current Technologies		Satisfied, with some concerns	Not so satisfied	Satisfied with UPS; Not so satisfied with PAFC and generators	Satisfied	Very satisfied	Satisfied, with some concerns	Satisfied, with some concerns	Satisfied, with some concerns

Table 2-6. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Government Market Segments.

	State and Local Government	Federal Agencies						
Market Segment	**Emergency Response***	**NOAA (National Weather Service)**	**EPA (Facilities)**	**NASA (Facilities)**	**DOE (Facilities)**	**National Parks**	**USCG**	**FAA****
User Concerns with Current Technologies	Generators – Mechanical failure of generator, Loss of fuel, and High emissions; Batteries – Unable to determine charge	UPS systems provide only 10 minutes of backup power, Looking for alternatives to provide support for long outages	PAFC is difficult to maintain, Issues with parts availability, Dissatisfaction with durability and reliability of the system, Emissions from generators	No concerns	No concerns	Emissions, High capital costs of system	Maintenance of generators, Limited backup runtime	Generators – Emissions, High operations and maintenance costs; Batteries – Limited runtime
Performance Factors Users are Most Satisfied with – Current Technologies	Reliability, Lifetime, Start-up time, Fuel Availability	Annual operating cost, Start-up time, Emissions, Reliability	Fuel availability, Lifetime, Operations and maintenance (only UPS and generators)	Capital cost, Lifetime of unit, Start-up time	Fuel availability, Reliability, Ease of use, Lifetime	Data not available	Data not available	Data not available
Market Growth Potential for Backup Power	High	High	Low	Low	Low	Low	Medium to High	Medium to High
Interest in Alternatives for Backup Power	High interest	High interest	Low interest	Low interest	Low	High interest	High interest	High interest
Awareness of PEM Fuel Cells for Backup Power	Some level of awareness	Some level of awareness	Limited awareness	High level of awareness	Limited awareness	Some level of awareness	Limited awareness	Some level of awareness
Key Decision Factors for Capital Purchases	Initial capital cost, Payback period, Return on investment, Need for backup power	Initial capital cost, Payback period, Return on investment	Payback period	Payback period, Initial capital cost, Return on investment	Need, Funding availability, and Priority	Sustainability, Policy requirements, Initial capital costs, Return on investment	Return on investment, Energy savings, Lifetime	Return on investment, Initial capital cost
Importance of Government Incentives in Purchasing	Important	Important	Very important	Not so important	Not so important	Important	Important	Important
Potential Opportunity for PEM Fuel Cells in Backup Power Applications the Near-term	High	Medium	Low	Low	Low	Low	Medium	Medium
Drivers for PEM Fuel Cell Adoption	Environmental concerns, Regulatory	Need for longer runtime, Size requirements are a	"Green" image, User is building new facilities and	Historical use of fuel cell by the user for other	Energy efficiency	Lack of emissions from PEM fuel cells	Looking for longer runtime for certain applications	Dissatisfaction with operations and maintenance of

Table 2-6. Analysis of the Potential for PEM Fuel Cells in Backup Power Applications in Government Market Segments.

	State and Local Government	Federal Agencies						
Market Segment	**Emergency Response***	**NOAA (National Weather Service)**	**EPA (Facilities)**	**NASA (Facilities)**	**DOE (Facilities)**	**National Parks**	**USCG**	**FAA****
	requirements, Need for longer runtime, Size requirements are a good fit	good fit	is looking for alternative technologies	applications				batteries and generators, Size requirements are a good fit for PEM fuel cells
Barriers to PEM Fuel Cell Adoption	Initial capital cost is a consideration, Track record of others using PEM fuel cells is important	Capital cost of the PEM fuel cell may be a barrier, Unknown reliability of PEM fuel cells a concern	PEM fuel cells may be limited by size, Durability and capital costs of PEM fuel cells a concern	Availability of funds for non-critical facility (non-critical) expenditures, Decision to purchase is determined by total lifecycle cost of PEM fuel cells against alternatives	Availability of funds for non-critical facility (non-critical) expenditures, Limited information of PEM fuel cells	Availability of funds, Users are sensitive to initial capital cost, Users perceive that PEM fuel cells are not reliable	Power size of PEM fuel cells may limit application, Capital cost is a consideration for users in this segment, Reliability of PEM fuel cell may be a concern	Capital cost is the key financial consideration for users in this segment

*Emergency Response market includes state emergency response agencies, police stations, fire houses, and public service answering points (PSAPs).
**Individual segment analysis based on fiscal year 2005 surveys.

2.2.2 Composite Analysis of Trends in Backup Power Markets

Responses from 79 surveys and six protocol-based interviews from both phases of research are analyzed quantitatively across all backup market segments in this section. Twelve respondents in the backup power market were involved in the testing of the first version of the Phase 1 survey instrument. As a result, the analysis presented below will not include responses from these respondents on whether they had considered alternatives, whether incentives are important to them in making decisions, and if hydrogen fuel is a cause for concern.

2.2.2.1 Survey Participant Profile

Phase 1 and Phase 2 involved surveys of small, medium, and large companies. Table 2-7 identifies the size of respondents' organizations and the total number of respondents in both phases of research. For backup power, 39 respondents were from organizations with less than 500 employees; 18 respondents were from organizations with 500 to 3,000 employees, and 22 respondents were from organizations with over 3,000 employees.

Table 2-7. Number of Respondents to Phase 1 and Phase 2 Surveys by Size of Organization.

	Small	Medium	Large	Total Number of Respondents
Backup Power User	39	18	22	79
Specialty Vehicle User	4	5	17	26
Specialty Vehicle Manufacturers	12	7	5	24
Total by Size	55	30	44	129

2.2.2.2 Frequency and Duration of Outages

When asked about the frequency and duration of outages, responses were varied. Only 35 of 79 respondents identified the frequency of outages. While 14 respondents indicated that they frequently experienced outages, they were unable to provide an exact number. Figure 2-1 identifies the frequency of outages experienced by respondents. Of the 35 respondents, 21 had experienced between 1 and 5 outages in the last 12 months, six had experienced between 6 and 10 outages, and six had experienced between 10 and 15 outages. Only one respondent reported over 15 outages in the past 12 months.

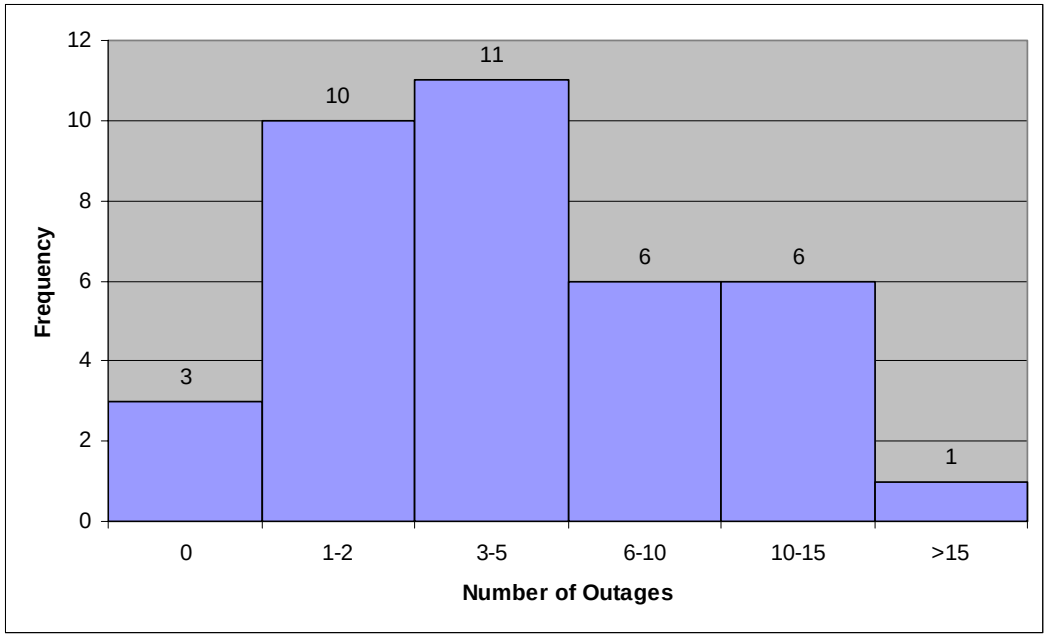


Figure 2-1. Number of Outages Experienced in the Past 12 Months.

Respondents were asked to estimate the duration of outages. Of the 79 respondents, 16 did not know the duration of outages experienced in the past 12 months. Outages less than 60 seconds were experienced 34% of the time, while outages over 5 minutes were experienced 22% of the time, outages between 5 minutes and 1 hour were experienced 22% of the time, and outages over 4 hours were experienced 13% of the time (Figure 2-2).

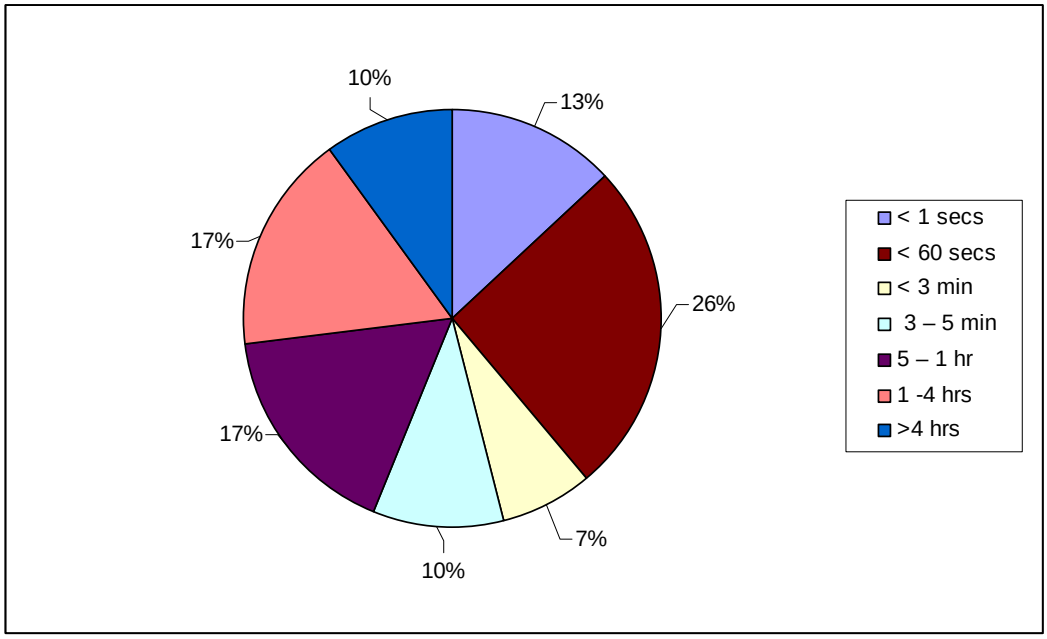


Figure 2-2. Duration of Outages Experienced in the Last 12 Months.

2.2.2.3 Current Backup Power Systems

Respondents were asked how backup power requirements are currently being met for their sensitive applications in both Phase 1 and Phase 2 surveys. Most respondents identified more than one source of backup power. Of the 79 respondents, 85% of the respondents used diesel or propane generators, 75% used UPS systems, and 46% used batteries to provide backup power. Approximately 14% of the respondents indicated that other forms of backup power were also used, including stand-by utility lines, wind power, and fuel cells (Figure 2-3).

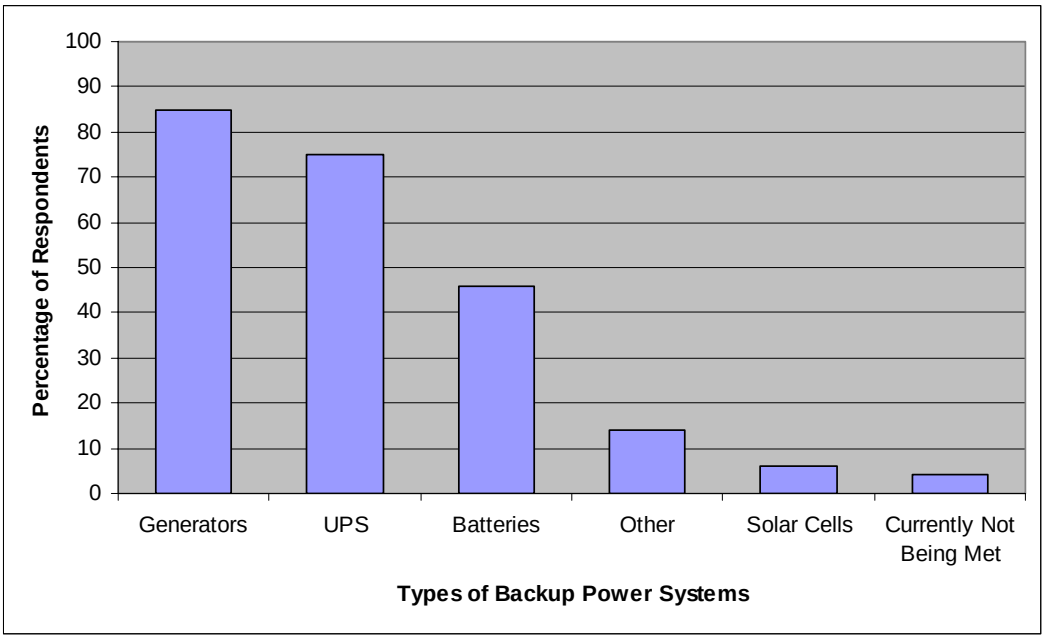


Figure 2-3. Current Sources of Backup Power.

2.2.2.4 Satisfaction with Current Systems

In the Phase 1 survey, respondents were asked to identify their level of satisfaction with their backup systems. Most users rated the performance of their system as good or very good. Of the 72 respondents in Phase 1, 57 respondents answered this question. The average response was 5.8 on a scale of 1 to 7, with 1 being not so good and 7 being very good. The mode of the distribution was 6 with a standard deviation of 0.96. Respondents were also asked if they had any specific concerns about their backup power systems; 44 respondents indicated that they did not have any concerns. Of the 28 respondents who identified concerns with current systems, 15% identified emissions as a concern (Figure 2-4).

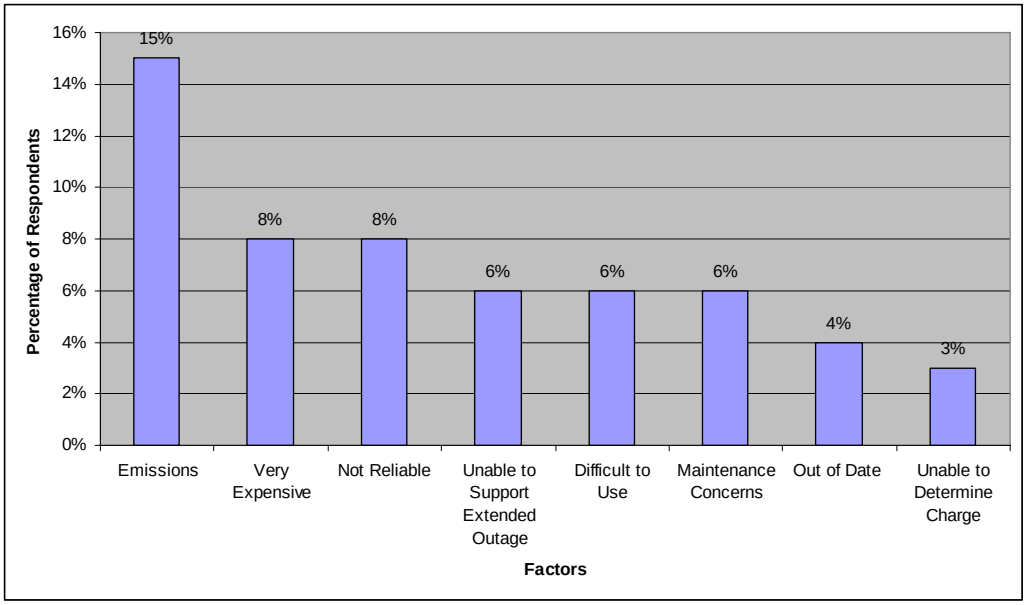


Figure 2-4. Factors of Concern with Current Backup Systems.

Users were asked to rate the performance of their backup power systems for a variety of characteristics. Of the 79 respondents, 75% of the respondents identified reliability as very good, 73% identified start-up time as very good, and 71% identified fuel availability as very good. However, of the 79 respondents, only 28% identified capital cost and 27% identified emissions as very good. Figure 2-5 shows the distribution of the ratings received for various backup system factors (on a scale of 1 to 7, 7 was very good and 1 not so good).

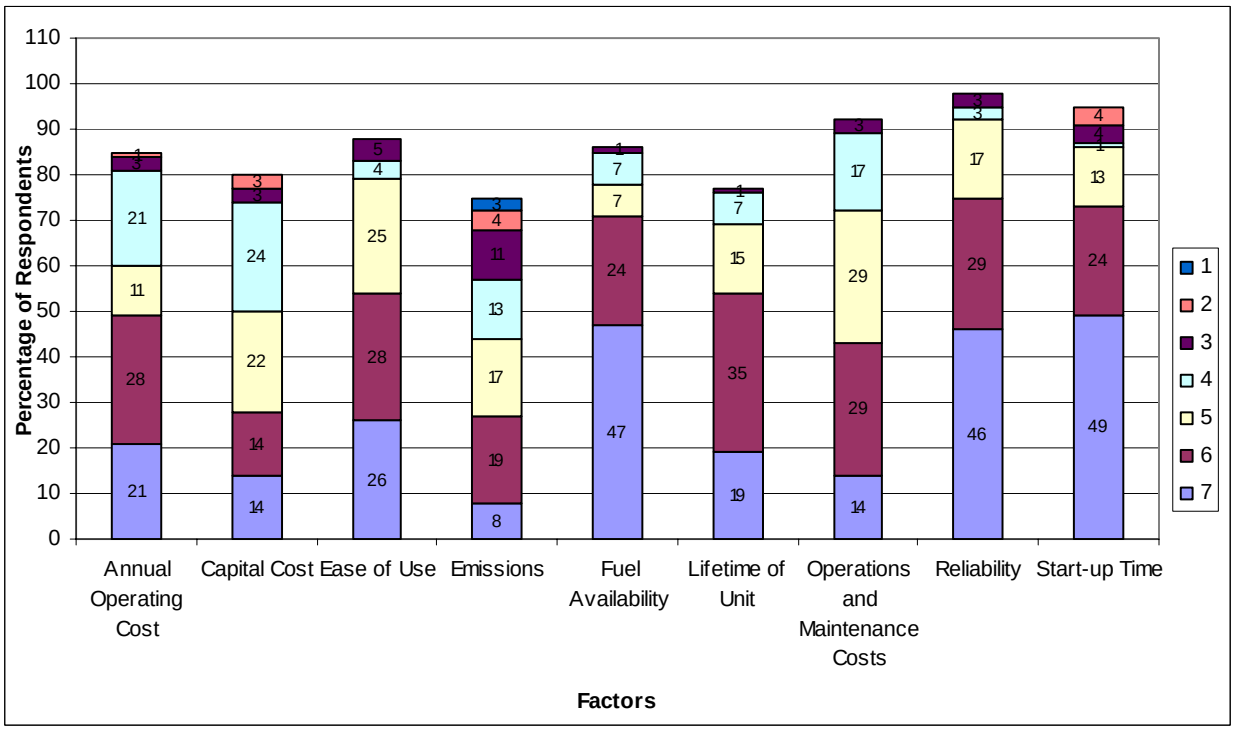


Figure 2-5. User Satisfaction with Various Backup Power System Characteristics.

2.2.2.5 Purchase Decision Factors

Users were also asked to identify the importance of various factors when selecting a backup power system (on a scale of 1 to 7, 7 was very important and 1 not so important). Of the 79 respondents, 98% identified reliability as very important, 78% identified start-up time as very important, 72% identified fuel availability as very important, 67% identified good experience with this type of system in the past as very important, 65% identified ease of use as very important, 62% identified lifetime of unit as very important, 50% identified capital cost as important, 45% identified emissions as very important, and only 39% identified annual operating cost as very important (Figure 2-6). When asked to identify three factors that would most influence their decision to purchase an alternative backup power system, users identified reliability, capital cost, and ease of use.

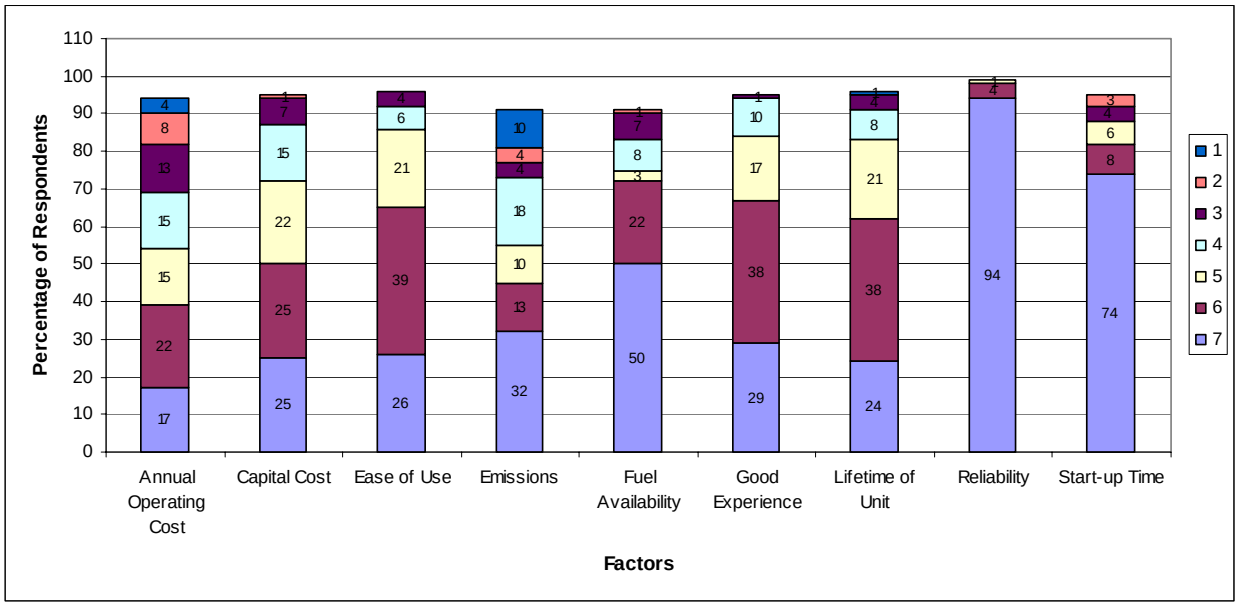


Figure 2-6. Importance of Various Factors in Selecting a Backup Power System.

2.2.2.6 Trends and Potential for Backup Power Applications

When asked if they had considered alternatives to their current sources of backup power, 30% of respondents indicated that they had considered alternatives. Of the respondents who had considered alternatives, 43% had considered fuel cells.

Users were asked if they were familiar with PEM fuel cells as a source of backup power. Of the 79 respondents, 63% were not familiar with PEM fuel cells, while 33% of the respondents were familiar with PEM fuel cells, and 4% of respondents did not answer this question. Of the respondents familiar with PEM fuel cells, 30% believed that PEM fuel cells will compete favorably with existing alternatives in the backup power market. Respondents familiar with PEM fuel cells indicated that the track record of others using PEM fuel cells and the availability of government incentives were the primary drivers for adoption, followed by environmental concerns, energy efficiency of PEM fuel cells, and the cost of not having electricity.

Of the 79 respondents, only 37 users responded to the question about whether they were concerned about hydrogen as a fuel. Just 22% of the respondents indicated that they had concerns about hydrogen as a fuel, while 59% indicated that they had no such concerns; the remaining 19% did not know enough about hydrogen to make an accurate determination.

Candidate users were asked to identify how capital purchase decisions were made in their organization for backup power. Of the 79 respondents, three users did not address this question. Respondents indicated that typically more than one factor was considered when making capital purchase decisions. Of the 79 respondents, 56% of the respondents indicated that initial capital cost was taken into consideration; 35% of the respondents indicated that return on investment was an important consideration; 35% mentioned that the payback period was an important consideration; and 11% indicated that a need for backup power would drive their purchase decisions.

Candidate users were asked if incentives are considered when making capital purchase decisions. Of the 79 respondents, 41% consider incentives when making capital purchase decisions; 28% did not consider incentives when making capital purchase decisions; 10% did not know if incentives were considered when making capital purchase decisions; 5% did not answer the question; and 16% were not asked the question.

2.3 Analysis of Specialty Vehicle Markets

This section presents qualitative and quantitative analyses of the key trends, drivers, and requirements identified by users and integrators for the adoption of PEM fuel cells in specialty vehicle markets. Analyses of trends in individual segments (section 2.3.1), as well as a composite analysis of trends across specialty vehicle markets (section 2.3.2), are presented in this section. Individual specialty vehicle market segment reports can be found in Appendix C. Detailed analyses of two specialty vehicle markets – forklifts in distribution centers and ground support equipment in airports – can be found in section 3.0.

2.3.1 Analyses of Individual Specialty Vehicle Market Segments Based on User and Integrator Responses

Of the 36 market segments analyzed, 12 market segments were analyzed for their potential to adopt PEM fuel cells in specialty vehicles in the near-term (2008). The number of respondents for each market segment and the sizes of the organizations surveyed are presented in Table 2-8. This section presents Battelle's analysis of the trends in individual specialty vehicle segments, as determined through surveys, interviews, and secondary research.

The UAV and UUV markets were examined to identify potential near-term applications. Market research indicated that early applications for UAVs and UUVs were for military applications. Limited primary information was available on user requirements, and secondary information indicated that PEM fuel cells are in development for these markets. For ice resurfacers, no primary information could be gathered on user requirements due to non-response to surveys. Secondary information indicates that there is some concern about indoor emissions from ice resurfacers and the capital costs of PEM fuel cells when integrated as a power source. For motorized bicycles and scooters, secondary research indicates that primary markets will be

outside of the U.S. Furthermore, limited information was available on user requirements in the U.S. As a result, information on UAVs, UUVs, ice resurfacers, and bicycle and scooter market segments are not presented in the individual segment analysis presented in Table 2-9. Secondary information gathered on these market segments is presented in Appendix C.

Table 2-8. Total Number of Respondents and Size of Organizations Surveyed for Specialty Vehicles.

Market Segment	Number of Survey Respondents*	Number of Interviewees	Size of Survey Respondent's Organization+		
			Small	Medium	Large
Automatic Guide Vehicles	3	-	1	1	1
Mining Vehicles	5	2	2	2	1
Airport Ground Support Equipment	13	8	4	1	8
Forklifts	17	3	4	4	9
Golf Carts+	3	1		1	1
Turf Maintenance Vehicles	3	-	1	1	1
Commercial Sweepers	3	-	1	1	1
Ice Resurfacers	-	-	-	-	-
Wheelchairs	3	-	-	2	1
UAVs	1	1	1		
UUVs	-	2			
Motorized Bicycles/Scooters	-	-	-	-	-
Total	51	17	14	13	23

Small is classified as 500 employees or less, medium is classified as 500 to 3000 employees, and large is over 3000 employees;
*Includes integrators. + Two responses were received from one golf cart manufacturer.

All market segments indicated concerns over their current mode of operation except the wheelchair and automatic guide vehicle markets. Of the eight specialty vehicle market segments analyzed for PEM fuel cell opportunities to 2015, four are interested in alternative technologies: airport ground support equipment, forklifts, golf carts, and turf maintenance equipment (Table 2-9). Except for the forklift market segment, users are interested in alternatives to ICE-powered vehicles to meet emission requirements and to decrease operations and maintenance requirements. In the forklift market segment, users are interested in technologies that can increase their productivity and provide alternatives to batteries. Trends in this market segment indicate that users are concerned about the maintenance and safety aspects of lead-acid batteries. Reliability is of paramount importance when selecting a specialty vehicle power source among all market segments analyzed. Other factors that are important include the lifetime of the unit, the availability and affordability of fuel, and ease of use. Except the golf cart and wheelchair market segments, all market segments consider return on investment when making capital purchase decisions. Government incentives are more important in those market segments with regulatory concerns (airports and mining). Fuel availability is a critical requirement for adoption of PEM fuel cell-powered specialty vehicles.

Table 2-9. Specialty Vehicle Market: User and Integrator Analysis Data.

Market Segment		Airport Ground Support Equipment	Forklifts	Mining Vehicles	Automatic Guide Vehicles	Golf Carts	Turf Maintenance Vehicles	Commercial Sweepers	Wheelchairs
Applications		Baggage tractors, Cargo tractors, Tow/pushback tractors, Push out tractors, Belt loaders	Material handling	Load-haul-dump vehicles, Skid-steer loaders, Shuttle cars/ramcar/shield haulers, Roof bolters, Personnel vehicles, Road graders, Drill jumbos	Materials handling vehicles in manufacturing and assembly plants	Golf courses, Individual users, Gated communities, Hospitals, Parking facilities, Warehouses, Universities, Manufacturing industry, Shuttle and tram users	Walking and Riding mowers, Golf courses, Sports fields, schools, Municipalities, Landscapers, Individual/ residential consumers	Automatic sweepers, Scrubbers, Burnishers, Blowers, Dryers, Carpet extracters, Floor moppers; Commercial use, Industrial use, Residential use	Power wheelchairs and racing wheelchairs; Limited mobility individuals and dealers (who sell products to hospitals and care providers)
Most Critical Applications		Baggage tractors, Pushback tractors, Belt loaders in Airports	Material handling (rider reach trucks and pallet reach truck applications) in distribution centers	Loaders, Haulers, Drill jumbos	Pallet trucks in manufacturing facilities like automotive assembly plants and paper manufacturing	Cars/carts in golf courses	Riding mowers used by landscaping companies	Heavy industrial applications with concerns about product contamination, Large manufacturing facilities with multiple shifts and complicated logistics	All of the above
Economics and Other Downtime Impacts		High; Results in loss in productivity and increased operation and maintenance costs	High; Results in loss in productivity, disruptions in distribution, and increased operation and maintenance costs	High; Results in loss in productivity, disruptions in distribution, increased operation and maintenance costs, and safety issues	High; Results in disruption in distribution and loss in productivity	Low; Results in customer dissatisfaction	High; Results in loss of productivity and increase in operations and maintenance costs	Medium to High; Dependent on type of operations; Results in disruption of production and decline in productivity	Low; Results in decreased individual mobility and in customer dissatisfaction
Types of Specialty Vehicles Used		Battery vehicles, ICE vehicles - gasoline, diesel, and propane	Battery vehicles, ICE vehicles - diesel and propane	Battery vehicles, ICE vehicles - diesel, gasoline, and propane	Battery systems	Battery vehicles, ICE vehicles - gasoline	ICE vehicles - gasoline and diesel	Battery vehicles, ICE vehicles - gasoline, diesel, and propane	Battery vehicles and propane ICE
User Requirements	**Reliability**	Very important	Very important	Very important	Very important	Very important	Very important	Very important	Very important
	Capital Cost	Very important	Important	Important	Important	Very important	Very important	Very important	Very important
	Lifetime	Very important	Very important	Important	Very important	Very important	Very important	Very important	Very important
	Annual Operating Cost	Very important	Very important	Important	Important	Very important	Very important	Very important	Very important

Table 2-9. Specialty Vehicle Market: User and Integrator Analysis Data.

Market Segment		Airport Ground Support Equipment	Forklifts	Mining Vehicles	Automatic Guide Vehicles	Golf Carts	Turf Maintenance Vehicles	Commercial Sweepers	Wheelchairs
User Requirements	Emissions	Important	Very important	Very important	Not applicable	Very important	Very important	Very important	Very important
	Start-up Time	Important	Important	Important	Very important	Important	Important	Important	Very important
	Time Between Refueling	Important	Important	Important	Very important	Not so important	Important	Important	Not so important
	Ease of Use	Very Important	Important	Very important	Very important	Very important	Very important	Very important	Very important
	Fuel Availability	Important	Very important	Important	Not applicable	Very important	Very important	Very important	Very important
	Good Experience	Important	Very important	Very important	Very important	Very important	Very important	Very important	Important
Most Important User Requirements		Reliability, Lifetime of unit, Annual operating cost	Reliability, Lifetime of unit, Fuel availability, Capital cost	Reliability, Good experience with the system, Ease of use, Emissions	Reliability, Start-up time, Lifetime	Capital costs, Lifetime, Fuel availability	Capital costs, Emissions, Fuel Availability	Capital costs, Lifetime, Emissions	Capital costs, Ease of use, Reliability, Safety
User Satisfaction With Current Technologies		Satisfied, with some concerns	Not so satisfied	Satisfied, with some concerns	Satisfied	Satisfied, with some concerns	Not so satisfied	Satisfied, with some concerns	Satisfied
User Concerns with Current Technologies		ICE vehicles - hazardous emissions; Battery vehicles - inconvenient to recharge, takes to long to recharge, and causes hazardous spills and leaks	ICE vehicles - emissions are a concern, operations and maintenance is a concern; Battery vehicles - inconvenient to recharge, causes leaks and spills, takes too long too recharge, cool, and equalize the batteries, and lifetime is reduced with fast recharging	ICE vehicles - hazardous emissions; Battery vehicles - spills and leaks, inconvenient to recharge, and takes to long to change batteries	No concerns when sealed lead-acid batteries are used	Concerns with reliability and performance of ICE vehicles	Concerns with noise and emissions from ICE vehicles	ICE vehicles - hazardous emissions; Battery vehicles - spills and leaks, inconvenient to recharge, and requires venting	Some concerns with weight of the batteries
Market Potential for Specialty Vehicles		Medium	High	High	Low	High	High	Medium	Low-Medium
Interest in Alternatives for Specialty Vehicles		High for ICE vehicles	High for batteries and ICE vehicles in high use operations	Limited interest	No interest	Medium for replacing ICE vehicles	High for replacing diesel ICE vehicles	Limited interest	Limited interest

Table 2-9. Specialty Vehicle Market: User and Integrator Analysis Data.

Market Segment	Airport Ground Support Equipment	Forklifts	Mining Vehicles	Automatic Guide Vehicles	Golf Carts	Turf Maintenance Vehicles	Commercial Sweepers	Wheelchairs
Awareness of PEM Fuel Cells for Specialty Vehicles	High level of awareness	Some level of awareness	Some level of awareness	Limited to no awareness	Limited awareness	Limited awareness	Limited awareness	Limited awareness
Key Decision Factors for Capital Purchases	Return on investment, Total lifecycle costs, Total lifetime of the system	Return on investment, Payback period, Initial capital costs	Return on investment, Initial capital cost, Payback period	Return on investment	Initial capital cost	Return on investment, Initial capital cost	Initial capital costs, Return on investment	Initial capital cost
Importance of Government Incentives in Purchasing	Important	Not so important	Important	Not so important	Not so important	Not so important	Not so important	Important
Potential Opportunity for PEM Fuel Cells in the Near-term	Medium	High	Low-Medium	Low	Low	Low	Low	Low
Drivers for PEM Fuel Cell Adoption	Environmental concerns, Other regulatory drivers	Users are interested in increasing productivity, Users are interested in alternatives to batteries, Environmental concerns	Environmental concerns, Regulatory drivers	No apparent drivers	No apparent drivers, Some users are concerned about emissions	Environmental concerns, Users are looking for ways to reduce operations and maintenance costs	No apparent drivers, Some users are concerned about emissions	No apparent drivers, Some manufacturers have considered PEM fuel cells as battery rechargers
Barriers to PEM Fuel Cell Adoption	Capital costs and lifetime of PEM fuel cells may be a concern	Fuel availability, capital costs, and lifetime of PEM fuel cells may be a concern, Serviceability of PEM fuel cells also a concern	Users are unsure that PEM fuel cells are reliable and durable for heavy duty applications, Limited interest in alternatives, Users are price sensitive, Also concerns over the safety of hydrogen exist	Lack of reliability information on PEM fuel cells, Concerns about cost of PEM fuel cells, Ability to maintain and service systems	Users make their decisions to purchase based on initial capital cost, PEM fuel cells will have to be competitive with electric vehicles	Users are sensitive to capital costs, Weight restrictions for turf vehicles may limit the application of heavy hydrogen tanks, Performance has to be competitive with ICE vehicles before users will switch	PEM fuel cells are limited technically and may not be a suitable alternative in high power draw applications, Capital costs are a barrier, Performance has to be competitive with ICE vehicles	Users are sensitive to capital costs, Lack of a practical hydrogen distributing system

2.3.2 Composite Analysis of Trends in Specialty Vehicle Markets Based on User Responses and Manufacturer Responses

2.3.2.1 Specialty Vehicle User Responses

Survey Participant Profile

Responses were received from 26 specialty vehicle users. Of these users, 17 were large organizations with over 3,000 employees, five were from medium sized companies with 500 to 3,000 employees, and four were from small sized companies with less than 500 employees (Table 2-7). At the time of this composite analysis only 28 survey responses were received; as a result, responses from 28 surveys and 11 protocol-based interviews from both phases of research are analyzed across all specialty vehicle market segments in this section. The response from one large forklift user was excluded in this analysis but included in the individual segment analysis discussed in section 3.0.

Impact of Downtime

Of the 26 respondents, 8% of respondents experienced downtime events in the past 12 months lasting between 5 and 30 minutes; 15% of the respondents experienced downtime events lasting between 30 minutes and 1 hour; 38% of respondents experienced downtime events lasting between 1 and 4 hours; 31% of the respondents experienced downtime events between 4 and 8 hours; 31% of the respondents experienced downtime events lasting over 8 hours; and 12% did not know the duration of the experienced downtime incidents.

Users in the Phase 1 survey were asked to identify the impacts of downtime incidents. Of the 13 respondents, 12 indicated that downtime results in a loss of productivity through decreased movement of materials; 10 indicated that downtime increased operations and maintenance costs; and 10 reported decreases in labor productivity due to downtime incidents. Respondents indicated that downtime incidents greater than 4 hours were very disruptive to their operations. Disruptions between 30 minutes and 4 hours were not as disruptive because backup vehicles could be utilized in the interim period. If backup vehicles were not available, downtime incidents of 30 minutes could severely disrupt operations.

Specialty Vehicles Currently in Use

Respondents were asked to identify the types of specialty vehicle systems currently in use. Of the 26 respondents, 69% used electric vehicles, 38% used diesel ICE, 35% used propane ICE, and 19% used gasoline ICE. The majority of respondents used more than one type of specialty vehicle, which varied by application. For example, for heavy lifting or pushing, users of forklifts and airport tugs typically utilized ICE equipment.

User Satisfaction with Specialty Vehicles

When asked about their satisfaction with current specialty vehicles in Phase 1 research, most specialty vehicle users indicated that they were satisfied with their current mode of operation. Three of 13 respondents did not respond to this question. Specialty vehicle users were asked to rate their satisfaction on a scale of 1 to 7, with 7 being very satisfied and 1 being very dissatisfied. The average response was 5.1 with a standard deviation of 1.3. The mode of the distribution was 6. However, of these 13 respondents, eight identified concerns with the current mode of operation. The primary concerns identified were spills and leaks from batteries, the

inconvenience of recharging batteries, the time required to swap out batteries, and the time required for refueling and/or recharging.

In Phase 1 and Phase 2 surveys, users were asked to rate the performance characteristics of their specialty vehicles currently in use on a scale of 1 to 7, with 1 being not so good and 7 being very good. Approximately 85% of the respondents identified fuel availability as very good; 62% identified reliability as very good; 62% identified start-up time as very good; and 61% identified operations and maintenance costs as very good. Users were less satisfied with capital cost (46%) and time between refueling (38%). Ratings of user satisfaction by performance factors are presented in Figure 2-7.

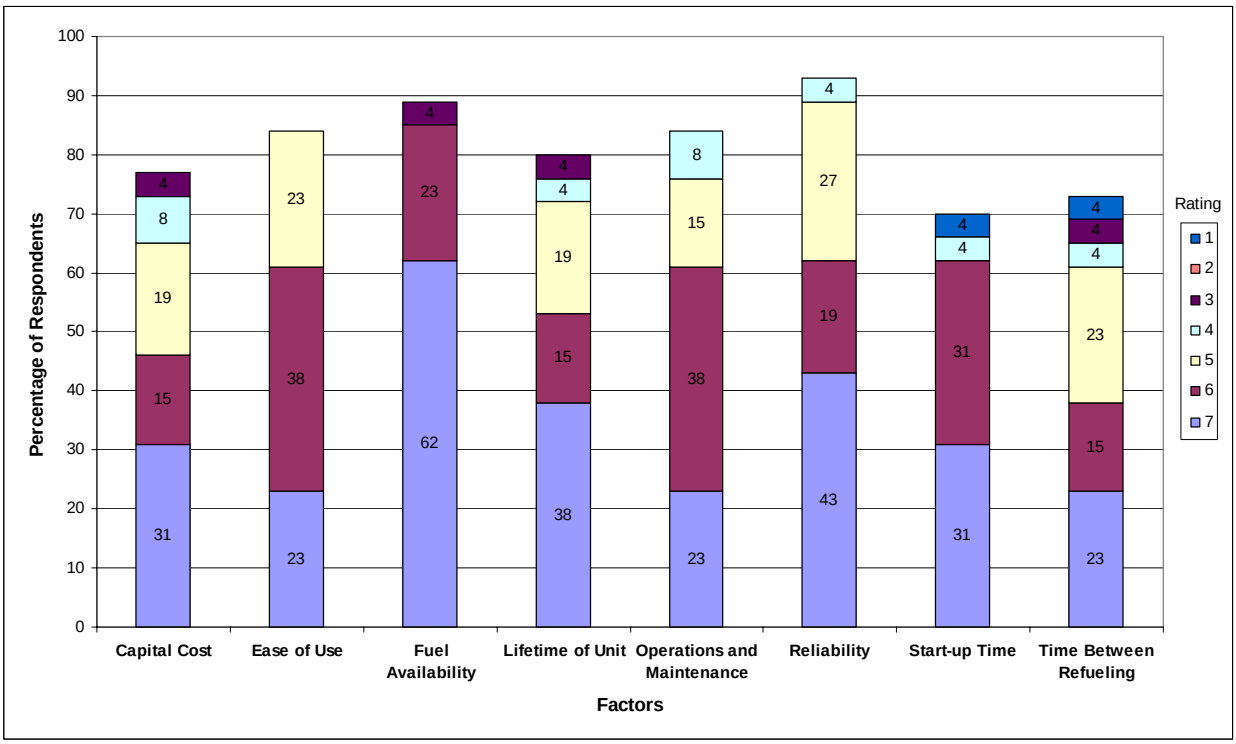


Figure 2-7. User Satisfaction with Specialty Vehicle Characteristics.

Purchase Decision Factors

Users were also asked to identify the importance of various characteristics when selecting specialty vehicles on a scale of 1 to 7, with 1 being not so important and 7 being very important. All respondents identified reliability as very important when selecting a specialty vehicle. Approximately 73% of the respondents identified the lifetime of the unit as important; 70% identified annual operating cost as important; 66% identified ease of use as very important; and 65% identified fuel availability and good experience with the system as very important. Time between refueling (42% of respondents) and start-up time (46% of respondents) were considered less important than most of the other factors identified by specialty vehicle users. The importance of various performance factors when selecting a specialty vehicle is presented in Figure 2.8.

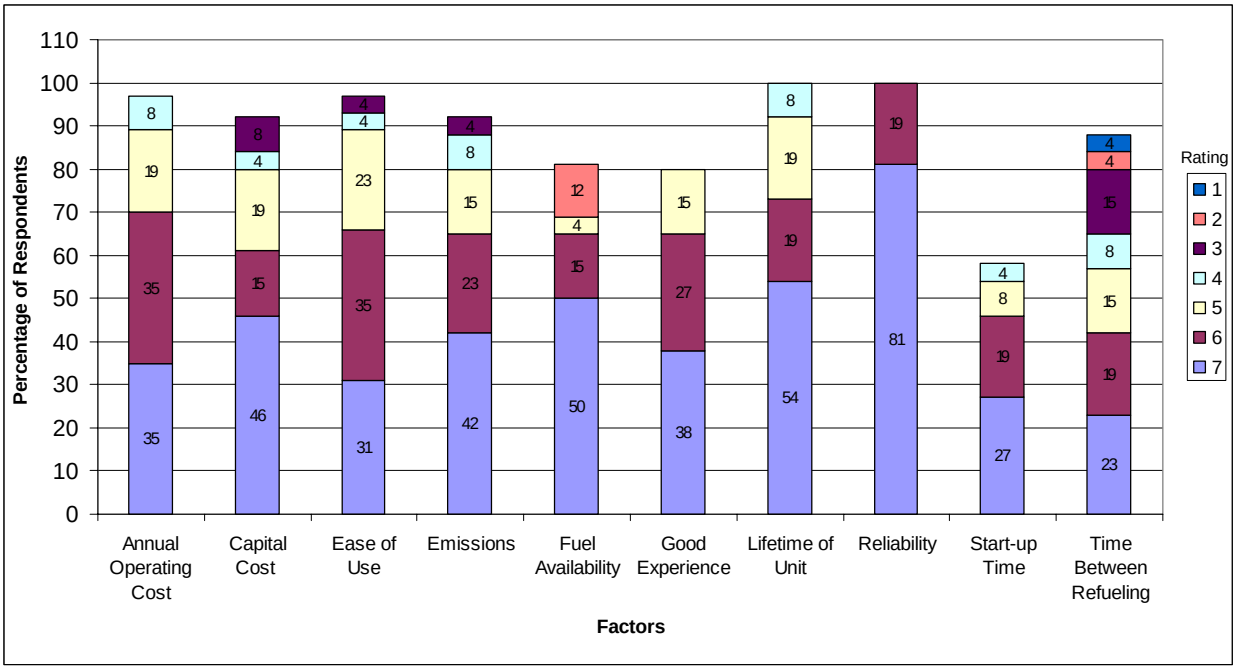


Figure 2-8. Importance of Various Characteristics When Selecting a Specialty Vehicle.

Capital purchase decisions are made based on a variety of factors. Approximately 48% of the respondents indicated that purchase decisions were based on return on investment; 20% indicated that decisions were made on initial capital cost; 20% indicated that they considered payback period. In addition, of the 26 specialty vehicle users surveyed, 48% indicated that incentives were considered, 33% indicated that incentives were not considered, and 19% did not know if incentives were considered when making purchasing decisions.

Potential for PEM Fuel Cells in Specialty Vehicles

When asked if users had considered alternatives, respondents were evenly split. Half (50%) of the respondents indicated that they had considered alternatives, while the other half had not. Airport tug users had considered alternatives such as compressed natural gas vehicles and adding more electric vehicles to their fleet. Approximately 62% of the respondents had not heard of PEM fuel cells as an alternative, while 38% had. Of the 20 users that responded, 25% thought that PEM fuel cells would compete favorably with current power sources, while 75% did not. The primary factors identified as driving the adoption of PEM fuel cells, in order of frequency, are: environmental concerns, availability of government incentives, costs incurred from downtime, track record of others using PEM fuel cells, energy efficiency of PEM fuel cells as compared to alternatives, and dissatisfaction with current mode of operation. Respondents were asked if hydrogen was a cause for concern. Of the 21 specialty vehicle users who responded to the question, 43% indicated that they were concerned about hydrogen, 33% did not know if hydrogen concerned them, 14% were not concerned, and 10% were somewhat concerned.

2.3.2.2 Specialty Vehicle Manufacturer Responses

Survey Participant Profile

Responses from 23 integrators are summarized in this section. A total of 24 survey responses were received from manufacturers of airport ground support equipment, forklifts, automatic guide vehicles, commercial sweepers, golf carts, lawn mowers, UAVs, and wheelchairs. Responses were received from 11 small companies with less than 500 employees, seven medium companies with 500 to 3,000 employees, and five large companies with more than 3,000 employees. Two responses were received from a large golf cart manufacturer. Survey questions were qualitative in nature and were designed to provide insight into manufacturers' satisfaction with current technologies and interest in alternative technologies, as well as the potential for PEM fuel cells to be used by their organizations. Respondents to the survey were product development managers, directors or managers of R&D, directors of marketing, marketing managers, or sales managers.

Most Critical Applications and Impact of Downtime

Of the eight segments analyzed, from the manufacturer's perspective, forklift users, automatic guide vehicle users, and airport ground support equipment users are most severely impacted by downtime. Downtime results in productivity losses, production and distribution disruptions, and increased operations and maintenance costs.

Satisfaction with Current Technologies

Of the manufacturers surveyed, 88% manufactured and/or distributed battery-powered vehicles, 29% manufactured and/or distributed propane ICE-powered vehicles, 42% manufactured and/or distributed diesel ICE-powered specialty vehicles, and 38% manufactured and/or distributed gasoline ICE-powered vehicles. Manufacturers indicated that safety concerns with regard to batteries are minimal, especially when appropriate handling and safety methods are used. Because users do not always follow the recommended methods, there is some concern regarding spills and leaks of acid from batteries, disposal of batteries, weight of batteries, and wastewater containment from washing of batteries. The primary concerns identified with ICE-powered vehicles were emissions. Only 13% of the manufacturers surveyed were dissatisfied with their current mode of operation. However, 50% of the respondents indicated that there was opportunity to improve and had considered alternatives.

Perceptions and Potential for PEM Fuel Cells in Specialty Vehicles

Of the 24 responses received, 71% of respondents had heard of PEM fuel cells for specialty vehicles, 42% have considered PEM fuel cells as alternatives for their applications, and 25% considered PEM fuel cells to be a viable alternative for their applications. Cost, reliability, lifetime, fuel availability, and performance when subjected to varied power draws were identified as the most important factors when considering alternatives.

Manufacturers in the forklift, airport tug, turf equipment, commercial sweeper, and automatic guide vehicle markets were among those that considered PEM fuel cells as a viable alternative to existing power sources. Manufacturers noted that while PEM fuel cells may be viable for some users, certain requirements would need to be met before widespread adoption could occur, including the availability and affordability of hydrogen fuel and storage options, service and maintenance infrastructure, a supply chain for PEM fuel cells, and more durable PEM fuel cells.

Manufacturers indicated that important drivers for the PEM fuel cell market will include: a demonstrated return on capital investment, demonstrated improvements in productivity, government incentives, and demonstrated environmental benefits. Of the manufacturers surveyed, 33% were unsure of whether hydrogen would be a cause for concern among users, while 29% indicated that it would not. Only approximately 8% of the manufacturers surveyed indicated that hydrogen may be a cause for concern.

2.4 Analysis of Most Promising Near-term and Mid-term Pre-Automotive Markets

To prioritize near-term and mid-term markets, the rating criteria developed in consultation with DOE and industry (section 1.1.1) were applied to market research data for the 36 market segments (Appendix C). These rating criteria were applied to identify a set of near-term and mid-term markets (Table 2-10) for PEM fuel cells in both backup and specialty vehicle applications. Near-term markets are those in which PEM fuel cells have a unique value proposition, based on the rating criteria, and tend to be less sensitive to cost. Mid-term markets are those in which PEM fuel cells can provide value over existing technologies if specific barriers (including capital cost) are addressed.

Table 2-10. Most Promising Near-term and Mid-term Markets.

Near-term Markets (By 2008)		Mid-term Markets (Beyond 2012)	
Backup Power	**Specialty Vehicles**	**Backup Power**	**Specialty Vehicles**
▪ Telecommunications ▪ Emergency response communications* ▪ Federal agencies – FAA, NOAA, USCG	▪ Forklifts in distribution centers* ▪ Ground support equipment in airports*	▪ Railways ▪ Electric utilities ▪ Data centers ▪ Water and wastewater utilities ▪ Financial service providers ▪ Other government agencies (backup power for buildings, police stations, fire stations) ▪ Healthcare ▪ Airports ▪ Manufacturing ▪ Grocery stores	▪ Automatic guided vehicles ▪ Turf maintenance vehicles ▪ Industrial tow tractors ▪ Mining vehicles ▪ Golf carts

*Selected for further analysis.

A detailed assessment of the value proposition for PEM fuel cells was conducted in three near-term market segments: emergency response backup power, forklifts in distribution centers, and ground support equipment in airports. While telecommunications is the most promising near-term market, this market segment was analyzed in detail in an earlier report and therefore is not included in this analysis. [19] The FAA, NOAA, and USCG also represent promising near-term

[19] Battelle. 2006. Economics of Stationary PEM Fuel Cell Systems. For the Department of Energy, DOE Contract No. DE-FC36-03GO13110.

markets in federal agencies; however, adoption in these markets is driven by the availability of funds and the mandates set under the provisions of EPAct 2005. As a result, the most likely near-term opportunities where adoption can be expected due to the value that PEM fuel cells offer were chosen for further analysis.

3.0 MARKET OPPORTUNITY ASSESSMENT OF THREE NEAR-TERM PRE-AUTOMOTIVE MARKETS

This section presents the market opportunity for PEM fuel cells in three near-term pre-automotive market segments including state and local emergency response agencies, forklifts in high-throughput distribution centers, and airport ground support equipment. For each near-term market opportunity, the value proposition of PEM fuel cells is determined through analysis of market requirements as identified through secondary research, user requirements and user satisfaction, as determined through primary research, lifecycle cost analysis of PEM fuel cells and competing alternatives, and a sensitivity analysis of various factors on the costs of owning and operating a PEM fuel cell. Analysis of the market penetration of PEM fuel cells in three cases is also presented for each near-term market segment.

3.1 PEM Fuel Cells in Backup Power Applications in State and Local Emergency Response Agencies

3.1.1 Market Attributes

3.1.1.1 Market Segment Description

The emergency response market segment is comprised of state and local agencies that are responsible for providing or coordinating emergency response services, including: fire agencies, police agencies, emergency medical services, and state emergency management agencies. Fire agencies are establishments primarily engaged in firefighting and other related fire protection activities. Police agencies are establishments primarily engaged in law enforcement, traffic safety, police, and other activities related to the enforcement of the law and preservation of order. Emergency medical service providers, including first responders, paramedics, and emergency medical technicians (EMTs), administer early (pre-hospital) treatment to those in need of urgent medical care and transport sick or injured parties to medical care facilities. State emergency management agencies are responsible for coordinating all phases of homeland security and disaster response activities within the state.

This analysis examines general backup power needs within the emergency response market segment and includes a more detailed look at one promising application for fuel cells at radio tower sites. Table 3-1 identifies the primary Standard Industrial Classification (SIC) and North American Industry Classification System (NAICS) codes associated with emergency response; these codes were used to help characterize the market and identify potential survey participants.

Within the emergency response market segment, backup power is primarily used to support 911 call centers, including the equipment required to operate computer-aided dispatch units; radio network infrastructure, including radio and microwave transmitter sites; basic facility operations; and emergency lighting.

Table 3-1. SIC and NAICS Codes Relevant to State and Local Departments of Emergency Response.

2-Digit Sic Codes	41 – Local and suburban transit and interurban highway passenger transportation 92 – Justice, public order, and safety
4-Digit SIC Codes	4119 – Local passenger transportation, nec[20] 9221 – Police protection, law enforcement 9224 – Fire protection 9229 – Public order and safety, nec
NAICS Codes	621910 – Ambulance services 922120 – Police protection 922160 – Fire protection 922190 – Other justice, public order, and safety activities

The backbone of the emergency response system is the 911 call response network – the official national emergency number in the United States and Canada. A 911 call travels over dedicated phone lines to the 911 answering point closest to the caller, and trained personnel then send the emergency help needed. The most important elements of 911 networks, and therefore the most critical applications of backup power, are the 911 call centers (including the telephones, computers, and other equipment used to handle calls) and the radio network infrastructure used by state and local emergency response agencies for communication.

Every 911 call for emergency assistance in the United States is answered by a 911 call center, also known as a Public Safety Answering Point (PSAP).[21] At the PSAP, the operator verifies the caller's location, determines the nature of the emergency, and decides which emergency response teams should be notified. Sometimes, a single primary PSAP will answer for an entire region. In most cases, the caller is then transferred to a secondary PSAP, from which help will be sent. Secondary PSAPs are sometimes located at fire dispatch offices, municipal police headquarters, hospitals, or ambulance dispatch centers. Typically, PSAPs are operated by counties but can also be run by municipalities or other governmental jurisdictions.

Radio networks enable reliable communications in emergency situations. Some radio networks are designed to support communications within a single agency. More sophisticated networks allow agencies to communicate with one another. For example, Ohio's Multi-Agency Radio Communications System (MARCS) provides mobile voice, data, vehicle location, and computer-aided dispatching services within a single computer system that is shared by multiple state agencies. MARCS allows multiple emergency response agencies to communicate with each other from anywhere in Ohio. Radio networks are comprised of several different types of electrical equipment, including radio and microwave towers, signal transmitters and receivers, and computer switching gear.

In addition to backup power for 911 call centers and radio network infrastructure, backup power is also needed by state emergency management agencies and other response organizations for emergency response field operations, which require on-site electricity generation for field phones, computers, and medical units.

[20] Not Elsewhere Classified.
[21] Mohney, D. 2004. Call Centers Prepare For The Worst. Available at http://mrtmag.com/mag/radio_call_centers_prepare/index.html [Accessed July 2006].

The impact of power outages on this market segment can be catastrophic. Emergency preparedness and response operations depend on the reliability and quality of first responders' energy supplies. If primary grid power goes down, so can 911 and state emergency communication centers, first responder stations, hospitals, control centers, traffic signals, public transportation, and vital infrastructure such as water pumping and filtration systems. For example, severe flooding in the wake of Hurricane Katrina caused power outages across the Gulf Coast, making it impossible in many areas to deliver emergency supplies and diesel fuel for backup power. The lack of electricity, lights, and communications throughout the region made emergency response missions extremely difficult. Some 911 calls went unanswered for several days because of power outages. Many hospitals and other critical emergency services were unable to rely on their backup diesel generators due to lack of fuel or mechanical failure, with fatal consequences.[22] In contrast, the fuel cell in the New York Police Department's Central Park Station kept the facility running during the big blackout of 2003.[23]

Commonly used technologies that provide backup power to emergency response agencies include generators (diesel and propane), uninterruptible power supplies (UPS), and batteries. Generators are typically used to provide support for both critical and non-critical loads. Unlike UPS systems and batteries, generators can provide backup power for extended periods of time (with adequate fuel supplies). Batteries and UPS systems are generally used as short-term backup power for telecommunications equipment and computer systems and can be used in conjunction with generators. UPS systems provide sufficient power to run the equipment for several minutes to several hours until the generators can take over. Batteries and UPS are typically used only to power critical loads.

3.1.1.2 Market Size

Current market size data for the emergency response market segment are provided below as the number of potential fuel cell adopters. Table 3-2 provides data on the primary SIC codes related to emergency response. SIC Code 4119 (local passenger transportation, nec) covers ambulance services; SIC Code 9221 (police protection, law enforcement) covers police services; SIC Code 9224 (fire protection) covers fire response services; and SIC Code 9229 (public order and safety, nec) covers state emergency management agencies. It should be noted that correctional institutions (SIC Code 9223) also serve an important role in public safety and may someday represent an opportunity for fuel cell integration; however, these institutions are not considered a potential market at this time, and therefore are not covered here. In Table 3-2, only those eight-digit SIC specialties deemed relevant to emergency response services are shown.

The size of the emergency response market is significant. As illustrated in Table 3-2, there are 5,770 ambulance services; over 3,000 state, county, and municipal police agencies; and 20,632 fire departments in the United States. An estimated 99% of the U.S. population has access to

[22] Clean Energy Group. 2005. Energy Security & Emergency Preparedness: How Clean Energy Can Deliver More Reliable Power for Critical Infrastructure and Emergency Response Missions. Available at http://www.cleanegroup.org/Reports/CEG_Clean_Energy_Security_Oct05.pdf [Accessed July 2006].
[23] UTC Power. 2006. Electrical Jam in Central Park. Project Profile P133-R082306. Available at http://www.utcpower.com/fs/com/Attachments/PP_NYPDW.pdf [Accessed December 2006].

some type of 911 service. Recent estimates of the total number of primary and secondary PSAPs in the U.S. range from 6,124 to 6,183.[24,25]

Table 3-2. Number of Emergency Response-Related Organizations.

Industries: Local Passenger Transportation, Nec (SIC Code 4119); Police Protection (SIC Code 9221); Fire Protection (SIC Code 9224); Public Order and Safety, Nec (SIC Code 9229)				
SIC Code	**SIC Description**	**No Bus.**	**Total Emps.**	**Total Sales ($)**
4119-9902	Ambulance service	5,770	145,310	6,327.6
9221-0000	Police protection	6,747	272,986	4.2
9221-0100	Police protection, interstate and federal	43	6,428	N/A[26]
9221-0101	Bureau of criminal investigation, government	620	26,239	N/A
9221-0102	State highway patrol	569	18,299	N/A
9221-0103	State police	1,006	55,373	N/A
9221-0200	Police protection, regional	139	10,073	N/A
9221-0201	County police	419	23,755	N/A
9221-0202	Marshals' office, police	351	9,001	5.4
9221-0203	Municipal police	1,620	68,866	0.2
9221-0204	Sheriffs' office	2,918	168,887	0.5
9221-0400	Police protection, level of government	46	685	N/A
9221-0401	Police protection, Federal government	33	490	N/A
9221-0402	Police protection, State government	118	5,423	0.3
9221-0403	Police protection, County government	195	13,161	N/A
9221-0404	Police protection, Local government	1,306	37,639	1.9
9224-0000	Fire protection	5,958	130,669	5.5
9224-0400	Fire protection, level of government	17	417	N/A
9224-0401	Fire protection, Federal government	7	27	0.2
9224-0402	Fire protection, State government	124	3,408	N/A
9224-0403	Fire protection, County government	175	4,046	N/A
9224-0404	Fire protection, Local government	781	15,225	0.2
9224-9901	Fire department, not including volunteer	5,685	139,685	2.2
9224-9902	Fire department, volunteer	14,947	286,415	2.2
9224-9903	Fire marshals' office, government	122	3,207	N/A
9224-9904	Fire prevention office, government	130	3,263	N/A
9229-9901	Disaster preparedness and management office, government	92	1,790	N/A
9229-9902	Emergency management office, government	528	12,262	0.2
	Total	**50,466**	**1,463,029**	**6,351**

Sales figures are in millions. Source: www.zapdata.com, accessed July 2006.

Market research indicates that hundreds of radio towers are used for emergency response in each state. Estimates made by emergency response professionals interviewed for this analysis range from 120 towers in a small but densely populated mid-Atlantic state to approximately 500 towers in a much larger and more populous state. As of 2003, the State of Washington owned and operated 296 microwave towers, backed up by emergency generators and batteries.[27] There are

[24] National Emergency Number Association. 2006. 9-1-1 Fast Facts. Available at http://www.nena.org/911_facts/911fastfacts.htm [Accessed June 2006].
[25] Clean Energy Group. 2005. Energy Security & Emergency Preparedness: How Clean Energy Can Deliver More Reliable Power for Critical Infrastructure and Emergency Response Missions. Available at http://www.cleanegroup.org/Reports/CEG_Clean_Energy_Security_Oct05.pdf [Accessed July 2006].
[26] N/A: Not Applicable.
[27] State Interoperability Executive Committee. 2003. Inventory of State Government-Operated Public Safety Communications Systems. Available at http://isb.wa.gov/committees/siec/publications/inventoryreport1203.pdf [Accessed July 2006].

201 towers supporting Ohio's MARCS; most of these towers are backed up by emergency generators in the 20 to 25 kW range.[28] Based on these figures, the number of radio tower sites in the U.S. can be roughly estimated. Averaging figures from both a large state (500 sites) and a small state (120 sites) results in 310 towers per state; multiplying this number by 50 results in an approximate nationwide total of 15,500 radio tower sites. There is evidence that the number of radio sites will expand, at least in some areas, as demands on communication systems increase. For example, the number of towers in Maryland is expected to grow from 120 to approximately 200 in a few years.[29]

3.1.1.3 Market Trends

The use of backup power for emergency response equipment and facilities is supported by industry standards but mandated by only a small number of states. Industry organizations such as the National Emergency Number Association (NENA) have published standards recommending that PSAPs be equipped with long-term emergency power supplies and that telephones and other crucial devices be connected to UPS equipment.[30] At least two states currently mandate the use of backup power at PSAPs. New York requires all PSAPs to have an engine-driven generator, supported by a UPS system that maintains power during the transition from commercial power to the generator, as an emergency power source for all critical applications.[31] Illinois requires all PSAPs to maintain a backup power source "capable of supplying electrical power to serve the basic power requirements of the PSAP, without interruption, for a minimum of four hours" and to test the backup power source monthly.[32] It seems likely that, after the catastrophe witnessed in the Gulf Coast as a result of Hurricane Katrina, more states may adopt such regulations.

Despite the lack of a comprehensive mandate, interest in using alternative energy sources to support emergency preparedness efforts appears to be growing. As of 2005, 15 U.S. states had established clean energy funds; many of these states are supporting on-site clean energy projects at critical facilities to minimize dependence on grid power during emergencies. Clean energy technologies used in these projects include solar photovoltaics (PV), fuel cells, wind power, and advanced battery systems.[33]

Fuel cell systems have been used to provide backup (and, in one case, primary) power to emergency response equipment and facilities, as summarized below:

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[28] Personal Communication between Rachel Sell (Battelle) and Mark Patchen (Ohio Emergency Management Agency), June 2006.
[29] Personal Communication between Rachel Sell (Battelle) and Tom Miller (Maryland Institute for Emergency Medical Services System), July 2006.
[30] National Emergency Number Association. 2001. Recommended Generic Standards for E9-1-1 PSAP Equipment. NENA Technical Reference NENA-04-001 Issue 2. Available at http://www.nena.org/media/files/NENA_04-001.pdf [Accessed July 2006].
[31] Official Compilation of New York Codes, Rules, and Regulations. 2004. Minimum Standards Regarding Equipment, Facilities and Security for Public Safety Answering Points. 21 NYCRR §5203.3. Available at http://www.dos.state.ny.us/fire/911program/part5203.htm [Accessed July 2006].
[32] Illinois Administrative Code. 2004. Standards of Service Applicable to 9-1-1 Emergency Systems: Public Safety Answering Point. 83 IAC 725.505. Available at http://www.ilga.gov/commission/jcar/admincode/083/083007250E05050R.html [Accessed July 2006].
[33] Clean Energy Group. 2005. Energy Security & Emergency Preparedness: How Clean Energy Can Deliver More Reliable Power for Critical Infrastructure and Emergency Response Missions. Available at http://www.cleanegroup.org/Reports/CEG_Clean_Energy_Security_Oct05.pdf [Accessed July 2006].

- A wireless communications microwave site in Elk Neck State Park, Maryland, was one of the first sites to use a fuel cell backup power system.[34] The Elk Neck tower, which consists of a single-channel microwave repeater radio tower, supports several tenants, including the State of Maryland's enhanced 911 (E-911) Communications System. The state park is currently using two 1 kW ReliOn systems for extended backup to the site. E-911 radios are configured to run on a 48 volt (V) power system normally supplied through primary grid power. The total peak power load for this equipment configuration ranges from 200 to 450 watts (W). The integrated backup power solution aims to avoid any microwave radio downtime, since microwave communication systems are so critical. During Hurricane Isabel and in its aftermath (September 2003), the fuel cell system enabled critical radio communications over the microwave network for Maryland State Police and emergency medical response services until primary grid power was restored.

- Ohio's MARCS microwave radio towers utilize four ReliOn Independence 1000® PEM fuel cells to provide long-term, emergency backup power to Ohio's critical digital communication infrastructure. The towers are located in Butler, Otway, Tiffin, and Washington Township, Ohio.[35]

- The Washington Park Fire Station in Denver, Colorado, is using a PEM fuel cell to provide a portion of the facility's electricity and heat.[36]

3.1.2 Market Segment Analysis

The market analysis for the emergency response segment is divided into two sections. Section 3.1.2.1 summarizes the results of Phase 1, and section 3.1.2.2 summarizes the results of Phase 2. The Phase 1 survey examined a broad range of applications within the emergency response segment including 911 call centers and the associated radio infrastructure. Results of the Phase 1 analysis suggested that the most promising application of PEM fuel cells in the emergency response market segment was for radio communications towers managed by state and local emergency response agencies. The Phase 2 surveys and interviews focused specifically on requirements for backup power for radio towers maintained by these agencies. As responses in Phase 1 addressed the user requirements for the broad range of applications, they are analyzed separately and are not combined with the Phase 2 analysis.

3.1.2.1 Phase 1 Analysis

In Phase 1, approximately 150 emergency service agencies were contacted, and 15 responses were received in the form of completed surveys. In addition, four interviews were conducted with individuals familiar with the requirements for backup power in this market. Information gleaned from the surveys and interviews is summarized below.

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[34] Saathoff, S. 2004. Fuel Cells As Backup Power For State Government Communications Sites. Fuel Cell Today. Available at http://www.fuelcelltoday.com/FuelCellToday/FCTFiles/FCTArticleFiles/Article_866_Fuelcellsasbackuppower0904.pdf [Accessed July 2006].

[35] Fuel Cells 2000. 2006. Multi-Agency Radio Communications System Microwave Radio Towers. Available at http://www.fuelcells.org/db/project.php?id=833#5 [Accessed July 2006].

[36] Governor's Office of Energy Management and Conservation. 2006. Fuel Cell to Power Denver's Washington Park Fire Station. Available at http://www.energyvortex.com/pages/headlinedetails.cfm?id=527&archive=1 [Accessed July 2006].

Survey Participant Profile

Representatives of various emergency service agencies participated in the survey, including law enforcement agencies, PSAPs, public safety service agencies, and public safety communications organizations. Responses were received from ten small agencies (i.e., < 500 employees), two medium-sized agencies (i.e., 500 to 3,000 employees), and three large agencies (i.e., > 3,000 employees). Respondents to the survey were directors of state emergency service agencies, 911 coordinators/administrators, and police lieutenants.

Respondents identified several functions that are typically supplied with backup power, including 911 call centers; dispatch telephones and computer systems; radios, wireless communications facilities and radio infrastructure; emergency lighting; and security systems for jails, fire stations, and police stations. Critical functions requiring backup power, according to the responses received, include remote radio sites, dispatch radios, computers, and telephones.

Frequency of Power Outages

When asked about the total number of outages experienced by their facilities, responses varied from no outage to approximately 25 outages per year. Approximately 40% of the survey respondents experienced 1 to 5 outages in the last 12 months (Figure 3-1). When asked about the duration of power outages, most reported that outages were estimated to last between 1 second and 1 hour; two could not estimate the duration. Respondents indicated that long outages (> 1 hour) are very disruptive to emergency operations.[37] All respondents indicated that power outages severely impact their operations and can result in one or more of the following: lives lost, security breaches, implementation of emergency management plans, and disruptions in production.

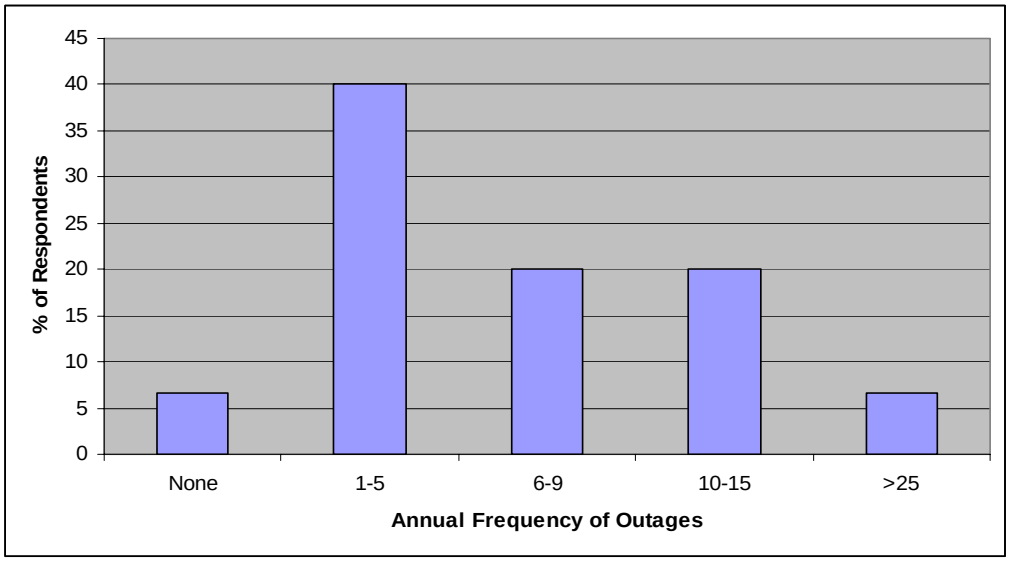

Figure 3-1. Number of Outages Experienced by Survey Respondents in the Past 12 Months (n=13).

[37] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so disruptive", responses of 4 to 5 were classified as "somewhat disruptive", and responses of 6 to 7 were classified as "very disruptive".

Current Backup Power Systems

Types and sizes of systems used to provide backup power vary significantly. Figure 3-2 shows the distribution of the sizes of systems used by respondents. The generators used to provide backup power are typically 30 kW and larger, while batteries and UPS systems are smaller in size, from < 5 kW to approximately 30 kW. The total number of batteries, UPS systems, and generators used by facilities varies, based on the size of a facility and the number of dispatch centers, radios, and wireless sites it operates.

Interviewees also elaborated on their current backup power systems. One interviewee noted that their emergency communication district supports eight PSAPs, all of which use UPS systems to support their 911 radio systems and a backup generator for emergency power. These UPS units range in size from 1.8 kW to 10 kW, depending on the size of the PSAP. Most generators used at the PSAPs are larger than the UPS units. Individual PSAPs are responsible for maintaining power (and purchasing backup UPS systems and generator equipment) for their dispatch radio systems. The interviewee noted that all PSAPs generally try to adhere to NENA standards.

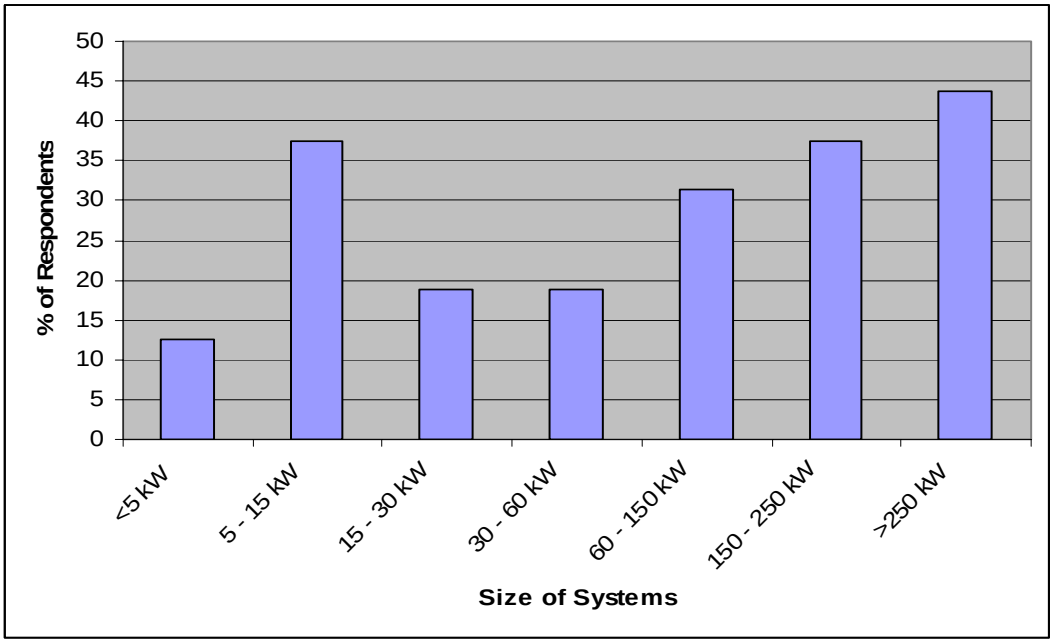

Figure 3-2. Size of Backup Power Systems in Use (n=15).

Another interviewee described the systems they have installed for their 68 PSAPs statewide. Critical applications are hooked up to a UPS system, including the computers that take emergency calls, telephone networks, radios, the consoles used by telephone operators, and supporting electronics. The interviewee added that radio towers and antennae may be located in remote locations (e.g., on mountain tops), requiring the use of generators for primary power in cases where power lines cannot be extended to the mountain.

Purchase Decision Factors

Based on responses received, the most important criteria considered when purchasing emergency response backup power systems include reliability and fuel availability. Start-up time, capital

cost, ease of use, good experience with the system, and lifetime of unit were also identified as very important criteria.[38] Of the seven individuals who responded to this question, all identified reliability and fuel availability as being very important. Start-up time, capital cost, ease of use, lifetime of unit, and good experience with PEM fuel cell systems in the past were identified as important factors. Emissions and annual operating cost were relatively less important than the aforementioned factors.

Satisfaction with Current Systems

Respondents were generally pleased with the overall performance of their current backup power systems. Of the ten respondents who addressed this question, all but one described the overall performance of their system as good or very good. However, when asked if they had any concerns with their current backup power system, five respondents indicated that they had some concerns. For generators, respondents indicated that concerns included mechanical failure of the generator, loss of fuel, and high emissions. For battery-operated systems, one respondent indicated that they were unable to determine charge. When asked to rate their current backup systems against the purchase decision criteria described above (i.e., reliability, capital cost, etc.), all but one respondent indicated that their satisfaction with current technology ranged from good to very good for all factors except emissions. One respondent was disappointed by the performance of backup power systems in place for all factors.

Potential for PEM Fuel Cells in Emergency Response

Respondents indicated that there is a growing need for backup power in the emergency response market and that mandates are a key driver for backup power in public communication systems. Of the 15 surveys received, only four respondents had heard of using fuel cells for backup power. Of these four respondents, only two respondents indicated that PEM fuel cells would compete in areas with low surge draws, and two respondents indicated that, unless fuel cells' capacity was increased, fuel cells would not be able to compete in providing backup power for entire facilities. Respondents indicated that they were not concerned by the use of hydrogen as a fuel. When asked what would drive them to adopt PEM fuel cells, four respondents indicated that the cost of not having electricity and the track record of others using fuel cells would be key drivers. Two respondents had considered fuel cells as alternatives.

An interviewee who said his organization currently has a radio tower with a fuel cell for backup power compared traditional backup power sources to fuel cells. The interviewee explained that fuel cells have the benefit of being low maintenance, requiring no oil, antifreeze, or preventive maintenance. The major disadvantage of fuel cells noted was their cost, as generators are still much cheaper. The interviewee also noted that hydrogen supply can be a problem and that a better infrastructure is needed to support the storage of large volumes of hydrogen. The interviewee suggested that drivers for fuel cell use would be increased power capacity and reduced costs (e.g., a fuel cell system capable of generating 10 to 15 kW at a capital cost of ~$20,000 would be a potential catalyst for purchasing).

[38] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so important", responses of 4 to 5 were classified as "somewhat important", and responses of 6 to 7 were classified as "very important".

Respondents indicated that a variety of factors are taken into account when making capital purchase decisions, including initial capital cost, period for payback, and return on investment. Respondents were split on the influence of incentives on purchase decisions, indicating that the cost of purchase often determined whether one would be swayed by incentives.

3.1.2.2 Phase 2 Analysis

The Phase 2 analysis focused on backup power requirements for radio communications towers. In Phase 2, 24 PSAPs were contacted about backup power at radio tower sites, and 11 surveys were completed. In addition, eight interviews were completed with survey participants. Four respondents in the Phase 2 analysis also answered questions in the Phase 1 analysis. As the Phase 2 analysis is presented separately from the Phase 1 analysis, survey responses from these four users are included in the section below.

Survey Participant Profile

Responses were received from three state-level emergency communications agencies and eight county-level 911 call centers. All organizations surveyed were considered small, with less than 500 employees. Respondents were typically PSAP directors or communications coordinators.

Frequency of Power Outages

Survey participants were asked about the total number of disruptive outages experienced at their radio tower sites in the past year. Answers ranged from zero to six and included: zero outages (one user); one outage (one user with eight radio tower sites); three outages (three users); four outages (one user with 48 radio tower sites); five outages (one user); and six outages (one user). Three users did not specify a number but said they experienced numerous outages related to weather (Hurricane Katrina, lightning strikes) and old infrastructure. Respondents indicated that power outages typically last anywhere from a few seconds to several days. Five users specified that outages often last 4 hours or more; three indicated that they typically last less than 3 minutes.

Users expect their backup systems to provide power until grid power can be restored. According to respondents, this period of time could range from just 4 hours to 2 weeks. One user expects their generators to run for 2 weeks, while another specified 10 days for their generators and 30 to 36 hours for batteries. Two expect their backup systems to run at least 1 week. One specified 5 to 6 days, and three others expect generators to run 2 to 3 days. Two of the respondents use only UPS system support for their radio sites and expect those systems to run for 4 hours and 8 hours.

Current Backup Power Systems

PSAP representatives were asked to describe their current backup power systems, including type of system, power output, approximate number of systems in that power range, and the estimated hours the system runs per year (including routine maintenance time). Eleven of the 12 respondents operate generators at some of their radio tower sites; eight use propane generators; five use diesel generators, and two use natural gas generators. Power output ranges for generators varied from 6 kW to 300 kW. The majority of users had power outputs between

6 kW and 100 kW. Only two respondents identified higher power output ranges. Systems less than 80 kW were typically propane-powered, while the larger systems were diesel-powered.

While some sites use combined UPS-generator systems, not all radio tower sites use backup generators. Three of 12 respondents indicated they use battery-only systems at their sites. One county PSAP relies only on UPS system support – which lasts up to 8 hours – for its remote sites; a generator is only used at the 911 dispatch center. Another PSAP relies only on UPS system support at three sites, and a generator at a fourth site. A third county PSAP uses battery systems at all 15 of its remote sites; only two or three sites that need to be climate-controlled have generators.

Others said they rely on combined UPS-generator systems at most or all of their sites. One respondent has UPS-generator systems at seven of the eight sites they operate. A second county PSAP has UPS-generator systems at nine of its ten sites; the other is located in a national forest and uses only a solar cell. One state communications center has combined UPS-generator systems at all of its 29 sites. Another state communications center uses UPS-generator systems at 200 of its 203 sites; the other three sites use fuel cell systems and a fuel cell-generator system.

Just one PSAP indicated that they do not use batteries – only ICE-powered generator systems – at their radio towers.

Backup System Maintenance

Information was collected on maintenance requirements of the participants' backup systems to help understand how fuel cells might compare.

Respondents were asked to estimate the annual hours of operation of their backup systems, including routine maintenance and actual backup operation. Responses ranged from 12 to 200 hours per year, with most operating less than 72 hours. Seven of eight respondents indicated that their systems operated between 12 and 72 hours per year. Only one respondent estimated 200 hours of runtime per year.

Labor requirements for each backup power system at radio tower sites ranged from 2 to 72 hours per year per site. Of the nine respondents that answered this question, seven reported less than 12 hours per year per site as typical labor requirements. Two organizations indicated that they enlist contractors to service their backup generator and battery systems. Other than labor, users indicated that maintenance costs can also include oil, filters, hoses, and coolant for generator systems. Batteries were cited as the primary maintenance cost associated with UPS systems. A respondent that operates one natural gas generator and four UPS systems estimated that their non-labor maintenance costs total $1,000 per year, including both ICE maintenance materials and batteries.

Nine respondents indicated that they follow the manufacturer's maintenance requirements for their backup systems. Two respondents follow another schedule; one indicated he checks the system more frequently, and another said he checks radio tower sites quarterly.

Users were also asked about the expected lifetime of their ICE generator systems, batteries, and battery chargers. Respondents expected generators to last between 10 and 20 years, with 20 years being cited by approximately half the respondents. Respondents expected battery systems to last between 2 and 10 years, with 2 years being the most common response (modal) and 5 years being the average of responses. The expected lifetime of battery chargers ranged from 5 to 20 years, with 10 years being the most common response. Nine respondents indicated that they do not require a designated space for battery charging. Just one indicated that a designated space was required and estimated the size of this space to be 50 square feet.

Purchase Decision Factors

Users were presented with a list of decision factors they might consider when evaluating a backup power system for radio tower sites, and asked which factors they considered very important.[39] All respondents identified reliability as very important, and 82% cited fuel availability as very important. Lifetime of the unit, start-up time, ease of use, and good past experience with this type of system were cited as very important by 73% of respondents, followed by capital cost (36%), annual operating cost (18%), emissions (18%), and interest in using novel, cutting-edge technology (9%). These results are summarized in Figure 3-3.

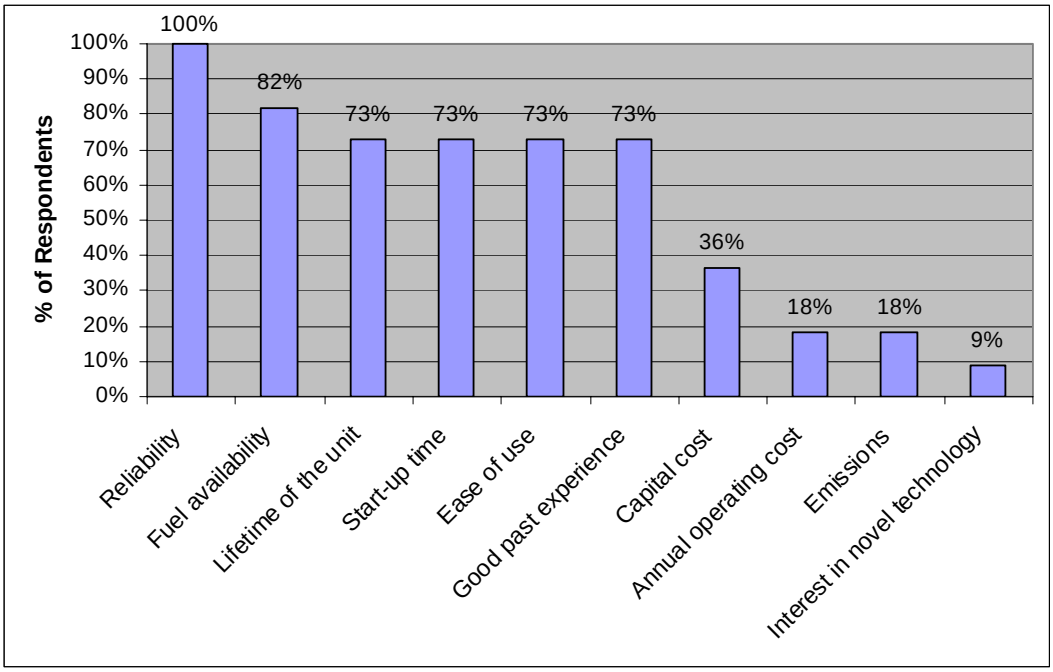

Figure 3-3. Decision Factors Identified as Very Important in Evaluating Backup Power Systems (n=11).

When users were asked which three factors, of those listed in the chart above, would most influence their decision to purchase a backup system for radio towers powered by an alternative technology, reliability and capital cost were the most important. Ninety percent of respondents to the question identified reliability as one of the three most important factors. It is interesting to

[39] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so important", responses of 4 to 5 were classified as "somewhat important", and responses of 6 to 7 were classified as "very important".

note that in Figure 3-3 above, capital cost was considered a very important factor by just 36% of users evaluating backup power systems. However, capital cost was identified by 70% of these respondents as one of the three most important factors influencing alternative technology purchase decisions, as noted in Figure 3-4. This may suggest that while performance factors such as lifetime and start-up time will help get a new technology on a "short list" for evaluation, reliability and capital cost will ultimately drive the purchase decision. The third most commonly cited factor was lifetime of the unit, which 40% of survey respondents indicated would most influence their decision to purchase an alternative backup power technology. Other factors cited included: start-up time; ease of use; good past experience; fuel availability; annual operating cost; and emissions. These results are summarized in Figure 3-4.

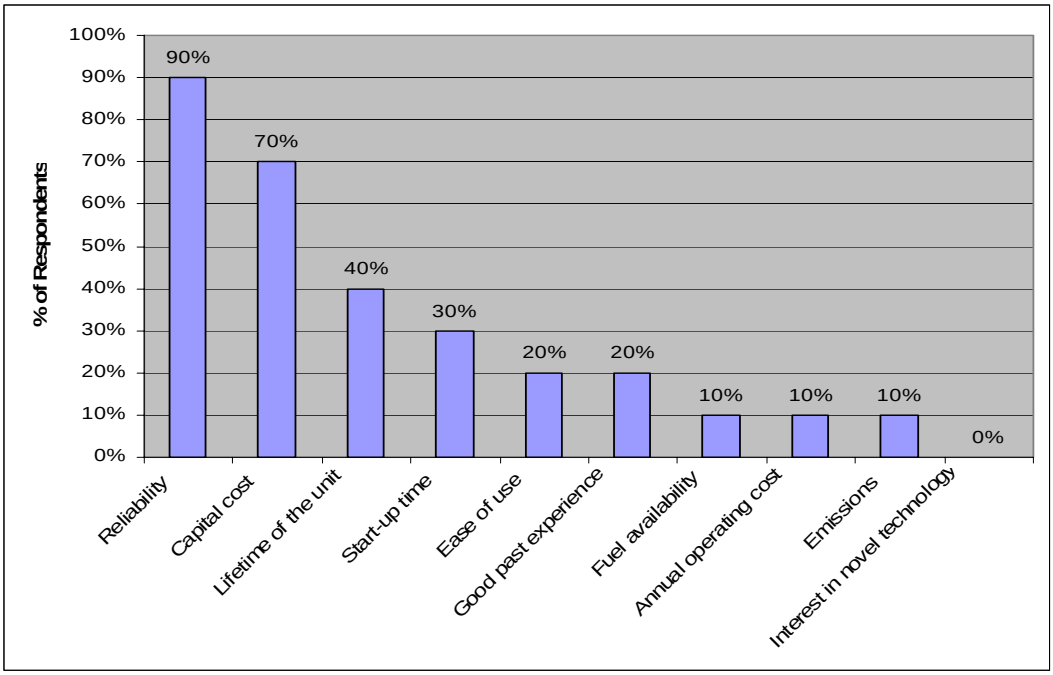

Figure 3-4. Factors that Most Influence Backup Power System Purchase Decisions (n=10).

Satisfaction with Current System

Users were asked to rate their level of satisfaction with their current backup power systems for radio towers, based on a set of characteristics provided. The proportion of respondents who believe their current systems' performance is "very good"[40] for each characteristic are presented in Figure 4-5 below. Respondents appear to be most satisfied with the lifetime (82%) and reliability (73%) of their current systems. It is important to note that reliability and lifetime of the system are also factors identified as very important by the greatest number of users (Figure 3-3), suggesting that current systems are performing well in the areas that matter most to users.

[40] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so good", responses of 4 to 5 were classified as "good", and responses of 6 and 7 were classified as "very good".

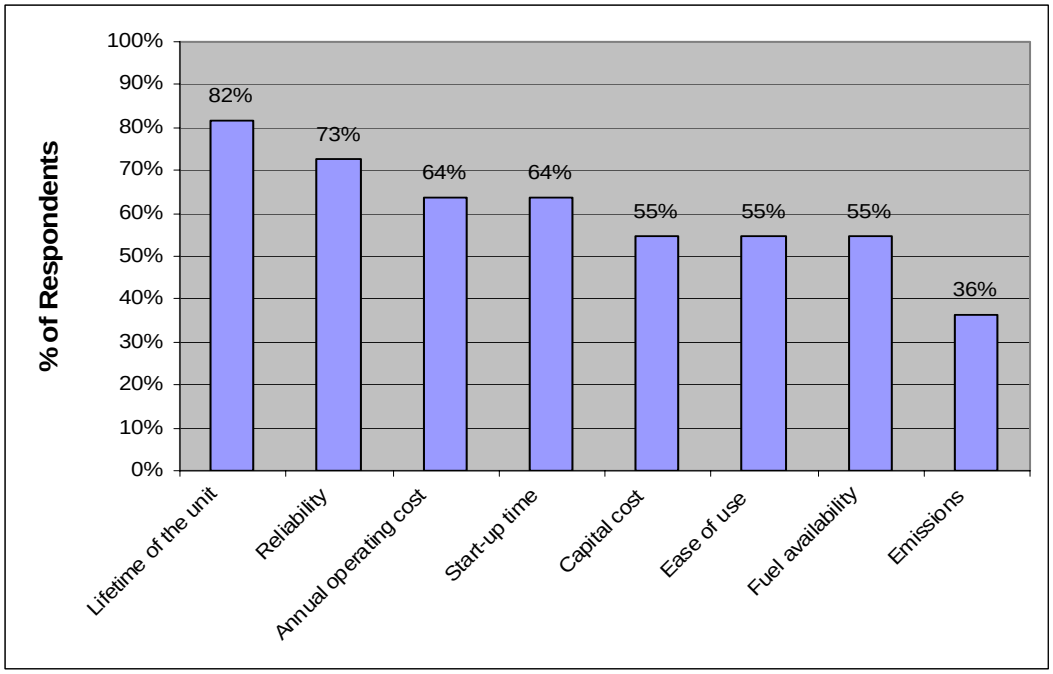

Figure 3-5. Characteristics of Current Systems that Users Identified as Very Good (n=11).

Potential for PEM Fuel Cells in Emergency Response Radio Towers

In follow-up interviews, users were asked about their familiarity with PEM fuel cells and whether they thought fuel cells were likely to compete favorably with existing backup power systems. Five users (out of eight respondents) were aware of the potential for PEM fuel cells to be used for backup power at radio tower sites, while three users had not heard of PEM fuel cells as a backup power source. One respondent believed that PEM fuel cells would compete with existing sources, particularly at new sites with a modest, constant power demand. This respondent specifically liked that there are no moving parts and that fuel cells can run for extended periods. Another user thought that fuel cells would compete with larger systems (e.g., a 100 kW unit) but not with his smaller propane generators. A third user believed that current technologies suffice and fuel cells are not needed at this time. One of the current users of PEM fuel cell backup systems believed that PEM systems would be adopted more widely if costs came down and the power density increased (larger kW output, smaller footprint).

With the exception of the two organizations that currently have fuel cell systems installed, most of the interviewees had not considered alternatives to their current backup power systems. One reported they considered only diesel and natural gas options and decided on diesel because of fuel availability. Similarly, a state agency representative stated that the agency had considered replacing their diesel generator with a propane generator, but were concerned about fuel availability and the higher cost of fuel. One county had evaluated turbines because they can burn a variety of fuels, have few moving parts, and require little maintenance. One respondent had evaluated a 1 kW fuel cell system as a battery replacement at a 911 call center. While this user thinks fuel cells are an excellent choice, the organization decided against using them because of cost (the state was financing the system, so there were cost limitations) and serviceability (it may be difficult to find a fuel cell technician in rural areas).

Survey participants were asked about potential concerns over the use of hydrogen as a fuel for backup power systems. While emergency responders may want to learn more about hydrogen as a fuel source, there did not appear to be a great level of concern among emergency response survey participants. Of the 11 respondents to this question, four individuals indicated that they were not so concerned, four were moderately concerned, and three individuals indicated they did not know enough about hydrogen to specify a level of concern.

In follow-up interviews respondents were asked what factors would convince them to procure a fuel cell-powered backup system. Two county PSAPs indicated that dissatisfaction with their current mode of operation may persuade them to procure a fuel cell, although one admitted he did not know enough about fuel cells to respond with certainty. Another respondent said that longer runtimes (i.e., a system that could run for days without interruption) would convince his organization to procure a fuel cell system.

Five interviewees addressed the issue of how capital purchase decisions for backup power systems are made within their organizations. Four respondents indicated that their organizations tend to emphasize initial capital costs. As governmental organizations, the ability to make capital expenditures depends on fiscal year budget allocations. Two respondents indicated that their agencies pay for capital equipment out of current budgets or with grants from state and federal agencies. One county said they use both cash reserves and loans at times. This respondent indicated that a loan guarantee program might influence the county's decision to purchase a fuel cell system. However, because loans are not typical for this type of capital investment, a loan guarantee program is not considered a useful incentive for this sector. No respondents reported that their organizations conduct a formal return-on-investment analysis.

Users surveyed were asked whether they considered the availability of government incentives when making capital purchase decisions. Three users indicated that they do consider incentives, and two responded that they do not, although others mentioned that they seek grant funding at times for such investments.

3.1.2.3 Market Research Summary Analysis

There is a critical need for backup power in the emergency response segment, because the impact of power outages can be catastrophic. Continuous power is particularly important for 911 call centers and radio towers. While some form of backup power is typically used at radio tower sites, an effort by some states to mandate backup power for emergency response communications may be a harbinger of growth in this market as other states follow.[41] Several key observations can be noted from user surveys, interviews, and secondary research with respect to backup power requirements, usage patterns, customer satisfaction with current systems, and users' understanding of PEM fuel cells:

- A variety of backup power capacities are used by emergency response agencies, with capacities for radio tower sites ranging from > 5 kW to 300 kW. Larger systems are

[41] Congressional Research Service. 2005. An Emergency Communications Safety Net: Integrating 911 and Other Service. CRS Report to the Congress. Available at http://www.fas.org/sgp/crs/homesec/RL32939.pdf [Accessed December 11, 2006].

typically used only when the system supports both a technical (radio tower, computer aided dispatch) and non-technical (lights, air-conditioning, facility power) mission.

- Currently, the state and local government entities that manage emergency response radio towers rely on propane and diesel generators, UPS systems, and batteries for backup power; and most rely on combined battery-generator systems. At PSAPs, batteries and UPS systems are used to meet backup power needs less than 30 kW. Generators are typically used for backup power greater than 30 kW. Propane generators are typically used for small power capacities (up to 60 kW), and diesel generators are used for large power capacity.
- Most organizations surveyed operate their backup power systems for less than 72 hours per year. Respondents expect UPS systems and battery systems to run 4 to 8 hours and generator systems to be able to run from 2 days to more than a week.
- Typical maintenance for backup power systems is less than 12 hours per year per site. Users typically follow the manufacturer's recommended maintenance schedules.
- Respondents are satisfied with the performance of current backup power systems, particularly with system lifetime and reliability. Respondents reported some concerns with generators, including emissions, mechanical failures, and high annual operating costs.
- The factors that would most influence respondents' decisions to purchase radio tower backup power systems powered by an alternative technology are reliability, capital cost, and lifetime of the unit.
- Awareness of PEM fuel cells is limited in this market.
- Emergency response organizations emphasize initial capital costs over longer-term return on investments when making capital purchase decisions.
- Financial incentives and grants that can reduce initial capital costs are considered by this market segment when making purchasing decisions.

3.1.3 Cost Analysis of PEM Fuel Cells

Our market research suggests that widespread market acceptance of PEM fuel cells is dependent on reliability and cost of the technology as compared to established alternatives. Although our market research suggests that users are generally satisfied with the status quo, there is potential for adoption of alternative technologies that provide lower emissions, longer runtimes, and are easy to use and maintain. Currently, batteries and battery-generator systems are the backup solutions of choice for radio tower sites in the emergency response market segment. Criticality of the site determines whether batteries or battery-generator systems are used. The type of backup system used varies by radio transmitter site and is highly dependent on power requirements (e.g., size of site, power draw, and voltage needs), type of installation (e.g., interior or exterior), and required backup time.

To determine if PEM fuel cells are a cost competitive alternative for this market, the lifecycle cost of PEM fuel cells, batteries, and generators typically used to provide backup power at radio sites are analyzed. Three different installation scenarios based on backup size and capacity are examined. The scenarios are based on candidate user input on typical applications of backup power at their sites. In these scenarios it is assumed that PEM fuel cells supply power to only critical applications at the radio tower sites.

This analysis examines the discounted NPV of using PEM fuel cells compared to batteries and generators using assumptions consistent with the H2A model.[42] Hydrogen fuel is assumed to be provided through pressurized canisters. For all three scenarios, a discount rate of 8% and an inflation rate of 1.9% are applied. No disposal costs are assumed for any of the technologies. It is assumed that disposal costs are rolled into the initial capital cost of the system. Lifecycle costs of PEM fuel cells with and without incentives specified in EPAct 2005 are analyzed.[43] The battery replacement schedules utilized in the analysis are 3 and 5 years, based on user responses to surveys. Section 3.1.3.1 provides the assumptions used in the three scenarios, and section 3.1.3.2 provides the lifecycle cost comparisons.

3.1.3.1 Lifecycle Cost Analysis Assumptions by Scenario

Scenario 1 assumes that the radio transmitter site is a new installation and requires 48 to 52 hours of backup power per year at 5 kW. This scenario compares the NPV of PEM fuel cells to battery-generator systems for a 15-year period with a 3-year and 5-year replacement cycle for batteries. Users have indicated that, in such an installation, batteries are designed to provide 4 hours of backup time, and the diesel generator is designed to provide 48 hours of backup time. To facilitate comparative analysis for this installation, the PEM fuel cell system includes enough fuel to provide 52 hours of backup time at 5 kW, essentially replacing the battery-diesel generator system. The PEM fuel cell system in this installation uses batteries to provide an hour of ride-through. The PEM fuel cell system in this installation uses an outdoor enclosure. In this scenario, it is assumed that the site experiences frequent extended outages (52 hours per year), and as a result, the generator and PEM fuel cell are refueled annually. No residual value for the installed technologies is assumed at the end of 15 years.

Scenario 2 compares the cost of a PEM fuel cell to a battery-generator system at a new remote radio transmitter site that requires extended runtime due to its critical nature (Table 3-3). The site has power requirements of 5 kW and is an exterior installation requiring up to 1 week of backup time. User input indicates that, at such an installation, batteries provide 8 hours of backup time, and the diesel generator provides 168 hours of backup time at 5 kW. For this installation, the PEM fuel cell includes enough fuel to provide 176 hours of backup time at 5 kW. It is assumed that the PEM fuel cell at this site requires an outdoor enclosure. The PEM fuel cell system in this installation uses batteries sized to provide 1 hour of ride-through. It is also assumed that the radio site rarely experiences extended outages, and as a result, the fuel in the generator and PEM fuel cell are replaced every 5 years. A system lifetime of 15 years is assumed for both the PEM fuel cell and the generator. No residual value for the installed technologies is assumed in this scenario. The NPV of PEM fuel cells is compared to battery-generator systems over the 15-year lifetime of the systems with a 3- and 5-year replacement cycle for batteries.

Scenario 3 analyzes the lifecycle cost of a PEM fuel cell compared to a battery-generator system at a new radio transmitter site that requires 3 days of backup power at 3 kW. Some users have indicated that, until reliability of PEM fuel cells is completely proven, they would not consider them as replacements to diesel generators. Other users have indicated that batteries are

[42] DOE Hydrogen Program: DOE H2A Analysis. DOE H2A Analysis. www.hydrogen.energy.gov/h2a_analysis.html [Accessed August 2006].
[43] Under EPAct 2005, fuel cells receive a 30% tax credit that is capped at $1,000 per kW of generating capacity.

problematic, and they would welcome reliable alternatives to batteries. As a result, in Scenario 3, lifecycle costs are evaluated for replacing a battery-generator system, a battery-only system, and a generator-only system with a PEM fuel cell. In this scenario, batteries, sized to 1.6 kW, provide power for 8 hours during an outage for technical loads (radio transmitter only). The generators, sized to 3 kW, provide power for 72 hours during an outage for technical and non-technical loads (facility power, air conditioning, and lights). Expected annual usage is approximately 12.8 kWh for the batteries and 216 kWh for the diesel generator. One PEM fuel cell is designed to carry both the technical and non-technical loads with hydrogen fuel for 72 hours at 3 kW to facilitate comparison with the battery-generator system and the generator-only system. The second PEM fuel cell is designed to carry only technical loads for 8 hours at 2 kW and is compared with the battery-only system. For this scenario, it is assumed that this is an interior installation and no enclosures are necessary. The PEM fuel cell system in this installation uses batteries sized to provide 30 minutes of ride-through. It is assumed that the site undergoes frequent outages, and as a result, the fuel is replaced in the diesel generator and PEM fuel cell on an annual basis. This analysis assumes a 15-year payback period with a 5-year replacement cycle for batteries. No residual value for the installed technologies is assumed in this scenario.

Table 3-3 identifies the cost assumptions used in all three scenarios.

Table 3.3. Lifecycle Cost Analysis Assumptions by Scenario.

	Scenario 1			Scenario 2			Scenario 3			
	Batteries	**Diesel Generator**	**PEM Fuel Cell**	**Batteries**	**Diesel Gen.**	**PEM Fuel Cell**	**Batteries**	**Diesel Generator**	**PEM Fuel Cell (Replacing Bat-Gen. System)**	**PEM Fuel Cell (Replacing Battery Only)**
Size (kW)	5	5	5	5	5	5	1.6	3	3	2
Lifetime (yrs)	3 or 5	15	15	3 or 5	15	15	5	15	15	15
Backup Time (hrs)	4	48	52	8	168	176	8	72	72	8
Usage (kWh/Yr)	20	240	260	40	840	880	12.8	216	216	16
Unit Cost ($)	7,000[1]	10,000	15,000	14,000	10,000	15,000	4,480	8,000	9,000	6,000
Engineering Installation Costs ($)	6,500[2]	4,000[3]	5,000[4]	6,500[2]	4,000[3]	5,000[4]	2,080[2]	2,400[3]	4,000[4]	4,000[4]
Non-Engineering Installation Costs ($)	3,000[5]	4,400[5]	17,075[1,4,5]	3,000[5]	4,400[5]	17,075[1,4,5]	2,000[5]	4,400[5]	2,075[1,5]	1,550[1,5]
Battery Charger ($)	2,000	-	-	2,000	-	-	2,000	-	-	-
Transfer Switch ($)	-	2,400	-	-	2,400	-	-	2,400	-	-
Fuel Tank ($)	-	2,000	-	-	2,000	-	-	1,200	-	-
Moon Pad ($)	-	-	1,200[5]	-	-	1,200[5]	-	-	1,200[5]	1,200[5]
Battery Ride-Through ($)	-	-	875[1]	-	-	875[1]	-	-	525[1]	350[1]
Outdoor Enclosure ($)	1,000	-	15,000[4]	1,000	-	15,000[4]	-	-	-	-
Maintenance Costs ($/yr)	560[6]	1260[7]	140[8]	560[6]	1260[7]	140[8]	560[6]	1260[7]	140[8]	140[8]
Fuel Usage	None[12]	1.4 gal/hr	75 slpm	None[12]	1.4 gal/hr	75 slpm	None[12]	1.4 gal/hr	45 slpm	30 slpm
Cost of Fuel ($/yr)	None	202[9]	495[10]	None	706[9]	1,650[10]	-	302[9]	405[10]	30
Tank Rental ($/yr)	-	-	1782[11]	-	-	5,940[11]	-	-	1458[11]	108

[1] Battery cost is based on $0.35 watt-hour. USACE ERDC CERL. 2004. Initial Report ReliOn Inc Backup Power for Mission Critical Loads.
[2] Assumes engineering services installation cost of $1300/kW. Data obtained from Battelle market research surveys.
[3] Assumes engineering services installation cost of $800/kW. Data obtained from Battelle market research surveys.
[4] Industry communication, September 2006.
[5] Personal communication between Kathya Mahadevan (Battelle) and George Milne (HavePower), September 2006 .
[6] Routine maintenance – Assumes 2 hours a quarter at $70/hr. Data obtained from Battelle surveys.
[7] Routine maintenance – Assumes 2 hours per quarter at $70/hr. Data obtained from Battelle market research surveys. Oil filter changes and tune-ups annually $700. Personal communication between Kathya Mahadevan (Battelle) and George Milne (HavePower), September 2006.
[8] Routine maintenance – Assumes 1 visit a year for 2 hours a year at $70/hr. Data obtained from Battelle market research surveys.
[9] Assumes $3 per gallon of diesel. Diesel generator provides 72 hours of backup in Scenario 3.
[10] Assumes 1 cylinder at 261 ft^3 provides 8 kWh of runtime. Cost per cylinder is $15. Personal communication between Kathya Mahadevan (Battelle) and John Osickey (ReliOn), September 2006.
[11] Assumes tank rental of $4.5 per month per tank. Personal communication between Kathya Mahadevan (Battelle) and Kevin Coyne (Praxair), September 2006.
[12] Negligible amount of electricity is used to recharge batteries.

3.1.3.2 Lifecycle Cost Analysis Results by Scenario

Results for Scenario 1 (52 hours of Backup Power)

In scenario 1, the 15-year analysis period with a 3-year and 5-year battery replacement cycle indicates that PEM fuel cells are competitive on a NPV basis with the incumbent solution both with and without tax incentives (Table 3-4).

The NPV of total capital costs for PEM fuel cells is lower than the NPV of total capital costs of the incumbent solution in both battery replacement schedules. The NPV of the capital costs of a battery-generator system with a 3-year battery replacement schedule is 20.2% greater than the NPV of the capital costs of PEM fuel cells without incentives. This difference is reduced to 9% with the 5-year battery replacement schedule between the NPV of the two systems.

The operation and maintenance costs, including the cost of fuel, are 16% lower for the battery-generator system than PEM fuel cells for both battery replacement schedules. In this analysis, battery replacement is assumed to be a capital cost expense, while fuel is considered a maintenance cost.

Over the 15-year lifetime of the systems, the NPV of the total costs of the PEM fuel cell system without incentives is approximately 9% lower than the NPV of the total costs of the battery-generator system in a 3-year battery replacement schedule. With incentives, in the 3-year battery replacement schedule, the NPV of the total cost of PEM fuel cells is 16% less than the NPV of the total cost of the incumbent solution. The 5-year battery replacement schedule results in the NPV of the total costs of the battery-generator system being slightly lower than the NPV of the total costs of the PEM fuel cell without incentives. Incentives in this scenario (with 5-year battery replacement schedule) make the NPV of the total costs of PEM fuel cells more attractive over the 15-year analysis period by 7%.

Table 3-4. Scenario 1: 5 kW for 52 hours - NPV of PEM Fuel Cells and Battery-Generator System over 15-Year Analysis Period with a 3-Year and 5-Year Battery Replacement Schedule.

3-Year Battery Replacement Schedule			
	Battery-Generator System	**PEM Fuel Cell without Tax Incentive**	**PEM Fuel Cell with Tax Incentive**
NPV of Total Capital Costs ($)	50,337	40,158	35,441
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	19,656	23,496	23,496
NPV of Total Cost of System ($)	69,860	63,521	58,804
5-Year Battery Replacement Schedule			
	Battery-Generator System	**PEM Fuel Cell without Tax Incentive**	**PEM Fuel Cell with Tax Incentive**
NPV of Total Capital Costs ($)	41,560	37,964	32,247
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	19,656	23,496	23,496
NPV of Total Cost of System ($)	61,082	61,326	56,609

Results for Scenario 2 (176 hours of Backup Power)

Over the 15-year analysis period with both battery replacement schedules in scenario 2, PEM fuel cells are not competitive with the incumbent solution based on the NPV of the total cost of the system (Table 3-5). However, in this scenario, PEM fuel cells do require less capital investment than the incumbent solution (based on the NPV of the total capital costs).

With a 3-year battery replacement schedule and without incentives, PEM fuel cells are approximately 9% more expensive than the battery-generator system based on NPV of the total cost of the system. With incentives, the difference between the NPV of the total cost of the two systems is reduced to approximately 5%. With a 3-year battery replacement schedule and incentives, the NPV of total capital cost of PEM fuel cells is 49% less than the NPV of total capital cost of the incumbent solution.

With the 5-year battery replacement schedule, NPV of the total cost of the PEM fuel cell is approximately 25% (without incentives) to 21% (with incentives) higher than the NPV of the total cost of the battery and generator system. PEM fuel cells require less capital investment than do batteries and generators, by approximately 29% (without incentives) to 37% (with incentives), with a 5-year battery replacement schedule.

In scenario 2, the cost of hydrogen storage severely impacts the operation and maintenance costs of PEM fuel cells. Hydrogen fuel tank rental and storage costs for 176 hours of runtime account for 98% of the annual operation and maintenance costs for PEM fuel cells in this scenario.

Table 3-5. Scenario 2: 5 kW for 176 hours - NPV of PEM Fuel Cells and Battery-Generator System over 15-Year Analysis Period with a 3-Year and 5-Year Battery Replacement Schedule.

3-Year Battery Replacement Schedule			
	Battery-Generator System	**PEM Fuel Cell without Tax Incentive**	**PEM Fuel Cell with Tax Incentive**
NPV of Total Capital Costs ($)	75,887	43,750	39,032
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	17,692	59,104	59,104
NPV of Total Cost of System ($)	93,129	102,403	97,686
5-Year Battery Replacement Schedule			
	Battery-Generator System	**PEM Fuel Cell without Tax Incentive**	**PEM Fuel Cell with Tax Incentive**
NPV of Total Capital Costs ($)	58,333	41,556	36,838
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	17,692	59,104	59,104
NPV of Total Cost of System ($)	75,575	100,209	95,491

Results for Scenario 3 (72 hours of Backup Power Generation)

Incentives in this scenario impact the capital cost investment required and make PEM fuel cells significantly more attractive than the battery-generator system, battery-only system, and a new installation generator-only system.

In scenario 3, the 15-year payback analysis with a 5-year battery replacement schedule shows that PEM fuel cells require less capital investment and operation and maintenance costs than the battery-generator system (Table 3-6). Without incentives, the NPV of the total cost of the PEM fuel cell system is 28% less than the battery-generator system.

When compared to the generator-only system, PEM fuel cells require more capital investment and operation and maintenance investment over the 15-year analysis period. The NPV of the total cost of PEM fuel cells is $33,901, as compared to $28,283 for newly installed generators and $24,886 for replacement generators (Table 3-6).

Table 3-6. Scenario 3: 3 kW for 72 hours - NPV of PEM Fuel Cells, Battery-Generator System, and Generator-Only System over 15-Year Analysis Period with a 5-Year Battery Replacement Schedule.

	Battery-Generator System	Generator (New Installation)	Generator Replacement (No Installation Costs)	PEM Fuel Cell without Tax Incentive	PEM Fuel Cell with Tax Incentive
NPV of Total Capital Costs ($)	26,800	13,209	9,813	14,540	12,653
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	20,628	15,184	15,184	19,471	19,471
NPV of Total Cost of System ($)	47,318	28,283	24,886	33,901	32,014

Over the 15-year analysis period, PEM fuel cells are less expensive than batteries alone, both with and without incentives (Table 3-7). The NPV value of the total cost of the PEM fuel cell system is less than the battery-only system by 26% (without incentives) and 36% (with incentives) over the 15-year analysis period with a 5-year battery replacement schedule. As compared to the battery-only system, PEM fuel cells require approximately 50% less operation and maintenance investment.

Table 3-7. Scenario 3: 2 kW for 8 hours - NPV of PEM Fuel Cells and Battery-Only System over 15-Year Analysis Period with a 5-Year Battery Replacement Schedule.

	Battery	PEM Fuel Cell without Tax Incentive	PEM Fuel Cell with Tax Incentive
NPV of Total Capital Costs ($)	13,600	11,329	9,442
NPV of Fixed O&M Costs ($) (Including Cost of Fuel)	5,444	2,702	2,702
NPV of Total Cost of System ($)	19,037	14,023	12,136

3.1.3.3 Lifecycle Cost Summary

The lifecycle cost analyses above show that PEM fuel cells can compete effectively with current technologies – both battery-generator systems and battery-only systems – when shorter runtimes are required (i.e., 8 to 72 hours). When runtimes of 176 hours are required, the high cost of hydrogen storage tank rental and use makes PEM fuel cells less attractive than the alternatives from a lifecycle cost perspective. The results are summarized in Table 3-8. PEM fuel cells are more competitive in a 3-year battery replacement schedule than a 5-year battery replacement schedule. Tax incentives for PEM fuel cells significantly impact the lifecycle costs of PEM fuel cells, making them more attractive than the incumbent solutions for shorter runtimes.

Table 3-8. Comparison of NPV for Total Cost of System: 8-Hour, 52-Hour, 72-Hour, and 176-Hour Runtime Scenarios.

	3-Year Battery Replacement			5-Year Battery Replacement							
	Battery-Gen.*	PEMFC+ without Tax Incentive	PEMFC with Incentive	Battery-Gen.	PEMFC without Tax Incentive	PEMFC with Tax Incentive	Gen. New Installation	Gen. Repl. Existing Installation	Battery-only	PEMFC without Tax Incentive	PEMFC with Tax Incentive
8-hour Runtime									19,037	14,023	12,136
52-hour Runtime	69,860	63,521	58,804	61,082	61,326	56,609					
72-hour Runtime				47,318	33,901	32,014	28,283	24,886			
176-hour Runtime	93,129	102,403	97,686	75,575	100,209	95,491					

*Gen. is generator, + PEMFC is PEM fuel cell

3.1.4 Sensitivity Analysis

3.1.4.1 Sensitivity Analysis Modeling Analysis Methodology

Single-factor sensitivity analysis was performed to show the variability in average annual system cost as individual factors are varied while all other factors are held constant. The base values for each factor are the same as the values used in the scenario 1 lifecycle cost analysis shown in Table 3-3. Here, each factor was allowed to vary by +/-10% of the base assumption. The results of the sensitivity analysis are presented in a tornado diagram (Figure 3-6). The factor that shows the greatest cost leverage is graphed at the top, with other factors arrayed below it in descending order of cost leverage. Two numbers are shown at each end of the horizontal bar graph for each factor. The upper number is the average cost per year of owning and operating the PEM fuel cell if this factor is varied by 10% from base assumptions, holding all other factors at base assumptions. In brackets under the average cost figure is the value of the factor when varied by 10%.

The factors varied in the PEM fuel cell backup power cost sensitivity analysis are shown in Table 3-9. For example, the base value assumed for the life of the ride-through batteries was 5.0 years; the high value (+10%) is 5.5 years, and the low value (-10%) is 4.5 years. In the sensitivity analysis, the average annual cash outlay for use of a PEM fuel cell was calculated using Equation 1. Hydrogen cost, tank cost, and operation and maintenance (O&M) costs are annual averages. Installation costs include engineering and non-engineering costs, moon pad (installation pad), and outdoor enclosure listed in Table 3-3 for scenario 1.

$$\overline{C} = \frac{(Fuel\,Cell\,Cost + Installation\,Cost)}{Fuel\,Cell\,Life} + \frac{Battery\,Cost}{Battery\,Life} + Hydrogen\,Cost + Tank\,Cost + O\,\&\,M\,Cost \qquad \text{Equation 1}$$

Table 3-9. Cost Assumptions for PEM Fuel Cell Backup Power Sensitivity Analysis: +/-10% Base Assumption.

	Base Value	-10% of Base Value	+10% of Base Value
O&M Cost, $	140	126	154
Ride-through Batteries, $	875	788	963
Ride-through Battery Life, years	5.0	4.5	5.5
Fuel (hydrogen), $/year	495	446	545
Fuel Cell Cost, $	15,000	13,500	16,500
Installation Cost, $	38,275	34,448	42,103
Hydrogen Tank Rental, $/year	1,782	1,604	1,960
Fuel Cell Life, years	15	13.5	16.5

3.1.4.2 Sensitivity Analysis Results

The results of the sensitivity analysis are shown in Figure 3-6. For a PEM fuel cell used in backup applications, improving the fuel cell life has the largest impact on the average annual cost.

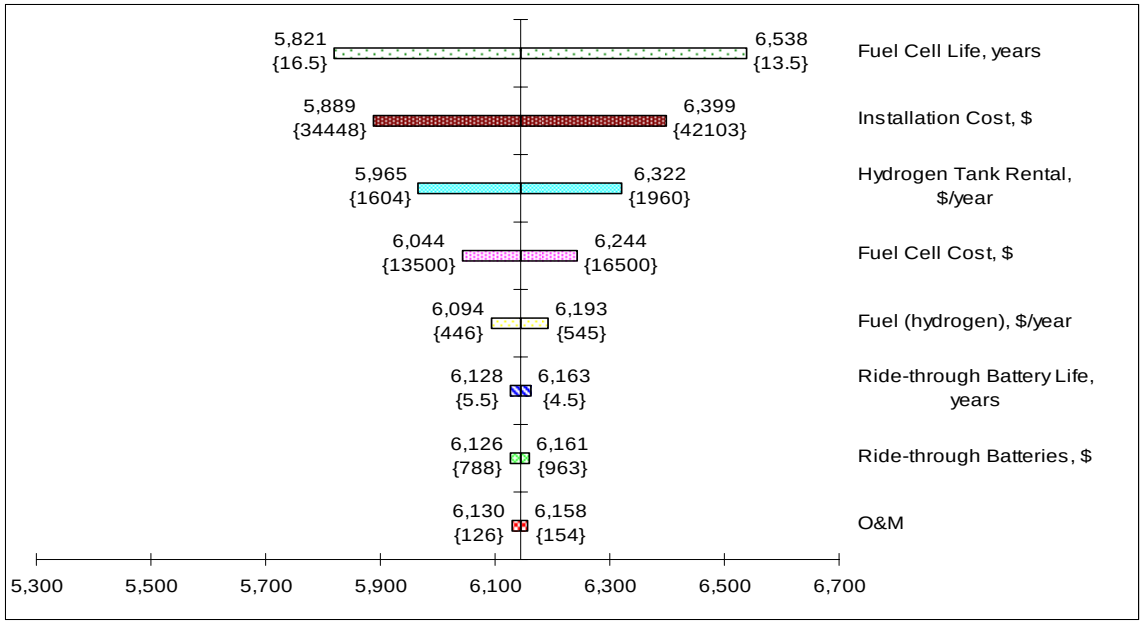

Figure 3-6. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell Backup Power System.

Installation cost is the second largest cost driver of the cost of owning and operating a PEM fuel cell. Hydrogen tank rental and fuel cell cost are the third and fourth largest cost drivers. The cost of hydrogen, batteries (and battery life), and operation and maintenance costs have a smaller leverage on the cost of owning and operating the PEM fuel cell system. In the scenario where longer periods of backup electricity are required (176 hours, rather than 48 hours), the cost of hydrogen tank rental becomes a more important cost driver.

3.1.5 Market Penetration Analysis

3.1.5.1 Market Penetration Assumptions

The market penetration potential of PEM fuel cells (adoptions and sales) when key cost and performance criteria are met as compared to competing alternatives, is presented in this section.

Extrapolating from published data and user interviews, it is estimated that there are about 15,000 registered emergency response radio towers in the U.S. today. However, the total number of emergency response communication towers, including unregistered towers, may be as high as 60,000. Based on survey data and existing regulations, it is anticipated that all emergency response communication towers have, or will acquire, backup power sufficient for 48 hours or longer. To meet this requirement, it is anticipated that batteries will be supplemented with other equipment for power generation. As a basis for the market penetration analysis, the research team conservatively used 15,000 registered towers to estimate annual purchases of backup power systems.

Three separate cases were assumed for the market penetration analysis. In the base case, no government actions are taken. In the communication case, the government provides some form of outreach or information to the market on the value of PEM fuel cells. In the subsidy case, the government subsidizes purchases of PEM fuel cells at a cost of $1,000 per kW. Table 3-10 summarizes the assumptions that were used for these three cases. For all three cases, it was assumed that a diesel backup system and PEM fuel cells each need to be replaced after 15 years. It is further assumed that the purchase of backup systems is evenly distributed over time. Therefore, backup power for 1,000 towers was purchased in the first year of PEM fuel cell introduction (15,000 towers/15 years). It is assumed that PEM fuel cells will penetrate approximately 40% of this market (400 towers).

For all three cases, it was assumed that the PEM fuel cells were 5 kW systems at a cost of $15,000 ($3,000/kW). It is expected that, as sales increase, the cost of production will decrease. It is further expected that, as PEM fuel cells begin penetrating the market, competing ICE generators will lower their prices to prevent erosion of market share. Both the lower production costs and the response of competing industries will likely to drive down price. Therefore, it was assumed that the price of PEM fuel cells will decrease 5% per year for 10 years. The price is assumed to be stable (given constant dollars) after that time.

For all three cases, it was assumed that the value of PEM fuel cells to the market will be significantly greater than competing technologies. Because of this higher value, market penetration will occur initially. This is an optimistic but plausible assumption because of the lower maintenance costs and higher reliability that PEM fuel cells are expected to provide.

Table 3-10. Assumptions for PEM Fuel Cell Adoption for Backup Power Applications at Emergency Response Radio Towers*.

Assumption	Base Case	Communication Case	Subsidy Case
Market Growth Rate	8.7% for five years; 6% falling by 1% every two years; stable at 2%	8.7% for five years; 6% falling by 1% every two years; stable at 2%	8.7% for five years; 6% falling by 1% every two years; stable at 2%
Government Actions	None	Communications	Subsidize purchase at $1,000/kW
Values of *p* and *q*	p = 0.008 q = 0.423	p = 0.012 q = 0.423	p = 0.070 q = 0.423
Total U.S. Emergency Response Communication Towers with 48 Hour Backup Power	15,000	15,000	15,000
Initial Number of Communication Towers Purchasing Backup Power Annually	1000	1000	1000
Initial Annual Number of Communication Towers Purchasing Fuel Cell Backup Annually, *m*	40% of total market; 400	40% of total market; 400	40% of total market; 400
Average Initial Cost of 5 kW System for each Tower ($)	15,000	15,000	15,000
Rate of Price Reduction	5% per year for 10 years; stable thereafter	5% per year for 10 years; stable thereafter	5% per year for 10 years; stable thereafter
Final Share of Backup Power	100%	100%	100%
Life of Fuel Cells and Diesel Generators	15 years	15 years	15 years

*Assumes that PEM fuel cells are cost competitive and offer superior performance compared to competing alternatives.

3.1.5.2 Market Penetration Results

The models show that the subsidy case achieves the greatest market penetration. The price of PEM fuel cells is assumed to be driven down by competitive pressures. Based on previous estimates of the change in fuel cell cost with increasing volumes,[44] only the subsidy case achieves fast enough growth for the price to exceed cost.

The models show that, in the base and communication cases (Figures 3-7 through 3-10), the first years in which 500 units will be sold annually, are 14 years and 13 years, respectively, after commercial introduction. In the subsidized case (Figures 3-11 and 3-12), 500 units are sold annually much earlier, eight years after commercial introduction. Further, the models show that, in the base and communication cases, the first years in which $5 million in sales are achieved will again be 13 years and 12 years, respectively, after commercial introduction. In the subsidized case, $5 million in sales occurs much earlier, in seven years. Assuming that a $1,000 per kW subsidy for 5 years is used to spur early purchases of PEM fuel cells, the cost to government would be about $3.35 million.

[44] Battelle. 2006. Economics of Stationary PEM Fuel Cell Systems. For the Department of Energy, DOE Contract No. DE-FC36-03GO13110.

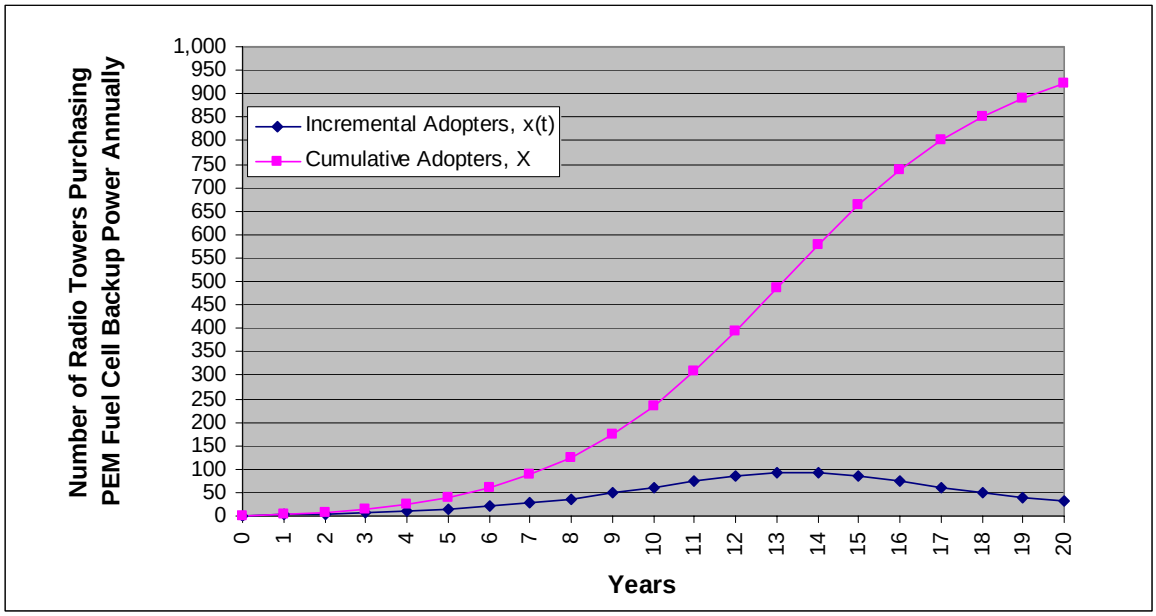

Figure 3-7. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Base Case.

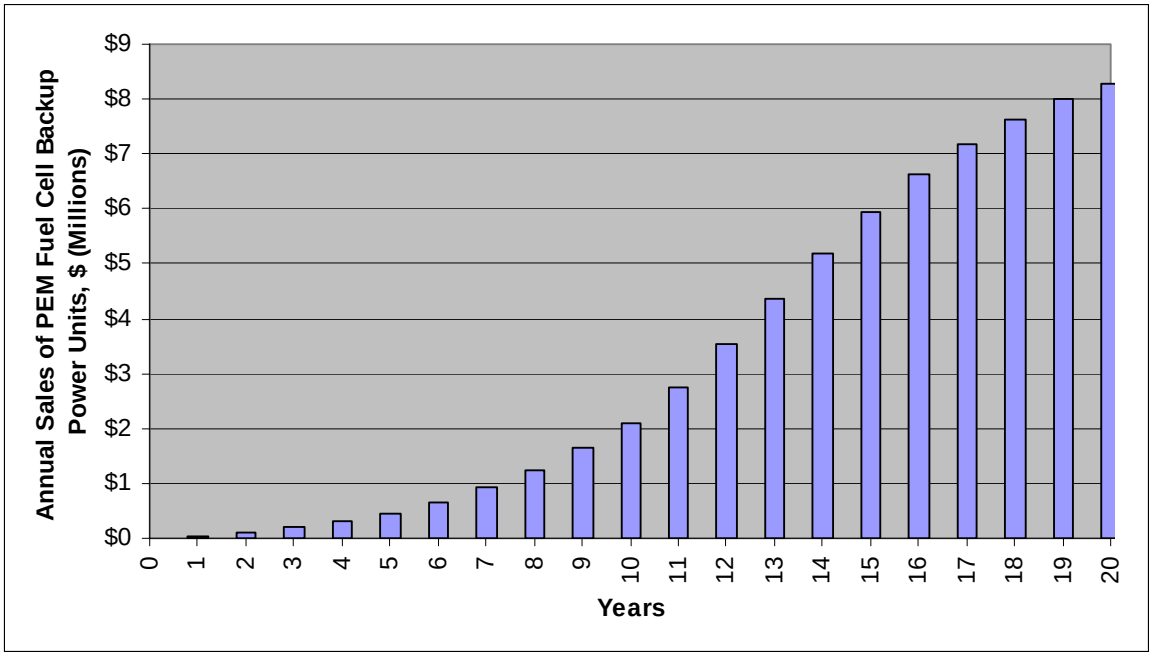

Figure 3-8. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Base Case.

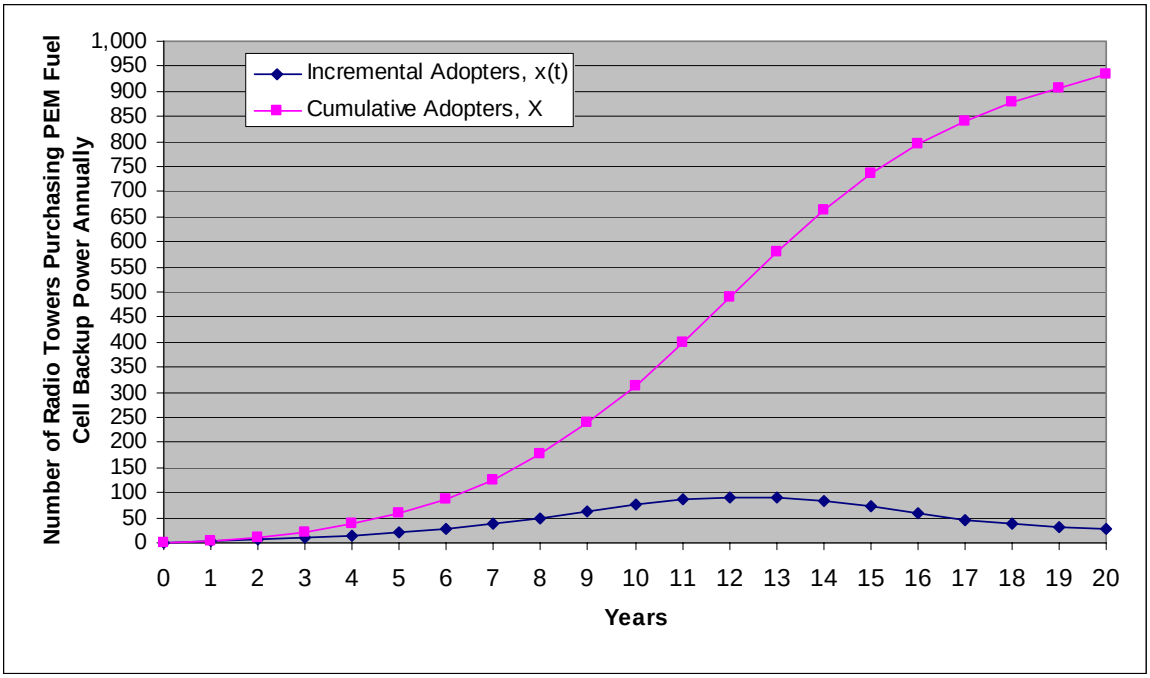

Figure 3-9. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Communication Case.

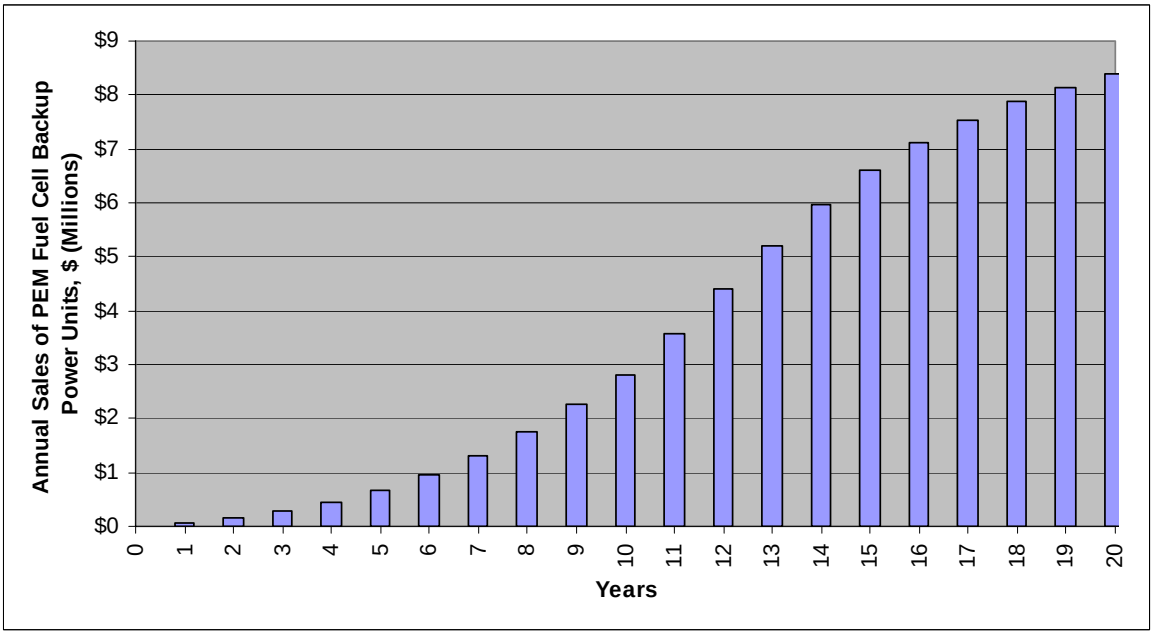

Figure 3-10. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Communication Case.

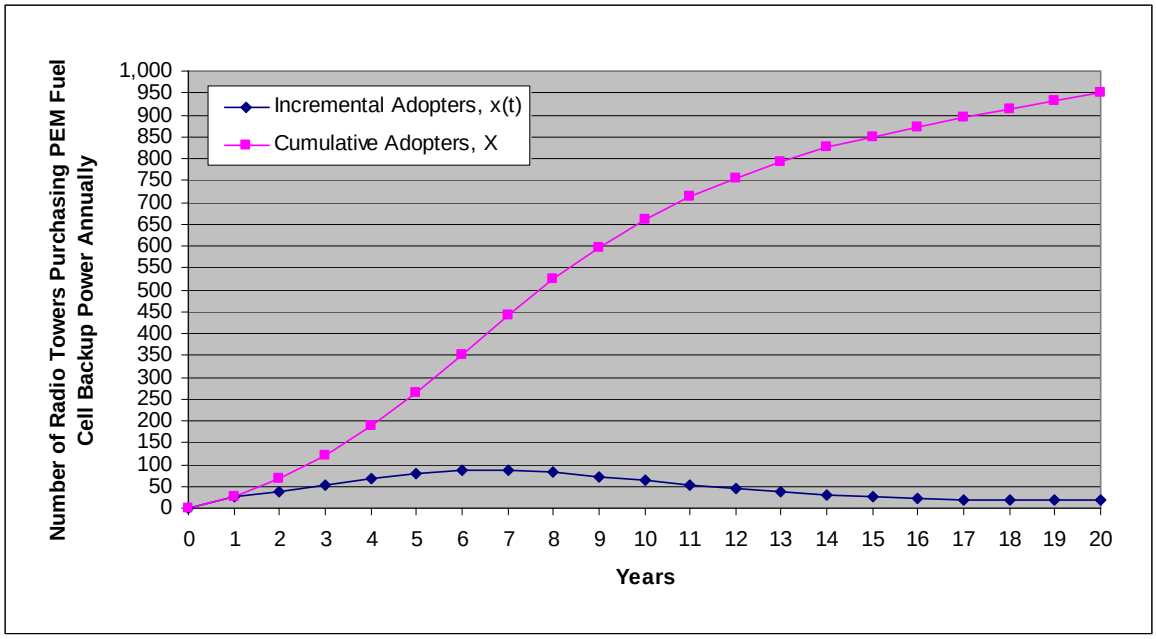

Figure 3-11. Adoptions of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Subsidy Case.

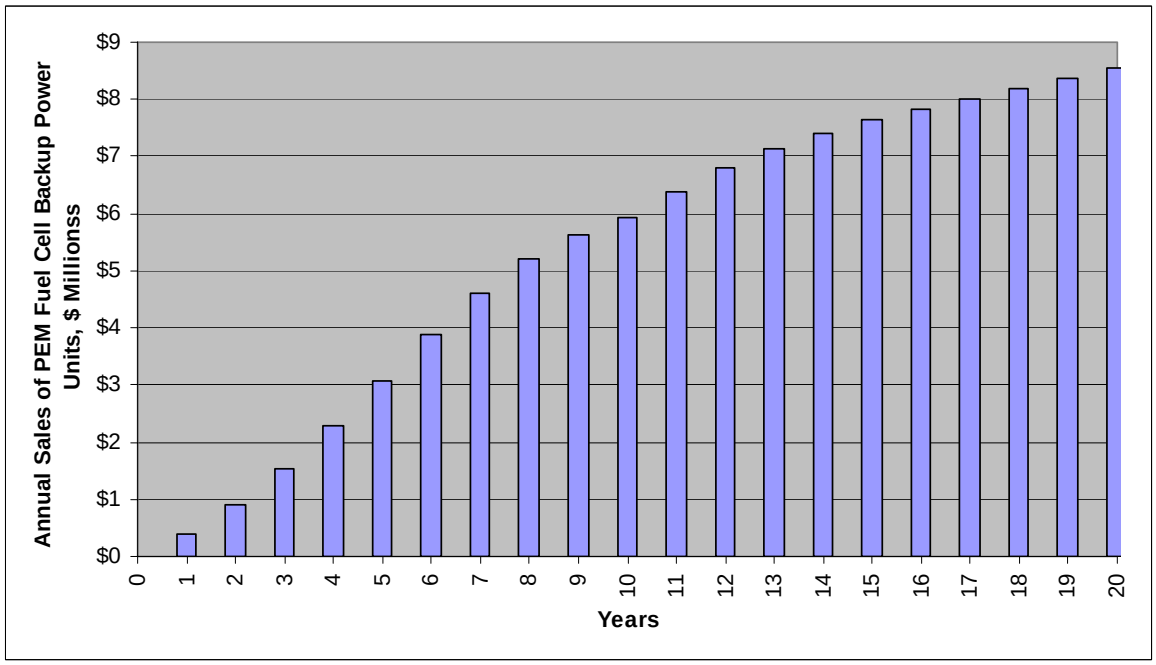

Figure 3-12. Sales of PEM Fuel Cell Backup Power for Emergency Response Communication Towers in the Subsidy Case.

Table 3-11 provides a summary of the sales and market share data presented for each of the three cases described above.

Table 3-11. Summary of PEM Fuel Cell Penetration Assuming Alternative Cases.

	5 Years After Commercial Introduction			10 Years After Commercial Introduction			15 Years After Commercial Introduction			20 Years After Commercial Introduction		
	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case
Annual Sales (Units)	40	58	266	234	314	659	664	735	851	922	933	951
Annual Sales ($ millions)	<.5	<1	3	2.10	2.82	5.91	5.96	6.6	7.64	8.28	8.38	8.54
Market Share (%)	3	4	17	12	16	34	30	33	38	37	38	38

3.1.6 Value Proposition for PEM Fuel Cells

The emergency response market segment appears to represent a promising early niche for PEM fuel cells as a backup power source at some radio tower sites. It is expected that improvements in the application of PEM fuel cells in the telecommunications sector will drive the adoption of PEM fuel cells at radio tower sites in the emergency response market segment. Emergency response radio towers represent an adequately sized market, and growth is expected in the number of towers using backup power in the next few years as more states consider mandating backup power at PSAPs and radio tower sites. Various user requirements (for system size, reliability, ease of use, durability, and start-up time at smaller radio sites with backup requirements of 8 to 72 hours) fit well with the performance of PEM fuel cells relative to alternatives. Furthermore, fuel cells have been demonstrated successfully as a source of backup power for emergency response radio tower sites in at least three locations. It is anticipated that PEM fuel cells will penetrate other applications in the emergency response segment as the technology matures.

PEM fuel cells offer many advantages over incumbent technologies. Compared to batteries, PEM fuel cells offer longer, continuous runtime and are more durable in harsh environments. Compared to generators, PEM fuel cells have lower maintenance requirements, since they have fewer moving parts; can be monitored remotely, reducing actual maintenance time; and have lower emissions.

PEM fuel cells also offer potential cost advantages over competing technologies under some conditions in this market segment. The lifecycle cost analysis shows that PEM fuel cells are cost competitive with current technologies – both battery-generator systems and battery-only systems – when shorter runtimes are required (i.e., the equivalent of 1 to 3 days). A key opportunity for PEM fuel cells will be for backup power to radio tower sites in harsh environments, which can shorten the lifetime of batteries. PEM fuel cells offer a lifecycle cost advantage over battery-

generator systems when battery lifetime is shorter, and are similar in cost to battery-generator systems when batteries are replaced on a 5-year schedule. The value proposition for PEM fuel cells deteriorates relative to incumbent technologies when extended runtimes are required (i.e., the equivalent of 7 days). Under these conditions, the high cost of hydrogen storage and use drives up the lifecycle cost of PEM fuel cells.

Financial incentives, demonstration projects, and fuel availability will be critical in order for PEM fuel cells to exploit these advantages and compete effectively with current backup power technologies for radio towers. Market penetration modeling illustrates that near-term adoption increases with government subsidies that reduce the capital cost of the fuel cell, such as those enacted under EPAct 2005. Incentives may be even more important in this sector than others, given the emphasis users place on capital cost in making purchase decisions. Reliability testing and demonstration projects will also be key to adoption, as reliability is another high priority purchase decision factor. Users in this market segment will need to see data that prove PEM fuel cells to be as reliable or more reliable than incumbent technologies before they adopt. Fuel availability is a final issue that will need to be addressed if PEM fuel cells are to succeed in this market. Users will need to be assured that hydrogen can be supplied in appropriate quantities and stored in a cost-effective manner.

3.2 PEM Fuel Cells in Forklifts at High Throughput Distribution Centers

3.2.1 Market Attributes

3.2.1.1 Market Segment Description

Forklifts are a type of material handling equipment, used by various industries, to move materials to, through, and from production processes in receiving, storage, packing, and shipping. By mechanizing materials handling, forklifts increase productivity and reduce production costs. Table 3-12 identifies the SIC and NAICS codes for manufacturing of forklifts. These codes were utilized to guide market research.

Table 3-12. SIC and NAICS Codes for Forklift Manufacturing.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Code	3537 – Industrial trucks and tractors
NAICS Code	333924 – Industrial trucks, tractors, mobile straddle carriers and stacker machinery

Forklift trucks are available in many variations and load capacities. They can be powered by batteries or ICEs fueled by gasoline, propane, or diesel. The Industrial Truck Association (ITA) has defined seven classes of forklift trucks:

- Class 1 – battery-powered motor trucks with cushion or pneumatic (air filled) tires. Class 1 forklifts include four sub-categories, or lift codes, which are:
    - Lift Code 1 – counter balanced rider type, stand-up
    - Lift Code 4 – three-wheel battery-powered, sit-down
    - Lift Code 5 – counter balanced rider, cushion tire, sit-down
    - Lift Code 6 – counter balanced rider, sit-down rider (includes pneumatic tire models)
- Class 2 – battery-powered motor narrow aisle trucks with solid tires

- Class 3 – battery-powered hand trucks or hand-rider trucks with solid tires
- Class 4 – ICE-powered sit-down rider forklifts with cushion tires, generally suitable for indoor use on hard surfaces
- Class 5 – ICE-powered sit-down rider forklifts with pneumatic tires, typically used outdoors, on rough surfaces or significant inclines
- Class 6 – battery- or ICE-powered ride-on units with the ability to tow at least 1,000 pounds (lbs); this class is designed to tow cargo rather than lift it
- Class 7 – rough terrain forklift trucks with pneumatic tires; these are almost exclusively powered by diesel ICE and are used outdoors.

Battery-powered forklifts (Class 1, 2, and 3) are typically used in indoor materials handling applications that do not require large lift capacities. In some instances, battery-powered forklifts are selected primarily for worker safety. These applications include confined spaces, cold storage, and food retail (primarily grocery stores).[45] Class 1, 2, and 3 forklifts are typically used in multi-shift operations by warehousing, distribution centers, third-party logistics suppliers, shipping and receiving, and manufacturing. Class 4, 5, and 6 trucks are typically used in construction, agriculture, manufacturing, large warehousing, recycling, beverage and bottling, trucking, and garden supply operations. They are also used in the manufacturing and processing operations of paper and allied products; lumber and wood products; building supplies; stone, clay, and glass products; and primary metal products. Class 1 forklifts can be used in similar applications to Class 4 or Class 5 forklifts. Typically, Class 2 and Class 3 forklifts are used in those applications where ICE-powered forklifts are not practical, such as indoor environments and narrow aisles.

Although battery-powered forklifts are designed for indoor operations, a number of manufacturers are offering equipment features, such as different types of tires, which enable battery-powered models to be used in a wider variety of environments. Class 1 battery-powered forklifts are available in a wide variety of lift capacities from 3,000 lbs to over 20,000 lbs. Most Class 1 forklifts sold in the U.S. today are in the 3,000 to 6,000 lb lift capacity range. There does not seem to be a large penetration of Class 1 battery-powered forklifts with lift capacities greater than 6,000 lbs.[46]

Forklifts with spark-ignited engines that are also used indoors have lift capacities between 3,000 and 16,000 lbs. ICE-powered forklifts with compression ignition engines have lift capacities over 6,000 lbs and can exceed 40,000 lbs. Forklifts range from 50 HP (approximately 37 kW) to over 175 HP (approximately 130 kW).

The annual hours of usage vary significantly among different types and users of forklift trucks. The usage pattern can vary from continual use to four or five hours per shift. In 1995, the Gas Technology Institute (GTI) reported that the range of battery-powered forklift runtimes varied from 500 hours to 3,500 hours per year, with a mean of about 2,250 hours per year.[47] For ICE forklifts, the GTI reported that the average annual hours of usage are approximately 1,800 to

[45] Antelope Valley Air Quality Management District. 2006. Chapter VII. Forklifts. Available at http://www.avaqmd.ca.gov/carlm/g_forklift.pdf [Accessed March 2006].
[46] California Air Resources Board. 2006. Draft Forklift Project Criteria. Available at http://www.arb.ca.gov/msprog/moyer/fl_crit.pdf [Accessed June 2006].
[47] Gas Technology Institute. 1995. Industrial Truck Market Analysis.

1,900 hours per year. The same report found that 69% of Class 1 and 2 battery-powered forklifts operate one shift a day, 16% operate two shifts, and 15% operate three shifts. For ICE forklifts, GTI noted that 59% operate one shift and almost 40% operate two shifts. On average, it was noted that both battery- and ICE-powered forklifts operate 1.5 shifts a day, five days a week. GTI also reported that battery-powered (Class 1 or 2) forklifts on average are recharged after 11 clock (not meter) hours. Thus, battery-powered forklifts operating in multiple shifts typically use multiple battery packs and require battery change-out equipment. The average propane tank was replaced or refilled after 15 hours.

The price of forklift trucks varies according to class. New battery-powered forklifts can cost 20-40% more than ICE-powered trucks of a comparable size. A 5,000 lb walkie stacker battery-powered forklift retails for $18,000 to $25,000 plus $2,000 to $5,000 for one battery and charger. Quotes received from Crown Equipment indicate that battery-powered forklift trucks can range from approximately $8,000 for a 6,000 to 8,000 lb rider pallet truck to $75,000 for a 3,000 lb narrow aisle stock picker.[48] On the other hand, a 5,000 lb ICE-powered forklift can range from $16,000 to $28,000. A 10,000 lb diesel ICE forklift truck ranges in price from $28,000 to $45,000.[49]

Battery-powered forklift trucks have lower lifecycle costs compared to ICE-powered models. This is due to lower maintenance costs, lower fueling costs, and a longer useful life. Operating costs can range from $1 per hour for small battery-powered forklift trucks to over $20 per hour for Class 7 diesel forklift trucks. In a study conducted by the Electric Power Research Institute (EPRI), one user found that the median service life for battery-powered forklifts was 11 years, as compared to 7.5 years for ICE-powered versions.[50]

Battery-powered forklifts are typically powered by lead-acid batteries that can typically provide enough power for one 8-hour shift, which translates into 5 to 6 hours of constant usage. The primary advantages of battery-powered forklifts are that they produce zero emissions and they can be used indoors. However, the disadvantage of the battery-powered forklift is battery change-out and downtime, which impacts productivity and increases costs of operation. In a typical operation, battery change-out takes 20 to 45 minutes. Charging the battery takes 8 hours, plus 8 hours of cooling time before the battery can be used. Due to this slow charging speed, multiple shift operations must typically keep extra batteries charged and available. The battery chargers are typically located in a dry, ventilated, and temperature-controlled location, because batteries release oxygen and hydrogen during charging. Furthermore, because overcharging of the battery can often result in acid spills, it is necessary to locate battery charging operations away from other operations so that spills can be easily disposed. In locations where space is at a premium, battery charging stations can be costly.

ICE-powered trucks run on a variety of fuels including gasoline, diesel, liquid propane gas (LPG), and compressed natural gas (CNG). The main benefit of the ICE engine is the ease of refueling (< 30 seconds). While ICE-powered forklifts are cheaper to buy, the cost of

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[48] Personal communication between Kathya Mahadevan (Battelle) and Rich Bair (OKI Systems). April 2006.
[49] Buyerzone.com. 2006. New and Used Forklift Pricing. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide7.html [Accessed June 2006].
[50] Southern California Edison. 2006. Electric Transportation. Available at http://www.sce.com/PowerandEnvironment/ElectricTransportationOld/Non-roadApplication/Forklifts.htm [Accessed June 2006].

maintenance is high. In addition, refueling equipment and storage equipment are an added cost. In many cases, dual fuel equipment is available to switch between LPG and diesel.

3.2.1.2 Market Size

Current data on the number of businesses manufacturing forklift trucks and other industrial trucks and tractors are provided below in Table 3-13. Within this table, only those eight-code SIC specialties deemed likely to be involved in forklift manufacturing are shown.

Table 3-13. Number of Companies Potentially Involved in Forklift Manufacturing.

Industry: Industrial Trucks and Tractors (SIC Code 3537)				
SIC Code	**SIC Description**	**No Bus.**	**Total Emps.**	**Total Sales ($)**
3537-0000	Industrial trucks and tractors	391	9,184	2,049.5
3537-0208	Forklift trucks	207	5,587	3,847.4
3537-0210	Lift trucks, industrial: fork, platform, straddle, etc.	147	8,550	6,527
3537-0211	Pallet loaders and unloaders	9	383	67.1
3537-0212	Palletizers and depalletizers	12	228	24.5
3537-0213	Stackers, power (industrial truck stackers)	1	1	0.1
3537-0215	Straddle carriers, mobile	4	10	0.7
3537-0216	Tractors, used in plants, docks, terminals, etc.: industrial	17	2,544	58.2
3537-0218	Trucks: freight, baggage, etc.: industrial, except mining	147	2,139	88.7
	Total	**935**	**28,626**	**12,663.2**

Sales figures are in millions. Source: www.zapdata.com, accessed May 2006.

Forklift trucks are used by a variety of industries, including, but not limited to, manufacturing, construction, mining, agriculture, food, retail, internet retailers, and wholesale trade. Forklifts are widely used by these industries at manufacturing sites, distribution centers, and warehousing operations to move goods within the facility or to load goods for shipping to other sites. Discrete process and service industry sectors found in construction (SIC Codes 15-17), manufacturing (SIC Codes 20-39), and service sectors (SIC Codes 40-59) are all users of forklifts.

Most of these industries have shown sales growth over the past decade, particularly for businesses involved in online sales and direct marketing through catalogs and television. Internet sales rose approximately 25% in 2005.[51] To support these increased sales, most businesses today have extensive supply chains, and the use of appropriate solutions for order picking and transporting to facilitate the movement of goods is critical to their bottom line. In 2003, total demand for material handling equipment by end users in the U.S. was approximately $16,450 million. This demand is expected to grow to $24,900 million by 2013 (Table 3-14). Of the end users listed in Table 3-14 below, nondurable goods, food and beverages, and electrical and electronic equipment end-user markets have the greatest demand for material handling equipment.

[51] Plunkett Research. 2006. Major Trends Affecting the Retail Industry.

Table 3-14. Material Handling Equipment Demand by End-User Market to 2013 in Millions of Dollars.[52]

Material Handling Equipment	Demand ($Million)				
	1993	1998	2003	2008	2013
Total Material Handling Demand by End-User*	12,325	17,865	16,450	20,350	24,900
Durable Goods Manufacturers	4,460	6,985	5,680	7,230	8,960
Primary and Fabricated Metals	304.4	410.8	634	466	516
Industrial Machinery and Equipment	196.3	282.8	255	380	485
Electrical and Electronic Equipment	407.5	583.8	570	749	965
Motor Vehicles and Parts	263.2	366.5	374	461	569
Other Durable Goods	235.4	312.1	319	357	413
Nondurable Goods Manufacturers	2,155	2,945	2,630	3,260	3,980
Food and Beverages	400.2	463.2	498	580	672
Paper Products	127.9	158.5	164	186	204
Chemical Products	229.7	277.3	299	358	429
Non Durable Goods	666.2	781	919	1,091	1,315
Other Industries	5,710	7,935	8,140	9,860	11,960

*Material handling equipment includes conventional material handling (industrial trucks, conveying equipment, hoists, cranes, and monorails) and automated handling equipment.

Total shipments of forklifts and other lift trucks in the U.S. in 2003 were valued at $3,190 million, and this figure is expected to grow by 5% per year to 2013 (Table 3-15). Battery-powered forklifts are approximately 58% of the total forklift market and are projected to retain a constant share through 2013. Shipments of battery-powered forklift trucks in 2003 were valued at approximately $1,850 million, and this figure is expected to grow 31% to $2,420 million in 2008. Battery-powered riding forklift trucks account for approximately 80% of the current and projected total battery-powered forklift market, while battery-powered narrow aisle forklift trucks account for approximately 20% of the current and projected total battery-powered forklift market.

Shipments of ICE-powered forklift trucks totaled $1,285 million in 2003, and this figure is expected to grow to $1,650 million in 2008. LPG-powered forklift trucks occupied the highest market share of ICE-powered forklift trucks shipped in 2003, with shipments valued at approximately $765 million. LPG-powered forklifts accounted for 60% of the ICE-powered forklift market in 2003, gasoline-powered trucks accounted for 16%, diesel-powered trucks accounted for 16%, and CNG-powered trucks accounted for 8%. By 2013, market share of diesel-powered trucks is projected to decline to 15% and LPG-powered trucks are expected to increase to 61% of the total ICE-powered forklift truck market (Table 3-15).

[52] The Freedonia Group, Inc. 2004. Material Handling to 2008: Equipment and Systems. Cleveland, OH, The Freedonia Group, Inc.

Table 3-15. Manufacturers' Shipments of Forklift Equipment in the United States in Millions of Dollars.[53]

Equipment	1993	1998	2003	2008	2013
Industrial Trucks and Lifts	4,195	6,030	5,770	7,290	9,140
Forklifts and Other Lift Trucks	2,320	3,425	3,190	4,130	5,230
Battery-powered Forklifts and Other Lift Trucks	1,335	1,970	1,850	2,420	3,060
Riding Trucks	1,080	1,580	1,470	1,920	2,420
Narrow Aisle Trucks	255	390	380	500	640
Internal Combustion Engine	955	1,405	1,285	1,650	2,100
LPG	545	825	765	995	1,280
Gasoline	150	230	210	265	330
Diesel	170	230	200	250	310
Natural Gas	90	120	110	140	180
Hand Lifts and Trucks	30	50	55	60	70

The ITA conducts an annual survey of its members to identify the numbers of forklift trucks shipped in the U.S. In 2004, ITA members reported that 91,194 battery-powered forklift trucks and 74,228 ICE-powered forklift trucks were shipped (Table 3-16). The exact number of forklift trucks manufactured and shipped to an end user, the type of forklift truck, and their application could not be identified, as this information is considered proprietary.

Table 3-16. U.S. Factory Shipments of Class 1, 2, 3, 4 and 5 Forklifts.*

Year	Battery-Powered Rider (Class 1 And Class 2)	Battery-Powered Hand (Class 3)	ICE-Powered (Class 4 and Class 5)	Total (Class 1 - Class 5)
2000	56,090	49,121	85,993	191,204
2001	45,980	37,210	61,507	144,697
2002	39,235	36,445	55,928	131,608
2003	40,463	36,659	63,365	140,487
2004	46,886	44,308	74,228	165,422

*Years are not comparable since this data is submitted on a yearly basis by members of the Industrial Truck Association. Membership changes are not reflected in these numbers.

Market research data were reviewed to identify the existing population of battery-powered and ICE-powered forklift trucks in the U.S. No information on the current population of battery-powered forklift trucks could be obtained. The most recent data available (1996 population estimates) identified 441,999 ICE-powered forklift trucks in use in the U.S. Of that total, 22,099 were gasoline-powered ICE forklift trucks, 376,593 were LPG-powered forklift trucks, and 43,307 were CNG-powered forklift trucks (Table 3-17). If a growth rate of 5% per year is assumed, the estimated current total population of ICE-powered forklift trucks in the U.S. is approximately 755,967 trucks in 2006.

The top seven forklift truck manufacturers are Toyota Industries Corporation, Linde, Jungheinrich Deutschland, NACCO Corporation, Mitsubishi Heavy Industries, Crown

[53] The Freedonia Group, Inc. 2004. Material Handling to 2008: Equipment and Systems. Cleveland, OH, The Freedonia Group, Inc.

Equipment Corporation, and Komatsu Forklift. Examples of potential large end users in the U.S. include: Wal-Mart, Costco, Target, Kroger, Coca-Cola, Anheuser-Busch, PepsiCo, Home Depot, Lowes, Ford Motor Company, General Motors, Honda, and Toyota.

Table 3-17. Total Population of ICE Forklift Trucks in the United States in 1996.[54]

Equipment Description	Minimum Horsepower	Maximum Horsepower	Average Horsepower	Total Population
Gasoline 4 Stroke Forklifts	25	40	36.12	1,645
Gasoline 4 Stroke Forklifts	40	50	45.16	5,876
Gasoline 4 Stroke Forklifts	50	75	62.77	9,466
Gasoline 4 Stroke Forklifts	75	100	89.03	691
Gasoline 4 Stroke Forklifts	100	175	144.7	4,399
Gasoline 4 Stroke Forklifts	175	300	215.8	22
LPG-Forklifts	25	40	33.44	31,264
LPG-Forklifts	40	50	45.43	68,337
LPG-Forklifts	50	75	58.18	179,857
LPG-Forklifts	75	100	79.83	13,136
LPG-Forklifts	100	175	131.5	83,590
LPG-Forklifts	175	300	215.8	409
CNG-Forklifts	40	50	48	43,307
Total Population				**441,999**

3.2.1.3 Market Trends

Companies are focused on increasing productivity and decreasing the costs associated with their supply chains. At distribution centers and warehouses, operation and maintenance of forklifts are a significant cost. For battery-powered forklifts, fast charging has emerged as a potential solution for recharging batteries to increase productivity in heavy-use applications. Fast charging is typically recommended for three-shift operations. Fast chargers can automatically detect the level of discharge of the battery and supply only the amount of power required to restore it to full power. Forklift trucks can be recharged during breaks, lunch, shift changes, and at night. With fast chargers, batteries can be brought to 80% charge in less than two hours, do not need equalizing time, and can be used immediately. Complete recharge and equalizing of charge for batteries is necessary only once a week with fast chargers. Fast chargers are compatible with existing batteries, and the same charger can be used to charge multiple voltage batteries (24V, 36V, 48V). Though fast charging requires high initial investment, it decreases the need for extra batteries, as well as the time needed to change batteries, and decreases warehouse space requirements for battery storage. While lifecycle costs of batteries are estimated to be 20% lower with fast charging units, the lifetime of batteries is reduced. Fast charging also improves worker safety because lift truck operators are not handling heavy batteries. Fast charging is considered to be more suitable for continuous applications with well-managed schedules and workforces. Ford Motor Company has contracted with PosiCharge

[54] EPA, 2005. Non-Road Engine Population Estimates. EPA-420-R-05-022. Available at http://www.epa.gov/OMS/models/nonrdmdl/nonrdmdl2005/420r05022.pdf#search=%22Non-Road%20Engine%20Population%20Estimates.%20EPA420-R-05-022.%22 [Accessed June 2006].

to install fast charging in all of its North American plants.[55] With fast chargers, Nestle has been able to shave 15% off the costs associated with the old battery changing scenario.[56]

PEM fuel cell-powered forklifts have also emerged as potential alternatives to battery- and ICE-powered forklifts. PEM fuel cell forklifts require minimal time for refueling and have significantly less maintenance than battery-powered forklifts, whose batteries must be regularly charged, refilled with water, and replaced. In addition, the fuel cell system ensures constant power delivery and performance, eliminating the reduction in voltage output that occurs as batteries discharge. These and other features make fuel cell-powered forklifts potentially well-suited to conditions in multi-shift operations. Fuel cell-powered forklifts also have advantages over ICE-powered forklifts, including zero emissions, quiet operation, and longer runtimes between refueling. A study exploring the economics of converting an entire warehouse from batteries to fuel cells indicates that sites with high labor rates and multiple shifts are good initial targets of the technology. The process of delivering hydrogen to the fuel cell system and long stack life must be demonstrated for fuel cell technology to be commercially successful.[57]

An annual business trends survey conducted by the ITA indicates that manufacturers are split on whether fuel cells will make up a significant share of the forklift market in the next two to five years. The survey indicates that manufacturers think that more forklift trucks will begin to use fast charging technology in the next five years.[58]

Several tests have begun to demonstrate the feasibility of fuel cell-powered forklifts. Hydrogenics Corporation recently completed forklift demonstrations at GM of Canada's car assembly plant in Oshawa and FedEx Canada's logistics hub at Toronto International Airport. Lead-acid batteries in two Hyster Class 1 5,500 lb sit-rider forklifts provided by NACCO Materials Handling Group were replaced with HyPM 10 fuel cell packs. The HyPM 10 incorporates a 10 kW fuel cell power module for base load requirements and energy storing ultracapacitors to handle peak loads and long-duration transients, and to capture braking energy. In this demonstration, PEM electrolyzers were used to refuel the forklifts. The fuel cell deployment at GM's Oshawa Car Assembly Plant ran for 3 months and logged over 900 hours of operation.[59]

Recently, Cellex Power completed a first round of testing of direct hydrogen PEM fuel cell forklifts at Wal-Mart stores in Bentonville, Arkansas. The fuel cell-powered pallet trucks ran approximately 1.2 to 1.5 times longer than lead-acid batteries and could be refueled in about 1 minute. Wal-Mart plans to support the commercialization process of the Cellex fuel cell power system for battery-powered forklifts and has agreed to a second round of testing. Four Crown

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[55] Kempfer. L. 2006. Fast Chargers Power-up Lift Trucks. Material Handling Management. Available at http://mhmonline.com/viewStory.asp?sID=%7B49839030-D53D-4594-8E5C-36E3C4419485%7D&S=1 [Accessed June 2006].
[56] Andel, T. 2004. Not All Lift Trucks Are Created Equal. Logistics Today. Available at http://www.logisticstoday.com/sNO/6460/iID/20887/LT/displayStory.asp [Accessed June 2006].
[57] Medwin, S. 2005. Application of Fuel Cells to Forklift Trucks. Industrial Utility Vehicle Magazine. Volume 7, Issue 5. Available at http://www.specialtyvehiclesonline.com/images/Raymond_FC.pdf#search=%22Application%20of%20Fuel%20Cells%20to%20Forklift%20Trucks%22 [Accessed September 2006].
[58] Carinci, A. 2005. Results of the 2005 Business Trends Survey. ITA Fall Meeting. Available at http://www.indtrk.org/docs/2005BusinessTrends.ppt [Accessed June 2006].
[59] McKinnon, M. 2005. Forklifts Hoist Fuel Cells to Commercial Applications: Hydrogen-Powered Industrial Vehicles Lead the Way to Mass Market. Available at http://www.fuelcell-magazine.com/eprints/free/hydrogenicsoct05.pdf [Accessed June 2006].

PE4000 series forklifts will be retrofitted by Cellex Power.[60] For fuel cells in forklifts, the predicted payback period is 3 to 4 years for both the fuel cell-based forklift and the hydrogen infrastructure. The expected savings are $5,000 per year per truck according to Cellex Power. These savings are comprised of the avoidance of several costs: the hard costs associated with battery changing, the extra maintenance costs associated with maintaining batteries, reduced productivity caused by drivers having to stop and drive over to a battery changing station, and the voltage drop that comes during the last half-hour of battery life.

Companies are also seeking alternative solutions to ICE-powered forklifts due to the problem of emissions from ICE-powered forklifts. In 2004, EPA adopted emission standards for non-road spark ignition (SI) engines above 25 HP/19 kW, including forklifts, airport service equipment, generators, compressors, welders, aerial lifts, and ice grooming machines. Beginning in 2007, manufacturers will be required to use optimized engines, including new diagnostic systems, to meet more stringent standards that call for a 90% reduction in NO_x, hydrocarbon, and carbon monoxide emissions.[61] More recently, the California Air Resources Board (CARB) has proposed to adopt more stringent emissions standards and test procedures for large spark-ignition engines (> 19 kW), including forklifts, sweepers/scrubbers, industrial tow tractors, and ground support equipment.[62] CARB proposes the adoption of EPA's 2007 model-year emission standard and a more stringent 2010 model-year emissions standard. CARB has also proposed stricter emission standards for fleets in use that would require them to reduce their emissions by retrofit or by replacement of engines or equipment with cleaner models by 2009. The proposal provides exemptions for lift trucks that cannot be retrofitted in the agricultural sector and for owners of three lift trucks or less.

3.2.2 Market Segment Analysis

The market analysis for forklift applications in distribution and warehousing is divided into two sections. Section 3.2.2.1 analyzes responses from Phase 1 surveys of manufacturers of forklifts. These surveys were conducted to determine the market opportunities for PEM fuel cells from the manufacturers' perspective. It is anticipated that these manufacturers will also serve as potential integrators of fuel cells into their products. Section 3.2.2.2 analyzes the responses received from users of forklifts in the food, beverage, and retail market sector conducted during Phase 1 and Phase 2. This analysis summarizes user requirements for forklift vehicles reported by survey respondents.

3.2.2.1 Manufacturer Response Analysis

In Phase 1, 11 forklift manufacturers were contacted and four responses were received. Information gleaned from the surveys is summarized below.

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[60] Forkliftaction.com. 2005. Fuel Cells on Crown Forklifts Pass Wal-Mart Test. Newsletter #221. Available at http://www.forkliftaction.com/news/story_2521.htm [Accessed June 2006].

[61] EPA. 2002. Regulatory Announcement: Emission Standards for Non-Road Engines. EPA-420-F-02-037. Available at http://www.epa.gov/otaq/regs/nonroad/2002/f02037.pdf#search=%22Regulatory%20Announcement%3A%20Emission%20Standards%20For%20Non-Road%20Engines%22 [Accessed June 2006].

[62] California Air Resources Board. 2006. Staff Report: New Emissions Standards, Fleet Requirements, and Test Procedures for Forklifts, and Other Industrial Equipment. Available at http://www.arb.ca.gov/regact/lore2006/isor.pdf [Accessed June 2006].

Survey Participant Profile

Of the manufacturers that responded, two were medium-sized forklift manufacturers (i.e., 500 to 3,000 employees), and two were small forklift manufacturers (i.e., < 500 employees). Job titles of respondents ranged from director of product strategy to manager of research and development to account manager. Manufacturers reported that they were involved in the manufacture of a variety of battery- and ICE-powered material handling equipment for various applications. Two manufacturers produced battery-powered forklifts only, and two manufacturers produced both battery- and ICE-powered forklifts. ICE-powered forklifts manufactured by respondents included diesel, propane, gasoline, and dual fuel types.

Applications

Respondents indicated that their products were used in a variety of markets, including warehousing, distribution centers, manufacturing, and assembly plants. Forklift users include grocery stores, third-party logistics providers, retail department stores, E-commerce retailers, home improvement and hardware stores, medical and pharmaceutical manufacturing, computer and electronics manufacturing, and paper and publishing. All respondents identified warehouses and distribution centers as the market segments most severely impacted by forklift downtime.

Satisfaction with Current Technologies

Respondents were asked to determine the impact of forklift downtime; all respondents identified that forklift downtime results in decreased operation, loss in productivity through decreased movement of materials, decreased labor productivity, and increased operation and maintenance costs.

Manufacturers were asked to assess their satisfaction with batteries and ICE currently integrated in their products. Three of four respondents indicated that they were happy with their current mode of operation (batteries and/or ICE). Of these respondents, two indicated that they were always looking for opportunities to decrease the total cost of operation, through improvements in productivity, reliability, maintenance cost, and fuel cost. One respondent indicated that, while they commonly use batteries, most of their users are dissatisfied with batteries. Batteries are heavy and dirty; charge cycles are difficult to track; if not watered regularly, the life of the battery is impacted; fast charging also results in reduced life of the battery; and continuous maintenance is required to extend the life of the battery. Manufacturers identified other issues of concern with the current mode of operation as indicated by their users, including hazardous acid spills from overcharging batteries, size and weight of batteries, wastewater containment from washing batteries down, battery disposal, vented gases from batteries, and exhaust emissions from ICEs.

Operations and Maintenance of Current Technologies

Manufacturers were asked about the typical maintenance schedules recommended to users. Respondents indicated that users are provided with an operation and maintenance checklist to ensure that a product remains in proper working order during its lifetime. Detailed maintenance checks are performed every 200 to 250 hours. For battery forklifts, users are required to follow a checklist on a daily basis to ensure that the product is in working order.

Potential for PEM Fuel Cells

Three of four respondents were aware of PEM fuel cells as an alternative to battery- and ICE-powered forklifts. All three respondents are currently evaluating fuel cells in forklifts. One respondent indicated that his company has also considered other alternatives including ICE-electric hybrids, ultracapacitor-lead-acid battery hybrids, and advanced ICE technology. Respondents indicated that paper studies, analysis of maturity and availability of products, competitive intelligence, user input, and reliability data from installation and testing of the product are considered when evaluating alternatives. One respondent emphasized that, to select an alternative, it is important that the product have good total cost of ownership, high reliability, and high performance compared to current technologies. One respondent indicated that suppliers with good engineering capabilities were also a critical factor in selecting the right alternative. Only one of the three respondents who were aware of PEM fuel cells considered PEM fuel cells a viable alternative today.

Barriers to successful integration of PEM fuel cells in forklifts, as identified by two respondents, include capital cost, stack life, infrastructure for hydrogen delivery, and local regulations for handling hydrogen. Key drivers to successful adoption of fuel cell forklifts by users, as identified by manufacturers, include demonstrated return on capital investment, improvements in productivity, and associated cost savings. Respondents did not believe that environmental concerns were a big driver. Respondents indicated that use of hydrogen as a fuel may concern customers but indicated that appropriate education would alleviate those concerns.

3.2.2.2 User Response Analysis

In Phase 1 and Phase 2, 28 forklift users were contacted and 13 responded. Five responses were received in the Phase 1 survey, and ten responses were received in the Phase 2 survey. Two users responded to both the Phase 1 and Phase 2 surveys. Three in-depth interviews were conducted with respondents of Phase 2 surveys. For respondents who answered both Phase 1 and Phase 2 surveys, only one response was taken into account for the various common questions. Information gathered from these surveys and interviews is summarized below.

Survey Participant Profile

Of the 13 forklift users who responded, nine were large organizations, two were medium-sized organizations, and two were small organizations. Title of respondents ranged from distribution center manager, logistics vice president, to distribution center manager. Responses were received from users in discount retailing, retail distribution, food manufacturing and distribution, and online merchandise distribution. Types of forklifts used varied among respondents, including pallet trucks, sit-down riders, stockpickers, tuggers, and utility carts. All respondents indicated that they used some form of pallet forklifts. Of the respondents, ten indicated that they use battery-powered forklifts, while eight indicated that they use propane forklifts.

Applications

Survey respondents were asked to identify the types of forklifts used in a typical facility, the typical applications for these vehicles, and the frequency of use. Reach trucks, stand-up and sit-down riders, pallet jacks, and stockpickers were all used to facilitate materials handling in

warehouses, distribution centers, and retail centers. The most common makes of forklifts the respondents reported using were: Crown, Yale, Hyster, Raymond, Nissan, Allis Chalmers, and Ottawa.

Battery-Powered Vehicles

Of the 13 respondents who indicated that they operate battery-powered vehicles, 11 indicated that battery-powered vehicles for materials handling typically ran for 2 to 3 shifts, operating 15 to 24 hours per day. Four respondents indicated that they ran vehicles 1 to 2 shifts per day, operating for 2 to 8 hours. The number of vehicles varied by facility; smaller facilities, such as retail outlets, typically maintained 1 to 8 vehicles; larger distribution centers would maintain as many as 250 vehicles.

Six of nine respondents indicated that forklift batteries are changed at least once per shift; of these, one respondent indicated that batteries sometimes are changed two times per shift, depending on use. Three of nine respondents indicated that they did not need to change or recharge batteries because they used smart chargers that keep batteries charged and running at peak capacity for an entire shift, and that it was rare to spend more than 15 minutes a week on battery maintenance. Times to change and charge batteries varied greatly and were dependent upon the application. Responses for battery change-out times ranged from 10 minutes to 1 hour per day.

Battery lifetime ranged from 4 to 9 years. Five of nine respondents indicated that battery life was approximately 5 to 7 years. For battery chargers, respondents indicated that charger lifetime was 5 to 15 years. Respondents did not indicate concern over the cost to dispose of batteries; old batteries were either traded with new batteries under contracts with specialty vehicle service providers, or disposed of without cost.

ICE-Powered Vehicles

Respondents used LPG-powered ICE vehicles primarily for heavy materials handling. Of the eight respondents who used propane trucks, four respondents indicated that refueling takes minimal time. Propane tanks are pre-filled and switched out when empty. One noted that refueling occurred 2 to 3 times per day, for a total of 15 minutes per day. Required maintenance varied; respondents reported maintenance times of 1 to 4 hours per month. For three respondents, costs for maintenance (excluding labor) per truck ranged from $10 to $25 per month.

Downtime/Unscheduled Maintenance

Respondents indicated that all applications of forklift trucks were impacted by product downtime. Applications which are the most severely impacted are those served by reach trucks (which move items from hard- to easy-to-reach locations, and have no substitutes). All respondents stated that downtime could result in loss of productivity through decreased movement of materials, decreased labor productivity, and increased operation and maintenance costs. Regarding the level of disruption caused by product downtime, respondents indicated that longer periods of downtime (greater than 4 hours) were very disruptive to their operations.

Downtime due to maintenance was described as being extremely variable, depending on the cause of the vehicle problem, and could range from 1 hour to a few days. One respondent provided examples of typical repair jobs and times: brakes (4 hours), transmission (8 hours), engine (30 hours), and water pump (4 hours). Nine respondents indicated that they follow (or exceed) the manufacturer's recommended schedule for maintenance.

Downtime incidents varied significantly among the user respondents and were highly dependent upon the operator and maintenance schedules. Large distribution centers may experience two to three downtime incidents per battery-powered forklift and four downtime incidents per ICE-powered forklift per year. One respondent who operated a fleet of 374 battery-powered forklifts estimated that 1,004 labor hours were impacted by product downtime in the past 12 months. For this application, based on the average wage of $14 per hour (as provided by respondents), annual lost productivity was valued at approximately $14,000.

Battery-powered vehicle users noted that battery change-out operations lead to vehicle downtime and lost productivity. Respondents indicated that they have spare batteries and battery changing equipment to minimize downtime and lost productivity. For one-shift operations, users cited no impact of batteries, as batteries last for a full shift and can be charged at night to avoid vehicle downtime. Space requirements for battery change-out and charging were variable. Space requirements ranged from 19 ft^2 per forklift to 122 ft^2 per forklift depending upon the type of operation. The average space requirements for a retail distribution center were approximately 24 ft^2 per forklift.

Purchase Decision Factors

The percentage of users rating various factors as very important is shown in Figure 3-13.[63] Reliability, ease of use, and lifetime of unit were most frequently cited as very important factors when selecting forklifts. While very important to some users, capital costs and emissions were less frequently cited by users compared to reliability, ease of use, and lifetime of the unit.

[63] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so important", responses of 4 to 5 were classified as "somewhat important", and responses of 6 to 7 were classified as "very important".

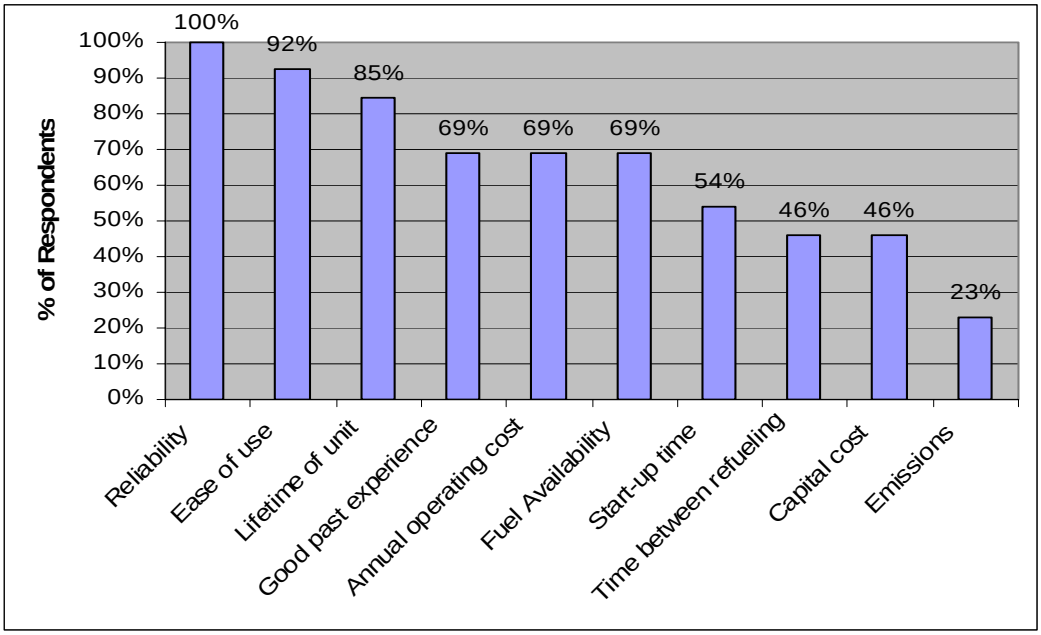

Figure 3-13. Factors That Most Influence Purchase Decisions (n=13).

When users were asked which three factors from the list above would most influence their decision to purchase a specialty vehicle powered by an alternative technology, a majority of the respondents identified reliability (72%), followed by capital cost (43%), fuel availability (29%), and lifetime of the unit (29%).

Satisfaction with Current Vehicles

In Phase 1 surveys, users were asked to rate the performance of their current forklifts. Two of five respondents indicated they were dissatisfied with the current performance of their forklifts. Concerns regarding performance of battery-powered forklifts included: batteries take too long to recharge, batteries are inconvenient to recharge and swap out, and batteries can produce hazardous emissions.

In Phase 1 and Phase 2, users were asked to rate their level of satisfaction with their current forklifts against the same set of characteristics they considered when selecting material handling products. Fuel availability (77%) followed by ease of use (69%), lifetime of unit (69%), and reliability (62%) were most frequently cited by users as "very good"[64] (Figure 3-14).

[64] On a scale of 1 to 7, responses of 1 to 3 were classified as "not so good", responses of 4 to 5 were classified as "good", and responses of 6 and 7 were classified as "very good".

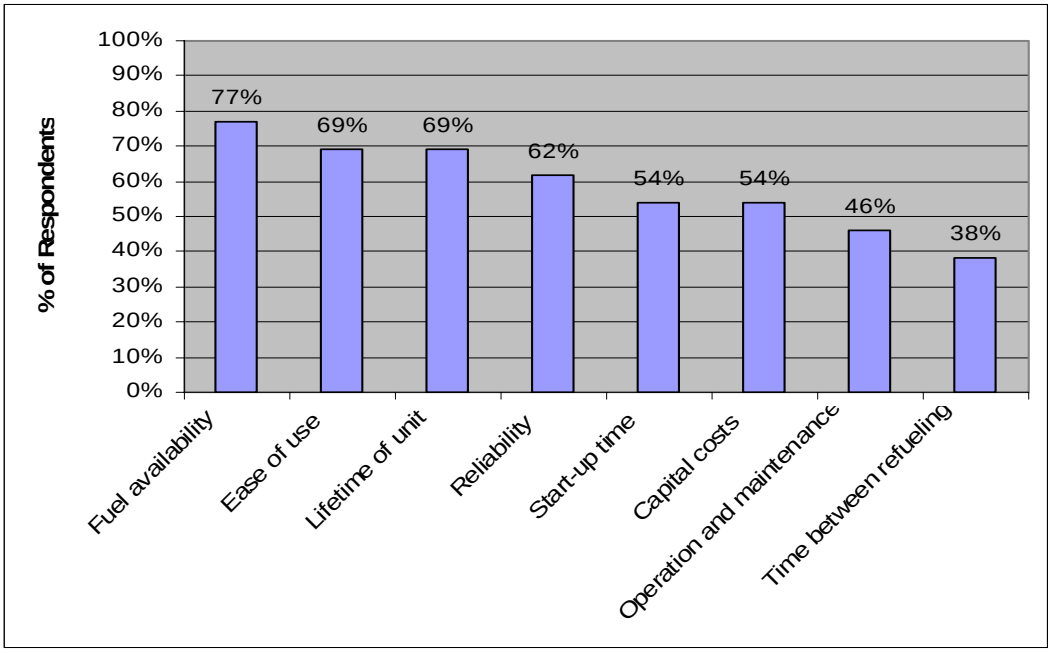

Figure 3-14. Characteristics of Current Systems That Users Identified as Very Good (n=13).

Potential for PEM Fuel Cells in Forklifts

In the Phase 1 survey, five users were asked about the trends and potential for PEM fuel cells in their marketplace. Four of five respondents to the Phase 1 survey anticipated a growing need for forklifts in their market. Three of the five respondents in Phase 1 had heard of PEM fuel cells and were currently evaluating alternative systems, including better battery systems, hydrogen fuel cells, and fast charging systems. All three respondents thought that PEM fuel cells would compete favorably with existing systems. One of these three respondents was concerned with the high initial capital cost of fuel cells, hydrogen fuel availability, and safety. Purchase decision drivers for PEM fuel cells, as identified by these three users, included costs incurred from downtime, efficiency of PEM fuel cells, environmental concerns, availability of government incentives, and the track record of others using PEM fuel cell vehicles.

Users were asked if the use of hydrogen as a fuel would concern them. Of the 12 respondents, four indicated that it would; two indicated that it would not; two indicated that it might be of concern; and two did not know enough to comment. Half of the eight users surveyed indicated that they consider government incentives when making purchase decisions. Respondents indicated that capital purchase decisions were made primarily on the basis of return on investment and payback period, although initial capital cost was also a consideration.

3.2.2.3 Market Research Summary

This section summarizes the information gathered through secondary and primary research on market trends and user requirements for forklifts in retail distribution and warehousing operations.

- The market for forklifts was $3.2 billion in 2003 and is projected to grow to $5.2 billion in 2013. Current and projected market share of battery-powered forklifts is approximately 58% of the total forklift market.
- Users of battery-powered forklifts are concerned about increasing productivity of operations by reducing the number of battery change-outs and increasing the lifetime of batteries. Air emissions regulations, particularly in California, may drive the conversion from ICE-powered to lower-emission forklifts.
- Fast charging systems and fuel cells are emerging alternatives to standard battery-powered and ICE-powered forklifts.
- Fast charging battery systems eliminate many of the disadvantages of standard battery-powered forklifts (i.e., long charging and cool-down time and the need for extra batteries) and are most suitable for multi-shift operations that work on predictable schedules and have a trained workforce. Fast charging also decreases the life of the battery and requires high initial capital investment.
- Compared to ICE-powered forklifts, fuel cell-powered forklifts offer zero emissions and are quieter.
- Compared to battery-powered forklifts, fuel cell demonstrations show that fuel cells offer longer runtime, faster return to service, and constant power.
- Fast charging may reduce the competitive advantages of the fuel cell for specific applications.
- Material handling in retail distribution is dominated by battery-powered forklifts. Forklift downtime impacts productivity in high-throughput operations.
- The most important decision factors in selecting an alternative powered forklift, in order of importance, are reliability, capital cost, fuel availability, and life of the unit.
- Current forklifts generally satisfy the factors that are most important to users.
- Emissions are not considered an important decision factor for most survey respondents.
- Battery charging and maintenance negatively impact productivity, resulting in some dissatisfaction with batteries.
- Spare batteries reduce downtime during charging, and smart charger or fast charging technologies are reducing the issue of charging time.
- Fuel cell-powered forklifts may provide value by reducing downtime costs, providing high efficiency, and addressing environmental concerns.
- Potential barriers to widespread PEM fuel cell-powered forklift adoption include: high capital cost; lack of hydrogen infrastructure/cost to purchase and store hydrogen; inadequate stack life; and local hydrogen regulation.

3.2.3 Lifecycle Cost Analysis

Distribution and warehousing operations currently use battery-powered forklifts to perform the majority of their indoor material handling and lifting. Surveys identify a significant interest among users, in alternatives to batteries in forklifts to increase productivity, especially in high-throughput operations. Surveys also indicate that while users in this segment make purchase decisions based on return on investment and payback period, initial capital cost is also an important consideration. To determine if PEM fuel cell-powered forklifts are a cost competitive alternative, this section analyzes the lifecycle costs of PEM fuel cell-powered forklifts compared to battery-powered forklifts for two different classes of forklifts. The lifecycle costs of PEM fuel cells as battery replacements in pallet trucks (Class 3) and sit-down rider trucks (Class 1) are evaluated in the following sections in two different continuous-use scenarios.

The analysis examines the discounted NPV of using PEM fuel cells compared to batteries and generators using assumptions consistent with the H2A model.[65] Hydrogen storage and delivery methods are not considered in this analysis. The $5 per kg cost of hydrogen used in this analysis assumes that storage and delivery costs are amortized in the hydrogen cost. For both scenarios, a discount rate of 8% and an inflation rate of 1.9% are applied. No disposal costs are assumed for any of the technologies. It is assumed that disposal costs are included in the initial capital cost of the system or that manufacturers allow trade-in of old systems. Lifecycle costs of PEM fuel cells are analyzed with and without incentives of $1,000 per kW, as currently authorized in EPAct 2005.[66] The battery replacement schedule utilized in this analysis is 5 years and was selected based on survey responses.

3.2.3.1 Lifecycle Cost Assumptions by Scenario

In scenario 1, it is assumed that pallet trucks (Class 3) operate 7 hours per shift, three shifts a day, and 7 days a week, which totals 7,644 hours per year. Cost assumptions used in this scenario are presented in Table 3-18. Lifecycle costs are analyzed with two and three replacement batteries per truck. It is assumed in this scenario that batteries are changed out once every shift. The cost of each battery in this scenario is $1,800. The PEM fuel cell uses a 3 kW stack with nickel-metal hydride (NiMH) batteries. Hydrogen costs are assumed to be $5 per kg. It is assumed in this analysis that the fuel cell module is replaced every 5 years.

In scenario 2, it is assumed that sit-down rider trucks (Class 1) operate 7-hour shifts, three shifts per day, and 5 days a week, which totals 5460 hours per year. Cost assumptions used in this scenario are presented in Table 3-18. For each forklift truck, lifecycle costs are analyzed with two and three replacement batteries per truck. Batteries are replaced once every shift. The cost of each battery for the pallet truck is $1,800 and for the sit-down truck is $4,000. The PEM fuel cell uses an 8 kW stack with ultracapacitors. The lifecycle of the ultracapacitor is assumed to be 10 years. Hydrogen costs are assumed to be $5 per kg. The cost of delivery and storage has been amortized into the aforementioned cost.

[65] DOE Hydrogen Program: DOE H2A Analysis. DOE H2A Analysis. www.hydrogen.energy.gov/h2a_analysis.html [Accessed December 2006].
[66] Under EPAct, fuel cells receive a 30% tax credit that is capped at $1,000/kW of generating capacity.

Table 3-18. Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts.

	Scenario 1		Scenario 2	
	Battery-Powered Pallet Truck	**PEM Fuel Cell-Powered Pallet Truck**	**Battery-Powered Sit-Down Truck**	**PEM Fuel Cell-Powered Sit-Down Truck**
Cost ($)	8,000	13,500	25,000	35,000
Lifetime (yrs)	15	15	15	15
Hours of Operation (hrs/yr)	7,644[1]	7644[1]	5,460[2]	5,460[2]
Cost of Accessories ($)	2,406[3]	-	2,406[3]	-
Battery Charger	1,800	-	1,800	-
Cranes/Hoists	210	-	210	-
Cost for Battery Room	396	-	396	-
Routine Maintenance Costs ($/yr)	3,600[4]	720[5]	3,600[4]	720[5]
Electricity/Hydrogen Fuel Costs ($/yr)	1,307[6]	4,380[7]	1,307[6]	5,612[8]
Time for Refueling (min/day)	30	3	15	3
Cost of Refueling/Recharging ($/yr)	8,213[9]	274[10]	2,925[11]	390[12]
Replacement Costs ($)	1,800 – Batteries every 5 years	9,000 – Fuel cell module every 5 years	4,000 – Batteries every 5 years	24,000 – Fuel cell module every 5 years 2,600 – Ultracapacitors every 10 years

[1] Forklift operates 7 hours per shift, 3 shifts per day, and 7 days a week.
[2] Forklift operates 7 hours per shift, 3 shifts per day, and 5 days a week.
[3] Schneider. A. 2004. Vistavia Warehousing, Inc. Global Perspectives on Accounting Education. Volume 1, 25-30.
[4] Routine maintenance is 5 hours per month at $60/hr. Data obtained from Battelle market research surveys.
[5] Routine maintenance is 2 hours per quarter at $90/hr. Data obtained from Battelle market research surveys.
[6] Cost of electricity charging is based on 2.85 kW per hour at 0.06 cents per kWh. Data obtained from L.D. Bailey and Associates. 2004. Electric vs. LP Gas Cost Comparison.
[7] Tank size is 0.8 kg. Runtime from single tank is approximately 8 hours. It is assumed that the tank is filled three times a day. Industry communication, September 2006.
[8] Tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Industry communication, September 2006.
[9] Battery swapping takes approximately 30 minutes. Operator charge is $15/hr. Battery is changed out once per shift.
[10] Fuel cell takes 1 minute to refuel. The fuel cell is refueled once every shift. Industry communication, September 2006.
[11] Battery swapping takes approximately 15 minutes. Operator charge is $15/hr. Battery is changed out once per shift.
[12] Fuel cell takes 3 minutes to refuel. It is refueled 2 times per day. Industry communication, September 2006.

3.2.3.2 Lifecycle Cost Results by Scenario

Results for Scenario 1 (Battery-Powered Pallet Truck)

In scenario 1, the NPV of the total costs of the PEM fuel cell-powered pallet truck is significantly less than the NPV of the total costs of the battery-powered pallet truck with two and three replacement batteries (Table 3-19). The NPV of the total costs of the PEM fuel cell pallet truck is 50% less than the NPV of the total costs of the battery-powered pallet truck with three replacement batteries, and 48% less than the NPV of the total costs of the battery-powered pallet truck with two replacement batteries.

The NPV of total operation and maintenance costs for PEM fuel cells is 59% less than that for battery-powered trucks. When NPV of total capital costs is considered, PEM fuel cell-powered pallet trucks without tax incentives require greater investment than battery-powered pallet trucks

over the 15-year analysis period. With incentives, the PEM fuel cell-powered pallet truck is more attractive, in terms of total capital investment required over the 15-year lifetime, than the battery-powered pallet truck with three batteries per truck.

Table 3-19. Scenario 1: Lifecycle Cost Comparison of PEM Fuel Cell- and Battery-Powered Pallet Trucks.

	Battery-Powered Pallet Truck (3 Batteries Per Truck)	Battery-powered Pallet Truck (2 Batteries Per Truck)	PEM Fuel Cell-Powered Pallet Truck without Incentive	PEM Fuel Cell-Powered Pallet Truck with Incentive
NPV of Capital Costs ($)	21,572	17,654	23,835	21,004
NPV of O&M Costs (Including the Cost of Fuel) ($)	127,539	127,539	52,241	52,241
NPV of Total Costs of System ($)	149,111	145,193	76,075	73,245

Results for Scenario 2 (Sit-Down Truck)

In scenario 2, the NPV of the total costs of the PEM fuel cell-powered sit-down truck without incentives is approximately 1% greater than the NPV of the total costs of the sit-down battery-powered truck with three replacement batteries. With incentives, PEM fuel cell-powered sit-down truck requires approximately 5% less investment than the sit-down battery-powered truck with three replacement batteries over the 15-year lifetime, on a total system cost basis. When compared to the battery-powered sit down truck with two replacement batteries per truck, the PEM fuel cell-powered truck requires approximately 8% more investment. With incentives, the PEM fuel cell-powered sit-down truck requires approximately 2% more investment that the battery powered sit-down truck with two replacement batteries per truck. Table 3-20 summarizes the lifecycle costs of the two systems in scenario 2. PEM fuel cells with and without incentives in this scenario require more capital investment over the 15-year lifetime when compared to sit-down battery-powered trucks with two and three replacement batteries. However, PEM fuel cells require less operation and maintenance over the 15-year lifetime.

Table 3-20. Scenario 2: Lifecycle Cost Comparison of PEM Fuel Cell- and Sit-down Battery-Powered Trucks.

	Battery-Powered Sit-down Truck (3 Batteries Per Truck)	Battery-Powered Sit-down Truck (2 Batteries Per Truck)	PEM Fuel Cell-Powered Sit-down Truck without Incentive	PEM Fuel Cell-Powered Sit-down Truck with Incentive
NPV of Capital Costs ($)	51,977	43,271	63,988	56,440
NPV of O&M Costs (Including the Cost of Fuel) ($)	76,135	76,135	65,344	65,344
NPV of Total Costs of System ($)	128,112	119,405	129,332	121,784

3.2.3.3 Lifecycle Cost Summary

From a lifecycle cost perspective, PEM fuel cell-powered pallet trucks require significantly less investment (calculated as NPV of costs) than battery-powered pallet trucks under conditions of near continuous use and battery change-out times of 30 minutes. The larger PEM fuel cell-powered sit-down trucks require slightly more investment than battery-powered sit-down forklift trucks in three shift operations with battery change-out times of 15 minutes. With incentives the PEM fuel cell-powered forklift is comparable to the battery-powered sit-down truck with three replacement batteries. The value of PEM fuel cell-powered forklifts is impacted by declining hours of operation (i.e., number of shifts), declining labor rates, the time required for battery change-outs, and the cost of hydrogen. While PEM fuel cell-powered forklift trucks require more initial capital investment than battery-powered forklift trucks, they require less investment in operation and maintenance over the lifetime.

3.2.4 Sensitivity Analysis

3.2.4.1 Sensitivity Analysis Modeling Methodology

Single-factor sensitivity analysis was performed to show the variability in average annual cost (cash basis) as individual factors were varied while all other factors were held constant. Each factor was allowed to vary by +/-10% of the base assumption. The results of the sensitivity analysis are presented in a tornado diagram (Figure 3-15). The factor that shows the greatest cost leverage is graphed at the top of the diagram, with other factors arrayed below it in descending order of cost leverage. Two numbers are shown at each end of the horizontal bar graph for each factor. The upper number is the average cost per year if this factor is varied by 10% from base assumptions, holding all other factors at base assumptions. In brackets under the average cost figure is the value of the factor when varied by 10%.

The factors varied in the PEM fuel cell-powered pallet truck cost sensitivity analysis are shown in Table 3-21. For example, the base value assumed for the forklift cost was $13,500, the high value (+10%) is $14,850, and the low value (-10%) is $12,150. In the sensitivity analysis, the average annual cash outlay ($\overline{C}$) for use of PEM fuel cells was calculated using Equation 1. Hydrogen cost and operations and maintenance costs used are annual averages.

$$\overline{C} = \frac{Forklift\,Cost}{Forklift\,Life} + \frac{Fuel\,Cell\,Cost}{Fuel\,Cell\,Life} + \frac{Battery\,Cost}{Battery\,Life} + Hydrogen\ Cost + O\ \&\ M\ Cost \qquad \text{Equation 1}$$

Table 3-21. Cost Assumptions for PEM Fuel Cell-Powered Forklift Sensitivity Analysis.

	Base	Low	High
Forklift Cost, $	13,500	12,150	14,850
Forklift Life, years	15	13.5	16.5
O&M, $ (Including Refueling Time)	1,541	1,387	1,695
Fuel Cell Replacement, $	9,000	8,100	9,900
Fuel Cell Life, years	5.0	4.5	5.5
Hydrogen, $/kg	5.00	4.50	5.50

3.2.4.2 Sensitivity Analysis Results

As shown in Figure 3-15, hydrogen cost has the greatest impact on annual cost of owning and operating a PEM fuel cell-powered pallet truck. This is followed by fuel cell life and fuel cell replacement costs. Improvements in these individual factors will have the greatest impact on annual operating cost of the PEM fuel cell-powered pallet truck.

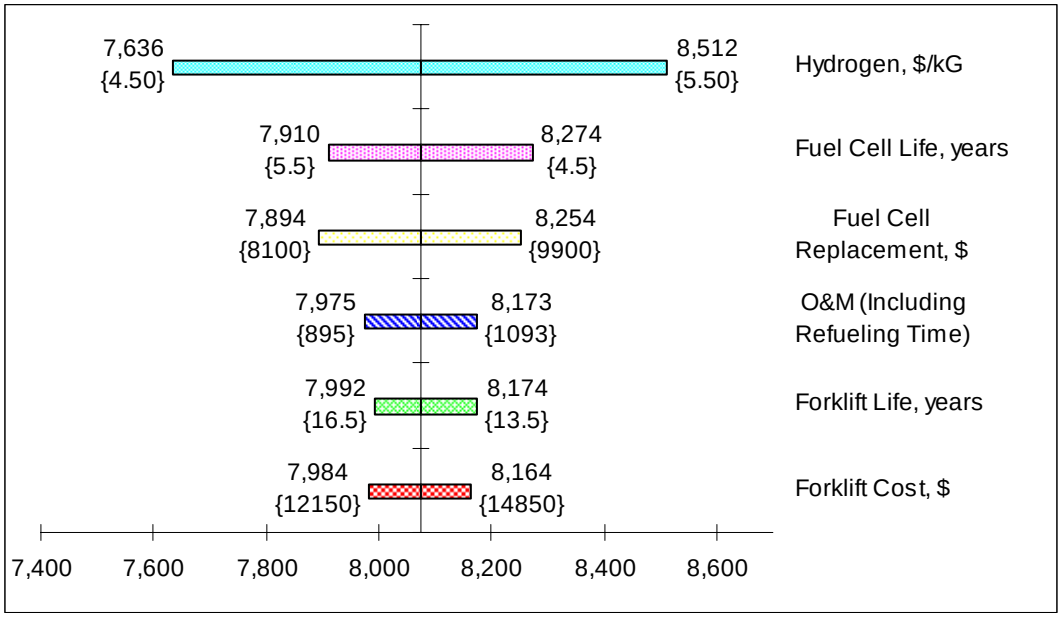

Figure 3-15. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell-Powered Pallet Forklift.

3.2.5 Market Penetration Analysis

3.2.5.1 Market Penetration Assumptions

The market penetration analysis assumes the following: cost-effective hydrogen fuel is available at the time of introduction; PEM fuel cell-powered forklifts are introduced as commercial products, and introduction can be scaled to meet demand. Table 3-22 shows the assumptions that were used for the three market adoption cases using PEM fuel cell-powered forklifts. In all three cases, it is assumed that PEM fuel cell-powered forklifts offer significant value as compared to battery-powered forklifts. PEM fuel cell-powered forklifts offer higher productivity, compared to batteries, by maintaining a constant level of power during operation and by providing rapid and easy refueling compared to replacing and recharging batteries.

For this analysis, the market for Class 1, 2, and 3 battery-powered forklifts was assumed to grow at a 5% annual rate so that the market for Class 1, 2, and 3 battery-powered forklifts in the year of introduction will be 108,606 units. It is assumed that 40% of this market is available for penetration by PEM fuel cell-powered forklifts. In all three cases, it was assumed that in the year of introduction battery-powered forklifts will be purchased at an average price of $20,000. For all three cases, it was assumed that the lifecycle cost of a forklift with a PEM fuel cell is comparative to the lifecycle cost of a battery-powered forklift. In some, but not in all cases, this is justified by the lifecycle analysis presented in the previous section of this report. A

competitive lifecycle cost assumes that affordable hydrogen (including costs of production, transportation, and storage) is available. Because PEM fuel cell-powered forklifts will be manufactured and sold by the same companies that sell battery-powered forklifts, industry reaction is not expected to yield high pressure on price. Price was held constant in this analysis.

The three cases analyzed vary in the assumed level of government interventions. The communication case assumes that the government will engage in communications that will increase the strength of the innovation parameter in the model. The subsidized case assumes that the government will subsidize the purchase of PEM fuel cells at $3,000 per unit for one year.

Table 3-22. Assumptions for PEM Fuel Cell-Powered Forklift Adoption in Distribution Centers and Warehouses.

Assumption	Base Scenario	Communication Scenario	Subsidy Scenario
Market Growth Rate	5%	5%	5%
Government Actions	None	Communications	Subsidize purchase @ $3,000/unit
Values of *p* and *q*	p = 0.008 q = 0.423	p = 0.012 q = 0.423	p = 0.070 q = 0.423
Initial Number of Class 1, 2, and 3 Battery-Powered Forklifts Purchased	108,606	108,606	108,606
Initial Number of Class 1, 2, and 3 PEM Fuel Cell Powered Forklifts Purchased *(m)*	40% of total forklift market; m = 43,442	40% of total forklift market; m = 43,442	40% of total forklift market; m = 43,442
Average Initial Price of PEM Fuel Cell-Powered Forklifts	$20,000	$20,000	$20,000
Rate of Price Reduction	Stable; no price reduction	Stable; no price reduction	Stable; no price reduction
Final Share of Battery-Powered Forklift Market	100%	100%	100%

3.2.5.2 Market Penetration Results

The results of the analysis for the three market adoption cases are shown in Figures 3-16 through 3-21. Assuming that PEM fuel cell commercial products and the associated hydrogen infrastructure are available, the models show that, with subsidies, the level of market penetration achieved is significantly more than that for the base and communication cases.

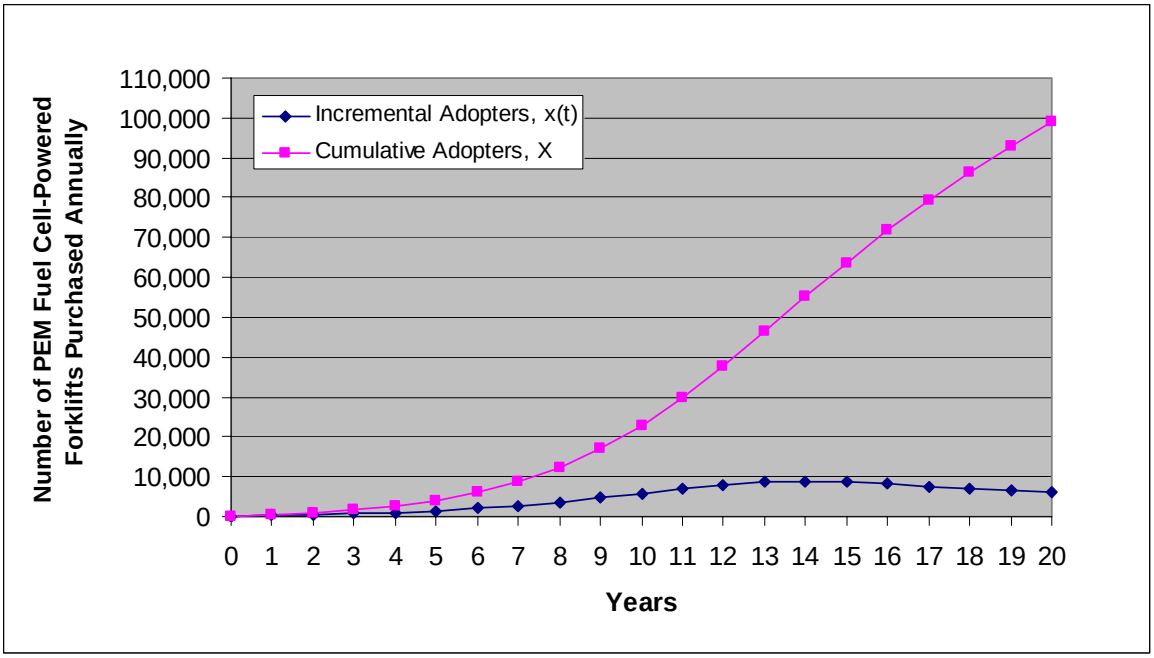

Figure 3-16. Adoptions of PEM Fuel Cell-Powered Forklifts in the Base Case.

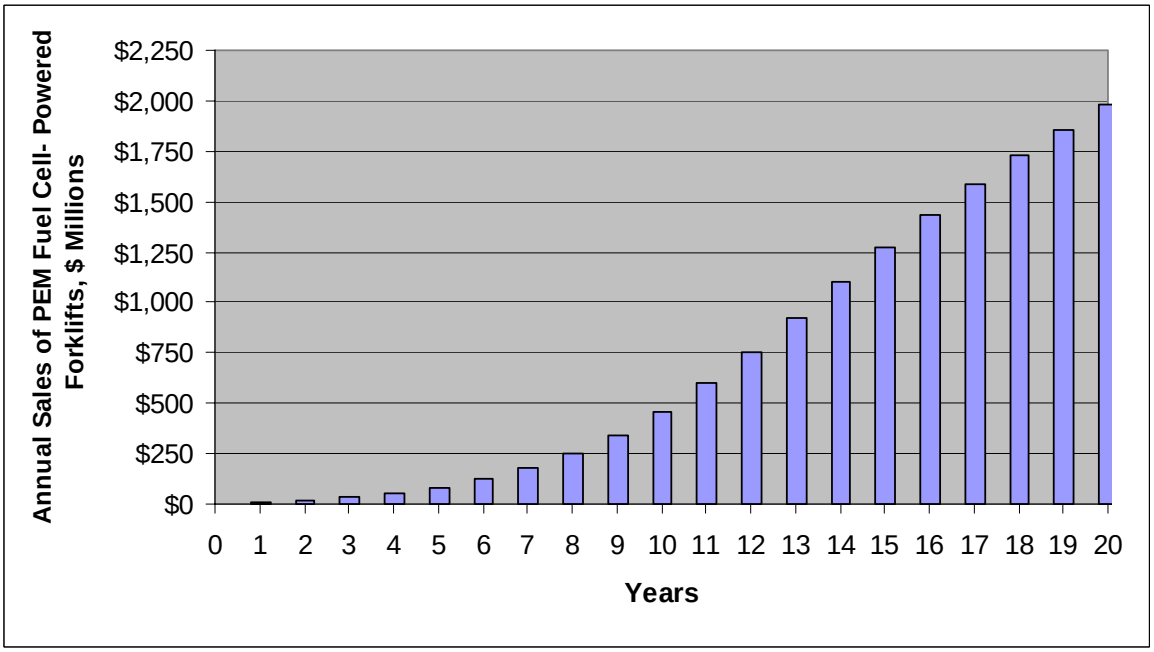

Figure 3-17. Sales of PEM Fuel Cell-Powered Forklifts in the Base Case.

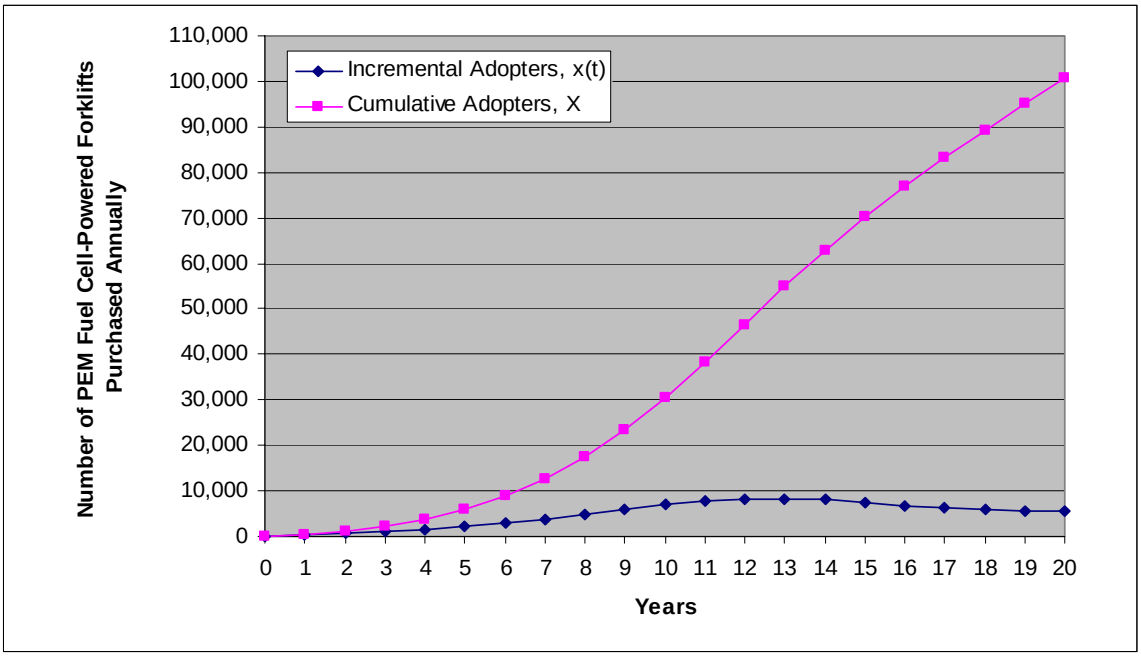

Figure 3-18. Adoptions of PEM Fuel Cell-Powered Forklifts in the Communication Case.

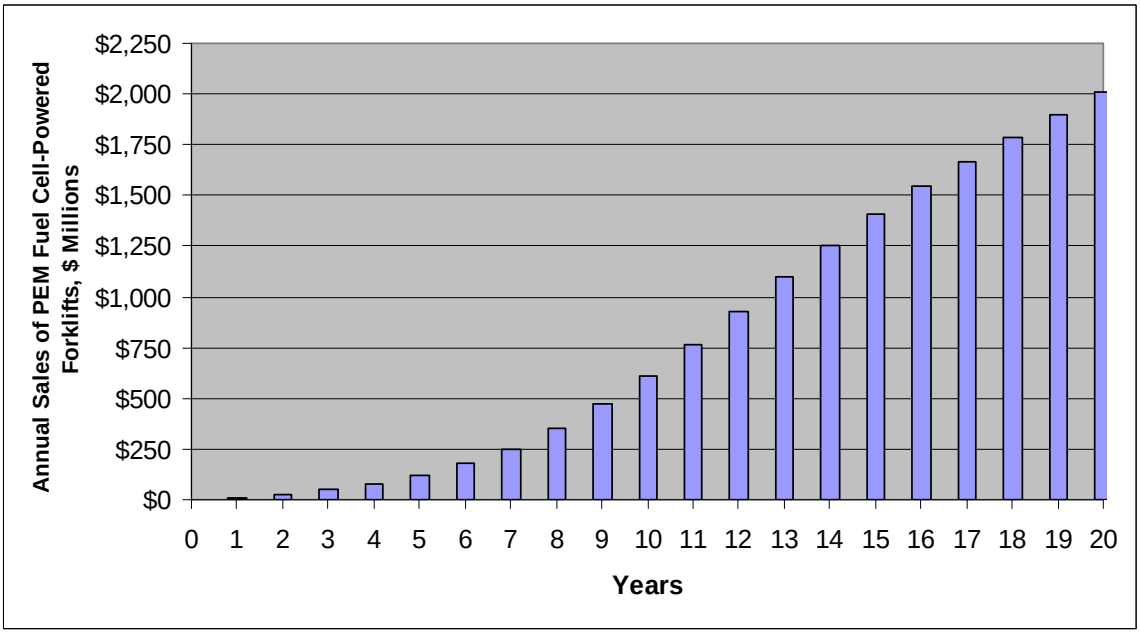

Figure 3-19. Sales of PEM Fuel Cell-Powered Forklifts in the Communication Case.

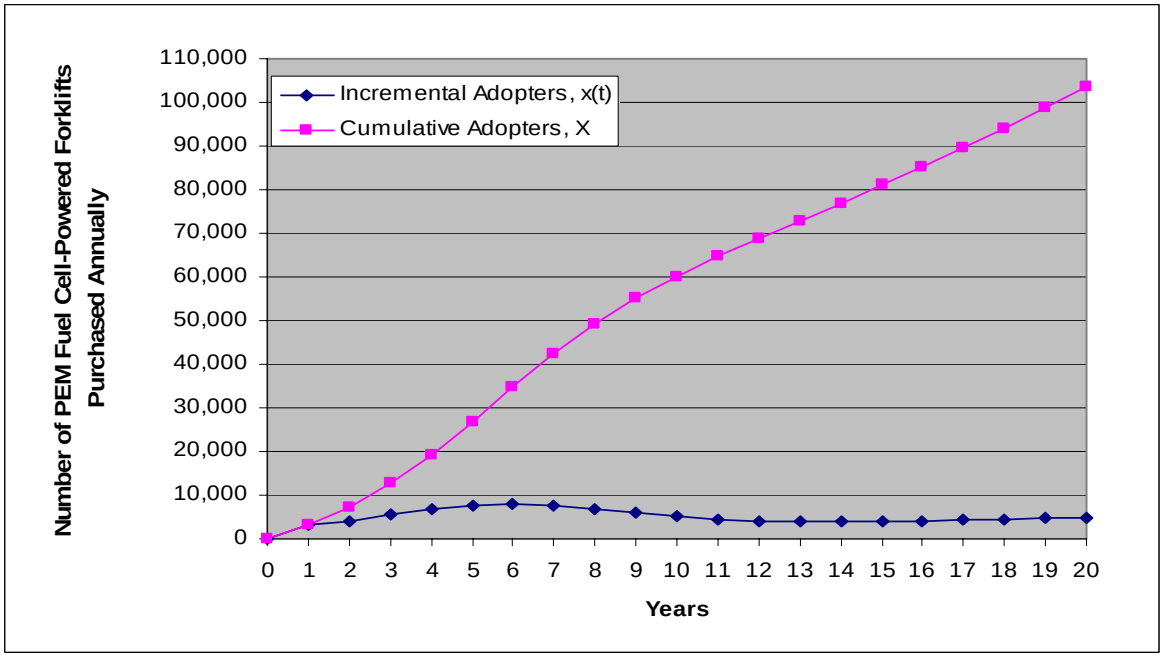

Figure 3-20. Adoptions of PEM Fuel Cell Forklifts in the Subsidy Case.

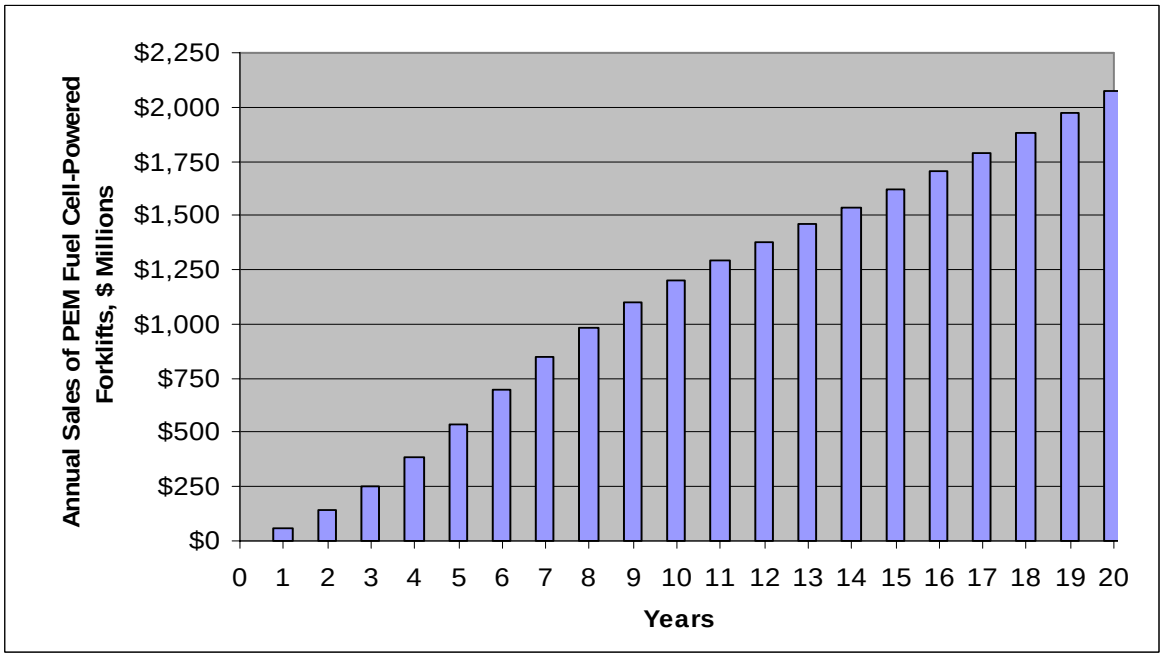

Figure 3-21. Sales of PEM Fuel Cell Forklifts in the Subsidy Case.

The models show that, for both the base and communication cases, the first year that 10,000 units are sold will be eight and seven years, respectively, after commercial introduction. In the subsidized case, 10,000 units are sold much earlier (three years after commercial introduction). Further, the models show that, in the base and communication cases, the first years that $100 million in annual sales are achieved will be six years and five years after commercial introduction, respectively. In the subsidized case, $100 million in sales are expected earlier, two

years after commercial introduction. Table 3-23 provides a summary of the sales and market share data presented for each of the three cases described above.

Table 3-23. Summary of Sales and Market Share for Alternative Market Adoption Cases for PEM Fuel Cell-Powered Forklifts.

	5 Years After Commercial Introduction			10 Years After Commercial Introduction			15 Years After Commercial Introduction			20 Years After Commercial Introduction		
	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case
Annual Sales (Units)	4,085	6,009	26,830	22,885	30,392	60,172	63,715	70,260	81,020	99,056	100,596	103,737
Annual Sales ($ millions)	82	120	537	458	608	1,203	1,274	1,405	1,620	1,981	2,012	2,075
Market Share (%)	3	4	19	13	17	34	28	31	36	34	35	36

3.2.6 Value Proposition for PEM Fuel Cell-Powered Forklifts

PEM fuel cell forklifts appear to represent a promising early opportunity for fuel cells in materials handling applications. Market research suggests that there are opportunities for alternative technologies to battery-powered forklifts in high-productivity environments. While lead-acid batteries are a known technology and are fairly reliable, there are concerns with their operation and maintenance, voltage drops as batteries discharge, and downtime during battery change-outs. Concerns over air quality are also driving users to look for alternatives to ICE-powered forklifts.

Currently, users are evaluating fast charging systems as an alternative that can increase the productivity of battery-powered forklifts. While fast charging systems eliminate many of the disadvantages of standard battery-powered forklifts (i.e., long charging and cool-down time and the need for extra batteries), they are most suitable for multi-shift operations that work on predictable schedules and have a trained workforce.

The forklift market segment represents a fairly large market opportunity for PEM fuel cells. Due to environmental regulation, it is anticipated that users will also be required to replace existing fleets with suitable alternatives. User requirements for runtime, refueling time, start-up time, operation and maintenance cost, and ease of use fit well with the capabilities offered by PEM fuel cell forklifts. However, for widespread PEM fuel cell-powered forklift adoption to be likely, reliability, capital costs, and fuel availability must be addressed. Unique benefits of PEM fuel cell-powered forklifts make them attractive for innovators. Specifically, PEM fuel cell-powered forklifts can be rapidly refueled, eliminating the time and cost of replacing batteries. The voltage delivered by the PEM fuel cell is constant as long as hydrogen fuel is available. PEM fuel cell-powered forklifts have zero emissions with only water and heat as wastes. PEM fuel cell-powered forklifts eliminate trips to the battery changing station, thus

decreasing unproductive time; lower energy costs by eliminating chargers; reduce vehicle repairs due to their fewer moving parts; and eliminate the battery storage and changing rooms.

Most users consider capital costs and lifecycle costs when evaluating an alternative technology. With hydrogen costs at $5 per kg, the smaller PEM fuel cell-powered pallet trucks on a lifecycle cost basis require significantly less investment (approximately 48 to 50%) than battery-powered pallet trucks in high-throughput applications. However, the larger PEM fuel cell-powered sit-down trucks require slightly more investment (approximately 2 to 7%) on a lifecycle cost basis than battery-powered sit-down trucks in continuous applications. While PEM fuel cell-powered forklifts require more capital investment than incumbent alternatives, they provide significant savings in operation and maintenance. The lifecycle cost of PEM fuel cell-powered forklifts is most sensitive to the variability in hydrogen cost and fuel cell life. Increasing hydrogen fuel cost negatively impacts the operation and maintenance costs. Furthermore, the value of PEM fuel cell-powered forklifts compared to alternatives varies significantly by application and is impacted by declining hours of operation and declining labor rates.

In order for PEM fuel cells to compete effectively in the forklift market segment with current and emerging technologies like fast charging, research and development to improve the durability and lifetime of PEM fuel cells and the development of infrastructure to supply and store hydrogen in a cost-effective manner are critical. Furthermore, because reliability is critical to users, demonstration projects that provide data on reliability and performance of PEM fuel cells are also essential to overcoming incumbent technologies in this market segment. Investment is necessary to establish robust supply chains to develop, manufacture, distribute, and service PEM fuel cells and associated components to meet the demands of this market. While the surveys in this analysis did not indicate that government incentives were important to users, incentives decrease capital costs and result in lower lifecycle costs of owning and operating PEM fuel cell-powered forklifts. These lower costs are critical to drive adoption of PEM fuel cells in this market segment.

It is also likely that the PEM fuel cells developed for forklifts will be a platform that can be used broadly as battery replacements in other material handling equipment, such as automatic guide vehicles, other industrial trucks, and ground support equipment. Early focus on a market where PEM fuel cells offer benefits, such as forklifts in high-throughput distribution centers, could be a strategic approach to establish credibility and a technology platform with which to enter the broader material-handling market. The supply-base development and expansion of manufacturing capability derived from such early markets provide necessary infrastructure for expansion into additional and broader markets.

3.3 PEM Fuel Cells in Airport Ground Support Equipment (GSE)

3.3.1 Market Attributes

3.3.1.1 Market Segment Description

The airport GSE market is comprised of various types of specialty vehicles used to service aircraft during ground operations. Examples of GSE that are commonly used in airport operations include:[67]

- Baggage tractors (or "tugs") – used to tow baggage trailers between the aircraft and terminal
- Aircraft pushback tractors – used to push the aircraft back from the terminal to the taxiway or tow aircraft to and from the hangar for maintenance
- Belt loaders – conveyor belts used to transfer baggage between the aircraft hold and baggage trailers
- Cargo loaders – vertical lift devices with conveyor belts or rollers used to transfer containers to the aircraft's hold
- Forklifts – used for moving cargo and equipment around the airport
- Utility vehicles – used for a variety of applications including transporting personnel
- Ground power units – ground-based mobile generators used to supply electricity to the aircraft when it is parked.

This analysis focuses on ground support tractors – both baggage tugs and aircraft pushback tractors – based on the results of exploratory research on the airport GSE market. The similar terms "tug" and "tractor" are used interchangeably in this report. These tractors are designed for use in all airport applications, including ground support equipment shops, aircraft maintenance hangars, fixed base operations, corporate flight departments, and military facilities.[68] Table 3-24 identifies the SIC and NAICS codes that cover manufacturing of ground support tractors. This information was used to identify manufacturers and users of GSE equipment.

Table 3-24. SIC and NAICS Codes for Ground Support Tractor Manufacturing.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Code	3537 – Industrial trucks and tractors
NAICS Code	333924 – Industrial trucks, tractors, mobile straddle carriers and stacker machinery

Ground support tugs can be powered by batteries or ICEs. ICE-powered vehicles can be fueled by diesel, gasoline, liquefied petroleum gas (LPG, or propane), compressed natural gas (CNG), and Jet A fuel. Frequently, 4-cylinder or 6-cylinder automotive engines are used. Among the ICE-powered products offered by the manufacturers identified for this analysis, diesel- and gasoline-powered vehicles were the most common, followed by propane and CNG. Only one manufacturer was found to offer models that were capable of running on jet fuel. The capacities of diesel and gasoline engines in airport tugs vary widely, ranging from 25 HP/19 kW to 300 HP/224 kW. Larger engines are required for aircraft pushback operations, whereas baggage tractors require smaller engines.

[67] Northeast States for Coordinated Air Use Management and Center for Clean Air Policy. 2003. Controlling Airport Related Air Pollution.
[68] Victory GSE. 2003. Push Back Tractors. Available at http://www.victorygse.com/equipment/pushback/index.php4 [Accessed June 2006].

Wet cell and sealed gel cell lead-acid batteries are used in battery-powered ground support tugs. Battery-powered tugs are used for handling baggage and cargo and for towing lower weight aircraft (e.g., for small regional airline operations). Among the battery-powered tugs offered by the manufacturers identified for this analysis, capacities ranged from 2.5 HP/1.9 kW (36V motor) to 100 HP/75 kW (340V motor). Numerous models were available in the 20 HP/15 kW to 40 HP/30 kW range.

ICE-powered baggage tractors are used more often in heavy-duty applications (e.g., pushback of jumbo jets), compared to the battery-powered models. ICE-powered products are not constrained by battery charging cycles and offer significantly greater horsepower, on average, than the battery-powered tugs. A 1995 memorandum to the Federal Aviation Administration (FAA) estimated that a typical aircraft pushback tractor was operated an average of 1,721 hours per year, while a baggage tug was operated an average of 1,021 hours per year (note: estimates include both ICE- and battery-powered vehicles. It is unknown whether the estimates account for potential differences in operating time, as described below).[69]

There are key differences between battery- and ICE-powered ground support vehicles. The upfront costs associated with battery-powered vehicles are approximately 30 to 35% higher than those associated with ICE-powered vehicles.[70] However, battery-powered vehicles are more economical than ICE-powered tugs in other ways. First, battery-powered tugs are more efficient than ICE-powered vehicles, because electric motors convert about 60% of energy into motion compared to the 10% converted by ICE.[71] Also, the motors of ICE vehicles continue to run while the vehicle is idle, which wastes fuel, whereas battery-powered vehicles are turned off when they are not performing tasks. Estimates indicate that ICE idling accounts for 20 to 70% of operating time and 10 to 50% of fuel consumption.[72] Therefore, an ICE-powered vehicle runs for an average of 3.75 hours per day, while a battery-powered vehicle is capable of performing the same amount of work in 1.3 to 1.9 hours of operating time.[73] Finally, battery-powered tugs can be more reliable and require less maintenance (with fewer moving parts) than ICE-powered vehicles. Using a battery-powered vehicle eliminates the need for tune-ups, engine overhauls, exhaust system and transmission maintenance, and oil changes. Typical maintenance costs for a battery-powered tug (including battery replacement) average $1,406 annually, while the same costs for a gasoline model reach $1,893 per year.[74] Minimal maintenance requirements and reliability are particularly attractive to the airline industry, which is extremely susceptible to the financial and schedule-related impacts of equipment downtime.[75]

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[69] Webb, S. 1995. Technical Data to Support FAA's Advisory Circular on Reducing Emissions from Commercial Aviation. Memorandum to Bill Albee, Federal Aviation Administration, and Rich Wilcox, Environmental Protection Agency.
[70] Gibson, R. 2006. The True Cost of Going Electric. Ground Support Magazine (March). Available at http://www.groundsupportmagazine.com/publication/article.jsp?pubId=1&id=1479 [Accessed June 2006].
[71] Southern California Edison. 2006. Electric Transportation – Non-Road Applications. Available at http://www.sce.com/PowerandEnvironment/ElectricTransportationOld/Non-roadApplication/AirportGSE.htm [Accessed June 2006].
[72] Southern California Edison. 2006. Electric Transportation – Non-Road Applications. Available at http://www.sce.com/PowerandEnvironment/ElectricTransportationOld/Non-roadApplication/AirportGSE.htm [Accessed June 2006].
[73] Gibson, R. 2006. The True Cost of Going Electric. Ground Support Magazine (March). Available at http://www.groundsupportmagazine.com/publication/article.jsp?pubId=1&id=1479 [Accessed June 2006].
[74] Southern California Edison. 2006. Electric Transportation – Non-Road Applications. Available at http://www.sce.com/PowerandEnvironment/ElectricTransportationOld/Non-roadApplication/AirportGSE.htm [Accessed June 2006].
[75] Mercer, M. 1999. Taking Ground Support To A Higher Plane. Diesel Progress North American Edition. Available at http://www.findarticles.com/p/articles/mi_m0FZX/is_2_65/ai_54169047 [Accessed June 2006].

The price of baggage and aircraft pushback tractors generally increases with a vehicle's drawbar pull (DBP) capacity. The higher the DBP, the heavier the load the vehicle is capable of carrying. For example, an aircraft pushback tug with a DBP of 4,000 lbs is capable of towing 60,000 lbs, and one with a DBP of 12,000 lbs can tow an 180,000 lb aircraft. Tugs with 3,000 to 12,000 lb DBP are available. ICE-powered tugs from various manufacturers ranged in price from approximately $20,000 (3,000 lb DBP) to $59,000 (12,000 lb DBP).[76]

Manufacturers of ground support vehicles may also produce other types of tow tractors for use in industrial (rather than airport) environments. However, some manufacturers of airport ground support tractors specialize in airport applications and do not produce general industrial vehicles. Although ground support tractors are used at airports, airport authorities typically are not in charge of purchasing and maintaining the equipment. Instead, airlines are directly responsible for purchasing the vehicles. Airlines also hire ground support personnel to operate and maintain the vehicles. Sometimes, airlines hire contractors that specialize in ground support operations to perform these activities.

3.3.1.2 Market Size

Current data on the number of businesses manufacturing and using airport tugs are provided below. SIC Code 3537, covering manufacturing of industrial trucks and tractors, is represented in Table 3-25. Note that this SIC Code includes industrial tractors that are not used in airports.

Table 3-25. Number of Companies Potentially Involved in Airport Tug Manufacturing - Industry: Industrial Trucks and Tractors (SIC Code 3537).

SIC Code	SIC Description	No Bus.	Total Emps.	Total Sales ($)
3537-0000	Industrial trucks and tractors	391	9,184	2,049.5
3537-0111	Stands, ground servicing aircraft	5	35	3.2
3537-0200	Trucks, tractors, loaders, carriers, and similar equipment	162	2,043	351.8
3537-0216	Tractors, used in plants, docks, terminals, etc.: industrial	17	2,544	58.2
3537-0218	Trucks: freight, baggage, etc.: industrial, except mining	147	2,139	88.7
	Total	**722**	**15,945**	**2,551.4**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Table 3-26 contains data on the number of potential adopters of airport GSE, including airports and flying fields (SIC Code 4581); air courier services (e.g., FedEx) (SIC Code 4513); scheduled air transportation providers (e.g., major airlines) (SIC Code 4512); and nonscheduled air transportation providers (e.g., charter flight operators) (SIC Code 4522). In both Table 3-25 and Table 3-26, only the eight-digit SIC Code specialties relevant to airport tugs are shown.

[76] Aero Specialties. 2006. Tractors, Tugs, & Pushbacks. Available at http://www.aerospecialties.com/productinfo/tractors/ [Accessed June 2006].

Table 3-26. Number of Potential Adopters of Airport Tugs.*

SIC Code	SIC Description	No Bus.	Total Emps.	Total Sales ($)
4581-0000	Airports, flying fields, and services	1,563	34,901	5,797.3
4581-0100	Hangars and other aircraft storage facilities	106	1,189	42.1
4581-0101	Aircraft storage at airports	67	485	29.3
4581-0200	Aircraft maintenance and repair services	1,405	25,102	2,984.2
4581-0202	Aircraft servicing and repairing	1,422	32,483	2,621.7
4581-0300	Airports and flying fields	51	1,216	38
4581-0301	Airport	1,665	30,122	5,610.9
4581-0302	Flying field, except those maintained by clubs	17	72	8.8
4581-0303	Military flying field	21	304	4.9
4581-9901	Air freight handling at airports	203	5,104	931.9
4581-9904	Airport terminal services	220	10,354	1,362.8
4581-9905	Airfreight loading and unloading services	53	611	54.9
4581-9906	Fixed base operator	46	856	96.2
4513-0000	Air courier services	903	22,815	3,332.6
4513-9901	Letter delivery, private air	135	9,004	2,988.4
4513-9902	Package delivery, private air	770	14,466	49,135.7
4513-9903	Parcel delivery, private air	55	2,102	11.4
4512-0000	Air transportation, scheduled	1,157	56,434	6,297.6
4512-9901	Air cargo carrier, scheduled	532	24,554	4,169.6
4512-9902	Air passenger carrier, scheduled	1,180	132,634	182,204.9
4512-9903	Helicopter carrier, scheduled	104	3,086	605.2
4522-0000	Air transportation, nonscheduled	524	6,632	1,027
4522-0100	Nonscheduled charter services	265	4,021	1,249.8
4522-0101	Air passenger carriers, nonscheduled	201	4,283	1,825.2
4522-0102	Flying charter service	946	10,508	2,055.9
4522-0103	Sightseeing airplane service	106	687	67.5
4522-9901	Air cargo carriers, nonscheduled	151	4,650	2,033.1
4522-9902	Air taxis	110	932	85.4
4522-9903	Ambulance services, air	218	4,365	1,103.5
4522-9904	Helicopter carriers, nonscheduled	334	3,807	1,148.7
	Total	**14,530**	**447,779**	**278,925**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.
*Users include the following industries: Airports, Flying fields, and Services (SIC Code 4581); Air courier services (SIC Code 4513); Air transportation, Scheduled (SIC Code 4512); and Air transportation, Nonscheduled (SIC Code 4522)

Secondary research identified detailed but slightly dated information on the population of ground support tractors in the U.S. In 1999, EPA estimated the proportions of pushback tugs and baggage tugs in the U.S. that operated on various types of fuels (Table 3-27).[77] More detailed information on ICE-powered tugs was provided in a 2005 EPA report on non-road engines (Table 3-28). This report, which documented the source of non-road engine population values in EPA's NONROAD emissions inventory model, provided the most recent population data available (termed "base year" data) for non-road engines in a wide range of vehicles and equipment. All data were obtained from Power Systems Research, an independent market research firm that surveyed engine manufacturers and users to derive its estimates. For ground support vehicles, the years 1998 and 2000 were designated as base years.[78] While the estimates

[77] EPA. 1999. Technical Support for Development of Airport Ground Support Equipment Emission Reductions. EPA-420-R-99-007.
[78] EPA. 2005. Non-road Engine Population Estimates. EPA-420-R-05-022. Available at http://www.epa.gov/OMS/models/nonrdmdl/nonrdmdl2005/420r05022.pdf#search=%22Non-Road%20Engine%20Population%20Estimates.%20EPA420-R-05-022.%22 [Accessed June 2006].

in Table 3-27 undoubtedly have changed in the last six years (e.g., CNG-powered tugs are now available and battery-powered tugs are being more widely adopted), they do provide a recent reference point for the industry.

Table 3-27. Estimated U.S. Ground Support Tractor Population by Power Source, 1999.[79]

Ground Support Equipment (GSE) Type	Engine Type	Estimated U.S. Population	Fraction of Type-Specific GSE
Aircraft Pushback Tractor	Diesel	2,113	76.6%
	Gasoline	489	17.7%
	CNG	0	0.0%
	LPG	63	2.3%
	Battery-Powered	94	3.4%
	All	**2,759**	**100%**
Baggage Tug	Diesel	4,399	41.9%
	Gasoline	4,863	46.3%
	CNG	0	0.0%
	LPG	973	9.3%
	Battery-Powered	270	2.6%
	All	**10,505**	**100%**

Considering the data presented above and probable growth (estimated at 4% per year) in the market since the EPA's inventory was completed in 1999, the research team estimates the total current population of baggage tractors to be less than 14,000 baggage tractors; for pushback tractors it is estimated to be about 3,600 units.

Leading manufacturers of airport tugs include TUG Technologies Corporation, FMC Technologies, TLD America, Taylor-Dunn Manufacturing Co., Charlatte America, and NMC-Wollard. In the U.S., potential large end-users of airport tugs include Delta Airlines, American Airlines, Southwest Airlines, Northwest Airlines, U.S. Airways, United Airlines, and Continental Airlines.

[79] EPA. 1999. Technical Support for Development of Airport Ground Support Equipment Emission Reductions. EPA-420-R-99-007.

Table 3-28. Total Population of ICE-Powered Ground Support Equipment in the United States in 1998 and 2000.[80]

Year	Equipment Description	Min HP/kW	Max HP/kW	Avg HP/kW	U.S. Population
1998	4-Stroke airport support equipment	3/2.2	6/4.5	4.9/3.6	897
1998	4-Stroke airport support equipment	6/4.5	11/8.2	8.2/6.1	102
1998	4-Stroke airport support equipment	11/8.2	16/11.9	16.0/11.9	363
1998	4-Stroke airport support equipment	16/11.9	25/18.6	18.4/13.7	19
1998	4-Stroke airport support equipment	25/18.6	40/29.8	37.0/27.6	21
1998	4-Stroke airport support equipment	40/29.8	50/37.3	46.0/34.3	7
1998	4-Stroke airport support equipment	50/37.3	75/55.9	59.0/44.0	23
1998	4-Stroke airport support equipment	75/55.9	100/74.6	86.2/64.3	97
1998	4-Stroke airport support equipment	100/74.6	175/130.5	113.0/84.3	287
1998	LPG-airport support equipment	25/18.6	40/29.8	37.0/27.6	21
1998	LPG-airport support equipment	40/29.8	50/37.3	46.0/34.3	7
1998	LPG-airport support equipment	50/37.3	75/55.9	59.0/44.0	23
1998	LPG-airport support equipment	75/55.9	100/74.6	86.2/64.3	97
1998	LPG-airport support equipment	100/74.6	175/130.5	113.0/84.3	287
2000	Diesel-airport support equipment	6/4.5	11/8.2	8.3/6.2	1,124
2000	Diesel-airport support equipment	11/8.2	16/11.9	11.7/8.7	3
2000	Diesel-airport support equipment	16/11.9	25/18.6	21.2/15.8	14
2000	Diesel-airport support equipment	25/18.6	40/29.8	38.5/28.7	41
2000	Diesel-airport support equipment	40/29.8	50/37.3	41.0/30.6	57
2000	Diesel-airport support equipment	50/37.3	75/55.9	62.8/46.8	1,176
2000	Diesel-airport support equipment	75/55.9	100/74.6	84.2/62.8	2,142
2000	Diesel-airport support equipment	100/74.6	175/130.5	141.1/105.2	6,327
2000	Diesel-airport support equipment	175/130.5	300/223.7	221.4/165.1	2,124
2000	Diesel-airport support equipment	300/223.7	600/447.4	419.0/312.5	2,481
2000	Diesel-airport support equipment	600/447.4	750/559.3	655.0/488.4	263
2000	Diesel-airport support equipment	1,000/745.7	1200/894.9	1071.0/798.7	16
	Total Population				**18,019**

Note: Category of Ground Support Equipment is not limited to aircraft tractors and baggage tugs.

3.3.1.3 Market Trends

There has been movement in recent years away from ICE-powered airport ground support vehicles and toward battery-powered vehicles. Air quality is a major concern at airports, particularly within terminal buildings where a significant amount of baggage and cargo handling takes place. Emissions from ICE-powered vehicles, including carbon monoxide, nitrogen oxides hydrocarbons, and particulates, can have a dramatic impact on air quality in these environments, requiring airports to modify air circulation patterns and structural designs to ensure the health and safety of employees working within the terminals.[81]

[80] EPA. 2005. Non-road Engine Population Estimates. EPA-420-R-05-022. Available at http://www.epa.gov/OMS/models/nonrdmdl/nonrdmdl2005/420r05022.pdf#search=%22Non-Road%20Engine%20Population%20Estimates.%20EPA420-R-05-022.%22 [Accessed June 2006].

[81] Miami International Airport. 2001. Environmentally Friendly Battery Operated Tugs Debut at MIA. Available at http://www.miami-airport.com/html/archieved_press_release_154.html [Accessed June 2006].

Since as early as the mid-1990s, the airline industry has been investigating the benefits of using electricity or alternative fuels instead of gasoline and diesel fuel in ground support vehicles.[82] New environmental standards may further encourage the airline industry to transition away from ICE-powered vehicles. EPA recently proposed new emissions standards applicable to non-road diesel engines. These standards, to be implemented in phases between 2008 and 2014, will require diesel engine manufacturers to outfit new engines with advanced emission control technologies. New diesel-powered ICE-powered ground support vehicles will be required to meet these standards.[83]

The California Air Resources Board (CARB) has proposed to adopt more stringent emission standards and test procedures for large (> 25 HP/19 kW), spark-ignited engines in various types of equipment, including forklifts, sweepers/scrubbers, industrial tow tractors, and ground support equipment.[84] Ground support equipment includes forklifts, tugs, belt loaders, bob-tails, cargo loaders, lifts, air conditioners, service trucks, de-icers, fuel delivery trucks, and ground power units. CARB has proposed the adoption of EPA's 2007 model-year emission standard and a more stringent 2010 model-year emissions standard. CARB also has proposed stricter emission standards for fleets in use and would require operators of in-use fleets to reduce their emissions by retrofitting existing equipment or replacing uncontrolled engines with zero or low-emission engines by 2009.

Emissions from ground support vehicles impact not only the air within airport environments but also the air quality of the surrounding community. This could potentially become a concern, particularly in air quality nonattainment areas. The FAA and EPA identified a total of 126 U.S. airports in 8-hour nonattainment or maintenance areas.[85] This creates further incentive for regional air quality boards and state agencies to support cleaner GSE technology deployment because they want to avoid being penalized for nonattainment.

In the years since the figures shown in Table 3-27 Table and Table 3-28 were estimated (1999/2000), the airline industry has taken steps to replace ICE-powered tugs with battery-powered models. For example, in 2001 a major ground support service provider at Miami International Airport committed to replacing most of its gas-fueled baggage tugs in an attempt to improve terminal air quality, which had been degraded by emissions from the ICE-powered vehicles.[86]

Federal and state agencies have also begun advancing programs that support low-emission GSE. In April 2000, Congress authorized the Inherently Low-Emissions Airport Vehicle (ILEAV) Pilot Program as part of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21). AIR-21 authorized ten ILEAV project grants for up to $2 million each under

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[82] Webb, S. 1995. Technical Data to Support FAA's Advisory Circular on Reducing Emissions from Commercial Aviation. Memorandum to Bill Albee, Federal Aviation Administration, and Rich Wilcox, Environmental Protection Agency.
[83] FAA. 2005. Aviation and Emissions - A Primer. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/AEPRIMER.pdf#search=%22Aviation%20and%20Emissions%20-%20A%20Primer%22 [Accessed June 2006].
[84] California Air Resources Board. 2006. Staff Report: New Emission Standards, Fleet Requirements, And Test Procedures For Forklifts And Other Industrial Equipment. Available at http://www.arb.ca.gov/regact/lore2006/isor.pdf [Accessed June 2006].
[85] FAA. 2005. List of U.S. Commercial Service Airports and their Nonattainment and Maintenance Status. Available at http://www.faa.gov/airports_airtraffic/airports/environmental/vale/media/vale_eligible_airports.xls [Accessed September 2006].
[86] Miami International Airport. 2001. Environmentally Friendly Battery Operated Tugs Debut at MIA. Available at http://www.miami-airport.com/html/archieved_press_release_154.html [Accessed June 2006].

the FAA Airport Improvement Program (AIP). The program, which ran between 2001 and 2005, gave airports the opportunity to evaluate numerous types of mobile and stationary low-emission technologies. A total of $6.7 million was allocated to six airports during this period, including Dallas/Fort Worth, Sacramento, Denver, San Francisco, and Baltimore-Washington international airports, and Baton Rouge Metropolitan Airport. Most projects involved conversion of gasoline- and diesel-powered ICE vehicles to new vehicles running on electricity and CNG.[87]

In light of the success of the ILEAV Program, FAA and EPA have expanded the initiative to all commercial airports listed in the FAA National Plan of Integrated Airport Systems (NPIAS) and located in EPA-designated air quality nonattainment areas through the Voluntary Airport Low Emission (VALE) program. The VALE program allows airport sponsors to use the AIP and Passenger Facility Charges (up to $4.50 for every enplaned passenger) to finance low-emission vehicles, refueling and recharging stations, gate electrification, and other airport air quality improvements.[88] This includes the conversion of airport vehicles and ground support equipment to low-emission technologies, modification of airport infrastructure to support use of alternative fuels, and a pilot program to explore retrofit technology for airport ground support equipment. The VALE program creates opportunities for fuel cell-powered vehicles to enter this market.[89]

Many airlines have voluntarily agreed to reduce emissions from their ground support vehicle fleets. For example, major airlines have forged agreements with state agencies in both California and Texas to reduce emissions from ground support vehicles by converting gasoline and diesel equipment to alternative fuels and electricity.[90] Air carriers operating in California's South Coast air basin entered into a Memorandum of Understanding (MOU) with CARB in 2002, committing to reduce hydrocarbon and NO_x emissions from new and in-use GSE. While the MOU was terminated in late 2005, under CARB's new proposed emission requirements those airlines still would be required to meet the MOU's zero-emission requirement for existing fleets by 2010.[91]

As alternatives to battery- and ICE-powered tugs, hydrogen-powered tugs are being developed for both military and commercial applications. The U.S. Air Force has developed a prototype fuel cell-powered ground support vehicle for testing. For this effort, Concurrent Technologies Corporation integrated Enova Systems' 120-kW HybridPower drive system with a Hydrogenics 65-kW fuel cell system in an aircraft tug. The tug will be tested at select Air Force bases and civil airports throughout the country.[92] In 2006, General Hydrogen Corporation partnered with Air Canada to investigate the use of fuel cell power packs in tugs used to tow baggage to and

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[87] FAA. 2006. Final Report: Inherently Low Emission Airport Vehicle Pilot Program. Available at http://www.faa.gov/airports_airtraffic/airports/environmental/vale/media/ileav_report_final_2005.pdf#search=%22Final%20Report%3A%20Inherently%20Low%20Emission%20Airport%20Vehicle%20Pilot%20Program%22 [Accessed June 2006].
[88] FAA. 2006. Voluntary Airport Low Emissions (VALE) Program. Available at http://www.faa.gov/airports_airtraffic/airports/environmental/vale/ [Accessed September 2006].
[89] FAA. 2005. Aviation and Emissions - A Primer. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/AEPRIMER.pdf#search=%22Aviation%20and%20Emissions%20-%20A%20Primer%22 [Accessed June 2006].
[90] FAA. 2005. Aviation and Emissions - A Primer. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/AEPRIMER.pdf#search=%22Aviation%20and%20Emissions%20-%20A%20Primer%22 [Accessed June 2006].
[91] California Air Resources Board. 2006. Staff Report: New Emission Standards, Fleet Requirements, And Test Procedures For Forklifts And Other Industrial Equipment. Available at http://www.arb.ca.gov/regact/lore2006/isor.pdf [Accessed June 2006].
[92] BioAge Group, LLC. 2005. Enova Electric Drives in Two More Fuel Cell Prototypes. Available at http://www.greencarcongress.com/fuel_cells/ [Accessed June 2006].

from aircraft. The project, funded in part by the Government of Canada, will be conducted at Air Canada's Ground Support Equipment site at Vancouver International Airport. General Hydrogen's power packs, which contain Ballard Power Systems' fuel cell stacks, are capable of operating up to three times longer on a single fueling than their battery-powered counterparts.[93] Finally, Ford Motor Company has produced a 4.6-liter, hydrogen-fueled, V6 engine that a major ground support equipment manufacturer is now using to develop off-road vehicles, including tow tractors.[94]

Industry analysts have noted several advantages of fuel cell-powered tugs. While their performance is similar to that of other battery-powered tugs, a fuel cell tug remains fully charged at all times and does not experience performance lag at the end of a shift like battery-powered tugs do. Lastly, refueling with hydrogen can be significantly more convenient and faster than changing or recharging a battery.[95]

3.3.2 Market Segment Analysis

The market analysis for ground support applications in airports is divided into two sections. Section 3.3.2.1 analyzes responses from Phase 1 surveys of manufacturers of GSE. These surveys were conducted to determine the market opportunities for PEM fuel cell-powered GSE from the manufacturers' perspective. It is anticipated that these manufacturers will also serve as potential integrators of fuel cells into their products. Section 3.3.2.2 analyzes the responses received from users of GSE, including airports, airlines, and GSE service providers, conducted during Phase 1 and Phase 2. This analysis summarizes user requirements for GSE vehicles reported by survey respondents.

3.3.2.1 Manufacturer Response Analysis

Twelve GSE manufacturers were asked to complete a survey, and four responses were received. Two interviews were also conducted. Information gleaned from this research is summarized below.

All of the system integrators who responded were small manufacturers (less than 500 employees) of tow tractors and other ground support vehicles. Two of the four manufacturers worked exclusively in the aviation industry, while the other two also produced tow tractors for general industrial use. Respondents from manufacturing organizations were typically affiliated with marketing departments. Three of the four manufacturers offered ICE- and battery-powered vehicles, while the fourth offered battery-powered vehicles only. Two of the ICE-powered manufacturers offered diesel-, propane-, and gasoline-powered vehicles; one offered diesel only.

When asked about safety concerns, a manufacturer noted that any safety issues with batteries had been resolved long ago. Another responded that disposal was once a concern, but major battery companies are now handling disposal. He added that wet-cell batteries can spill, but such spills

[93] BioAge Group, LLC. 2006. General Hydrogen in Fuel-Cell Luggage Tug Project with Air Canada. Available at http://www.greencarcongress.com/fuel_cells/ [Accessed June 2006].
[94] Weeks, B. 2005. Making a Case for Hydrogen in the GSE Industry. Ground Support Magazine (May). Available at http://www.groundsupportmagazine.com/publication/article.jsp?pubId=1&id=1044 [Accessed June 2006].
[95] Weeks, B. 2005. Making a Case for Hydrogen in the GSE Industry. Ground Support Magazine (May). Available at http://www.groundsupportmagazine.com/publication/article.jsp?pubId=1&id=1044 [Accessed June 2006].

are extremely rare. The third manufacturer pointed out that there is the possibility of electric shock during battery maintenance. The fourth manufacturer noted that batteries contain a significant amount of acid, which corrodes the tugs more than an ICE would.

Only one manufacturer commented on maintenance requirements, indicating that proper ICE maintenance is easier for their customers than proper battery maintenance.

All four manufacturers were aware of the potential for PEM fuel cells to be used as substitutes for existing power sources in their products. Two manufacturers had not considered replacing ICEs or batteries with fuel cells, although one of the two had sold a tug to another company for fuel cell R&D. One manufacturer is currently testing and demonstrating a fuel cell-powered tug. The fourth has considered using fuel cells but, because of the company's small size (and limited R&D budget), has not been able to develop anything so far. The two companies that have considered using fuel cells reported that they were responding to customer needs. One noted that airlines began discussing the removal of fossil fuels from the tarmac nearly a decade ago. The same two manufacturers pointed out that any energy source must be capable of meeting the customer's needs (i.e., towing requirements). One added that energy sources must be low-cost and easy to refuel. The manufacturer that is already demonstrating a fuel cell tug suggested that fuel cells will be a viable energy source in these vehicles, noting that he is already seeing a major shift in the forklift market, which will drive a shift in the tow tractor market (because tow tractors tend to follow forklifts). This respondent expects that fuel cells will begin to be used in forklifts and tow tractors in the very near future (within 12 months). Another manufacturer noted that fuel cells would only be viable if they could be refueled without having to install an expensive refueling station. An airport authority representative noted that fuel cells would need to provide the same operational characteristics as existing tug power sources, and they would need to withstand outdoor storage in extreme temperatures and weather conditions.

Two manufacturers identified drivers and barriers for fuel cell use in their products. Cost was cited as a major barrier by both manufacturers, particularly the cost of refueling stations. One manufacturer considered the small size of his organization as a barrier, while the other cited availability of hydrogen. The manufacturer with a fuel cell vehicle in development has no timeline for commercial release but plans to target airline and automotive applications when the vehicle does become commercially available. Regarding drivers, one manufacturer indicated that the costs of refueling would have to be reduced. The other noted that the technology must be developed to the point where it is cost-effective for the industry; right now, the infrastructure is prohibitively expensive.

All manufacturers expressed an interest in working with DOE to develop fuel cell products. One noted that DOE would have to provide sufficient resources to conduct R&D, since the company currently does not have such resources.

3.3.2.2 Ground Support Equipment User Response Analysis

Thirty users of ground support tugs were asked to participate in a detailed survey, and nine surveys were completed. Three surveys were completed as part of the Phase 1 analysis, and six surveys were completed as part of the Phase 2 analysis. In addition, eight of these users also

participated in follow-up interviews as part of the Phase 2 analysis. Information from these surveys and interviews is summarized below.

Survey Participant Profile

All but one of the users represented organizations of 3,000 or more employees. Of the users who responded, four were commercial airlines, three were aviation ground support service providers, one was a parcel delivery company, and one represented a regional airport authority. Respondents from these organizations were typically airport station or GSE managers.

Applications

Survey respondents were asked to identify the types of specialty vehicles used in a typical facility, the typical applications for which these vehicles are used, and the frequency of use.

A large airline with its hub at a large international airport operates over 600 baggage tugs and 78 aircraft pushback tractors. About 40% of its baggage tug fleet at the hub airport is battery-powered, primarily with 25 HP/18.5 kW vehicles with a 3,500 lb DBP. The rest are 3,000 and 5,000 lb DBP gasoline-powered ICE baggage tugs. The airline's pushback tow tractors are diesel vehicles with a power output ranging from 100 HP/75 kW to 255 HP/190 kW and a DBP ranging from 16,000 to 78,000 lbs. These vehicles typically operate 18 to 20 hours per day, so limited time is available for maintenance and battery recharging.

A regional airline operating at a mid-sized international airport has 38 baggage tugs, all of which are gasoline-powered but one, which is a diesel-powered ICE tug. Most of these baggage tugs have a 3,000 lb DBP and operate about 17 hours per day. The airline owns three diesel- and gasoline-powered ICE aircraft tow tractors for moving aircraft between the terminal and hangar; the tow tractors operate an estimated 8 hours per day. The airline also runs 14 battery-powered aircraft pushback tractors, which operate 17 hours/day. The battery-powered vehicle pushback tractors run on two 36V batteries. Another regional airline at a major international airport has a very similar fleet of equipment with 32 baggage tugs and 15 pushback tractors. They operate these vehicles on a nearly continuous basis, 24 hours per day. A final airline surveyed has 7 baggage tractors (gas and diesel) and 4 tow tractors at a mid-sized international airport, which they also operate 24 hours a day, 7 days a week.

Respondents from the GSE service providers and the parcel delivery company surveyed tended to have shorter operating times than the airlines, suggesting that downtime may be less of an issue for this sub-segment. Three of the four operate their vehicles for 6 to 9 hours per day. One specified that it had just 6 baggage tugs at a typical facility, while others said the number ranged from just a few to several hundred per facility. Three of these organizations use predominantly diesel- and gas-powered ICE tractors. Just one ground support services organization surveyed operates only battery-powered vehicles – it has a fleet of eleven 48V burden carriers at a mid-sized international airport. Use of battery-powered vehicles was required by that particular airport.

Battery-Powered Vehicles

Six of the nine survey respondents indicated that they had some battery-powered vehicles in their fleet of baggage and aircraft pushback tractors. Users were asked detailed questions about their battery-powered vehicles, including how often they have to charge or change batteries, time required for battery maintenance, and battery lifetime. Three companies indicated that it was not necessary to change batteries during a typical 8-hour shift; just one specified that it has to change out its batteries for a cargo tractor each shift, and two did not provide information. Two companies noted that they do not change out batteries at all; they use the 4 to 6 hours of downtime each evening to recharge the vehicles. One of these companies uses rapid chargers, and the power supply will last the entire 18 to 20 hour day. The other said that the 4 to 6 hour recharge time is not sufficient for their vehicles and they often do not last a full 18 to 20 hour day. In these cases they are forced to double up baggage loads or find another vehicle.

Three respondents indicated that battery change-out time does not typically impact productivity, as long as they get a full charge at night, while three indicated that it does impact productivity. Unscheduled downtime, however, does have a major impact on productivity, particularly for airlines. One user noted that downtime can have very serious consequences, particularly when tow tractor capability is lost. Another indicated that they maintain enough vehicles at their hub to ensure continued operations in the event that a vehicle goes down, requiring a higher capital investment in GSE to manage this risk. However, it was noted by one user that, in most airport operations, other airlines tend to be cooperative and will share their equipment in order to avoid interruptions in flight schedules.

The survey asked users about battery maintenance in order to understand how it compared to maintenance for ICE-powered vehicles. Two users surveyed estimated their battery maintenance time at 2 to 3 hours per month. They typically follow or exceed the preventive maintenance schedule recommended by manufacturers. According to the manufacturers, maintenance of battery-based products primarily involves daily recharging and checking the water level in flooded lead-acid batteries. One manufacturer noted that battery life is often reduced by improper maintenance (e.g., failing to charge them daily and exposing them to extreme temperatures). Another manufacturer noted that both battery-powered and ICE-powered vehicles are subject to routine maintenance after the first 200 hours of service; this maintenance is repeated at 500 hours and every 1,000 hours thereafter.

When asked about safety concerns with battery-powered vehicles, none of the users identified any concerns. Users indicated that the expected lifetime for batteries in battery-powered baggage tugs ranged from 2 to 7 years. They expect battery chargers to last anywhere from 3 to 15 years.

Space requirements for battery charging can represent a sizeable cost for airlines because they typically lease space from airports based on square footage occupied. Respondents were asked to specify space requirements for battery charging, and answers varied widely. One airline with 14 battery-powered vehicles said they require just 5 square feet of space for recharging; a respondent with 11 vehicles has 100 square feet of dedicated space; and a third with 250 battery-powered vehicles at a large international airport indicated that their battery charging space occupied approximately 37,000 square feet.

ICE-Powered Vehicles

For ICE-powered vehicles, users were asked to describe tank refill frequency, tank fill time, and maintenance time and cost. Of the four who responded to this question, two typically refill their ICE-powered vehicles twice per day (or once per shift) and two refill them once per day. Refill time ranged from an estimated 2 to 18 minutes per vehicle. For one airline at a large international airport, refueling time represents a significant labor cost at an estimated 24 man-hours per day for all vehicles.

ICE-powered tugs are generally subject to the same maintenance requirements as any other ICE-powered vehicle (e.g., oil and other fluid changes). According to users, maintenance time for tugs was estimated at 3 to 6 hours per month, which is slightly more than the average time estimated for battery-powered vehicles.

Some users were asked whether they had safety concerns with their ICE-powered vehicles. None of the respondents identified any concerns with ICE-powered vehicle use and safety. Only one manufacturer noted any safety concerns with ICE-powered tugs; this concern was noise.

Downtime/Unscheduled Maintenance

Respondents were asked to specify which of the various ground support vehicle applications are most affected by unscheduled downtime. Of the seven who responded to this question, four indicated that all applications are critical and equally affected by downtime. Two indicated that baggage handling applications were most critical, and one indicated that aircraft pushback applications were the most affected.

As far as the frequency of downtime incidents experienced, one airline estimated that average downtime was approximately 7.4% on all equipment. Downtime incidents for other respondents ranged between four and 30 incidents of downtime per vehicle per year. Two others did not specify a number but said that downtime incidents can occur daily or weekly. One user commented that downtime was a rare event and could not estimate its frequency. Of the respondents that estimated downtime frequency, three reported that a typical downtime incident lasts greater than 8 hours; one reported that incidents generally last between 4 and 8 hours; and one specified less than 30 minutes. The number and duration of incidents suggests that downtime may represent a significant cost for these users.

Purchase Decision Factors

Of the various factors considered by users when selecting a specialty vehicle, the following were identified as "very important"[96] by users: capital cost (7 users); reliability (7 users); annual operating cost (5 users); lifetime of the unit (5 users); time between refueling or recharging (4 users); fuel availability; good past experience with this type of system (4 users); ease of use (4 users); emissions (3 users); and start-up time (2 users). These results are summarized in Figure 3-22 below.

[96] On a scale of 1 to 7, responses of 6 and 7 are classified as "very important".

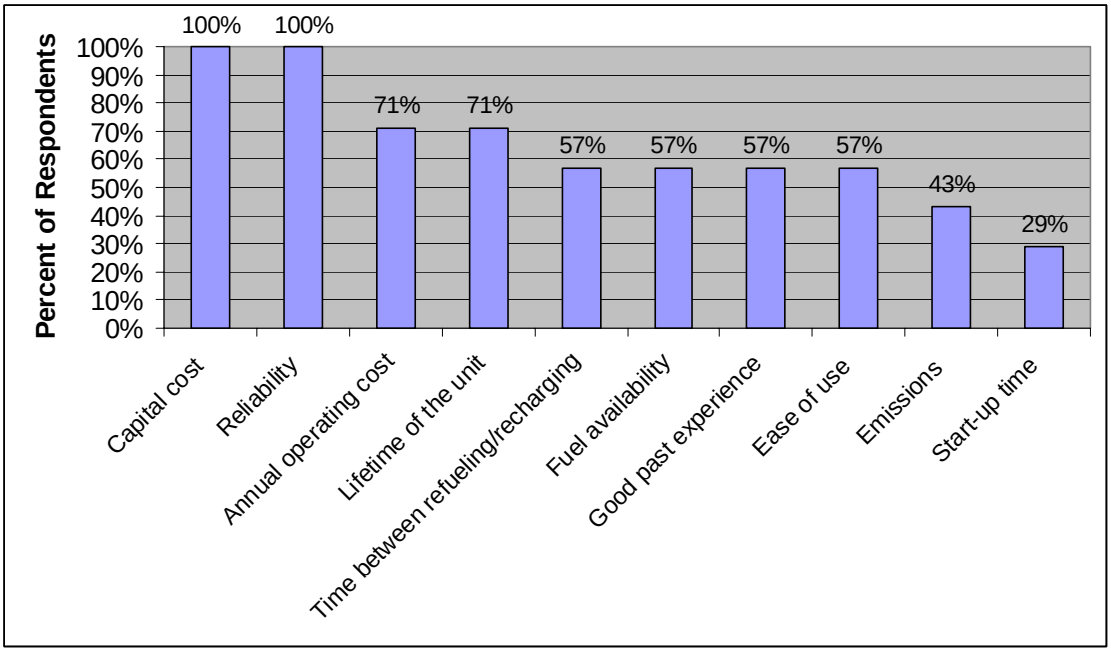

Figure 3-22. Specialty Vehicle Purchase Decision Factors Identified as Very Important (n=7).

While capital cost was identified as a very important factor by the greatest number of people, reliability ultimately may be a more important decision factor. When users were asked which three factors from the list above would most influence their decision to purchase a specialty vehicle powered by an alternative technology, all respondents to the question identified reliability (7 users). Operating costs (5 users), lifetime of the unit (4 users), capital cost (3 users), and fuel availability (1 user) were also identified as among the three most important factors influencing specialty vehicle purchase decisions.

Satisfaction with Current Vehicles

Users were asked to rate their level of satisfaction with their current specialty vehicles against the same set of characteristics (Figure 3-23). The greatest number of users identified start-up time as very good[97] (7 users), followed by fuel availability (6 users), reliability (5 users), and ease of use (5 users). While users appear to have a high level of satisfaction with start-up time and fuel availability, it is interesting to note from the analysis above that neither of these factors are among the most important to users. Reliability, however, is among the most important decision factors; just over half of the users surveyed classified reliability as very good.

[97] On a scale of 1 to 7, responses of 6 and 7 are classified as "very good".

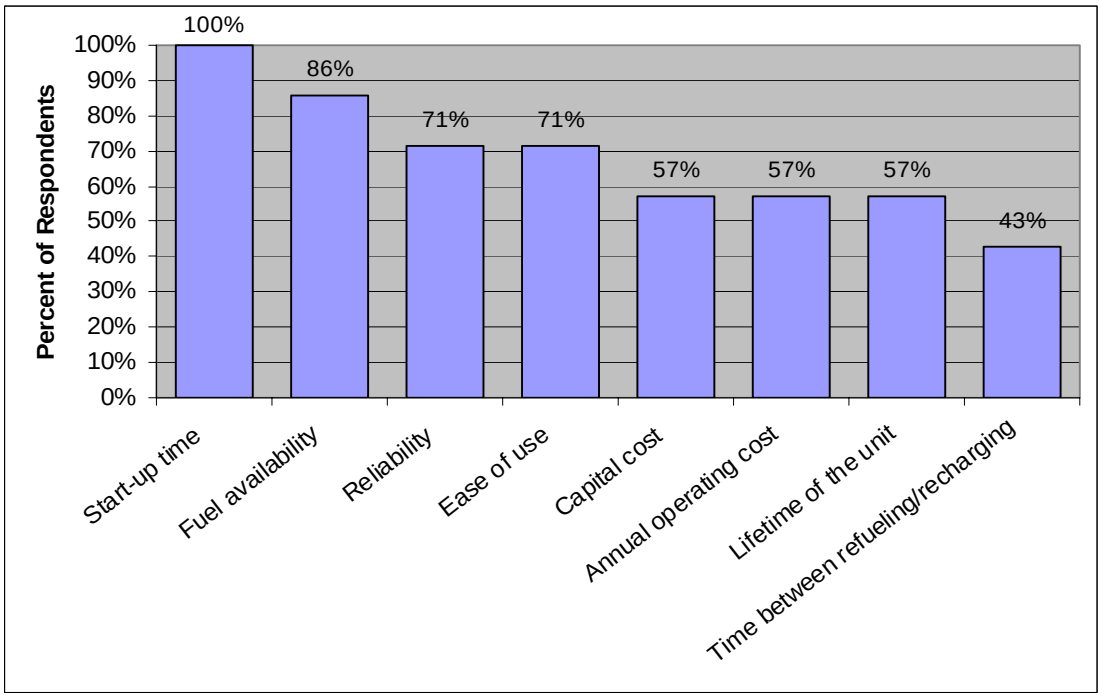

Figure 3-23. Characteristics of Current Systems that Users Identified as Very Good (n=7).

Trends and Potential for PEM Fuel Cells in Airport Tugs

Three users provided feedback on market trends. They all agreed that there will be a growing need for specialty vehicles in the ground support equipment market over the next several years. Four users have considered alternatives to their current battery- or ICE-powered products. Two users considered fuel cell airport tugs, two users considered hybrid vehicles, and another who is currently using an ICE-powered vehicle has considered battery-powered vehicles.

Just half of eight respondents had heard of PEM fuel cells as a potential power source for ground support vehicles. Of these, two users do not believe that PEM fuel cells will compete favorably with existing products any time soon. One pointed out that the cost must come down before fuel cell-powered vehicles can compete. Another user cited the lack of a hydrogen infrastructure as a major barrier. Only one user indicated that fuel cells would be well received in the industry due to a growing interest in alternative fuel sources; however, the user was unsure whether fuel cells could compete technically with existing power sources.

In follow-up interviews respondents were asked what factors would convince them to procure a fuel cell-powered ground support vehicle. A parcel delivery company said that longer time between refueling (longer runtimes), proven durability (i.e., it can withstand the daily rigors of use by ground support personnel), and reduced vehicle emissions would convince them to procure a fuel cell ground support vehicle. It was noted that the airline industry and GSE manufacturers are working toward reducing emissions from airport vehicles and aircraft, particularly in areas with strict emission laws. The drive to reduce emissions was echoed by an airport authority representative, who cited efforts to replace ICE-powered ground support equipment with battery-powered vehicles in nonattainment areas. Two aviation service

providers emphasized incentives and operating costs as important drivers. One indicated that financial incentives would be more likely to influence their decision than dissatisfaction with a current technology, suggesting greater price sensitivity; the other stated that any improvements in the area of fuel and maintenance costs would get a lot of attention from them, as would availability of government incentives. Two airlines stated that fuel savings and ease of maintenance (i.e., reduced time for repairs and reduced parts to stock) would be important drivers.

Survey participants were asked about potential concerns over the use of hydrogen in airport ground support tractors. Users were asked to rate their level of concern on a scale of 1 to 7, with 1 being not at all concerned and 7 being very concerned. In general, there appears to be a relatively low level of understanding about hydrogen safety among potential airport ground support vehicle users. Three individuals provided scores ranging from 3 to 6, and three users indicated that they did not know enough about hydrogen to answer the question, although one of these respondents explained that airlines are accustomed to using hazardous fuels and probably would not be too concerned. An airport authority representative said that he assumed hydrogen storage and safety codes would be satisfied, but thought there could be potential misconceptions about safety among users.

In follow-up interviews, respondents were asked whether they would be interested in testing a fuel cell at one of their sites. All seven interviewees responded positively. Four indicated that they would definitely be interested, although one pointed out they would need guarantees that they would not be liable for equipment since their ground support agents have a reputation for being extremely hard on equipment. Three others said they would probably be interested; one said it would depend on the incentives available, and another speculated that since their company was testing fuel cells in automobiles they would probably be willing to test them in ground support vehicles too.

Eight respondents addressed the issue of how capital purchase decisions for specialty vehicles are made within their organizations. Six users indicated that their organizations conduct a formal return-on-investment analysis (incorporating total lifecycle costs, not just capital costs) when making purchase decisions. One airline at a large international airport stated that their company typically expects a one-year payback, but will at times extend that to three years. Two users also noted that they try to extend the life of the vehicle as long as possible; one said that many of their tractors are more than 20 years old. While only one user identified this as a standard procedure, it is important to consider that specialty vehicle users may have a predetermined and pre-approved make and model of ground support tractors that they typically purchase. This can make getting approval for any alternatives a greater challenge. Availability of government incentives are considered by five of the users when making a purchasing decision. One airline noted that they participated in the ILEAV program for a few years as part of an effort to acquire battery-operated baggage tractors. Another airline does not typically consider incentives, but said they are open to new ideas if something works better.

3.3.2.3 Market Research Summary Analysis

Through nine surveys and eight follow-up interviews with users, and surveys with four manufacturers, information was collected on the airport GSE market (focusing on baggage

tractors and aircraft pushback tractors). This included information on user requirements, usage patterns, customer satisfaction with current systems, and perceptions regarding PEM fuel cells as an alternative power source. Information gathered through these surveys and interviews, as well as information obtained through secondary research, is summarized below.

- The total estimated current market size for baggage tractors is 14,000 baggage tractors and 3,600 pushback tractors. The vast majority of these vehicles are ICE-powered; however, recent trends in the market for GSE suggest a move away from ICE and toward battery-powered vehicles.
- Proposed new emission standards by EPA, and even stricter standards for California-based airports proposed by CARB, are driving airports to transition to lower emission GSE.
- Federal programs, including VALE, provide financial incentives to airports and airlines to convert their fleets of GSE, including baggage and pushback tractors, to low-emission technologies.
- Efforts to reduce emissions, particularly in nonattainment areas, will drive the replacement of ICE-powered vehicles with alternatives in the near future, and currently battery-powered vehicles are the most widely known alternative. While battery-powered vehicles are quickly making inroads to this market, fuel cell tugs are also being developed and will be tested.
- At major airports where baggage tractors run nearly continuously, time required for maintenance and battery charging requires costly backup equipment or results in loss of productivity.
- GSE service providers and parcel delivery companies surveyed tended to have shorter operating times than the airlines, suggesting that downtime may be less of an issue for this sub-segment of the market.
- Battery charging and unscheduled downtime required by inadequate charge time can impact productivity, particularly for airlines. Unscheduled maintenance on GSE is frequent enough to present a significant cost to users. At least one airline interviewed relies on rapid chargers for battery-powered vehicles and maintains extra vehicles to ensure continued operations if a vehicle were to go down – both of which can require sizeable investments. Space required for battery charging can also represent a significant cost.
- While capital cost is an important factor considered by all users when making ground support tractor purchase decisions, reliability and operating costs appear to be the most important factors that influence these purchase decisions.
- Users are fairly satisfied with the performance of their current vehicles; however, it is interesting to note that factors they are most satisfied with – start-up time and fuel availability – are not among the most important purchase decision factors to users.
- Many ground support tractor users have considered alternatives to their current battery- or ICE-powered products, and some have looked at PEM fuel cell-powered vehicles as alternatives.
- The ability to demonstrate cost savings – operating and maintenance costs and financial incentives that reduce capital cost – will be key factors in supporting the adoption of PEM fuel cell-powered vehicles as alternatives to battery-powered vehicles.

- Hydrogen safety is not considered a major barrier, because airlines are accustomed to dealing with hazardous fuels; however, users have a relatively low level of understanding about hydrogen safety, and education will be required.

3.3.3 Lifecycle Cost Analysis

Fleets of baggage tractors currently in operation are a mix of diesel-, propane-, and battery-powered vehicles. While most users are satisfied with their current mode of operation, there is increasing interest in seeking alternatives to ICE-powered vehicles to meet emission requirements at airports. Government programs like the VALE program are providing monetary support to facilitate the transition to cleaner vehicles, including battery-powered vehicles and fast charging battery systems. As a result, many users are currently considering the replacement of older ICE-powered vehicles with cleaner options.

This lifecycle analysis compares PEM fuel cells in baggage tractors to current technologies. Baggage tractors are considered the most attractive near-term application in the GSE segment based on Battelle's market research. To determine whether fuel cells are a suitable alternative, the lifecycle costs of a 3,000 lb DBP PEM fuel cell-powered baggage tractor are evaluated against similarly sized diesel- and battery-powered baggage tractors in three different scenarios. Scenario 1 compares the lifecycle costs of vehicles operating for six hours a day, representing a relatively low operating time for baggage tractor use, based on survey data. Scenarios 2 and 3 compare the lifecycle costs of vehicles operating for 18 hours a day, representing a typical operating time for baggage tractors owned by a large airline at a major airport. In scenario 2, it is assumed that batteries are changed out during the day to ensure continuous operations for 18 hours. In scenario 3, fast charging systems are used at the end of the day, and batteries maintain a full charge for the entire 18 hours of operation.

For all three scenarios, the NPV of total costs of the system is calculated over a 15-year analysis period. A discount rate of 8% and an inflation rate of 1.9% are applied. All assumptions are consistent with the H2A model.[98]

3.3.3.1 Lifecycle Cost Analysis Assumptions by Scenario

Scenario 1 (6 Hours of Runtime)

Scenario 1 compares the lifecycle costs of PEM fuel cell-powered baggage tractors with both diesel- and battery-powered baggage tractors for six hours of continuous operation per day (Table 3-29). It is assumed that each battery-powered baggage tractor in this scenario has only one battery that is recharged at the end of the day. It is assumed that recharging stations occupy approximately 100 square feet at a typical facility and are built at a cost of $25 per square foot.

[98] DOE Hydrogen Program: DOE H2A Analysis. 2006. DOE H2A Analysis. Available at www.hydrogen.energy.gov/h2a_analysis.html [Accessed December 2006].

Table 3-29. Scenario 1: Cost Assumptions for Net Present Value Analysis of Baggage Tractors for 6 Hours per Day Runtime.

	Diesel-Powered ICE Baggage Tractor	Battery-Powered Baggage Tractor	PEM Fuel Cell-Powered Baggage Tractor
Size (lbs)	3,000	3,000	3,000
Cost ($)	25,000	30,000	35,000
Lifetime (yrs)	20	20	15
Yearly Hours of Operation[1]	2,190	2,190	2,190
Routine O&M Costs ($/yr)	1,920[2]	1,440[3]	1,280[4]
Other O&M Costs ($/yr)	800[5]	-	-
Cost of Fuel ($/yr)	5,475[6]	266[7]	2,190 ($5/kg) 3,504 ($8/kg)[8]
Cost of Refueling/Recharging ($/yr)	578[9]	-	91[10]
Battery Charger ($)	-	2,000	-
Replacement Costs ($)	-	5,000 – Year 5 and 10	15,000 – Year 10 2,600 – Year 10

[1] Assumes that baggage tractors work 6 hours a day, 365 days a year. Assumption based on Battelle market research surveys.
[2] Assumes 12 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[3] Assumes 9 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[4] Assumes 4 hours of maintenance per quarter at $80 per hour. Assumption based on Battelle market research surveys.
[5] Assumes $200 per quarter for other O&M. Other O&M costs include oil changes, filters, and brake fluid. Assumption based on Battelle market research surveys.
[6] Assumes a 15 gallon tank which is refueled once every three days. Cost of diesel is assumed at $3 per gallon. Size of tank based on diesel tow tractors in the marketplace. Industry communication, August 2006.
[7] Cost of electricity for charging the batteries. Assumption based on Battelle market research surveys.
[8] It is assumed that the fuel cell tractor holds 3.6 kg of hydrogen. The tank is filled once every 3 days at $5 per kg and $8 per kg. Industry communication, August 2006.
[9] It takes approximately 19 minutes to refuel per day. Refueling occurs once every three days. Assumes labor rate of $15/hr. Assumption based on Battelle market research surveys.
[10] It takes approximately 3 minutes to refuel the hydrogen in the fuel cell. In this scenario the tank is refueled once every three days. Industry communication, August 2006.

The fuel cell-powered baggage tractor is designed to carry up to 15 kW of load. The fuel cell-powered baggage tractor uses a 5 kW PEM fuel cell with ultracapacitors to support peak demands. In this scenario it is assumed that the fuel cells are replaced every 10 years for $15,000. The ultracapacitors are also replaced at 10 years for $2,600. Residual value for all three types of baggage tractors is $5,000. The lifecycle costs of hydrogen fuel for the PEM fuel cell-powered baggage tractor are examined at $5 per kg and $8 per kg. Hydrogen storage and delivery methods are not considered in this analysis. The $5 and $8 per kg cost of hydrogen used in this analysis assumes that storage and delivery costs are amortized in the hydrogen cost.

Scenario 2 (18 Hours of Runtime with Battery Change-outs)

In scenario 2 the baggage tractor operates 18 hours a day (Table 3-30). This is consistent with the operating time reported by airlines at major airports. Scenario 2 assumes that each battery-powered vehicle has two batteries that are changed out to maintain operation throughout the 18-hour period. The battery replacement schedule is every 5 years at a cost of $5,000. In this analysis, it is assumed that batteries are changed out when discharged. Each battery-powered vehicle in this scenario has two replacement batteries. It is assumed that recharging stations occupy approximately 100 square feet at a typical facility and are built at a cost of $25 per square foot.

Table 3-30. Scenario 2: Cost Assumptions for NPV Analysis of Baggage Tractors for 18 Hours per Day Operation with Battery Change-outs.

	Diesel-Powered ICE Baggage Tractor	Battery-Powered Baggage Tractor	PEM Fuel Cell-Powered Baggage Tractor
Size (lbs)	3,000	3,000	3,000
Cost ($)	25,000	30,000	35,000
Lifetime (yrs)	20	20	15
Yearly Hours of Operation[1]	6,570	6,570	6,570
Routine O&M Costs ($/yr)	1,920[2]	1,440[3]	1,280[4]
Other O&M Costs ($/yr)	800[5]	-	-
Cost of Fuel ($/yr)	16,425[6]	800[7]	6,570 ($5/kg) 10,512 ($8/kg)[8]
Cost of Refueling/Recharging ($/yr)	1,734[9]	1,825[10]	274[11]
Battery Charger ($)	-	2,000	-
Replacement Costs ($)	-	5,000 – Year 5 and 10	15,000 – Year 5 and 10 2,600 – Year 10

[1] Assumes that baggage tractors work 18 hours a day, 7 days a week. Assumption based on Battelle market research surveys.
[2] Assumes 12 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[3] Assumes 9 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[4] Assumes 4 hours of maintenance per quarter at $80 per hour. Assumption based on Battelle market research surveys.
[5] Assumes $200 per quarter for other O&M. Other O&M costs include oil changes, filters, and brake fluid. Assumption based on Battelle market research surveys.
[6] Assumes a 15 gallon tank which is refueled once every day. Cost of diesel is assumed at $3 per gallon. Size of tank based on diesel tow tractors in the marketplace. Industry communication, August 2006.
[7] Cost of electricity for charging the batteries. Assumption based on Battelle market surveys.
[8] It is assumed that the fuel cell tractor holds 3.6 kg of hydrogen. The tank is filled only once a day at $5 per kg and $8 per kg. Industry communication, August 2006.
[9] It takes approximately 19 minutes to refuel per day. Refueling occurs once per day. Assumes labor rate of $15/hr. Assumption based on Battelle market research surveys.
[10] It takes approximately 10 minutes to change out a battery. Assumes that, to run 18 hours a day, battery has to be changed out 2 times. Assumes a labor rate of $15/hr. Batteries are charged at night. Assumption based on Battelle market research surveys.
[11] It takes approximately 3 minutes to refuel the hydrogen in the fuel cell. The tank is refueled once per day. Industry communication, August 2006.

The fuel cell baggage tractor uses a 5 kW fuel cell with ultracapacitors to support peak demands. Lifecycle costs of the PEM fuel cell-powered baggage tractor in this scenario are examined with the cost of hydrogen at $5 per kg and $8 per kg. Costs of the PEM fuel cell-powered baggage tractor were assumed to be $35,000 based on information provided by fuel cell manufacturers on the potential cost of fuel cells for this application. It should be noted that this is an estimated cost and that the actual commercial product may be different than what has been quoted in this analysis. The analysis assumes a 10-year life for the ultracapacitors, and replacement costs are assumed to be $2,600.[99] The cost of ultracapacitors is expected to go down with increasing production volumes. Scenario 2 assumes that the PEM fuel cell stack will be replaced every 5 years at $15,000. The residual value of diesel-powered baggage tractors and battery-powered electric baggage tractors at the end of 15 years is assumed to be approximately $5,000.

[99] Personal communication between Kathya Mahadevan (Battelle) and Scott Thompson (Maxwell Technologies), September 2006.

Scenario 3 (18 hours of Runtime with Fast Charging)

Assumptions for scenario 3 (Table 3-31) are similar to scenario 2 with the exception of costs for battery recharging and capital costs for the battery-powered baggage tractor. Some baggage tractor users do not change out batteries during the day and instead use fast charging during the 6-hour window of overnight downtime. Because batteries are charged at the end of the day and do not interrupt operations, no downtime costs are associated with recharging. Capital costs, however, will increase due to the cost of fast charging battery ports. Fast charging battery ports, such as those installed in airports through the ILEAV program, are assumed to cost $15,000.[100]

Table 3-31. Scenario 3: Cost Assumptions for NPV Analysis of Baggage Tractors for 18 Hours per Day Operation with Fast Charging.

	Diesel-Powered ICE Baggage Tractor	Battery-Powered Baggage Tractor	PEM Fuel Cell-Powered Baggage Tractor
Size (lbs)	3,000	3,000	3,000
Cost ($)	25,000	30,000	35,000
Lifetime (yrs)	20	20	15
Yearly Hours of Operation[1]	6,570	6,570	6,570
Routine O&M Costs ($/yr)	1,920[2]	1,440[3]	1,280[4]
Other O&M Costs ($/yr)	800[5]	-	-
Cost of Fuel ($/yr)	16,425[6]	200[7]	6,570 ($5/kg) 10,512 ($8/kg)[8]
Cost of Refueling/Recharging ($/yr)	1,734[9]	-	274[10]
Fast Charger ($)	-	15,000 per charging port	-
Replacement Costs ($)	-	5,000 – Year 5 and 10	15,000 – Year 5 and 10 2,600 – Year 10

[1] Assumes that baggage tractors work 18 hours a day, 365 days a year, 7 days a week. Assumption based on Battelle market research surveys.
[2] Assumes 12 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[3] Assumes 9 hours of maintenance per quarter at $40 per hour. Assumption based on Battelle market research surveys.
[4] Assumes 4 hours of maintenance per quarter at $80 per hour. Assumption based on Battelle market research surveys.
[5] Assumes $200 per quarter for other O&M. Other O&M costs include oil changes, filters, and brake fluid. Assumption based on Battelle market research surveys.
[6] Assumes a 15 gallon tank which is refueled once everyday. Cost of diesel is assumed at $3 per gallon. Size of tank based on diesel tow tractors in the marketplace. Industry communication, August 2006.
[7] Cost of electricity for charging the batteries. Assumption based on Battelle market research surveys.
[8] It is assumed that the fuel cell tractor holds 3.6 kg of hydrogen. The tank is filled only once a day at $5 per kg and $8 per kg. Industry communication, August 2006.
[9] It takes approximately 19 minutes to refuel per day. Refueling occurs once per day. Assumes labor rate of $15/hr. Assumption based on Battelle survey responses.
[10] It takes approximately 3 minutes to refuel the hydrogen in the fuel cell. The tank is refueled once per day. Industry communication, August 2006.

3.3.3.2 Lifecycle Cost Results by Scenario

Scenario 1 Results (6 Hours of Runtime)

The battery-powered baggage tractors are most economical based on the lifecycle cost analysis presented in Table 3-32. The NPV of the total costs of the PEM fuel cell-powered baggage tractor is 32% more than the NPV of the total cost of the battery-powered baggage tractor and 30% less than the NPV of the total cost of the diesel-powered baggage tractor with hydrogen at

[100] Personal communication between Kathya Mahadevan (Battelle) and Jake Plante (Federal Aviation Administration), September 2006.

$5 per kg. With hydrogen at $8 per kg, the NPV of total costs of the battery-powered baggage tractor is 42% less than the NPV of the total costs of the PEM fuel cell-powered baggage tractor. While diesel-powered baggage tractors require the lowest capital investment, over the lifetime they require significant investment in operation and maintenance. In this scenario, the change in the cost of hydrogen impacts the investment required to operate and maintain a PEM fuel cell-powered baggage tractor over the 15-year lifetime. Despite the increase in hydrogen costs, PEM fuel cell-powered baggage tractors are more attractive than diesel baggage tractors in this scenario.

Table 3-32. Scenario 1: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel-, and Battery-Powered Baggage Tractors for 6 Hours of Runtime.

	Diesel-Powered Baggage Tractor	Battery-Powered Baggage Tractor	PEM Fuel Cell-Powered Baggage Tractor (H_2 - $5 per kg)	PEM Fuel Cell-Powered Baggage Tractor (H_2 - $8 per kg)
NPV of Total Capital Costs ($)	21,537	34,306	40,256	40,256
NPV of Total O&M Costs (Including Cost of Fuel) ($)	85,282	16,584	34,616	47,390
NPV of Total Costs of the System ($)	106,819	50,890	74,873	87,646

Scenario 2 Results (18 Hours of Runtime with Battery Change-outs)

The lifecycle cost analysis in scenario 2 shows that PEM fuel cell-powered baggage tractors with costs of hydrogen at $5 per kg require 41% less investment than diesel-powered baggage tractors over the 15-year analysis period based on the NPV of the total costs of the system (Table 3-33). The NPV of the total cost of the PEM fuel cell-powered baggage tractor is 36% more than the NPV of the total cost of the battery-powered baggage tractor. On a total capital cost basis, over the 15-year analysis period, PEM fuel cell-powered baggage tractors require 59% more capital investment than diesel-powered baggage tractors, while requiring only 15% more capital investment than battery-powered baggage tractors. When O&M costs over the 15-year analysis period are examined, diesel tugs require 2.5 and 5 times as much investment as PEM fuel cell-powered baggage tractors and battery-powered tractors, respectively. As illustrated in Table 3-33, battery-powered baggage tractors have the lowest operation and maintenance costs over the 15-year lifetime. Over the 15-year analysis period, PEM fuel cell-powered baggage tractors cost approximately 50% more in operation and maintenance than battery-powered baggage tractors.

The cost of hydrogen significantly impacts the investment required to operate and maintain the PEM fuel cell-powered baggage tractor. The NPV of the total cost of the PEM fuel cell-powered baggage tractor increases from $131,864 to $170,184 when hydrogen is varied from $5/kg to $8/kg. An increase in hydrogen cost to $8 per kg significantly impacts the competitiveness of PEM fuel cell-powered baggage tractors compared to battery-powered baggage tractors. The NPV of battery-powered baggage tractor costs are approximately 50% less over its lifetime than the PEM fuel cell-power baggage tractor when the cost of hydrogen is $8 per kg.

Table 3-33. Scenario 2: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel- and Battery-Powered Baggage Tractors for 18 Hours of Runtime with Battery Change-outs.

	Diesel-Powered ICE Baggage Tractor	Battery-Powered Baggage Tractor	PEM Fuel Cell-Powered Baggage Tractor (H_2 - $5 per kg)	PEM Fuel Cell-Powered Baggage Tractor (H_2 - $8 per kg)
NPV of Total Capital Costs ($)	21,537	45,189	52,890	52,890
NPV of Total O&M Costs (Including Cost of Fuel) ($)	202,964	39,516	78,973	117,293
NPV of Total Costs of the System ($)	224,501	84,705	131,864	170,184

Scenario 3 Results (18 hours of Runtime with Fast Charging)

Scenario 3 shows the impact of the higher capital costs associated with fast battery charging stations on the NPV of total system costs (Table 3-34). When just one port is installed (enabling one vehicle to be charged at a time during evening downtime), PEM fuel cell-powered baggage tractors are 48% more expensive than battery-powered baggage tractors. However, as the number of ports increases, so does the attractiveness of PEM fuel cell-powered baggage tractors compared to battery-powered baggage tractors. By installing three ports instead of one, PEM baggage tractors become just 35% more expensive than battery-powered baggage tractors. Realistically, airlines with large fleets of battery-powered baggage tractors will likely install more than one or two fast charging ports.

Table 3-34. Scenario 3: Lifecycle Cost Comparison of PEM Fuel Cell-, Diesel- and Battery-Powered Baggage Tractors for 18 Hours of Runtime with Fast Charging.

	Diesel-Powered Baggage Tractor	Battery-Powered Baggage Tractor (1 Fast Charging Port)	Battery-Powered Baggage Tractor (3 Fast Charging Ports)	PEM Fuel Cell-Powered Baggage Tractor (H_2 - $5 Per Kg)
NPV of Total Capital Costs ($)	21,537	53,177	81,842	52,890
NPV of Total O&M Costs (Including Cost of Fuel) ($)	202,964	15,942	15,942	78,973
NPV of Total Costs of the System ($)	224,501	69,119	97,425	131,864

It is also worth noting that this scenario assumes that operators adhere to a standard charging routine and ensure that the vehicles receive a full charge each night. According to some interviewees, this policy is not always put into practice and vehicles may run out of power before completing the required 18 hours of operation. As a result, airlines may be forced to maintain enough extra charged vehicles to ensure continuous operations. The cost of maintaining extra vehicles does not appear in the lifecycle cost analysis but should be considered when comparing the battery- and PEM fuel cell-powered baggage tractors.

3.3.3.3 Lifecycle Cost Summary

From a lifecycle cost perspective, PEM fuel cell-powered baggage tractors are less expensive than diesel-powered baggage tractors in both the low operating time (6 hours/day) and high operating time (18 hours/day) scenarios. This is true whether the cost per kg of hydrogen is $5 or $8 per kg. While the diesel tractors are more attractive from a capital cost perspective, the cost of diesel fuel and the O&M requirements have a notable impact on the NPV of the total system cost of the diesel tractor over a 15-year period.

Battery-powered baggage tractors have a superior lifecycle cost to PEM fuel cell-powered baggage tractors in both the low operating time and high operating time scenarios. The PEM fuel cell-powered tractor is impacted most by hydrogen and the durability of the fuel cell (15 years compared to 20 years for the battery-powered tractor). However, as the number of fast charging battery stations increases, the associated capital costs erode some of this cost advantage over PEM fuel cell-powered baggage tractors. So the size of the fleet may affect the attractiveness of battery-powered vehicles over PEM fuel cell-powered vehicles. Battery-powered baggage tractor lifecycle costs are most affected by capital cost for battery charging infrastructure, battery change-out time, and lifetime of the battery.

3.3.4 Sensitivity Analysis

3.3.4.1 Sensitivity Analysis Modeling Methodology

The factors that were varied in the PEM fuel cell sensitivity analysis are shown in Table 3-35. Each factor was varied by ±10% of the base assumption. For example, the base value assumed for the life of the PEM fuel cell-powered baggage tractor was 15 years; the high value (+10%) is 16.5 years, and the low value (-10%) is 13.5 years. In the sensitivity analysis, the average annual cash outlay ($\overline{C}$) for use of the PEM fuel cell-powered baggage tractor was calculated using equation 1. Hydrogen costs and operations and maintenance costs are assumed to be annual averages.

$$\overline{C} = \frac{Baggage\,Tractor\,Cost}{Baggage\,Tractor\,Life} + \frac{Fuel\,Cell\,Cost}{Fuel\,Cell\,Life} + \frac{Battery\,Cost}{Battery\,Life} + Hydrogen\ Cost + O\ \&\ M\ Cost \qquad \text{Equation 1}$$

Table 3-35. Cost Assumptions for PEM Fuel Cell-Powered Baggage Tractor Sensitivity Analysis: Base Assumption +/- 10%.

	Base Value	-10% of Base Value	+10% of Base Value
O&M (Including Refueling Time) ($)	1,554	1,399	1,709
Baggage Tractor Cost ($)	35,000	31,500	38,500
Baggage Tractor Life (years)	15	13.5	16.5
Fuel Cell Replacement, ($)	15,000	13,500	16,500
Fuel Cell Life (years)	5.0	4.5	5.5
Hydrogen ($/kg)	5.00	4.50	5.50

3.3.4.2 Sensitivity Analysis Results

The results of the sensitivity analysis are shown in Figure 3-24. The factors with the largest leverage on the average annual cost of PEM fuel cell-powered baggage tractors are, in descending order: the cost of hydrogen, the fuel cell life, and capital cost of the PEM fuel cell.

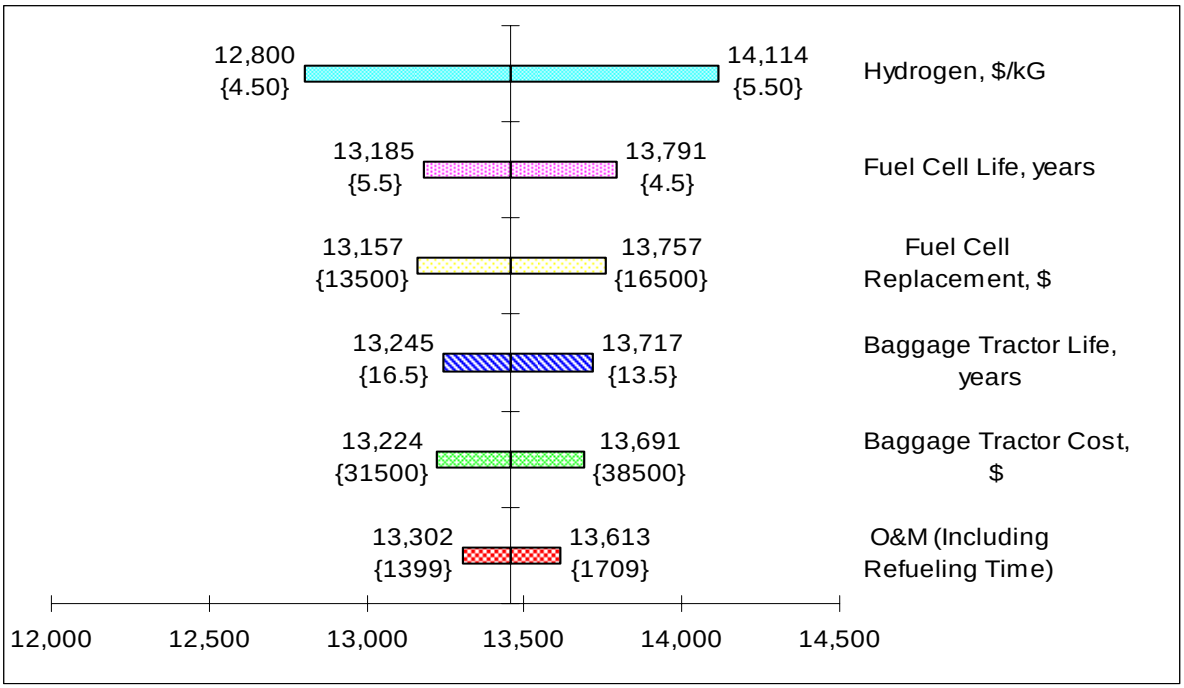

Figure 3-24. Sensitivity Analysis of Average Annual Cost of Owning and Operating a PEM Fuel Cell-Powered Baggage Tractor.

3.3.5 Market Penetration Analysis

3.3.5.1 Market Adoption Assumptions

Three cases were used to evaluate the potential market penetration of PEM fuel cells as a power source for airport baggage tractors. These cases vary in the extent of government interventions pursued. The base case assumes no government intervention. The communication case assumes that the government will engage in communications that will increase the strength of the innovation parameter in the model. The subsidized case assumes that for five years the government subsidizes the purchase of PEM fuel cells up to 50% of the cost of the baggage tractor (slightly less than $1,000 per kW). The subsidy makes the lifecycle cost of a PEM fuel cell-powered baggage tractor substantially lower than ICE-powered baggage tractors and comparable to battery-powered baggage tractors in some cases.

Table 3-36 shows the market penetration assumptions used in the three cases for adopting PEM fuel cell-powered baggage tractors. An EPA study showed that there were about 10,505 baggage tractors in use in 1999.[101] Assuming a 4% market growth rate, about 531 baggage tractors were purchased in 2006.

[101] EPA. 1999. Technical Support for Development of Airport Ground Support Equipment Emission Reductions. EPA-420-R-99-007.

For all three cases, it was assumed that the purchase of PEM fuel cell-powered baggage tractors is driven by regulation and that the value of PEM fuel cell-powered baggage tractors to the market will be significantly greater than diesel-powered baggage tractors and comparable to battery-powered tractors in some cases. As a result, it is assumed that only 40% of this market is available for penetration by PEM fuel cell-powered baggage tractors. It is also assumed that over time, PEM fuel cells will become more competitive with batteries. Therefore, the initial annual market for PEM fuel cell baggage tractors is 213 units for all three market adoption cases.

For all three cases, it was assumed that PEM fuel cell-powered baggage tractors were acquired at an initial cost of $26,000 per unit (substantial improvements to PEM fuel cell-powered baggage tractors were assumed). In the subsidized case, the subsidy would be $3,000 per unit. The three cases also assume that a hydrogen infrastructure is in place.

Table 3-36. Assumptions for PEM Fuel Cell-Powered Baggage Tractor Adoption in Airports.

Assumption	Base Case	Communication Case	Subsidy Case
Market Growth Rate	4%	4%	4%
Government Actions	None	Communications	Subsidize purchase @ $3,000 per unit
Values of *p* and *q*	p = 0.008 q = 0.423	p = 0.012 q = 0.423	p = 0.070 q = 0.423
Initial Number of Baggage Tractors Purchased	532	532	532
Initial Number of PEM Fuel Cell-Powered Baggage Tractors Purchased *(m)*	40% of baggage tractors; m = 213	40% of baggage tractors; m = 213	40% of baggage tractors; m = 213
Average Initial Price of PEM Fuel Cell Baggage Tractors	$26,000	$26,000	$26,000
Rate of Price Reduction	Stable; no price reduction	Stable; no price reduction	Stable; no price reduction

3.3.5.2 Market Penetration Results

The models show that, in the base and communication cases, the first year that 100 units are sold annually is ten years and nine years, respectively, after commercial introduction (Figures 3-25 and 3-27). In the subsidized case, 100 units are sold much earlier (five years after commercial introduction) (Figure 3-29). Further, the models show that, in the base and communication cases, the first years in which $1 million in annual sales are achieved will be seven years and six years after commercial introduction, respectively. In the subsidized case, $1 million in sales are expected three years after commercial introduction.

Predictions from the model are consistent with actual results from the ILEAV Pilot Program.[102] Grants potentially totaling $17 million were made available to airports to purchase cleaner alternative fuel vehicles. About 39% ($6.9 million) of the available funding was used. Purchases were made over a five-year period. The first year involved administrative execution

[102] FAA. 2006. Final Report: Inherently Low Emission Airport Vehicle Pilot Program. Available at http://www.faa.gov/airports_airtraffic/airports/environmental/vale/media/ileav_report_final_2005.pdf#search=%22Final%20Report%3A%20Inherently%20Low%20Emission%20Airport%20Vehicle%20Pilot%20Program%22 [Accessed June 2006].

`of the grant. Over the subsequent four years, funding was available for use. Purchases of vehicles under the grant program included 275 alternative fuel baggage tractors (about 69 per year of available funding). Of the 275 alternative fuel baggage tractors, 56% were battery-powered. The subsidy case for PEM fuel cells predicted that 248 baggage tractors (62 per year of available funding) would be purchased during a comparable time period with subsidies of about $1.2 million. Assuming that a $3,000 per unit subsidy for five years were used to spur early purchases of PEM fuel cell-powered baggage tractors, the cost to government would be about $1 million.

Table 3-37 provides a summary of the sales and market share data presented for each of the three cases described above.

Table 3-37. Summary of Sales and Market Share for Alternative Market Adoption Cases for PEM Fuel Cell-Powered Baggage Tractor Adoption in Airports.

	5 Years After Commercial Introduction			10 Years After Commercial Introduction			15 Years After Commercial Introduction			20 Years After Commercial Introduction		
	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case
Annual Sales (Units)	20	29	129	108	143	275	285	311	352	414	419	429
Annual Sales ($ millions)	.5	.8	3.4	2.8	3.7	7.2	7.4	8.1	9.1	10.8	11	11.2
Market Share (%)	3	4	20	14	18	35	30	32	37	35	36	37

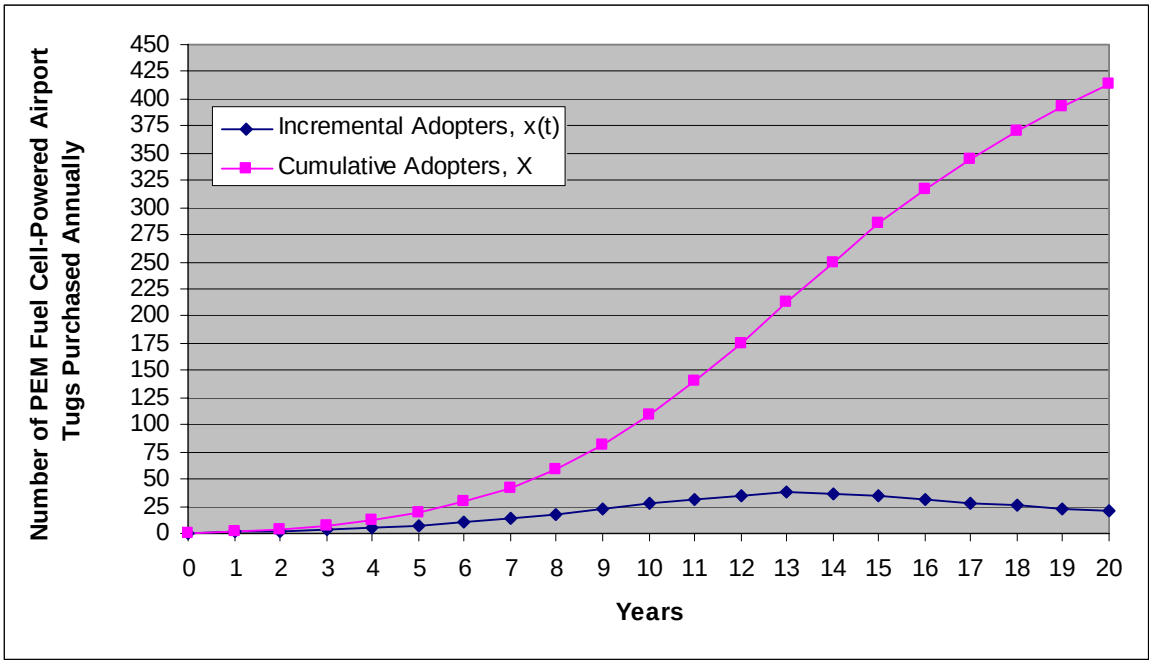

Figure 3-25. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Base Case.

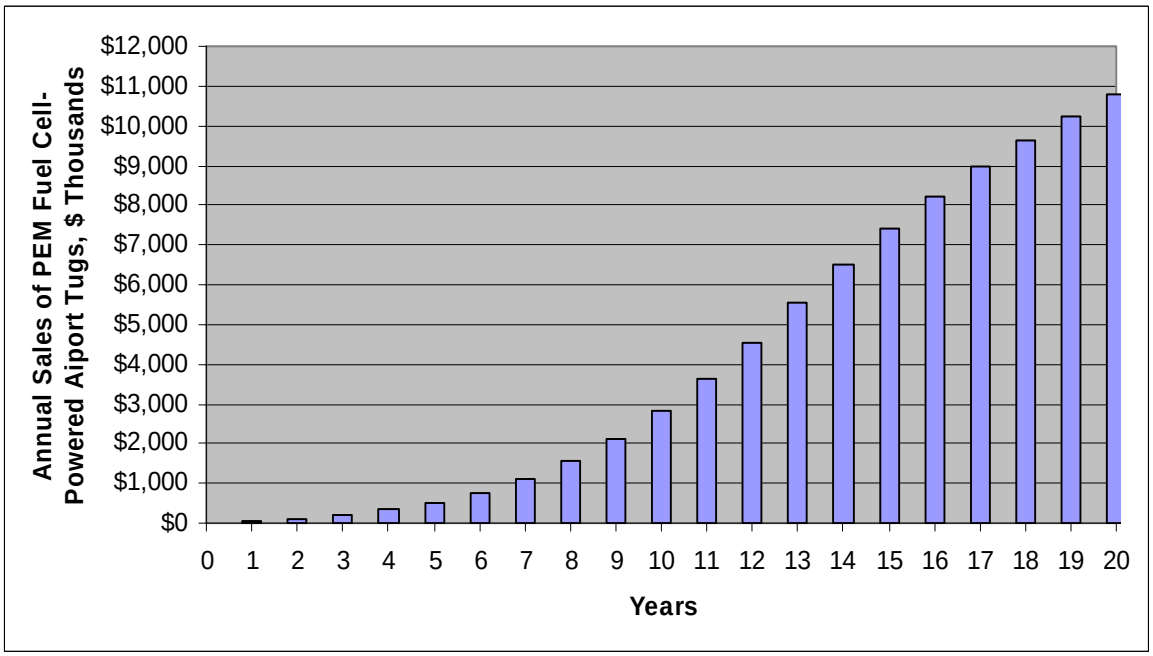

Figure 3-26. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Base Case.

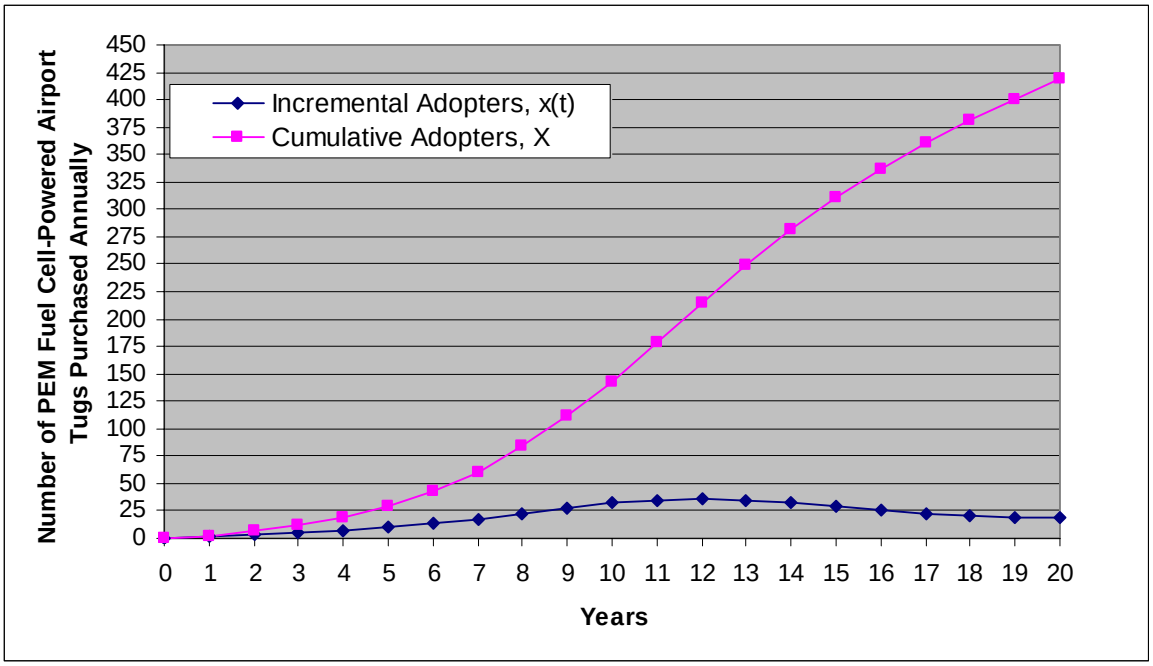

Figure 3-27. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Communication Case.

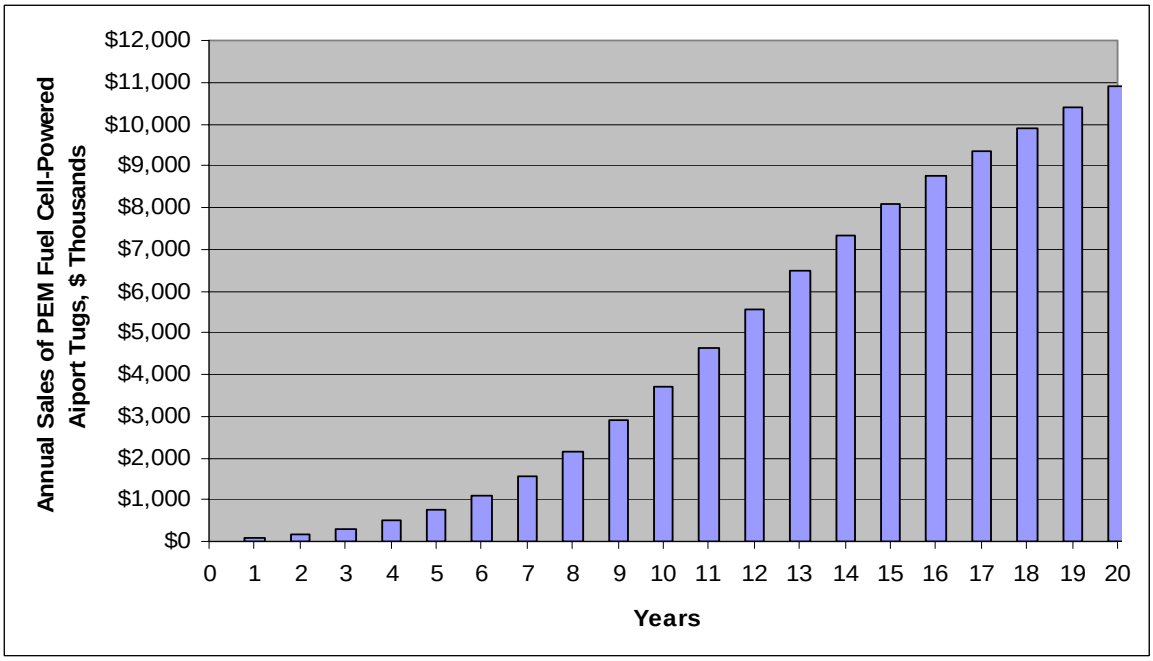

Figure 3-28. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Communication Case.

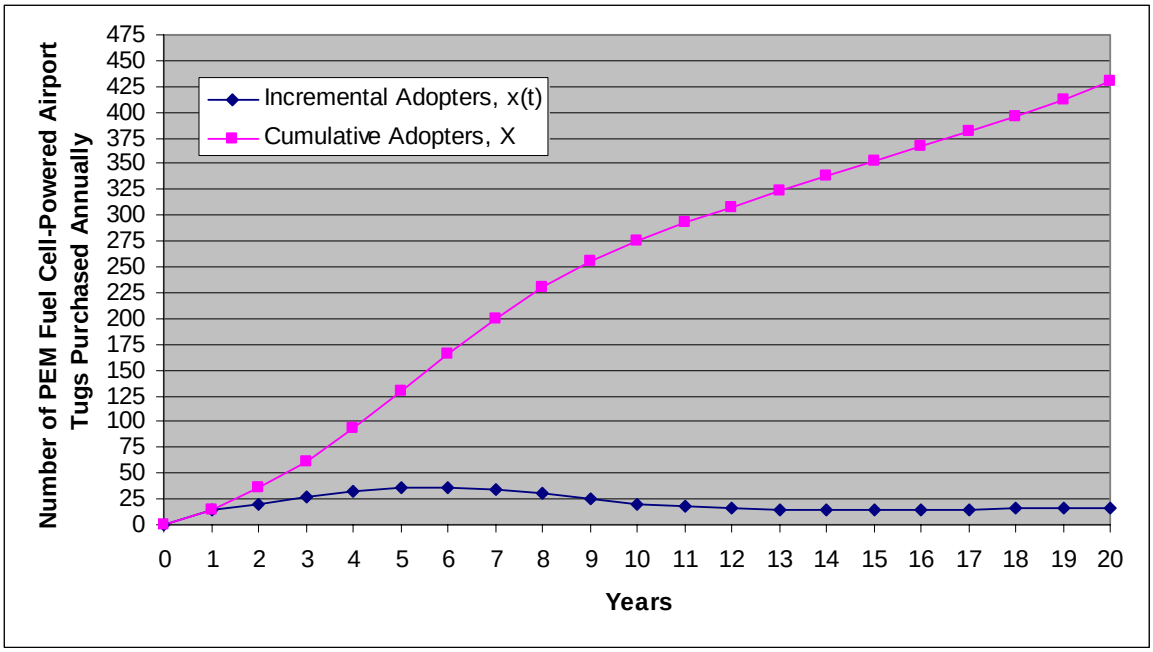

Figure 3-29. Adoptions of PEM Fuel Cell-Powered Baggage Tractors in the Subsidy Case.

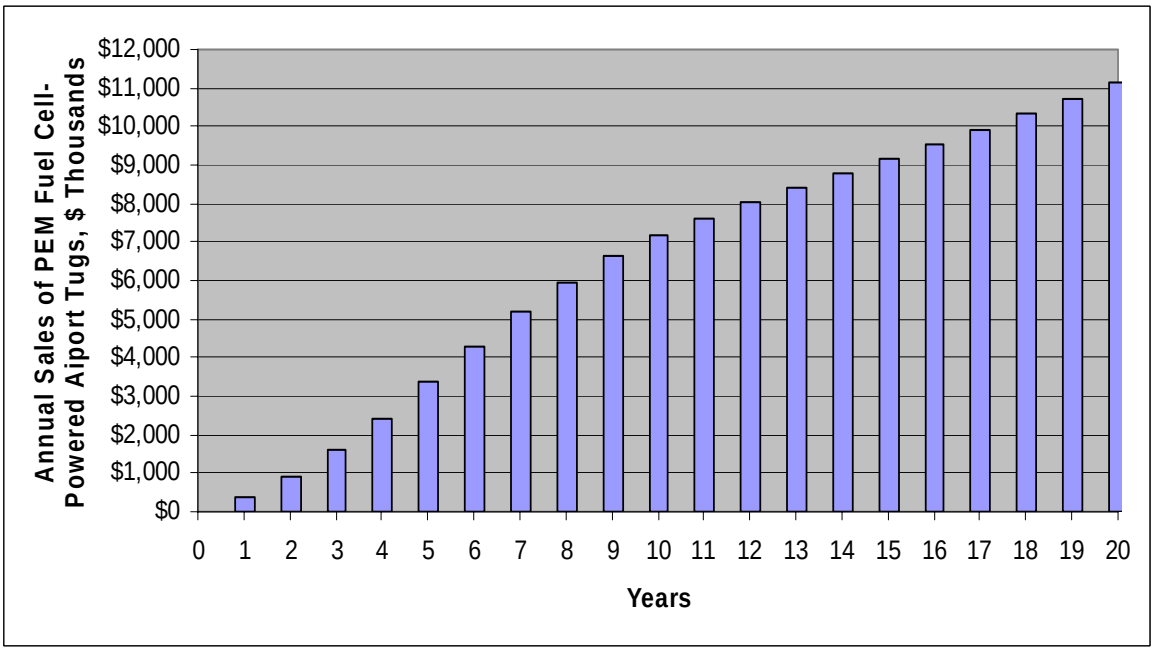

Figure 3-30. Sales of PEM Fuel Cell-Powered Baggage Tractors in the Subsidy Case.

3.3.6 Value Proposition for PEM Fuel Cells in Baggage Tractors

Airport ground support tractors represent a potentially attractive near-term market for PEM fuel cells if costs can be reduced. Air quality concerns and pressure to reduce emissions at airports and surrounding metropolitan areas are perhaps the most important drivers in this market. Many airports are located in emissions nonattainment areas, where the use of zero-emissions vehicles is

encouraged or even mandated.[103] Recent concerns over air quality at airports have led manufacturers and users of the ground support vehicles to consider alternatives to the industry standard, diesel- and gasoline-powered ICEs. Programs such as ILEAV and its successor, the VALE program, provide airports and airlines with an opportunity to evaluate low-emission technologies, including battery-, CNG-, LPG-, and PEM fuel cell-powered vehicles, in an airport environment. Increasingly strict state and regional air quality requirements, such as those proposed by CARB, will also create incentives for the adoption of low-emission GSE.

The relatively small market size – while a disadvantage in some respects – could potentially make it easy for the PEM fuel cell industry to quickly penetrate this market. Because the types of vehicles used to provide ground support services are similar to work tractors used in a variety of industrial applications, this market segment could also provide an important entry point to the broader market of work trucks and tractors. The technology development experience and credibility and demonstration experience gained might be readily translated to the much larger work trucks and tractors market. In addition, captive GSE fleets offer an opportunity to test distributed hydrogen generation and fueling for specialty vehicles, potentially diminishing the fueling infrastructure challenges associated with the use of PEM fuel cells on a larger or more distributed scale.

There are, however, several potential barriers to PEM fuel cells exploiting these market conditions. For PEM fuel cells to become a viable alternative in the airport ground support tractor market, they must: be cost effective; compete effectively against batteries; be able to enter the market quickly; have an available and affordable source of hydrogen; and become known by the airport industry and accepted as a reliable alternative.

The ability for PEM fuel cell-powered baggage tractors to compete effectively in this market will be largely determined by the ability to bring down lifecycle costs of PEM fuel cell-powered tractors relative to battery-powered incumbents. Currently, battery-powered baggage tractors have a superior lifecycle cost compared to PEM fuel cell-powered baggage tractors whether they are being used just one shift a day or being operated around the clock. However, the potential to improve the total costs of the PEM fuel cell-powered tractors exists through improvements in the cost of hydrogen and the durability of the PEM fuel cell.

While PEM fuel cells are not as attractive on a total cost basis, they offer many advantages over batteries. While batteries can meet power requirements for baggage tractors, they may not be capable of providing the horsepower required to tow large aircraft. Because fuel cells may outperform batteries with these heavier vehicles, the fact that fuel cells can support a wider variety of vehicles may provide a compelling case to some. Also, battery recharging can result in lost productivity or can require maintaining extra vehicles to ensure continued operations. If baggage tractor operators follow scheduled charging routines, this is less of an issue. The airline industry is strongly affected by unscheduled downtime, particularly where they maintain round-the-clock operations. Hence, PEM fuel cells may offer a time-saving cost advantage in these environments. Furthermore, the financial competitiveness of PEM fuel cells relative to batteries will depend on the size of the fleet and the number of battery charging stations required for

[103] Weeks, B. 2005. Making a Case for Hydrogen in the GSE Industry. Ground Support Magazine (May). Available at http://www.groundsupportmagazine.com/publication/article.jsp?pubId=1&id=1044 [Accessed June 2006].

keeping the fleet operational throughout the day. PEM fuel cell-powered tractors are expected to become more attractive as the size of the fleet, and the corresponding number of chargers required, increases.

For successful penetration of PEM fuel cell-powered GSE, demonstration projects and financial incentives, similar to those provided for low-emission vehicles under the VALE program, are critical. Initiatives must be directed to PEM fuel cell-powered baggage tractors and aircraft pushback vehicles in order to help prove that reliability, annual O&M cost, and operating performance are competitive with battery-powered vehicles. While existing incentives potentially create an opportunity for PEM fuel cell-powered baggage tractors to enter the airport baggage tractor market, the door may not be open for long. The ILEAV pilot program and its successor, the VALE program, are resulting in the creation of CNG and battery recharging infrastructures at major airports. These may strongly negatively influence the adoption of fuel cells where a hydrogen infrastructure would have to be built and additional airport space leased. To date, only a limited number of airports have made such commitments, but continued subsidies are likely to result in an increasing number of airports making comparable decisions and commitments within the next few years. To compete with other low-emission technologies currently penetrating the market, PEM fuel cells will need to enter the market quickly, and a hydrogen fueling infrastructure will need to be put in place.

Furthermore, PEM fuel cell-powered vehicles need to become more widely known and better understood by airports, airlines, aviation ground support service providers, and cargo and parcel delivery companies that use air service. Because those within the industry are not yet "sold" on fuel cells, a concerted effort to educate and inform them of the potential benefits of PEM fuel cells and the safety of hydrogen use will be essential to successful market penetration.

4.0 SUMMARY OF FINDINGS AND CONCLUSIONS

The pathway to fuel cell vehicles will likely include the introduction of direct hydrogen PEM fuel cells in near-term markets with fewer technical challenges than the automobile market. This study focused on identifying near-term market opportunities for direct hydrogen PEM fuel cells in "pre-automotive" applications that could support fuel cell industry growth and learning. However, Department of Defense applications were excluded from this scope of work. It includes an assessment of 36 likely near-term (2008) and mid-term (2012) market segments for PEM fuel cells in the 1 to 250 kW size range, as well as a detailed market and economic analysis of PEM fuel cells and competing alternatives in three of the most promising near-term markets.

The most promising near-term opportunities for PEM fuel cells in this size range are in specialty vehicle and backup power applications. PEM fuel cell systems are commercially available to support these applications and offer several potential advantages over current technologies, including lower emissions, lower O&M requirements, longer runtimes, and other productivity enhancement advantages. While both backup power and specialty vehicle users are generally satisfied with their current systems, specialty vehicle users did identify opportunities for improvement that correspond with these benefits. Across the various specialty vehicle markets analyzed, users are looking for alternatives to batteries to increase runtime and productivity, and reduce safety risks, and for opportunities to reduce O&M costs associated with their ICE vehicles. Backup power users identified few concerns with current systems, although the runtime to support extended power outages and emissions were identified as concerns by a small proportion of users. About half of specialty vehicle users had considered alternatives to their current power systems compared to 33% of backup power users surveyed.

The detailed analyses of three near-term markets suggest that PEM fuel cells offer a compelling value proposition in these markets under some circumstances. In backup power applications for emergency response radio towers, PEM fuel cells are competitive with battery-generator systems from a lifecycle cost perspective when shorter runtimes are required (i.e., 1 to 3 days). Fuel cells may also be more attractive from a lifecycle cost perspective when operating in harsh environments, which shorten the lifetime of batteries. However, PEM fuel cells were found to be much less attractive than alternatives when longer backup power runtimes are required (i.e., 1 week or more) due to the high cost of hydrogen storage and use. Financial incentives, demonstration projects, and fuel availability will be critical for PEM fuel cells to compete effectively in this segment and capture a sizeable market share in the near- to mid-term.

The analysis of PEM fuel cells for forklifts in indoor warehousing environments suggests that their value compared to alternatives varies significantly by application and is negatively impacted by declining hours of operation. PEM fuel cells can provide value over battery-powered forklifts in high productivity environments. When forklifts are operated under conditions of near continuous use, fuel cell vehicles are significantly less expensive than similar battery-powered systems from a lifecycle cost perspective. Advantages of PEM fuel cell systems operating under such conditions include rapid refueling, eliminating time and cost of replacing batteries, constant voltage delivery, increased productivity by eliminating battery recharging time, fewer repairs due to fewer moving parts, and elimination of battery storage/changing rooms

and associated costs. For widespread adoption in this market, reliability must be proven through demonstration projects, and capital cost and fuel availability must be addressed.

The third near-term market analyzed, airport ground support equipment, will be more difficult for PEM fuel cells to penetrate in the near-term. While PEM fuel cells offer a cost advantage over ICE-powered systems, which currently are the most widely used technology in baggage tractors, they are currently less attractive from a lifecycle cost perspective than battery-powered systems, regardless of frequency of use. Recent federal and state air quality regulation and federal incentive programs are driving airlines to use low emission alternatives to ICE, and batteries are well-positioned to gain market share. If PEM fuel cells are to compete effectively in this market, they will need to be more cost effective than battery systems, be able to enter the market quickly, and have an affordable source of hydrogen available. While the market for airport ground support vehicles may be less attractive than the others, successful demonstrations in this market may still provide value. The vehicles used are similar to those used in the broader, much larger market for industrial work trucks/tractors and may provide an important entry point.

To penetrate these near- and mid-term markets for PEM fuel cells in backup power and specialty vehicle applications, it will be critical to ensure an affordable and available source of hydrogen near the target markets. A strategic focus of DOE should be on the location of hydrogen and on corresponding incentives for hydrogen refueling.

Alternatives to PEM fuel cells exist that adequately meet critical market needs, although fuel cells do provide some incremental benefits over alternatives. To drive market penetration, incentives that lower initial capital costs likely will be necessary in the short term. A technical focus on durability, reliability, and reducing the cost of PEM fuel cells will also be critical for market adoption. Finally, awareness is a critical first step in purchasing. It will be important to communicate to potential users the benefits of PEM fuel cells over existing technologies, in addition to the experiences gained through fuel cell demonstrations.

APPENDIX A: Survey Instruments for Analysis of Pre-automotive Markets

A.1 Phase 1 Survey: Exploratory Research Questions for PEM Fuel Cell Manufacturers and Key Suppliers

The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) is focused on the development of hydrogen fuel cell vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, EERE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications in the public and private sector. In addition, EERE is also focused on facilitating market introduction of direct hydrogen PEM fuel cells to meet the requirements specified by the Energy Policy Act 2005.

To support EERE in this endeavor, Battelle is conducting an evaluation of private and public sector transition market opportunities for direct hydrogen PEM fuel cells in the 1-250 kW size range to 2015 (transition markets are "pre-automotive markets that include specialty vehicles, back-up power, and auxiliary power). Battelle is seeking your input to some exploratory questions regarding likely transition applications and markets, availability of products, and potential strategies for supporting market acceptance of direct PEM hydrogen fuel cells.

Battelle will use this information to identify likely pre-automotive market opportunities, evaluate the value proposition of PEM fuel cells in likely near-term markets, and identify strategies to facilitate the adoption of direct hydrogen PEM fuel cells.

Information provided in response to this questionnaire will be treated as business sensitive. Battelle requests disclosure of only non-proprietary information. Any information provided in response to this questionnaire will be kept confidential. The analysis will be performed without specific reference to the party providing the information.

Please answer the questions below to the best of your ability – use of phrases and short sentences <u>are preferred</u>. If you choose to skip a question, please indicate N/A or "prefer not to answer", as appropriate.

1. Name of company
2. Address
3. Name of contact
4. Job title
5. Contact information
6. Primary business of your company

7. What is the likely path of transition to automotive PEM fuel cells in 2015? (e.g., Backup power → Portable power→ Specialty vehicles→ Light duty vehicles - fleets)

8. What three specialty vehicle markets (e.g., forklifts, mining vehicles), do you believe are likely to be satisfied customers of direct hydrogen PEM fuel cells in the near-term (2008)?

9. What three specialty vehicle markets (e.g., automatic guide vehicles, unmanned vehicles), do you believe are potential adopters of direct hydrogen PEM fuel cells in the mid-term (2012) in the United States?

10. What three backup power markets, (e.g., data centers, airports), do you believe are likely to be satisfied customers of direct hydrogen PEM fuel cells in the near-term (2008) in the United States?

11. What three backup power markets, (e.g., grocery stores) do you believe are potential adopters of direct hydrogen PEM fuel cells in the mid-term (2012) in the United States?

12. Which five government agencies, in your opinion, are the most likely adopters of direct hydrogen PEM fuel cells in transition applications by 2008?

13. What are the benefits that would make fuel cells attractive to the most promising near-term (2008) backup power and specialty vehicle markets identified above, as compared to competing alternatives?

14. To facilitate direct hydrogen PEM fuel cell acceptance in the aforementioned markets what codes and standards issues need to be addressed immediately?

15. What other types of governmental support are required to facilitate the market acceptance of direct hydrogen PEM fuel cells in the specialty vehicle markets and back-up power markets in the near-term (2008)?

16. To ensure successful adoption of direct hydrogen PEM fuel cells beyond 2008 are there specific areas that require governmental support?

17. To identify high-priority transition markets, Battelle plans to utilize weighted rating criteria. Battelle is seeking your input on the importance of these criteria. Please weight (as high, medium, and low) the list of rating criteria for selecting high priority transition markets provided below.
    a) H-PEMFC product characteristics and their potential benefits must fit user requirements (high priority needs)
    b) H-PEMFC products are available for immediate application, or can be developed over the short-term
    c) H-PEMFC offer unique value to market segment not met by competing technologies

d) Sufficient market size and growth potential of the market segment to ensure current and continued fuel cell adoption
e) Cost of reaching the market, including product development and marketing, is reasonable
f) Demonstration of H-PEMFC in stationary applications in this market segment will contribute to increased learning of H-PEMFC technology operation, its reliability and cost-effectiveness by end-users, potentially leading to increased adoption of PEM fuel cells in the marketplace and impacting costs of PEM fuel cell through increased demand
g) Demonstration of H-PEMFC in this market segment will translate to improvements in automotive H-PEMFC design and development, from learning and demonstration of technology operation
h) Availability of financial support for demonstration of H-PEMFC technology
i) Codes and standards are in place or near complete to facilitate adoption of hydrogen technologies

18. What products does your organization have ready or will have ready by 2008 for back-up power applications and/or specialty vehicle markets (this includes distributed hydrogen generators, stacks)? Please provide model name and any literature on your product(s) including field studies.

19. Can you provide the current or estimated retail price for the aforementioned products?

20. Are you providing or planning to provide a warranty for the aforementioned products? If yes, please specify the period and cost (if in addition to the retail price).

21. Other comments –

A.2 Phase 1 Interview Protocol: Definition of Transitional Markets

Background

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for PEM fuel cells in stationary, off-road, and other pre-automotive applications.

The purpose of this survey is to use the expertise of Battelle and PNNL staff to help define market opportunities for direct hydrogen PEM fuel cells in transitional markets (i.e. pre-automotive) to 2015 within the private and government sectors. Transitional markets are composed of applications that have some operational characteristics similar to automotive PEM fuel cells. These operational characteristics could include frequent ON/OFF cycles (1-10 per day), the ability to quickly respond to requests for power, durability of approximately 3,000 - 5,000 hours with cycling, and approximately 50% efficiency at rated power. Ultimately these markets will help to advance the technology and develop reliable components for vehicle applications.

The research is also focused on gathering information on the most likely applications within those markets, potential users, and strategic partners that could support the demonstration and commercialization of direct hydrogen PEM fuel cells. Information on potential barriers to adoption in these transitional markets is also sought.

Interview Questions

1. What are the most likely transitional applications (e.g. back-up, intermittent power, battery replacement) and markets (e.g. telecom, forklifts) for direct hydrogen PEM fuel cells in the U.S. between now and the year 2015?

2. In your opinion, how will the transition to hydrogen fuel cell vehicles be accomplished over the next 10 years?

3. From the various transitional markets and applications identified to 2015, which of these markets and applications are likely near-term opportunities (to 2008)?

4. Can you identify specific early adopters in these near-term transitional markets? Are there any specific users you recommend we speak with to help determine market requirements for PEM fuel cells?

5. In your opinion, what is the value proposition of PEM fuel cells offer in these near-term transitional markets?

6. For these near-term opportunities, what are the critical barriers to commercialization of PEM fuel cells? Are there any market-specific barriers that come to mind for these markets? What are the technology specific barriers for transitional markets?

7. In the near-term transitional markets, what technologies are likely competitors to PEM fuel cells in the 1-250kW range?

8. Are you aware of specific developments with these competing technologies that could significantly impact PEM fuel cell market opportunity?

9. Are other fuel cells, like SOFC's and DMFC's likely competitors to PEM fuel cells in near-term transitional markets? If not, which markets are SOFC's and DMFC's fuel cells likely to be commercialized in, in the near-term?

10. To assist in the transition to hydrogen fuel cell cars, which specific near-term transitional markets should DOE focus on? What strategies might DOE employ to best facilitate the adoption of PEM fuel cells in the markets (e.g. demonstration projects, financial incentives, etc.)?

11. From your experience with development and push to commercialize fuel cell technology (e.g. through the SECA program), are there specific "lessons learned" that would like to share with us?

12. For further input, do you have suggestions on other experts at Battelle/PNNL that we should contact? Also, are there related reports or studies that you would recommend that we review?

A.3 Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications

Battelle, a non-profit research and development organization located in Columbus, Ohio is conducting research on user requirements for energy technologies and would appreciate your response to some exploratory questions regarding the use of backup power at your facilities.

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications.

The purpose of this survey is to help define market opportunities for direct hydrogen PEM fuel cells in markets to 2015. We have identified a subset of commercial, industrial, and institutional users for PEM fuel cells. We have identified your sector as a potential transitional market, and we are looking to understand the likely applications for PEM fuel cells and user requirements for new energy technologies including direct hydrogen fuel cells.

Battelle will use this information to perform analysis of likely transitional market opportunities for direct hydrogen PEM fuel cells, determine areas for R&D efforts in fuel cells, and to define opportunities for demonstration of PEM fuel cells.

Please answer the questions below to the best of your ability – use of phrases and short sentences <u>are preferred</u>. If you choose to skip a question, please indicate N/A or "prefer no to answer", as appropriate.

1. Name of Organization

2. Address

3. Name of Contact

4. Job Title

5. Primary Business of Your Organization

6. Approximately how many employees work for your organization?
    a. Small < 500
    b. Medium 500-3,000
    c. Large > 3,000

7. For what functions do you currently require backup power for?

8. Which of the above mentioned functions are most critical to your business operations?

9. About how many outages has your organization experienced in the last 12 months?

10. Can you estimate how long these power interruptions typically last? Please highlight or bold all that apply.
    a. < 1 second
    b. < 60 seconds
    c. < 3 minutes
    d. 3 – 5 minutes
    e. 5 minutes – to an hour
    f. 1 -4 hours
    g. 4 hours or longer
    h. Don't know

11. How disruptive would each of the following outages be if they occurred during normal operating hours? (Please determine level of disruption assuming no backup power) Please rate each on a scale of 1 to 7, with 1 being not disruptive and 7 very disruptive. Please highlight or bold all that apply.

    a. 1 second (Scale 1-7, with 1 not disruptive and 7 very disruptive)
        i. 1 2 3 4 5 6 7

    b. 3 minutes (Scale 1-7, with 1 not disruptive and 7 very disruptive)
        i. 1 2 3 4 5 6 7

    c. 1 hour (Scale 1-7, with 1 not disruptive and 7 very disruptive)
        i. 1 2 3 4 5 6 7

    d. 4 hours (Scale 1-7, with 1 not disruptive and 7 very disruptive)
        i. 1 2 3 4 5 6 7

    e. Don't Know

12. How many times a year do grid power outages occur that would be considered disruptive or very disruptive?

13. Could power outages at your organization result in any of the following? Please highlight or bold all that apply.

    a. Lives lost
    b. Security breach
    c. Implementation of emergency management plans

d. Disruptions in production
e. Disruptions in distribution
f. Other (e.g., loss of safe drinking water) _____
g. Power outage has no effect

14. How are your back-up power requirements currently being met? Please highlight or bold all that apply.
    a. Batteries
    b. Uninterruptible Power Systems
    c. Generators (diesel, propane)
    d. Solar Cells
    e. Others _____
    f. No back-up power systems

15. What is the typical size of the backup system that you use? Please highlight or bold all that apply.
    a. < 5 kW
    b. 5-15 kW
    c. 15-30 kW
    d. 30-60 kW
    e. 60-150 kW
    f. 150-250 kW
    g. > 250 kW
    h. _____kW

16. Approximately how many backup power systems do you currently have per facility? Can you estimate the number of backup power systems across all facilities in your organization? Please specify by size (e.g. we have approximately 30 - 15 kW diesel generators, 3-25kW UPS systems etc.)

17. What is the importance of the following factors in selecting a backup power system for your needs? Please rate each on a scale of 1 to 7, with 1 being not important and 7 very important. Please highlight or bold all that apply.

    a. Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not important, 7 very important)
        i. 1 2 3 4 5 6 7 Don't know

    b. Capital cost (Scale 1-7, 1 not important, 7 very important)
        i. 1 2 3 4 5 6 7 Don't know

    c. Lifetime of the unit (Scale 1-7, 1 not important, 7 very important)
        i. 1 2 3 4 5 6 7 Don't know

d. Annual operating cost (fuel and maintenance) (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

e. Emissions/environmental considerations or restrictions (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

f. Start-up time when power goes out (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

g. Ease of use, including regular maintenance (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

h. Fuel Availability (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

i. Good experience with this type of system in the past (Scale 1-7, 1 not important, 7 very important)
   i. 1 2 3 4 5 6 7 Don't know

18. Which of the above factors are most important? Choose up to three.

19. How would you rate the performance of your current backup power systems? Please rate each on a scale of 1 to 7, with 1 being not good and 7 very good. If answer is ≥4, then *skip to* Question 21.

20. What concerns, if any, do you have with the performance of your backup power system? Please identify the system of concern. Please highlight or bold all that apply.

21. Backup Power System(s) of Concern (for example Diesel Generator): _____
    a. Not reliable
    b. Difficult to use
    c. Emissions
    d. Unable to determine if the system has charge
    e. High capital cost
    f. Other (specify)_____
    g. No concerns

22. How would you rate your current backup power system for all of the following characteristics? Please rate each on a scale of 1 to 7, where 1 is not good and 7 is very good. Please highlight or bold all that apply.

    a. Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    b. Capital cost compared to alternatives (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    c. Operation and maintenance costs (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    d. Lifetime of the unit compared to alternatives (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    e. Annual operating cost (fuel and maintenance) (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    f. Emissions – environmental considerations or restrictions (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    g. Start-up time when power goes out (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    h. Ease of use, including regular maintenance (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

    i. Fuel Availability (Scale 1-7, 1 not good, 7 very good)
        i. 1 2 3 4 5 6 7 Don't know

23. Do you anticipate a growing need for backup power in your sector in the next three years? Please highlight or bold answer that applies.
    a. Yes
    b. No
    c. Don't know

24. Have you considered alternatives to your current backup power system? Please highlight or bold answer that applies.
    a. Yes. If yes, what have you considered?
    b. No

25. Have you heard of PEM fuel cells as a power source for backup power applications? Please highlight or bold answer that applies.
    a. Yes
    b. No (*if no, skip to Question 28*)

26. Do you believe that PEM fuel cells are likely to compete favorably with your existing backup power systems? Please highlight or bold answer that applies.
    a. Yes
    b. No. If no, why not?

27. Do you have any concerns about using hydrogen as a fuel? Please highlight or bold answer that applies.
    a. Yes
    b. No
    c. Don't know

28. What factors would drive your decision to purchase PEM fuel cells for backup power? Please highlight or bold all that apply.
    a. Cost of not having electricity or having a power failure (yes/no)
    b. Dissatisfaction with current mode of backup power (yes/no)
    c. Energy efficiency of PEM fuel cells as compared to alternatives (yes/no)
    d. Environmental concerns (yes/no)
    e. Availability of government incentives (yes/no)
    f. Track record of others using the PEM fuel cell system (yes/no)
    g. Other _____

29. How are capital purchase decisions for back-up power systems made in your organization? Please highlight or bold all that apply.
    a. Based on initial capital cost
    b. Based on payback period
    c. Based on return on investment
    d. Other _____
    e. Don't know

30. Are government incentives considered when making a purchasing decision? Please highlight or bold answer that applies.
    a. Yes
    b. No
    c. Don't know

31. What is the title of the person who selects the backup power systems that are purchased by your organization?

32. In the event that your market is selected as a promising transitional market for PEM fuel cells, can we contact you for more detailed information?
    a. Yes
    b. No

Thank you for your time in completing this survey!

A.4 Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles

Battelle, a non-profit research and development organization located in Columbus, Ohio is conducting research on user requirements for specialty vehicles and would appreciate your response to some exploratory questions regarding the use of these vehicles at your facilities.

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications.

The purpose of these questions survey is to help define market opportunities for direct hydrogen PEM fuel cells in markets before 2015. We are exploring a subset of industries that use specialty vehicles as potential near-term adopters for PEM fuel cell powered specialty vehicles. Specialty vehicles can include indoor and outdoor vehicles that perform a utility function such as forklifts, tugs, tow tractors, excavators, and golf carts amongst others. We would like to understand the likely applications for specialty vehicles, as well as user requirements with regard to size and performance of these vehicles, and user perceptions of direct hydrogen fuel cells.

Battelle will use this information to perform analysis of likely pre-automotive market opportunities for direct hydrogen PEM fuel cells, determine areas for R&D efforts in fuel cells, and to define opportunities for demonstration of PEM fuel cells.

Please answer the questions below to the best of your ability – use of phrases and short sentences <u>are preferred</u>. If you choose to skip a question, please indicate N/A or "prefer no to answer", as appropriate.

1. Name of Organization

2. Address

3. Name of Contact

4. Job Title

5. Primary Business of Your Organization

6. Approximately how many employees work for your organization? <u>Please highlight or bold the answer that applies.</u>
   a) Small < 500
   b) Medium 500-3,000
   c) Large > 3,000

7. Please identify the various types of specialty vehicles used by your organization and the typical application(s) it is used for?

Product -	Application –
Product -	Application –
Product -	Application –

8. Approximately how many specialty vehicle products do you have at a single facility? Can you estimate the number of specialty vehicles across all facilities in your organization as well? Please specify by type (e.g. approximately 30 – pallet trucks).
    a) Per facility -
    b) All facilities -

9. How many shifts do you run per day for the various applications identified in question 7? Do you run shifts all 7 days per week?

10. Of the various applications identified in question 7, which applications in your opinion, are most impacted by specialty vehicle downtime? (Downtime is defined as duration of unscheduled stoppage of equipment and does not include scheduled maintenance)

11. Specialty vehicle downtime in your industry results in the following. Please highlight or bold all answers that apply.
    a) Loss in productivity through decreased movement of materials (Yes/No)
    b) Decrease in labor productivity (yes/no)
    c) Increased operations and maintenance costs (Yes/No)
    d) Other ____
    e) None _____
    f) Don't know _____

12. About how many downtime incidents has your organization experienced with its current specialty vehicles in the last 12 months? Please specify across all applications.

13. Can you estimate how long these incidents of downtime typically last? Please highlight or bold all answers that apply.
    a) < 5 minutes
    b) 5-30 minutes
    c) 30 minutes – 1 hour
    d) 1 hour – 4 hours
    e) 4 hours – 8 hours
    f) > 8 hours
    g) Don't know

14. How disruptive would these incidents of downtime be if they occurred during normal operating hours? Please highlight or bold all answers that apply.
    a) < 5 minutes (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    b) 5-30 minutes (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    c) 30 minutes – 1 hour (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    d) 1 hour – 4 hours (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    e) 4 hours – 8 hours (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    f) > 8 hours (Scale 1-7, with 1 not disruptive and 7 very disruptive)
       1 2 3 4 5 6 7

    g) Don't know

15. Do your current specialty vehicles utilize any or all of the following? Please highlight or bold all answers that apply.
    a) Electric drive systems with batteries – yes/no
    b) Propane ICE[104] – yes/no
    c) Diesel ICE – yes/no
    d) Other ____

16. What are the typical operation and maintenance requirements for the specialty vehicles your organization uses? Please specify the frequency of these requirements
    a) Battery-based specialty vehicle products -
    b) ICE based specialty vehicle products -

17. What safety concerns, if any, do you have with regard to use of batteries and/or ICE engines for the specialty vehicle product(s) used by you?
    a) Batteries -
    b) ICE engines –

18. What is the importance of the following factors in selecting a specialty vehicle for your needs? Please highlight or bold all answers that apply.
    a) Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

[104] ICE = Internal Combustion Engine

b) Capital cost (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

c) Lifetime of the unit (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

d) Annual operating cost (fuel and maintenance) (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

e) Emissions – environmental considerations or restrictions (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

f) Start-up time (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

g) Time between refueling (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

h) Ease of use, including regular maintenance (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

i) Fuel availability (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

j) Good experience with this type of system in the past (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

19. Which of the above factors are most important? Choose up to three.

20. How would you rate the performance of batteries and/or ICE in your specialty vehicle product(s)? Please rate each on a scale of 1 to 7, with 1 being not good and 7 very good. If answer is ≥4, then *skip to* Question 22.

21. What concerns, if any, do you have with the performance of batteries and/or ICE in your specialty vehicle product(s)? Please identify the system of concern. Please highlight or bold all that apply.
    a) Takes to long to refuel
    b) Takes to long swap batteries
    c) Inconvenient to recharge
    d) Causes spills and leaks

e) Results in hazardous emissions
f) Unsafe
g) Other _____

22. How would you rate your current specialty vehicles against the following characteristics? Please rate each on a scale of 1 to 7, where 1 is not good and 7 is very good. Please highlight or bold all answers that apply.
    a) Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    b) Capital cost (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    c) Lifetime of the unit (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    d) Operation and maintenance costs (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    e) Start-up time (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    f) Time between refueling (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    g) Ease of use, including regular maintenance (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

    h) Fuel availability (Scale 1-7, 1 not important, 7 very important)
       1 2 3 4 5 6 7 Don't know

23. Do you anticipate a growing need for specialty vehicles in your industry in the next three years? Please highlight or bold the answer that applies.
    a) Yes
    b) No
    c) Don't know

24. Have you considered alternatives to your current battery and/or ICE based specialty vehicles? Please highlight or bold the answer that applies.
    a) Yes. If yes, what have you considered?
    b) No

25. Have you heard of PEM fuel cells as a power source in existing specialty vehicles? Please highlight or bold the answer that applies.
    a) Yes
    b) No (*if no, skip to Question 29*)

26. Do you believe that PEM fuel cells are likely to compete favorably with your existing battery and/or ICE based specialty vehicles? Please highlight or bold the answer that applies.
    a) Yes
    b) No. If no, why not?

27. What factors would drive your decision to purchase PEM fuel cell based specialty vehicles? Please highlight or bold all answers that apply.
    a) Cost incurred from downtime (yes/no)
    b) Dissatisfaction with current mode of operation (too cumbersome etc.) (yes/no)
    c) Energy efficiency of PEM fuel cells as compared to alternatives (yes/no)
    d) Environmental concerns (yes/no)
    e) Availability of government incentives (yes/no)
    f) Track record of others using the PEM fuel cell specialty vehicle product(s) (yes/no)
    g) Other -

28. Do you have any concerns about using hydrogen as a fuel? Please highlight or bold the answer that applies.
    a. Yes
    b. No
    c. Don't know

29. How are capital purchase decisions for specialty vehicles made in your organization? Please highlight or bold all answers that apply.
    a) Based on initial capital cost
    b) Based on payback period
    c) Based on return on investment
    d) Other -

30. Are government incentives considered when making a purchasing decision? Please highlight or bold the answer that applies.
    a. Yes
    b. No
    c. Don't know

31. What is the title of the person who selects the specialty vehicles purchased by your organization?

32. In the event that your industry is selected as a promising transitional market for PEM fuel cells, can we contact you for more detailed information?
    a. Yes
    b. No

Thank you for your time!

A.5 Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers

Battelle, a non-profit research and development organization located in Columbus, Ohio is conducting research on the requirements for fuel cells in specialty vehicles and would appreciate your response to some exploratory questions regarding your specialty vehicle products.

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications.

The purpose of these questions is to help define market opportunities for direct hydrogen PEM fuel cells in transitional markets (i.e. pre-automotive) to 2015. We have identified the specialty vehicle products you develop as a potentially good fit with these transition markets. Specialty vehicles can include indoor and outdoor vehicles that perform a utility function such as forklifts, tugs, tow tractors, excavators, and golf carts amongst others. We would like to understand the likely applications for PEM fuel cells in specialty vehicles, as well as user requirements with regard to size and performance of these vehicles.

Battelle will use this information to perform analysis of likely transitional market opportunities for direct hydrogen PEM fuel cells, to determine areas for R&D efforts in fuel cells, and to define opportunities for demonstration of PEM fuel cells.

Please answer the questions below to the best of your ability – use of phrases and short sentences are preferred. If you choose to skip a question, please indicate N/A or "prefer not to answer", as appropriate

1. Name of Organization

2. Address

3. Name of Contact

4. Job Title

5. Primary Business of Your Organization

6. Approximately how many employees work for your organization? Please highlight or bold answer that applies.
   a) Small < 500
   b) Medium 500-3,000
   c) Large > 3,000

7. Please identify the various types of specialty vehicle products manufactured or distributed by your company? Please specify the markets these products are typically used in.

Product -	Market –
Product -	Market –
Product -	Market –
Product -	Market –

8. Do your products use any or all of the following? Please highlight or bold all that apply.
   a) Electric drive systems with batteries – yes/no
   b) Propane ICE – yes/no
   c) Diesel ICE – yes/no
   d) Other ____

9. Of the various markets identified in question 7, which markets in your opinion, are most impacted by product downtime?

10. Product downtime in these markets results in the following. Please highlight or bold all that apply.
    a) Decreased operation (shifts/day) (Yes/No)
    b) Loss in productivity through decreased movement of materials (Yes/No)
    c) Decrease in labor productivity (yes/no)
    d) Increased operations and maintenance costs (Yes/No)
    e) Other ____
    f) None _____
    g) Don't Know _____

11. What are the operation and maintenance (O&M) requirements for your product (s)? Please specify the frequency of these requirements for the following.
    a) Battery based products O&M requirements -
    b) ICE based products O&M requirements -

12. What safety concerns, if any, do you have with regard to use of batteries and/or ICE engines in your product(s)?
    a) Batteries safety concerns -
    b) ICE engines safety concerns -

13. Is your company pleased with the performance of batteries and/or ICE engines in your product(s)?
    a) Yes
    b) No. Please elaborate.

14. Are you aware of PEM fuel cells as potential substitutes to batteries and/or ICE engines for your product(s)? Please highlight or bold the answer that applies.
    a) Yes
    b) No. If no, please skip to question 22.

15. Has your company considered PEM fuel cells as alternatives to batteries and/or ICE engines your product(s)? Please highlight or bold the answer that applies.
    a) Yes. If yes, please elaborate what alternatives were considered.
    b) No. If no, please skip to question 22

16. How do you evaluate alternative power systems for your specialty vehicle products?

17. What characteristics are most important when choosing an alternative?

18. Do you think that PEM fuel cells would be a viable alternative for your product needs? Please highlight or bold the answer that applies.
    a) Yes
    b) No
    c) May be
    d) Don't know

19. What barriers (research and development or market related barriers), if any, exist to the successful integration of fuel cells into your products?

20. If you are working on fuel cell products, when do you plan to introduce your fuel cell integrated products in the marketplace? Also, what applications are you targeting?

21. What are the key drivers for successful adoption of fuel cell based products by your customers?

22. Do you think hydrogen as a fuel would be a cause for concern with your customers? Please highlight or bold the answer that applies.
    a) Yes
    b) No
    c) May be
    d) Don't know

23. Would you be interested in working with the DOE to develop and demonstrate PEM fuel cells in your product(s)? Please highlight or bold the answer that applies.
    a) Yes
    b) No
    c) May be ____
    d) Don't know

24. As our project proceeds can we contact with further questions?
    a) Yes
    b) No

Thank you for your answers!

A.6 Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems

Battelle, a non-profit research and development organization located in Columbus, Ohio is conducting research on user requirements for energy technologies and would appreciate your response to some exploratory questions regarding the use of backup power at your facilities.

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications.

After reviewing over 25 market segments, four were identified as the most likely near-term users of PEM fuel cell systems: *forklifts in retail distribution markets, ground support vehicles in airports, backup power for radio tower sites in the emergency response market,* and *backup power for telecommunications.* The purpose of this survey is to help us to understand the likely applications and specific user requirements that PEM fuel cells would need to meet in order to provide a viable backup power alternative for emergency response systems.

Battelle will use this information to perform an economic analysis of hydrogen PEM fuel cells relative to competing technologies, to determine priority areas for R&D efforts in fuel cells, and to define opportunities for PEM fuel cell demonstration projects.

Please answer the questions below to the best of your. If you choose to skip a question, please indicate "not applicable", "do not know", or "prefer not to answer", as appropriate.

1. Name of Organization

2. Address

3. Name of Contact

4. Job Title

5. Primary Business of Your Organization

6. Approximately how many employees work for your organization?
   a. < 500
   b. 500-3,000
   c. > 3,000

7. In the last 12 months, about how many power outages at radio tower sites has your organization experienced that you considered disruptive to your operations?

8. Can you estimate how long these power interruptions typically last? Please highlight or bold all that apply.
    a. < 1 second
    b. < 60 seconds
    c. < 3 minutes
    d. 3 – 5 minutes
    e. 5 minutes – to an hour
    f. 1 - 4 hours
    g. 4 hours or longer
    h. Don't know

9. For how many hours of continuous operation do you expect your backup system to be able run at a radio tower site?

10. Please describe the backup power systems that your organization uses at your radio tower sites.

Backup system used (e.g. diesel generator with UPS, solar cells, batteries)	Equipment make and model	Power output (e.g. 15kW)	Approx # of systems in this power range

11. What are the estimated hours of operation of these backup system per year? Include routine maintenance operating time and actual backup operating time.

12. How much labor is required for maintenance of your current systems used at radio tower sites – both scheduled and unscheduled maintenance (hours per month)?

13. What is the estimated labor rate for staff who maintain your radio tower backup power systems ($ per hour)?

14. Do you follow manufacturer's recommended maintenance schedule for your backup power systems?
    a) Yes _____
    b) No _____ If not, what schedule do you use?

15. For a typical facility, please identify any maintenance costs you incur other than labor (e.g. filters) for your current backup systems at radio tower sites.

16. If you use an internal combustion engine backup system, please indicate the expected lifetime of the engine (years).

17. Do you use a battery in conjunction with an internal combustion engine for your radio tower sites? If yes, please indicate:

    a) Battery lifetime (years) _____

    b) Battery charger lifetime (years) _____

    c) Disposal costs for batteries ($) _____

18. Is a designated space required to perform battery change outs and to charge batteries?
    a) Yes _____ If yes, please estimate amount of space required (sq ft) _____
    b) No _____

19. What is the importance of the following factors in selecting a backup power system for radio tower sites that meets your needs? Please rate each on a scale of 1 to 7, with 1 being not important and 7 very important. Please highlight or bold all that apply.

20. Which 3 factors from the list above would most influence your decision to purchase a backup power system for radio tower sites with an alternative technology (e.g. a fuel cell powered system)? That is, if the fuel cell powered backup system performed better than your current technology in those 3 areas, you would consider buying it.

21. How would you rate your current backup power system for all of the following characteristics? Please rate each on a scale of 1 to 7, where 1 is not good and 7 is very good. Please highlight or bold all that apply.

    a) Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not good, 7 very good)
       1 2 3 4 5 6 7 Don't know

    b) Capital cost (Scale 1-7, 1 not good, 7 very good)
       1 2 3 4 5 6 7 Don't know

c) Operation and maintenance costs (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

d) Lifetime of the unit (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

e) Annual operating cost (fuel and maintenance) (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

f) Emissions – environmental considerations or restrictions (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

g) Start-up time when power goes out (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

h) Ease of use, including regular maintenance (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

i) Fuel Availability (Scale 1-7, 1 not good, 7 very good)
1 2 3 4 5 6 7 Don't know

22. Do you have any concerns about using hydrogen as a fuel? Rate your level of concern on a scale of 1 to 7, where 1 is not concerned and 7 is very concerned. Please highlight or bold the answer that applies.
1 2 3 4 5 6 7 Don't know

Thank you for your time in completing this survey!

A.7 Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications

Battelle, a non-profit research and development organization located in Columbus, Ohio is conducting research on user requirements for specialty vehicles and would appreciate your response to some exploratory questions regarding the use of these vehicles at your facilities.

The Department of Energy's Office of Energy Efficiency and Renewable Energy is focused on the development of hydrogen fuel vehicles by 2015 and realizes that there will likely be a lengthy transition period. In order to sustain industry and develop a supplier base for future automotive markets, DOE is focused on identifying market opportunities for Proton Exchange Membrane (PEM) fuel cells in stationary, off-road, and other pre-automotive applications.

After reviewing over 25 market segments, four were identified as the most likely near-term users of PEM fuel cell systems: *forklifts in retail distribution markets, ground support vehicles in airports, backup power for emergency response systems,* and *backup power for telecommunications.* The purpose of this survey is to help us understand user requirements with regard to size and performance for specialty vehicles, such as forklifts and airport tugs, which are used for industrial and commercial applications.

Battelle will use this information to perform an economic analysis of hydrogen PEM fuel cells relative to competing technologies, to determine priority areas for R&D efforts in fuel cells, and to define opportunities for PEM fuel cell demonstration projects.

Please answer the questions below to the best of your ability. If you choose to skip a question, please indicate "not applicable", "do not know", or "prefer not to answer", as appropriate.

1. Name of Organization

2. Address

3. Name of Contact

4. Job Title

5. Primary Business of Your Organization

6. Approximately how many employees work for your organization? Please highlight or bold the answer that applies.
   a) < 500
   b) 500-3,000
   c) > 3,000

7. Please identify the types of specialty vehicles used in a typical facility where you operate (e.g. distribution center, airport), the typical application(s) they are used for, and frequency of use.

Equipment make and model	Applications (e.g. materials handling in distribution center, airline baggage tractor)	Power output (e.g. 65 kW)	Type of engine (e.g. diesel engine, propane engine, electric)	# of hours per day vehicle operates (excluding main-tenance time)	# of shifts per day/ week vehicle operates	# of vehicles per facility

8. For battery-powered vehicles, please indicate:

Applications (e.g. materials handling in distribution center, baggage tractor)	# of times batteries are changed out in an 8-hour shift	Time required for battery maintenance (mins or hrs per battery per day)	Battery lifetime (years)

9. Does battery change-out time result in lost productivity or do you have extra vehicles to ensure continued operations?

10. How much does it cost your company to dispose of a battery?

11. Is a designated space required to perform battery change outs and to charge batteries?
    a) Yes ____ If yes, please estimate amount of space required (sq ft) _____
    b) No _____

12. What is the typical lifetime (years) of a battery charger?

13. For ICE[105]-powered vehicles, please indicate:

Applications (e.g. materials handling in distribution center, baggage tractor)	Tank fill time (minutes)	Tank refill frequency (times per shift)	Labor time required for ICE maintenance (hours per month or quarter)	Engine maintenance costs other than labor ($ per month or quarter)

14. What is the labor rate of a specialty vehicle operator?

15. Of the various applications identified in question 7, which applications in your opinion, are most impacted by specialty vehicle downtime? Downtime is defined as duration of unscheduled maintenance.

16. On average, how many times per year does unscheduled maintenance occur on your vehicles? Please specify for what applications/equipment.

17. Can you estimate how long these incidents of downtime typically last? Please highlight or bold all answers that apply.
    a) < 5 minutes
    b) 5-30 minutes
    c) 30 minutes – 1 hour
    d) 1 hour – 4 hours
    e) 4 hours – 8 hours
    f) > 8 hours
    g) Don't know

18. Do you follow manufacturer's recommended maintenance schedule?
    a) Yes _____
    b) No _____ If not, what schedule do you use?

19. What is the importance of the following factors in selecting a specialty vehicle for your needs? Please highlight or bold all answers that apply.

[105] ICE = internal combustion engine (e.g. diesel or propane engine)

a) Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

b) Capital cost (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

c) Lifetime of the unit (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

d) Annual operating cost (fuel and maintenance) (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

e) Emissions – environmental considerations or restrictions (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

f) Start-up time (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

g) Time between refueling or recharging (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

h) Ease of use, including regular maintenance (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

i) Fuel availability (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

j) Good experience with this type of system in the past (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

k) Interest in using novel cutting-edge technology
1 2 3 4 5 6 7 Don't know

20. Which 3 factors from the list above would most influence your decision to purchase a specialty vehicle powered by an alternative technology (e.g. a fuel cell powered vehicle)? That is, if the fuel cell vehicle performed better than your current technology in those 3 areas, you would consider buying it.

21. How would you rate your current specialty vehicles against the following characteristics? Please rate each on a scale of 1 to 7, where 1 is not good and 7 is very good. Please highlight or bold all answers that apply.

a) Reliability – comes on and operates continuously every time it is needed (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

b) Capital cost (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

c) Lifetime of the unit (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

d) Operation and maintenance costs (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

e) Start-up time (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

f) Time between refueling or recharging (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

g) Ease of use, including regular maintenance (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

h) Fuel availability (Scale 1-7, 1 not important, 7 very important)
1 2 3 4 5 6 7 Don't know

22. Do you have any concerns about using hydrogen as a fuel? Rate your level of concern on a scale of 1 to 7, where 1 is not at all concerned and 7 is very concerned. Please highlight or bold the answer that applies.
1 2 3 4 5 6 7 Don't know

Thank you for your time!

A.8 Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems

1. *Review any answers in the survey that are not clear.*

2. How are capital purchase decisions for backup power systems made in your organization? For example, do emphasize initial capital cost, return on investment over the life of the system?

3. Does your organization consider the availability of government incentives when making a capital purchasing decision for a backup power system?

4. How would your company typically finance investments in backup power systems? Out of current cash reserves or through a loan?

    i) Would the option of getting a loan guarantee for purchase of a fuel cell vehicle impact your decision? (A loan guarantee would allow banks to provide lower interest rates on loans).

5. What is the acceptable price range you would pay for a back up power system for a radio tower?

6. Have you considered alternatives to your current backup power system? If yes, what have you considered?

7. Have you heard of PEM fuel cells as a power source for backup power applications?

8. Do you believe that PEM fuel cells are likely to compete favorably with your existing backup power systems? If no, why not?

9. Would you be interested in testing the fuel cell at one of your sites?

10. What would convince you to procure a fuel cell-powered backup system? (e.g. dissatisfaction with current mode of operation, environmental concerns, etc)

A.9 Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications

1. *Review any answers in the survey that are not clear. Be sure we understand how many days per week the vehicle operates, as well as shifts per day.*

2. How are capital purchase decisions for specialty vehicles made in your organization? For example, do emphasize initial capital cost, return on investment over the life of the vehicle?

3. Does your organization consider the availability of government incentives when making a capital purchasing decision for (forklifts or airport tugs)?

4. How would your company typically finance investments in (forklifts or airport tugs)? Out of current cash reserves or through a loan?

    j) Would the option of getting a loan guarantee for purchase of a fuel cell vehicle impact your decision? (A loan guarantee would allow banks to provide lower interest rates on loans).

5. What is the acceptable price range you would pay for a (forklift or airport tug)?

6. Have you considered alternatives to your current battery and/or ICE based specialty vehicles? If so, what alternatives have you considered?

7. Have you heard of PEM fuel cells as a power source in existing specialty vehicles, such as (forklifts or airport tugs)?

8. Do you believe that PEM fuel cells are likely to compete favorably with your existing battery and/or ICE based specialty vehicles? If no, why not?

9. Would you be interested in testing the fuel cell at one of your sites?

10. What would convince you to procure a fuel cell-powered vehicle? (e.g. dissatisfaction with current mode of operation, environmental concerns, etc)

11. Would you be interested in participating in a focus group with other retail distribution centers regarding fuel cell use in forklifts?

APPENDIX B: Complete List of Respondents and Level of Participation

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
Backup Power	Airports	City of San Jose Airport	✓						
Backup Power	Airports	Hillsborough County Aviation Authority	✓						
Backup Power	Airports	Metropolitan Washington Airports Authority	✓						
Backup Power	Airports	Port of Portland Airport	✓						
Backup Power	Airports	Port of Seattle DBA Sea-Tac International Airport	✓						
Backup Power	Airports	Sacramento County Airport System	✓						
Backup Power	Casinos	Jumers Casino Rock Island	✓						
Backup Power	Chemical	ERCO	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Manufacturing	Worldwide (USA) Inc.							
Backup Power	Chemical Manufacturing	Dow Chemical	✓						
Backup Power	Computer and Electronic Products	AlfaMag Electronics LLC	✓						
Backup Power	Computer and Electronic Products	Catalyst Manufacturing Services, Inc.	✓						
Backup Power	Computer and Electronic Products	Multek Flexible Circuits, Inc.	✓						
Backup Power	Computer and Electronic Products	Texas Instruments	✓						
Backup Power	Electric Utility Substations	DTE Energy	✓						
Backup Power	Electric Utility Substations	WE Energies	✓						
Backup Power	Federal Agencies	DOE - Brookhaven National Laboratory	✓						
Backup Power	Federal Agencies	NASA - Glenn Research Center	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
Backup Power	Federal Agencies	NOAA - NWS	✓						
Backup Power	Federal Agencies	EPA	✓						
Backup Power	Federal Agencies	EPA - Edison Facility	✓						
Backup Power	Federal Agencies	EPA/NVFEL (National Vehicle and Fuel Emissions Laboratory)	✓						
Backup Power	Federal Agencies	USCG	✓						
Backup Power	Grocery Stores and Large Department Stores	Costco Wholesale	✓						
Backup Power	Grocery Stores and Large Department Stores	Giant Eagle	✓						
Backup Power	Grocery Stores and Large Department Stores	Herbco	✓						
Backup Power	Grocery Stores and Large Department Stores	Whole Foods Market, Inc.	✓						
Backup Power	Healthcare	Children's Hospital	✓						
Backup Power	Healthcare	VA Medical Center -	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
		Brecksville							
Backup Power	Healthcare	VA Medical Center - Chillicothe	✓						
Backup Power	Healthcare	VA Medical Center - Cincinnati	✓						
Backup Power	Healthcare	VA Medical Center - Dayton	✓						
Backup Power	Metal Processing and Refining	Blue Blade Steel	✓						
Backup Power	Metal Processing and Refining	California Cast Metal Association	✓						
Backup Power	Metal Processing and Refining	Hexacon Electric Company	✓						
Backup Power	Metal Processing and Refining	Mittal Steel (Slab Product Plant)	✓						
Backup Power	Mining	Stillwater Mining	✓						
Backup Power	National and State Parks	Pacific West Region, National Park Service	✓						
Backup Power	Oil and Gas Manufacturing - Production of Gasoline, Heating	Chevron San Ramon and Chevron Concord	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Oil								
Backup Power	Oil and Gas Manufacturing - Production of Gasoline, Heating Oil	Plains Pipeline LP	✓						
Backup Power	Professional Scientific and Technical Services	aspStation, Inc.	✓						
Backup Power	Professional Scientific and Technical Services	Battelle	✓						
Backup Power	Railways	Alaska Railroad Corporation	✓						
Backup Power	Railways	Arkansas Missouri Railroad	✓						
Backup Power	Railways	CSX Railroad	✓						
Backup Power	Railways	DMJM Harris Inc.	✓						
Backup Power	Railways	Large Railroad Company (2)	✓✓						
Backup Power	Ski Resorts	Aspen Skiing Company	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
Backup Power	State and Local Departments of Emergency Response	Baker County Emergency Services	✓						
Backup Power	State and Local Departments of Emergency Response	Boone County Sheriff's Office				✓			
Backup Power	State and Local Departments of Emergency Response	Bureau County Enhanced 9-1-1				✓		✓	
Backup Power	State and Local Departments of Emergency Response	Franklin County Sheriff's Office	✓						
Backup Power	State and Local Departments of Emergency Response	Governor's Office of Emergency Services (CA)				✓		✓	
Backup Power	State and Local Departments of Emergency Response	Huron County EMA	✓			✓		✓	
Backup Power	State and Local Departments of	KITTCOM (Kittitas County				✓			

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Emergency Response	911)							
Backup Power	State and Local Departments of Emergency Response	Lake Havasu City Police Department	✓						
Backup Power	State and Local Departments of Emergency Response	Martin County Sheriff's Office	✓						
Backup Power	State and Local Departments of Emergency Response	Miami-Dade Police Department	✓						
Backup Power	State and Local Departments of Emergency Response	Morrow County 911	✓						
Backup Power	State and Local Departments of Emergency Response	Ohio Emergency Management Agency	✓						
Backup Power	State and Local Departments of Emergency Response	Ohio MARCS (Multi-Agency Radio Communication				✓			

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
		System)							
Backup Power	State and Local Departments of Emergency Response	Orange County E911	✓						
Backup Power	State and Local Departments of Emergency Response	Pike County Sheriffs Office	✓						
Backup Power	State and Local Departments of Emergency Response	San Diego County Sheriff's Department	✓			✓			
Backup Power	State and Local Departments of Emergency Response	Sangamon County Emergency Telephone System	✓						
Backup Power	State and Local Departments of Emergency Response	Shelby County 9-1-1	✓			✓		✓	
Backup Power	State and Local Departments of Emergency Response	Shelby County Sheriff's Office	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
Backup Power	State and Local Departments of Emergency Response	Skagit 911				✓		✓	
Backup Power	State and Local Departments of Emergency Response	Washington State E911 Program	✓			✓			
Backup Power	State and Local Departments of Emergency Response	Pierce County Radio Communications							
Backup Power	Transportation Equipment	DaimlerChrysler	✓						
Backup Power	Transportation Equipment	NGK Spark Plugs	✓						
Backup Power	Water/Wastewater Treatment	CDM Inc.	✓						
Backup Power	Water/Wastewater Treatment	Columbia Wastewater Department	✓						
Backup Power	Water/Wastewater Treatment	Orange County Utilities (2)	✓✓						
Backup Power	Water/Wastewater Treatment	Champlain Water District	✓						
Backup Power	Water/Wastewater	City of	✓						

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Treatment	Columbus, Division of Water							
Backup Power	Water/Wastewater Treatment	City of Sandusky	✓						
Specialty Vehicles	Airport Tugs	A&G Mercury, A Division of A&G Mfg.		✓					
Specialty Vehicles	Airport Tugs	American Airlines			✓		✓		✓
Specialty Vehicles	Airport Tugs	DALGlobal Services			✓				✓
Specialty Vehicles	Airport Tugs	FMC Technologies, Inc.		✓					
Specialty Vehicles	Airport Tugs	Horizon Air/Seattle GSE Shop					✓		✓
Specialty Vehicles	Airport Tugs	JetBlue Airways			✓		✓		
Specialty Vehicles	Airport Tugs	Lektro Inc.		✓					
Specialty Vehicles	Airport Tugs	Matheson Flight Extenders, Inc.					✓		✓
Specialty Vehicles	Airport Tugs	Menzies Aviation					✓		✓
Specialty Vehicles	Airport Tugs	Trowin Industries, Inc.		✓					
Specialty Vehicles	Airport Tugs	UPS					✓		✓

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
Specialty Vehicles	Airport Tugs	US Airways – Seattle					✓		✓
Specialty Vehicles	Automated Guide Vehicles	Transbotics, Inc.		✓					
Specialty Vehicles	Automated Guide Vehicles	Egemin Automation		✓					
Specialty Vehicles	Automated Guide Vehicles	FMC Technologies, Inc.		✓					
Specialty Vehicles	Commercial Sweepers	Factory Cat		✓					
Specialty Vehicles	Commercial Sweepers	Nilfisk Advance		✓					
Specialty Vehicles	Commercial Sweepers	Tennant Corporation		✓					
Specialty Vehicles	Electric Lift Trucks/Forklifts	Advance Auto Parts					✓		
Specialty Vehicles	Electric Lift Trucks/Forklifts	Anonymous distribution center			✓				
Specialty Vehicles	Electric Lift Trucks/Forklifts	Anonymous online retail distributor					✓		
Specialty Vehicles	Electric Lift Trucks/Forklifts	B&B Forklifts		✓					
Specialty Vehicles	Electric Lift	Big Lots Stores,			✓				

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Trucks/Forklifts	Inc.							
Specialty Vehicles	Electric Lift Trucks/Forklifts	Dollar General Co.			✓				
Specialty Vehicles	Electric Lift Trucks/Forklifts	Home Depot					✓		✓
Specialty Vehicles	Electric Lift Trucks/Forklifts	Jacksonville Warehouse Companies					✓		
Specialty Vehicles	Electric Lift Trucks/Forklifts	Limited Brands Inc.			✓				
Specialty Vehicles	Electric Lift Trucks/Forklifts	Marzetti Company			✓		✓		
Specialty Vehicles	Electric Lift Trucks/Forklifts	Meijer					✓		
Specialty Vehicles	Electric Lift Trucks/Forklifts	Nacco Materials Handling Group, Inc.		✓					
Specialty Vehicles	Electric Lift Trucks/Forklifts	Nordstrom, Inc.					✓		✓
Specialty Vehicles	Electric Lift Trucks/Forklifts	OKI Systems		✓					
Specialty Vehicles	Electric Lift Trucks/Forklifts	Raymond Corp.		✓					
Specialty Vehicles	Electric Lift Trucks/Forklifts	Safety-Kleen					✓		✓
Specialty Vehicles	Electric Lift	Sam's Club					✓		

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
	Trucks/Forklifts								
Specialty Vehicles	Electric Lift Trucks/Forklifts	BJ's Wholesale Club					✓		
Specialty Vehicles	Golf Carts	Columbia ParCar Corp.		✓					
Specialty Vehicles	Golf Carts	Yamaha Golf Car Company		✓					
Specialty Vehicles	Lawn Mowers	Encore Power Equipment		✓					
Specialty Vehicles	Lawn Mowers	Exmark Manufacturing Company		✓					
Specialty Vehicles	Lawn Mowers	The Toro Company (Commercial Division)		✓					
Specialty Vehicles	Mining Vehicles	Arch Coal Inc., Arch Western Bituminous Group			✓				
Specialty Vehicles	Mining Vehicles	BHP Billiton – San Juan Coal Co.			✓				
Specialty Vehicles	Mining Vehicles	Foundation Coal Corporation			✓				
Specialty Vehicles	Mining Vehicles	Kennecott Greens			✓				

Table B-1. Survey and Protocol-Based Interview Respondents – Phase 1 and Phase 2 Research.

Application	Market Segment	Company	Responded to:						
			Phase 1 Survey: Exploratory Research Questions for Candidate Fuel Cell Users in Backup Power Applications	*Phase 1 Survey: Exploratory Research Questions for Specialty Vehicle Manufacturers*	*Phase 1 Survey: Exploratory Research Questions on Candidate User Requirements for Specialty Vehicles*	*Phase 2 Survey: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Survey: Candidate Fuel Cell Users in Specialty Vehicle Applications*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Backup Power Applications for Emergency Response Systems*	*Phase 2 Interview Protocol: Candidate Fuel Cell Users in Specialty Vehicle Applications*
		Creek Mining Company							
Specialty Vehicles	Mining Vehicles	Sterling Mining Company			✓				
Specialty Vehicles	Unmanned Aerial Vehicles	AeroVironment Inc.		✓					
Specialty Vehicles	Wheelchairs	Hoveround		✓					
Specialty Vehicles	Wheelchairs	Invacare		✓					
Specialty Vehicles	Wheelchairs	Pride Mobility Products Corp.		✓					

Table B-2. Phase 1 Industry Organizations Interviewed/Surveyed for General Industry Trends

Type of Stakeholder	Company
Research Organization	Battelle
Research Organization	Pacific Northwest National Laboratory
Venture Capital Firm	Battelle Ventures
Venture Capital Firm	Hydro-Quebec Capitech
Venture Capital Firm	Yellowstone Energy Ventures LP
Venture Capital Firm	Expansion Capital Partners
Venture Capital Firm	Mohr, Davidow Ventures
Venture Capital Firm	Crysalix Energy Management
Venture Capital Firm	ARCH Venture Partners
Venture Capital Firm	Rockport Capital Partners
Fuel Cell Company	Ballard Power Systems
Fuel Cell Company	Plug Power
Fuel Cell Company	ReliOn
Fuel Cell Company	Nuvera Fuel Cells
Fuel Cell Company	UTC Power
Fuel Cell Company	Millennium Cell
Fuel Cell Company	MTi MicroFuel Cells
Fuel Cell Company	Proton Energy Systems
Fuel Cell Company	Hydrogenics
Component Supplier	Arkema Inc
Component Supplier	Asbury Carbons
Component Supplier	GrafTech International
Component Supplier	Dana Corporation
Component Supplier	Süd-Chemie Inc.
Industry Trade Association	Methanol Institute
Hydrogen Supplier	Chevron Technology Venture

APPENDIX C: SUMMARY RESEARCH FOR MARKET SEGMENTS ANALYZED

Research Summary: Backup Power
Airports a-1
Amusement Parks..... b-1
Casinos.....c-1
Chemical Manufacturing d-1
Computers and Electronic Equipment Manufacturers e-1
Data Centers..... f-1
Electric Utility Substations..... g-1
Food Manufacturing Industry h-1
Federal Agencies.....i-1
Grocery Stores.....j-1
Hospitals.....k-1
Metals Processing and Refining l-1
Mining m-1
National and State Parks n-1
Original Equipment Manufacturers (OEMs) and Suppliers o-1
Petroleum Refineries p-1
Pharmaceuticals q-1
Railways r-1
Ski Resorts s-1
Water and Wastewater Treatment t-1

Research Summary: Specialty Vehicles
Electric Bicycles and Scooters..... u-1
Commercial Sweepers/Scrubbers.....v-1
Ice Resurfacers.....w-1
Golf Carts.....x-1
Lawnmowers.....y-1
Mining z-1
Unmanned Aerial Vehicles (UAVs) aa-1
Unmanned Underwater Vehicles (UUVs)..... bb-1
Wheelchairs cc-1

RESEARCH SUMMARY:
AIRPORTS

MARKET SEGMENT DESCRIPTION

This market segment includes establishments primarily engaged in operating, leasing, and maintaining airports and flying fields (except those maintained by aviation clubs); cleaning, servicing, repairing (except on a factory basis), maintaining, and storing aircraft; operating and renting airport hangars; and furnishing coordinated handling services for airfreight or passengers at airports. This industry also includes private establishments primarily engaged in air traffic control operations. This analysis considers the potential for PEM fuel cells for backup power at airports. Table a-1 identifies the SIC and NAICS classifications that cover airport operations.

Table a-1. SIC and NAICS Codes for Airport Operations.

2-Digit SIC Code	45 – Transportation by air
4-Digit SIC Code	4581 – Airports, flying fields, and airport terminal services
NAICS Code	488119 – Other airport operations

This market segment does not include: government air traffic control operations (classified in Public Administration, SIC Code 9621); aircraft modification centers and establishments primarily engaged in factory type overhaul of aircraft (classified in Manufacturing, SIC Code 37); and flying fields maintained by aviation clubs (classified in Services, SIC Code 7997).

The impacts of power outages at airports, whether caused by grid failure or backup power malfunctions, can include flight delays, security breaches, and disruptions in operations. The widespread blackout of August 2003 is an extreme example. Flights were delayed and in some cases airports were closed in Toronto, Newark, New York, Detroit, Cleveland, Montreal, Ottawa, Islip, Syracuse, Buffalo, Rochester, Erie, and Hamilton. Key airport operations were affected, halting flights out of affected airports for several hours or more. Critical functions which were affected included passenger air traffic control, security screening, and baggage x-ray systems. Blackouts also affected less critical, but still important systems, such as electronic ticketing. The delays in outgoing traffic impacted scheduling throughout the national (and international) air traffic system, as both passengers and planes missed scheduled flights at other (operating) airports. Some incoming flights were diverted to other airports, crowding those facilities. Neither the FAA nor the airlines could estimate the total number of flights that were affected.

As described above, power failures can cause a number of delays and disruptions in normal airport operations. Downtime is estimated to cost $668,586 per hour in the transportation sector.[106] Secondary research indicates that backup power is typically provided for a number of critical systems, including: security systems; incident command centers; critical computer systems and control rooms; telecommunications; minimal building functions (e.g., lighting); landing systems; navigational equipment; and runway lights.

[106] META Group, Inc. 2002. Quantifying Performance Loss: IT Performance Engineering and Measurement Strategies. Available at http://www.metagroup.com/us/displayArticle.do?oid=18750 [Accessed October 2006].

Some airports have additional emergency power for such functions as: additional lighting in public areas; ticket counters; bag screening systems; boarding bridges; police/fire buildings; fuel farm; regulator vault controlling airfield lighting; parking lots; and gas pumps.

Given the heightened security requirements following September 11, 2001, and the aftermath of the August 2003 blackout, the airport sector is concerned with ensuring a continuous power supply. Traditional backup power sources at airports include diesel generators and UPS systems. Gas turbines and alternate energy systems (e.g., solar power) may also be used to provide backup power. Examples of backup power systems at airports are presented below.

- *Diesel Generators* – Diesel generators appear to be the most popular backup power system at airports. Airports typically use several generators of varying sizes for different backup power applications; for example, Concord Regional Airport in North Carolina employs three backup power generators installed at strategic locations in the airport.[107] The three generators include: a 250 kW diesel generator set with a 405 gallon fuel tank and automatic transfer switch serves the main 18,000 square foot terminal building, which includes a concourse for arriving and departing passengers, an operations center, and offices. The generator holds enough fuel to run for more than 20 hours at full load, if necessary. A second on-site generator, a 100 kW diesel genset, provides backup power for the airport's instrument landing system, navigational equipment, and runway lights. A third unit, a 45 kW liquid propane gas-fueled genset, provides standby power for the airport's fuel farm.
- *Uninterruptible Power Supplies (UPS)* – UPS systems are generally associated with telecommunications equipment, computer systems, and other facilities such as airport landing systems and air traffic control systems, where even brief commercial power interruptions could cause injuries or fatalities, serious business disruption, or data loss.
- *Gas Turbine Power Plants* – Single gas turbine power generating plants are operated at some airports to improve regional electrical reliability and provide backup power for the airport in the event of a prolonged regional outage. One airport (San Francisco) issued a memorandum of understanding (MOU) with the Public Utilities Commission to site a single gas turbine power generating plant with a 48 MW capacity on airport property.[108] The plant would be activated in the event of a state-wide grid outage, providing backup power to the airport. Because the plant's 48 MW capacity is in excess of the airport's peak hour demands, the plant will also be able to serve communities surrounding the airport.
- Solar Energy – Some airports use solar energy. For example, FedEx announced plans in 2005 to build a 904 kW solar power array to provide electricity for its hub at Oakland International Airport. The solar panels, covering the roof of the company's two buildings at the airport, are expected to produce almost enough electricity to run FedEx's Oakland hub. The FedEx solar array will provide approximately 80% of the peak load demand for the shipping company's Oakland operations.[109]

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[107] Generac Power Systems, Inc. 2002. Generaction: Information for Specifying Engineers. Volume 2, Issue 2. Available at http://www.generac.com/PublicPDFs/Generaction_Vol2_Issue2.pdf [Accessed October 2006].
[108] San Francisco Airport Commission. 2004. Minutes. Available at http://www.flysfo.com/about/organization/pdf/minutes/M050404.pdf [Accessed July 2006].
[109] Sharp Electronics Corporation. 2004. FedEx to Build California's Largest Corporate Solar Power System on FedEx Facility in Oakland. Available at http://solar.sharpusa.com/files/sol_dow_Fedex_PR101804.pdf [Accessed October 2006].

MARKET SIZE

The market for backup power in the airline sector is difficult to determine. Table a-2 presents current data on the number of airfields nationwide.

Table a-2. Number of Businesses in the Airports, Flying Fields, and Services Industry (4581).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
4581-0000	Airports, flying fields, and services	1,513	35,344	6,258.6
4581-0100	Hangars and other aircraft storage facilities	104	1,187	45.5
4581-0101	Aircraft storage at airports	69	575	26.3
4581-0102	Airport hangar rental	94	960	77.8
4581-0103	Hangar operation	76	2,217	67
4581-0200	Aircraft maintenance and repair services	1,450	26,297	3,755.8
4581-0201	Aircraft cleaning and janitorial service	271	6,974	2,387.2
4581-0202	Aircraft servicing and repairing	1,369	30,416	2,620.7
4581-0203	Aircraft upholstery repair	41	381	33.5
4581-0300	Airports and flying fields	48	1,215	36.9
4581-0301	Airport	1,653	28,213	5,727.3
4581-0302	Flying field, except those maintained by clubs	14	68	8.7
4581-0303	Military flying field	22	305	5
4581-9901	Air freight handling at airports	205	5,988	1,055.2
4581-9902	Airport control tower operation, except government	53	2,582	46.6
4581-9903	Airport leasing, if operating airport	32	512	80.1
4581-9904	Airport terminal services	216	10,099	958.4
4581-9905	Airfreight loading and unloading services	54	597	65.7
4581-9906	Fixed base operator	47	879	108.2
	Total	**7,331**	**154,809**	**23,364.6**

Note: Sales figures are in millions. Source: www.zapdata.com, accessed October 2006.

A survey conducted by the Clear Airport Partnership for the DOE in 2003 assessed the energy consumption of 10 airports.[110] Information from these reports was used to estimate a total electricity use of nearly 8 billion kW hours per year at large- and medium-hub airports (Table a-3). However, the percentage of airports' total electricity consumption that is allocated to the generation of backup power is unclear.

[110] Clean Airport Partnership, Inc. 2003. 10 Airport Survey: Energy Use, Programs and Policies for Terminal Buildings. Report to the U.S. Department of Energy, May 16, 2003. Available at http://www.cleanairports.com/reports/cap10airportsurvey.pdf [Accessed October 4, 2006].

Table a-3. Electricity Use at Large- and Medium-hub Airports (1999).[111]

1999 Energy Use	Electricity Use
Large Hubs (69)	
▪ Average kW hours/year	• 85,539,918 kW hours/year
▪ Total kW hours/year	• 5,902,254,341 kW hours/year
Medium Hubs (48)	
▪ Average kW hours/year	• 43,345,075 kW hours/year
▪ Total kW hours/year	• 2,080,563,587 kW hours/year
Combined kW hours/year	**7,982,817,942 kW hours/year**

Note: The U.S. Department of Transportation's Bureau of Transportation Statistics 1999 report, "Airport Activity Statistics of Certificated Air Carriers" indicates that there are 69 large hubs, 48 medium hubs, 73 small hubs, and 604 non-hub airports in the U.S.[112]

MARKET TRENDS

There is growing international interest in reducing the use of petroleum fuels and the production of carbon emissions at airports through operational measures and new technologies including fuel cells.[113] The potential utility of fuel cells for backup power in airport/aviation applications has been considered primarily for communications equipment at control towers. A number of organizations, including the DOE and DoD, have supported fuel cell demonstration projects for various applications in the airport sector. A sampling of these projects is presented below:[114]

- **Albany Airport**, *Albany, New York:* Demonstration of Plug Power Inc.'s prototype GenCore began in July 2003, and was replaced by the GenCore 5T in February 2004. This fuel cell system served as the primary backup source for Verizon's remote terminal housing telecommunications equipment. Upon completion of the project, the project partner, Verizon, purchased several GenCore 5T systems, siting one at Albany Airport. Natural gas was used to supply hydrogen fuel.[115]
- **Keflavick Airport,** *Keflavick, Iceland:* A 5 kW PEM fuel cell (Plug Power Gencore) has been installed for telecommunication backup power at the Leifur Eríksson Air Terminal at Keflavik International Airport.[116]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells for backup power applications at airports, 42 airports were contacted and five responses were received. Three brief interviews were also conducted with U.S.-based international airports. One respondent represented a small airport, and four respondents represented medium-sized airports. Respondents indicated a variety of applications that require backup power, including:

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[111] Clean Airport Partnership, Inc. 2003. 10 Airport Survey: Energy Use, Programs and Policies for Terminal Buildings. Report to the U.S. Department of Energy, May 16, 2003. Available at http://www.cleanairports.com/reports/cap10airportsurvey.pdf [Accessed October 4, 2006].

[112] The U.S. Department of Transportation, Bureau of Transportation Statistics. 1999. Airport Activity Statistics of Certificated Air Carriers. Available at http://www.bts.gov/publications/airport_activity_statistics_of_certificated_air_carriers/ [Accessed October 4, 2006].

[113] Bayer, J. 2002. Fuel Cell Airport/Aviation Challenges and Opportunities. Presented at: Aviation Operation Measures for Fuel and Emissions Reduction Workshop, November 5-6, 2002. Available at http://www.icao.int/icao/en/env/workshop/ottawa_2002/judith_bayer.pdf [Accessed October 2006].

[114] Note: DoD has been particularly active in sponsoring fuel cell demonstration projects at air force bases. Additional examples of projects can be seen at: http://dodfuelcell.cecer.army.mil/res/site_list.php4 [Accessed October 2006].

[115] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed October 2006].

[116] U.S. Army Corps of Engineers. 2006. DoD Fuel Cell ERDC/CERL Projects. Available at http://dodfuelcell.cecer.army.mil/res/site_list.php4 [Accessed October 2006].

- Airfield lighting
- Security gates and other security systems
- Code-required lighting and functions in buildings
- Terminals
- Elevators
- Sewage pumps
- Ticket counters
- Parking structures
- Fueling station
- Towers
- Building lighting, building power
- Communications center power
- Domestic water
- Aircraft operations
- Fire departments
- Wastewater treatment plants
- Fire system supply pump houses
- Electrical distribution substations
- Additional lighting in public areas
- Baggage systems
- Boarding bridges
- Fuel farms
- Gas pumps
- Life safety systems
- Emergency lights
- Server networking

Three respondents stated that no backup power applications were less important than others. One reported that life safety equipment was most important, while another indicated that airfield lighting, communications center power, and security were the most important. One interviewee noted that critical computer systems, control rooms, and emergency lighting are critical. A second indicated that a backup system is currently being designed for an incident command center.

The small airport respondent estimated that three power outages had occurred in the last 12 months; these lasted less than 1 second but were very disruptive. Of the medium-sized airports, one respondent indicated that no outages had occurred in the past year, one estimated that six momentary partial outages had occurred (lasting less than 1 second up to 60 seconds), one reported eight outages (lasting 5 minutes to 1 hour), and another reported 10 outages (lasting 3 to 5 minutes, 5 minutes to 1 hour, and 1 to 4 hours). Respondents reported that the impact of these outages varied from somewhat disruptive to very disruptive. As expected, the longer the outage, the greater the disruption. All five respondents indicated that power outages could result in security breaches. Four stated that loss of lives and implementation of emergency management plans were possible consequences. Three respondents indicated that disruptions standard airport operations could result, and one stated that disruptions in movement of passengers and cargo might occur. Other possible consequences identified included loss of fire suppression capability and flight delays.

All respondents reported using UPS systems and generators for backup power. One interviewee also reported using solar power. All but one respondent also reported using batteries. Sizes of UPS systems ranged from less than 1 kW to 150 kW, while generators ranged from 35 kW to over 1,500 kW. The small airport reported utilizing three 1,500 kW diesel generators, one 1,000 kW diesel generator, two 600 kW diesel generators, and various smaller sized units depending on the system (e.g., two 120 kW UPS systems and other variously sized UPS systems). The medium-sized airports reported using a variety of systems, as shown in Table a-4.

Table a-4. Backup Power Systems Used at Four Medium-sized Airports.

	Airport 1	Airport 2	Airport 3	Airport 4
Diesel Generators	25, varying sizes: • < 5 kW: 10 • 50 - 100 kW: 5	17, ranging from 60 kW to 2 MW	13, ranging from 150 kW to 750 kW	For each of 6 facilities, sizes ranging from 250 kW to 650 kW

	• 200 - 400 kW: 5 • 900 - 1200 kW: 5			
UPS Units	20, varying sizes: • 15 kW: 7 • 35 kW: 3 • 40 kW: 4 • 75 kW: 6	3, ranging from 40 kVA to 150 kVA	1, 45 kVA UPS	Systems ranging from 0.5 kW to 60 kW for critical applications (security, baggage, life support)
Batteries		Several small battery banks for controlling switchgear	Batteries for phone systems and for each security control panel	
Feeders				6 feeders from the local utility – 2 for each primary facility

Respondents indicated that reliability, startup time, and good experience were the most important characteristics of their backup power systems. The next most important factor was emissions, followed by ease of use and fuel availability. The least important factors, although still rated as relatively important, were capital cost and lifetime of unit.

In general, all respondents reported that their current backup power systems were fairly good. However, the following concerns were identified: difficult to use, emissions, age of systems, storage tanks and battery charge cannot support an extended outage, high capital cost, and space issues. On average, respondents rated the performance of their current backup power systems on a scale of 1 to 7 with 7 being very good and 1 being not good as follows:[117] fuel availability (6); startup time (6); lifetime (5); reliability (5); operation and maintenance (5); ease of use (5); capital cost (5); annual operating cost (5); and emissions (3).

Two of the five respondents cited an increased need for backup power in 3 years, two did not anticipate additional backup power needs, and one expected a need for further backup in 5 years. Three respondents had considered alternative fuel sources. One respondent had considered installing additional feeders from a secondary electric utility substation which is fed from an independent source, other than the primary substation. Another had considered using gasoline generators to generate electricity. One interviewee had heard of fuel cells but did not think the return on investment would be sufficient motivation to invest in new technology. Only one of the respondents had heard of PEM fuel cells. One respondent had considered fuel cells but cited a number of barriers, including: large footprint (space requirements), insufficient power size, high cost, and unproven performance. The respondent had no concerns with using hydrogen as a fuel. According to this respondent, factors that would drive a decision to purchase PEM fuel cells are: cost of not having electricity, or having a power failure; energy efficiency of PEM fuel cells as compared to alternatives; environmental concerns; availability of government incentives; track record of others using PEM fuel cells; sufficient power capacity; and space requirements. Two respondents indicated that capital purchase decisions are made based on initial capital cost, payback period, and return on investment. Other considerations include annual operating costs, load requirements, need, and lifecycle cost. Four respondents stated that government incentives are considered in making purchasing decisions. Some respondents reported that the process for

[117] On a scale of 1 to 7, with 7 being very good and 1 being not very good.

making capital purchasing decisions involves presenting recommendations to senior staff; others reported that development committees make purchasing decisions.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Characteristics of fuel cells desired by airports include: large kW capacity, modular design, production of reliable, high-quality power, minimal noise, low emissions, high efficiency, capability for continuous operations, and ability for flexible siting. Secondary research did not generate a significant amount of information on the viability of PEM fuel cells in backup power applications at airfields except for backup of communications equipment at terminals and radio control towers. Primary research among the airports contacted also indicated a lack of interest in the near-term adoption of fuel-cell technology for backup power. Airports contacted for primary research noted a growing need for backup power, but added concerns that fuel cells were an expensive technology and not sufficiently tested.

Currently PEM fuel cells are limited to small power sizes and as a result may be suitable only for some backup power applications such as ticketing counters, emergency lighting and alarm systems, and communications equipment. It is anticipated that current technologies like UPS systems will meet user requirements for small critical distributed applications, while technologies such as turbines and solar power may emerge to meet larger backup power needs for facilities and terminals. Potential near-term niche applications for PEM fuel cells in this market segment are communications equipment at airport control towers and terminals. However, there are also a number of other barriers to the adoption of PEM fuel cells by airports for these applications. Lack of reliability data for application of PEM fuel cells at airports could deter users from adopting fuel cell technology. Furthermore, as capital purchase decisions are based on initial capital cost and the availability of government incentives, early adoption may be limited in this market segment.

RESEARCH SUMMARY:
AMUSEMENT PARKS

MARKET SEGMENT DESCRIPTION

This market segment encompasses establishments of the type known as amusement parks, kiddie parks, piers, and theme parks which may group together and operate a number of attractions, such as mechanical rides, amusement devices, refreshment stands, and picnic grounds. This analysis considers the potential for PEM fuel cells for backup power at amusement parks. Table b-1 identifies the SIC and NAICS codes associated with this market segment.

Table b-1. SIC and NAICS Codes for Amusement Parks.

2-Digit SIC Code	79 – Amusement and recreation services
4-Digit SIC Code	7996 – Amusement parks
NAICS Code	713110 – Amusement and theme parks

Amusement parks aim to make guests feel safe and secure. Safety and accident records are public knowledge; a safety incident will have an asymmetrical impact on public trust. Therefore, safety, and the perception of safety, are primary concerns at amusement parks. The August 2003 blackouts impacted a number of amusements parks in the Northeastern United States and eastern Canada. During this power outage at Cedar Point Amusement Park in Sandusky, Ohio, park employees had to help guests walk down the steps of a 200-foot-tall rollercoaster that had stopped on the lift hill due to the blackout.[118]

Large theme parks utilize redundant feeds for built-in reliability and often have their own dedicated medium- or high-voltage substations and distribute power themselves.[119] Emergency backup power is often provided to ensure safety on high-risk attractions, such as roller-coasters. Power is often provided only to specific applications in order to minimize cost while delivering benefit to the most critical applications. Parks will use backup power for functions other than safety. For instance, "four-dimensional" theaters use UPS systems to coordinate the technologies for audio, visual, and sensory input, which are difficult to re-synchronize following a power outage.[120]

A number of technologies, including UPS systems, are being used for backup power. Photovoltaic systems are being used to provide alternative energy sources. For instance, a 50 kW photovoltaic system provides primary power for a Ferris wheel at Pacific Park on the Santa Monica Pier. The system provides 71,000 kWh, which is more than sufficient to power the wheel, and excess energy is used to reduce the park's overall electric consumption.[121] There are no federal safety standards that require backup power on rides and other park services; amusement park rides and water slides are exempt from federal safety oversight. Saferparks, a

[118] Wikimedia Foundation, Inc. 2006. Northeast Blackout of 2003. Available at http://en.wikipedia.org/wiki/2003_North_America_blackout#Ohio.2C_USA [Accessed June 2006].
[119] Horwitz, B. 2002. The Big Thrill. Consulting-Specifying Engineer (September 1, 2002). Available at http://www.syska.com/Media/news/article.asp?Articles.ART_ID=133 [Accessed June 2006].
[120] Horwitz, B. 2002. The Big Thrill. Consulting-Specifying Engineer (September 1, 2002). Available at http://www.syska.com/Media/news/article.asp?Articles.ART_ID=133 [Accessed June 2006].
[121] Valentine, M. 1999. Fun With the Sun. The American Society of Mechanical Engineers. Available at http://www.memagazine.org/backissues/membersonly/february99/departments/input_output/input_out.html [Accessed June 2006].

consumers' organization for safer park rides, reports that amusement rides in the United States are regulated through a diverse patchwork of federal, state, and local laws, riddled with holes and special exemptions. Some amusement rides are subject to safety regulation at the state or local level. Carnival rides, go-karts, and inflatables are regulated under the Consumer Product Safety Act. Consumer protection laws vary widely from state to state, ride type to ride type, and venue to venue.[122]

MARKET SIZE

The U.S. has more than 600 amusement parks and traditional attractions. In 2005, 335 million people visited these venues and enjoyed more than 1.5 billion rides, generating $11.2 billion in revenues in 2005. Attendance and revenues at America's approximately 600 parks and attractions have increased nearly every year since 1990.[123] There are 22 amusement and theme park companies in the U.S. (NAICS Code 713110).[124] The top ten companies, by sales, are listed in Table b-2.

Table b-2. Top Ten U.S. Amusement and Theme Park Companies, by Sales.

Company Name	Location	Sales ($)
The Walt Disney Company	Burbank, CA	31,944.0
Sony Corporation of America	New York, NY	22,330.9
Anheuser- Busch Companies, Inc.	St. Louis, MO	15,035.7
NBC Universal, Inc.	New York, NY	14,689.0
Walt Disney Parks and Resorts, LLC	Lake Buena Vista, FL	9,023.0
Six Flags, Inc.	New York, NY	1,089.7
Cedar Fair, L.P.	Sandusky, OH	568.7
Coinstar, Inc.	Bellevue, WA	459.7
Hershey Entertainment & Resorts Company	Hershey, PA	220.4
Great Wolf Resorts, Inc.	Madison, WI	139.4

Sales figures are in millions. Source: Hoover's, Inc. 2006. Available at www.Hoovers.com. Accessed July 2006.

MARKET TRENDS

As noted above the amusement park industry is growing. It is also changing in nature, as rides and attractions require increased energy to power flashing lights, special effects, motors, and backup systems. As more and more cities adopt energy conservation regulations, increased energy-efficiency standards may eventually be applied to parks.[125] This acts as a driver for the adoption of more energy-efficient uses of sources of backup power.

A number of amusement parks have exhibited an interest in environmental stewardship; this could also imply a related interest in the use of energy sources which have lower environmental impact, such as fuel cells. Park environmental programs include Disney's "Environmentality™", which addresses water and energy conservation, the promotion of wildlife and habitat conservation, education, support of research and technology, accountability and evaluation, and waste minimization. However, at present, no fuel cell activity was found for this market.

[122] Saferparks. 2006. Safety Regulation. Available at http://www.saferparks.org/regulation/ [Accessed June 2006].
[123] International Association of Amusement Parks and Attractions (IAAPA). 2006. Amusement Industry Statistics. Available at http://www.iaapa.org/fastfacts.asp#indstats [Accessed June 2006].
[124] Hoover's Incorporated. 2006. Theme Parks Fact Sheet. Available at www.Hoovers.com [Accessed June 2006].
[125] Horwitz, B. 2002. The Big Thrill. Consulting-Specifying Engineer (September 1, 2002). Available at http://www.syska.com/Media/news/article.asp?Articles.ART_ID=133 [Accessed June 2006].

MARKET SEGMENT ANALYSIS

Sixteen amusement parks were contacted to further determine requirements for backup power and the potential for application of fuel cells. One interview was conducted, but no complete responses from amusement park representatives were received.

The one interview respondent reported that the amusement park currently uses diesel, gas, and natural gas generators to provide on-site backup power and maintains agreements with third-party providers to supplement on-site generation capabilities with portable generators. The company has not considered the use of fuel cell technology in its amusement parks. The respondent stated that the company has no plans for major additions to existing on-site backup generation capability, but there may be small projects that replace existing equipment and add new equipment as an integral part of larger capital projects.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Limited primary and secondary information was available to determine the potential for PEM fuel cells in this market segment. No specific drivers for adoption of alternative technologies could be determined in this market segment. Numerous parks are presently adopting solar power and other alternative power sources to support their growing energy requirements. Since the growth rate of amusement parks is low, it is likely that PEM fuel cells will have to compete in the same market space as newly adopted alternatives like solar power and wind-power. No information on the application of fuel cells at amusement parks could be located.

It is likely that the "green" image offered by PEM fuel cells may offer an incentive for amusement parks wanting to promote environmental stewardship. As safety features on rides and attractions are often hidden to maintain the guest experience, the small space requirements of PEM fuel cells might offer another advantage to using fuel cells as a source of backup power for amusement parks.[126] Additionally, as PEM fuel cells are scalable, the technology could be sized appropriately to meet a park's expanding power needs. However, the lack of demonstration projects in this sector, and the lack of response to surveys, may indicate that users in this sector are not prepared to pursue PEM fuel cell technology at this time. Furthermore limited secondary information on current and future backup power requirements suggests that the amusement park market is not an attractive market opportunity for PEM fuel cells in the near-term.

[126] Horwitz, B. 2002. The Big Thrill. Consulting-Specifying Engineer (September 1, 2002). Available at http://www.syska.com/Media/news/article.asp?Articles.ART_ID=133 [Accessed June 2006].

RESEARCH SUMMARY:
CASINOS

MARKET SEGMENT DESCRIPTION

The U.S. casino industry consists of land-based commercial casinos, riverboat casinos, tribal-run casinos, racetrack casinos, and card rooms. The casino industry includes land-based casinos both with and without lodging, as well as racetracks, riverboats, and dockside casinos. Commercial gaming (permitted in 11 states) and Indian casino operations (in 28 states) are subsets of the casino industry. This analysis considers the potential for direct hydrogen PEM fuel cells for casino backup power. Table c-1 identifies the SIC and NAICS codes associated with this market segment.

Table c-1. SIC and NAICS Codes for the Casino Industry.

2-Digit SIC Code	70 – Hotels, rooming houses, camps, and other lodging places
4-Digit SIC Code	7011 – Hotels and motels
8-Digit SIC Code	7011-0301 – Casino hotels
NAICS Code	721120 – Casino hotels

Casinos have been compared to hotels, one of the greatest energy users in the commercial sector, in light of the large amounts of energy that they consume. Energy costs in the lodging industry average nearly $2 per square foot per year, and the hotel industry spends about $500 per room per year for fuel and electricity.[127] However, casinos have an even greater need for energy and backup power than standard hotels because, in addition to the guest rooms, casinos have gaming floors, restaurants, bars, spa facilities, retail stores, event centers for concerts and conference exhibitions, night clubs, theaters, amusement park rides, health clubs, and other entertainment facilities. A key trend in the casino resort segment, "entertainment convergence" refers to casinos and resorts broadening the appeal of their facilities to attract more people and provide a variety of attractions that will entice guests to lengthen their stay.[128] The addition of these multiple uses and components increases the size of facilities and creates a correspondingly larger but also more diverse energy load.

Concerns about power reliability are a priority within this market sector due to the potential significant financial loss of gaming revenues. For instance, the power outage that lasted nearly 4 days in April, 2004 at the Bellagio in Las Vegas was estimated to have cost the company up to $3 million per day in revenues and $750,000 to $1 million daily in net operating income in addition to the equipment and overtime labor for repairs.[129]

An article on standby power plants in Las Vegas notes that, although emergency power systems typically are thought of as crucial for public health and safety, for casinos in Las Vegas, keeping power running nonstop to slot machines and other gaming operations is considered just as

[127] Fedrizzi, R. and J. Rogers. 2002. Energy Efficiency Opportunities: The Lodging Industry. Available at http://files.harc.edu/Sites/GulfCoastCHP/MarketAssessments/EnergyEfficiencyOpportunitiesLodging.pdf [Accessed July 2006].
[128] Fedrizzi, R. and J. Rogers. 2002. Energy Efficiency Opportunities: The Lodging Industry. Available at http://files.harc.edu/Sites/GulfCoastCHP/MarketAssessments/EnergyEfficiencyOpportunitiesLodging.pdf [Accessed July 2006].
[129] Findarticles™. 2006. Bellagio blackout doesn't dim Las Vegas' boomtown luster; Blau back with Wynn. Available at http://www.findarticles.com/p/articles/mi_m3190/is_17_38/ai_n6013745 [Accessed July 2006].

critical.[130] Applications for backup power at casinos include: emergency lighting and alarm systems, lights, surveillance cameras, heating and ventilation systems (i.e. air conditioning in Las Vegas), and some games.[131] In addition to the social and economic impacts, there are safety issues associated with losing power at a casino. Loss of power and public panic in a crowded area such as a casino can lead to a fire hazard. Interviews with fire officials indicate that backup power and redundant systems are desirable in order to prevent emergencies.[132]

Casinos produce a significant amount of electricity onsite and often use the grid as backup. Casinos typically use CHP systems to meet the electricity as well as hot and cold water requirements.[133] Casinos use a mixture of natural gas and diesel generators, CHP systems, UPS units, and other technologies to provide additional and backup power.

Examples of backup power operations in casinos include:

- Tulalip Tribes Casino: The casino's 2 MW generator provides sufficient power to run all of the electronic games and 90% of the casino lights. A second generator is planned to function as a source of backup power.[134]
- Casino Morongo: This casino in Banning, California installed a cogeneration plant to protect the new facility from rolling blackouts and other impacts from heavy usage in other parts of the state. The casino experiences low-voltage outages on a regular basis. The peak electrical load for the 28-story hotel tower, casino, and spa complex was estimated at 4.62 MW; the minimum electrical load was estimated at 3 MW, with an average load of 3.62 MW; and the new cooling system must have chilled water capacity of 3,600 tons with a 2,400-ton peak load. Allowing for 15% future load growth, the casino complex was estimated to need at least 5.3 MW. Furthermore, the facility required a minimum addition of 6 MW of diesel-fired generation to back up the gas-fired generators.[135]

MARKET SIZE

In 2005, there were an estimated 969 U.S. establishments in the casino industry, employing over 266,920 individuals. Total annual sales in this industry were reported at $52,520.102 million.[136] The breakdown by casino market and associated revenue for the 10 U.S. casino markets is shown in Table c-2.

The casino industry has been growing steadily. Total commercial casino revenues increased by approximately $15 billion (110%) over the 10-year period from 1994 to 2004. Total gaming

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[130] O'Malley, P.G. 2004. Standby Power Plants Make Sure the Lights Stay On in Las Vegas. Distributed Energy, the Journal for Onsite Power Solutions (May/June). Available at http://www.distributedenergy.com/de_0405_standby.html [Accessed July 2006].
[131] O'Malley, P.G. 2004. Standby Power Plants Make Sure the Lights Stay On in Las Vegas. Distributed Energy, the Journal for Onsite Power Solutions (May/June). Available at http://www.distributedenergy.com/de_0405_standby.html [Accessed July 2006].
[132] O'Malley, P.G. 2004. Standby Power Plants Make Sure the Lights Stay On in Las Vegas. Distributed Energy, the Journal for Onsite Power Solutions (May/June). Available at http://www.distributedenergy.com/de_0405_standby.html [Accessed July 2006].
[133] EPA. 2006. Combined Heat and Power Partnership. Available at http://www.epa.gov/chp/project_resources/hotels.htm [Accessed July 2006].
[134] Wolcott, J. 2003. Casino is 'high tech' facility, says engineer. Snohomish County Business Journal (May). Available at http://www.snohomishcountybusinessjournal.com/archive/tulalip03/hightech-tulalip03.htm [Accessed July 2006].
[135] Corum, L. 2005. Betting on Power at Casino Morongo. Distributed Energy, the Journal for Onsite Power Solutions (November/December). Available at http://www.forester.net/de_0511_betting.html [Accessed July 2006].
[136] Dun and Bradstreet. 2006. Zapdata industry report. Available at www.zapdata.com [Last updated May 2006; accessed June 2006].

revenues grew by $38.8 billion (97%) over the same period.[137] In 1988, Congress passed the Indian Gaming Regulatory Act, affirming tribal gaming as a legitimate tool for reservation development and tribal self-sufficiency. Today, nearly half (224) of the nation's 562 federally recognized tribes operate 354 gaming operations. Numbers of operations are increasing steadily.[138] Today, commercial casinos represent the largest share of gross gambling revenue (GGR) at $30.59 billion (39%).

Table c-2. Top 20 U.S. Casino Markets by Annual Revenue (2005).[139]

Casino Market	2005 Annual Gross Revenues
Las Vegas Strip	$6.031 billion
Atlantic City, NJ	$5.018 billion
Chicagoland, IN/IL	$2.441 billion
Detroit, MI	$1.229 billion
Tunica/Lula, MS	$1.187 billion
Connecticut	$982.65 million
St. Louis, MO/IL	$959.60 million
Reno/Sparks, NV	$920.22 million
Boulder Strip, NV	$885.99 million
Shreveport, LA	$814.23 million

MARKET TRENDS

For casinos, fire codes in a number of cities, including Las Vegas, mandate that critical fire and life safety functions must be up and running within 10 seconds of any power loss. In some complexes, additional regulations, such as the International Building Code and the national electrical requirements, also apply. The minimal amount of backup power is not specified in building and fire codes; however, regulations are designed to allow for safe evacuation of a building. Additional backup capacity is used to provide power for non-critical functions in case of an emergency.[140]

As noted above, a number of technologies are being used for backup power in casinos. Several projects whereby casinos have installed wind turbine operations may indicate an increased focus on green power.[141,142] This trend has been primarily seen in Indian casinos, although one commercial casino has also invested in green power.[143] To date, only one casino has installed fuel cell technology for backup power. The Mohegan Sun Casino in Connecticut installed a fuel cell to provide backup power for the Mohegan Energy, Environment, Economics, and Education

[137] American Gaming Association, Christiansen Capital Advisors LLC. 2006. Gaming Revenue: 10-Year Trends. Available at http://www.americangaming.org/industry/factsheets/statistics_detail.cfv?id=8 [Accessed August 2006].
[138] National Indian Gaming Association. 2006. Indian Gaming Facts. Available at http://www.indiangaming.org/library/indian-gaming-facts/index.shtml [Accessed December 13, 2006].
[139] The Innovation Group (TIG). 2006. Casino Statistics in the U.S. Available at http://www.theinnovationgroup.net/map_us.asp [Accessed April 2006].
[140] O'Malley, P.G. 2004. Standby Power Plants Make Sure the Lights Stay On in Las Vegas. Distributed Energy, the Journal for Onsite Power Solutions (May/June). Available at http://www.distributedenergy.com/de_0405_standby.html [Accessed July 2006].
[141] DOE. 2006. Tribal Energy Program. Spirit Lake Sioux: Project Summary. Available at http://www.eere.energy.gov/tribalenergy/title26/sl_sioux_summary.html [Accessed December 13, 2006].
[142] Native Wind. 2006. Timeline. Available at http://www.nativewind.org/html/timeline.html [Accessed December 13, 2006].
[143] Marina Energy. 2006. Borgata Goes Green; Signs 20-Year Contract with Marina Energy for Renewable Energy. Available at http://www.sjindustries.com/marina/marinanews/marina6.htm [Accessed December 13, 2006].

Center, which is located within the casino.[144] The system is based on Distributed Energy's UNIGEN® Regenerative Fuel Cell System and includes a high pressure (over 1,000 psi), high-output hydrogen generator.[145] The Mohegan system was also made possible by a grant from the Connecticut Clean Energy Fund.[146]

Mohegan Sun also installed two 200 kW phosphoric acid fuel cell (PAFC) systems that run on natural gas in March 2002. The Mohegan Sun was a Buy Down Recipient of the FY1996-1997 DoD Climate Change Fuel Cell Program.[147] The PAFC is used to provide electricity to the casino's UPS systems. The system is also part of the tribe's educational program. The primary driver for the installation of this system was to offset carbon dioxide emissions from diesel generators.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in the casino market, 35 casinos and casino organizations were contacted. The response rate for this segment was very low. Only two interviews were conducted, and one complete survey response was received. The survey response will be summarized first, followed by the interview responses.

Survey Summary

The one complete response was received from a small casino that employs less than 500 staff. The respondent reported that backup power is a critical requirement for casino surveillance, although management information systems also have backup power. The casino uses 15 to 30 kW UPS systems for backup power; however, the respondent noted that no outages have occurred in the past 11 years. While the casino has not experienced any power outages, the respondent indicated that a power failure could potentially result in security breaches and implementation of emergency management plans. The longer a power outage, the more disruptive it is expected to be.

The respondent rated the performance of the casino's current backup power systems on various characteristics: start-up time, ease of use, and fuel availability were considered very good; reliability and lifetime of the unit were considered good; capital cost, operation and maintenance costs, annual operating cost, and emissions were rated fair. The respondent noted no overall concerns with the casino's current backup power systems. It was noted that reliability was overall the most important factor in selecting a backup power system, although various other factors were important as well. Reliability, capital cost, lifetime of the unit, annual operating cost, emissions, start-up time, and fuel availability were considered very important. Ease of use (including regular maintenance) and good experience with a system were considered important factors. The casino has considered diesel generators but not fuel cells as an alternative backup power source. The respondent had not heard of PEM fuel cells for backup power applications.

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[144] Wallheimer, B. 2006. Connecticut leads national fuel cell effort. Norwich Bulletin (May 25, 2006). Available at http://www.boston.com/news/local/connecticut/articles/2006/05/25/connecticut_leads_national_fuel_cell_effort/ [Accessed December 13, 2006].
[145] The Mohegan Tribe. 2004. Press Room. Available at http://www.mohegan.nsn.us/pressroom/ViewPressRelease.aspx?articleID=73 [Accessed June 2006].
[146] The Mohegan Tribe. 2004. Press Room. Available at http://www.mohegan.nsn.us/pressroom/ViewPressRelease.aspx?articleID=73 [Accessed June 2006].
[147] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Accessed December 2006].

The respondent predicted a growing need for backup power in the casino sector. This may be due to growth in the casino industry. They noted that decisions for capital purchases are typically based on initial capital cost, payback period, and return on investment. Government incentives are also considered. The president of the company makes final decisions regarding the selection of backup power systems.

Interview Summary

One interviewee represented one of the largest casinos in world. The other also represented a large casino operation, with diverse properties. Both interviewees indicated that life safety systems, such as water pumps for sprinkler systems, ingress/egress lighting, emergency lighting, and emergency systems, were critical applications requiring backup power. Diesel generators were the primary source of backup power used by both interviewees. UPS systems were used for critical systems, but only for the 8 seconds or less that it takes for generator backup power to come online. One interviewee reported that UPS was also used to back up certain information technology (IT) equipment; UPS systems are distributed and sized to allow computer systems to shut down in an orderly manner, but UPS systems are not intended for prolonged use of equipment.

One interviewee reported that the size of backup power generation varies by property but is generally in the 1 to 3 MW range. The large casino also reported that each property is different in terms of the quantity of its fuel supply and how long it could last on backup power alone. In addition, the city, county, and state have requirements that apply to backup power for life safety systems.

The large casino interviewed reported experiencing no outages that lasted longer than 1 hour; as a result, outages were not a significant concern. However, the casino did report one past significant outage that was prolonged due to on-site equipment failure.

The large casino interviewed commented on the potential for PEM fuel cells to be used for backup power in casinos. The company is interested in new environmentally friendly operations and has begun a new Leadership in Energy and Environmental Design (LEED) project. However, the interviewee reported that they are satisfied with the existing backup power system and have not considered using PEM fuel cells.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The casino market appears to be a growing market with fairly large power requirements. Reliable backup power is a critical need for casinos. Despite the size and growth pattern of this industry, it is unlikely that PEM fuel cells will offer a unique value proposition in this market segment.

Most casinos have redundant power supplies in the form of additional power lines from the grid, large generators, and/or CHP units. As casinos are in the hospitality business, they also require an adequate supply of backup power to support both non-critical and critical functions. For critical functions, additional backup power is provided through UPS systems.

It appears that the power size (~ 1 to 5 MW) and lack of CHP efficiency of the commercial and pre-commercial PEM fuel cells is a limiting factor for application in this market segment. Additionally, many casinos have made large investments in generator and other backup power sources as well as cogeneration plants; to replace these investments, PEM fuel cells would need to be able to meet casinos' size requirements and offer a significant advantage over existing backup power sources. PEM fuel cells will likely be a better fit for backup power applications currently supported by UPS systems, including computers, emergency lighting, and sprinkler systems. However, UPS systems are sized to provide just enough run-time to cover operations until other sources of backup take over.

There are limited drivers for the adoption of PEM fuel cells in this market segment; no regulatory drivers were identified. There are few environmental efforts in the casino industry, which could serve as a market driver for the adoption of alternative energy technologies. However, here PEM fuel cells would have to compete with other sources of green power. Furthermore, the three casinos contributing to this analysis reported satisfaction with their current backup power systems and had not considered adopting PEM fuel cell technology.

Limited interest in alternatives for smaller backup applications, lack of technology fit for larger application, and lack of drivers suggests that this market segment is not an attractive market opportunity for PEM fuel cells in the near term.

RESEARCH SUMMARY:
CHEMICAL MANUFACTURING

MARKET SEGMENT DESCRIPTION

The chemical manufacturing industry is highly energy intensive and has many sub-sectors offering a variety of opportunities for the application of PEM fuel cells for backup power and grid parallel power. This analysis focuses on sub-sectors within the chemical industry that: a) use large quantities of hydrogen in their process, and/or b) produce hydrogen as a manufacturing by-product. It was assumed that because these sub-sectors currently maintain an on-site infrastructure for use and/or storage of hydrogen in industrial processes, they would be more likely to adopt hydrogen as a fuel source.

Several sub-sectors of the chemical industry met these criteria. The largest-scale processes using hydrogen in the chemical manufacturing industry include: ammonia synthesis, methanol synthesis, and other petrochemical and inorganic synthesis processes for hydrogenation.[148] Sub-sectors of the chemical industry that produce significant quantities of by-product hydrogen include chlor-alkali and sodium chlorate manufacturing.[149] Additional secondary research,[150] as well as recent fuel cell development activities in the chemical industry (e.g., see Dow Chemical and Nedstack demonstrations),[151] suggest that the most likely near-term opportunities for fuel cells within the chemical industry would focus on industries that meet the second criterion above, i.e., industries producing by-product hydrogen that could be used in fuel cell applications.

This analysis focuses on chlor-alkali and sodium chlorate manufacturing, as these industries have large-scale processes, are highly energy intensive, and produce hydrogen as a manufacturing by-product. Table d-1 provides the SIC and NAICS codes for these subsectors.

Table d-1. SIC and NAICS Codes for the Chlor-alkali and Sodium Chlorate Subsectors.

2-Digit SIC Code	28 – Chemicals and allied products
4- Digit SIC Codes	2812 – Alkalies and chlorine manufacturing 2819 – Industrial inorganic chemicals (includes sodium chlorate as well as other inorganic chemicals not otherwise specified)
NAICS Codes	325181 – Alkalies and chlorine manufacturing 325188 – All other basic inorganic chemical manufacturing (includes sodium chlorate as well as other inorganic chemicals not otherwise specified)

Most facilities in the chlor-alkali and sodium chlorate segments typically produce all or a portion of their own power via co-generation. Hydrogen generated during processes is typically used as fuel in the cogeneration units, sold as hydrogen gas, or vented. Backup power for facilities is provided at two levels: 1) an operation level backup, which includes all of the motors and the

[148] Manitoba Energy Development Initiative, Department of Energy, Science and Technology. 2003. Preliminary Hydrogen Opportunities Report. Available at http://www.gov.mb.ca/est/energy/hydrogen/hydrogen.pdf [Accessed September 2006].
[149] Manitoba Energy Development Initiative, Department of Energy, Science and Technology. 2003. Preliminary Hydrogen Opportunities Report. Available at http://www.gov.mb.ca/est/energy/hydrogen/hydrogen.pdf [Accessed September 2006].
[150] Frost & Sullivan. 2003. North American Stationary Fuel Cells Markets. ABI Research, #A426-14. Available at http://www.frost.com/prod/servlet/report-homepage.pag?repid=A426-01-00-00-00&ctxht=FcmCtx1&ctxhl=FcmCtx2&ctxixpLink=FcmCtx3&ctxixpLabel=FcmCtx4 [Accessed September 2006].
[151] NedStack Fuel Cell Technology B.V. 2006. PEM Power Plant: Stationary Power Generation with By-Product Hydrogen. Presented at Fuel Cell 2006, Raleigh-Durham, North Carolina. Available at http://www.fuelcell-magazine.com/PresentationsPDF/Nedstack06.pdf [Accessed September 2006].

large equipment, 2) and a control systems level backup, which includes support for critical systems to facilitate shut-down of manufacturing processes in a controlled fashion. Currently, most facilities have several levels of redundancy to support operations level backup to avoid even small levels of disruption. For example, the Dow facility in Midland, Texas, has two-level redundancy for their operations level backup. Redundancy is provided by power from the grid from two distinct sources, a nuclear plant and a gas-fired coal burning power plant. For control systems backup, a combination of battery backups, UPS systems, and generators are used.

Chlor-Alkali Market Segment Description

Chlorine and alkalies are typically co-produced via the electrolysis of salt water; they are some of the most important inorganic chemical commodities, and used in many diversified applications. They are primarily sold to industry for uses such as the production of pulp and paper, soaps and detergents, fibers and plastics, petrochemicals, fertilizers, solvents, disinfection chemicals and others. The most common chlor-alkali chemicals are chlorine (Cl_2) and sodium hydroxide (NaOH, caustic soda); other chemicals also include potassium carbonate, potassium hydroxide (caustic potash), sodium bicarbonate, and sodium carbonate (i.e., soda ash). Chlorine and chlorine derivative products comprise 45% of the country's gross domestic product.[152]

Typically, the chlor-alkali production process involves a brine system, an electrolysis system (electrolytic cell), a chlorine liquefaction process, caustic evaporation, and (if desired) hydrochloric acid synthesis. The chlorine and hydrogen produced in the electrochemical membrane process leave the cells at a pressure slightly higher than atmospheric pressure. After cooling in heat exchangers, chlorine undergoes additional processing in the form of chlorine liquefaction. The excess hydrogen is often further processed (along with chlorine) to generate hydrochloric acid, burned as fuel within the process (e.g., power for the caustic soda concentration), compressed and sold as a product, or vented to the atmosphere.

Sodium Chlorate Market Segment Description

Sodium chlorate is an oxidizing agent, used primarily to generate chlorine dioxide for bleaching paper pulp.[153] In the pulp and paper bleaching process, chlorine dioxide is a substitute for traditional chlorine, which has largely been phased out of the pulp and paper industry in the U.S. and elsewhere due to environmental concerns. In 2004, the application of sodium chlorate to chlorine dioxide production represented 99% of total consumption in North America.[154] Other minor applications of sodium chlorate include use as an herbicide, the production of other chlorates (potassium chlorate and sodium chlorite), and several other smaller applications.

Production of sodium chlorate is a multistage reaction where the electrode reaction products (chlorine and hydroxide) form hypochlorite, which then chemically is converted to sodium chlorate, and then purified by crystallization. The main part of this reaction, including production of hydrogen, takes place in the electrolytic cell.

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[152] ERCO Worldwide. 2006. Chlorine. Available at http://www.ercoworldwide.com/products_chlorine.asp [Accessed September 2006].

[153] Cellchem. 2002. Sodium Chlorate. Available at http://www.cellchem.com/docs/products-services/sodium_chlorate.htm [Accessed September 2006].

[154] Schlag, S. and K. Yagi. 2005. Chemical Economics Handbook Program - CEH Report: Sodium Chlorate. Available at http://www.sriconsulting.com/CEH/Public/Reports/732.1000/ [Accessed September 2006].

MARKET SIZE

The U.S. chemical industry is a nearly $1.67 trillion global enterprise; representing over 27% of total production. The U.S. is the largest chemical producer in the world, with over 9,500 chemical firms, which operate more than 13,000 facilities.[155] The chemical industry is also the second largest consumer of energy in manufacturing; production of organic chemicals accounts for the highest energy requirements of all chemical sectors. The U.S. chemical industry consumed about 6.1 quads (quadrillion Btu, or 1015 Btu) of energy in 1998.[156] The largest use of fuel energy is for heat and power (35%) in the boilers used to produce steam to drive chemical reactions and perform product separation and finishing operations. Heating and cooling processes account for an additional 25% of energy use.

Chlor-Alkali Market Size

As of July 2005, more than 500 companies produced chlor-alkali at over 650 sites worldwide.[157] In 2004, world production of caustic soda was estimated to be 51 million tons, and chlorine about 48 million tons.[158] About half of all plants are located in Asia, but many of these are relatively small. In the U.S., there are an estimated 206 establishments, employing over 13,290 people, with average annual sales of $13,667.3 million (Table d-2). Major chlor-alkali manufacturers in the U.S. include Dow, Formosa, Occidental Chemicals (OxyChem, and including Basic Chemicals Co.), Olin, Oxyvinyls, and PPG.[159,160]

Table d-2. Number of Businesses in the Alkalies and Chlorine Industry (2812).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2812-0000	Alkalies and chlorine	76	5,956	1,833.1
2812-0100	Alkalies	5	214	7.4
2812-0101	Caustic potash, potassium hydroxide	5	150	87
2812-0102	Caustic soda, sodium hydroxide	5	602	1.1
2812-0103	Potassium carbonate	2	6	1
2812-0104	Sal soda (washing soda), sodium carbonate (hydrated)	6	15	2
2812-0105	Soda ash, sodium carbonate (anhydrous)	9	1,818	2,934.1
2812-0106	Sodium bicarbonate	34	811	43.6
2812-9901	Chlorine, compressed or liquefied	64	3,718	8,758
	Total	**206**	**13,290**	**13,667.3**

Sales figures are in millions. Source: www.zapdata.com; accessed June 2006.

Sodium Chlorate Market Size

The three major developed regions of the world represent 87% of the total global sodium chlorate capacity - North America accounted for 63%, Western Europe for 23%, and Japan for 1

[155] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Chemicals Industry Analysis Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/chemicals/index.html [Accessed September 29, 2006].
[156] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Chemicals Industry Analysis Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/chemicals/index.html [Accessed September 29, 2006].
[157] Schlag, S. and K. Yagi. 2005. Chemical Economics Handbook Program - CEH Report: Sodium Chlorate. Available at http://www.sriconsulting.com/CEH/Public/Reports/732.1000/ [Accessed September 2006].
[158] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[159] The Innovation Group (TIG). 2004. Chemical Profile for Sodium Chlorate. Available at http://www.the-innovation-group.com/ChemProfiles/Sodium%20Chlorate.htm [Accessed June 2006].
[160] SRI Consulting. 2006. Directory of Chemical Producers. Available at http://www.sriconsulting.com/DCP [Accessed June 2006].

%.[161] Over 75% of world sodium chlorate capacity is operated by four companies - Eka Chemicals (a subsidiary of Akzo Nobel), Erco Worldwide, Kemira, and Canexus.[162] In the U.S., seven out of ten sodium chlorate facilities were operating in 2006 with a combined capacity of 772,000 short tons per year (100% $NaClO_3$ basis).[163] Top U.S. producers include Erco Worldwide, Eka Chemicals, FINNCHEM USA, and Kerr-McGee (Tronox, Inc). Increasing energy costs in recent years prompted several sodium chlorate plants in the U.S. to be idled, including ATOFINA's plant in Portland , Oregon, the Georgia Gulf plant at Plaquemine, Louisiana, and a Canexus plant in Taft, Louisiana (replaced by a lower-cost expansion of their sodium chlorate plant in Brandon, Manitoba, which is the world's largest sodium chlorate facility and has one of the lowest cost structures in the industry.)[164]

In the U.S. sodium chlorate industry, a subset of the industrial inorganic chemicals sector, there are approximately 1,200 establishments, employing 47,873 people, and generating annual sales of $25,048 million (Table d-3).

Table d-3. Selected Businesses in the Industrial Inorganic Chemicals Sector (2819).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2819-0000	Industrial inorganic chemicals, not elsewhere classified	1,020	43,709	22,759.9
2819-0102	Alkali metals: sodium, potassium	1	8	N/A
2819-0400	Sodium & potassium compounds	6	160	824.2
2819-0406	Sodium compounds or salts, inorg., ex. refined sod. chloride	6	201	697.3
2819-0407	Sodium hyposulfite, sodium hydrosulfite	4	57	5.4
2819-0408	Sodium silicate, water glass	2	31	N/A
2819-0409	Sodium sulfate, glauber's salt, salt cake	2	33	4.8
2819-0410	Sodium sulfides	1	700	N/A
2819-1001	Bleaching powder, lime bleaching compounds	5	29	1.2
2819-9902	Chemicals, high purity: refined from technical grade	111	2,213	632.6
2819-9903	Chemicals, reagent grade: refined from technical grade	42	732	122.2
	Total	**1,200**	**47,873**	**25,048**

Sales figures are in millions. Source: www.zapdata.com; accessed June 2006.

In a 2001 report by the Lawrence Berkeley National Laboratory, the chlor-alkali industry (SIC Code 2812) and the inorganic chemical industry (SIC Code 2819, which includes sodium chlorate manufacturing) were identified as two of 43 industries likely to be most susceptible to economic harm from disruptions in electricity supply.[165] To indicate the magnitude of each industry's susceptibility, Table d-4 shows total purchased electricity along with energy intensity for SIC Codes 2812 and 2819.

[161] Schlag, S. and K. Yagi. 2005. Chemical Economics Handbook Program - CEH Report: Sodium Chlorate. Available at http://www.sriconsulting.com/CEH/Public/Reports/732.1000/ [Accessed September 2006].
[162] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[163] SRI Consulting. 2006. Directory of Chemical Producers. Available at http://www.sriconsulting.com/DCP [Accessed June 2006].
[164] The Innovation Group (TIG). 2004. Chemical Profile for Sodium Chlorate. Available at http://www.the-innovation-group.com/ChemProfiles/Sodium%20Chlorate.htm [Accessed June 2006].
[165] Eto, J., J. Koomey, B. Lehman, N. Martin, E. Mills, C. Webber, and E. Worrell. 2001. Scoping Study on Trends in the Economic Value of Electricity Reliability to the U.S. Economy. LBNL-47911. Available at http://eetd.lbl.gov/emills/PUBS/PDF/LBNL_47911.pdf [Accessed December 13, 2006].

Table d-4. Purchased Electricity and Electricity Intensity for SIC Codes 2812 and 2819.[166]

SIC Code	Description	Purchased Electricity (Twh)	Electricity Intensity (Kwh/ 000 – Us$ Value Added)
2812	Alkalies and Chlorine	13.8	8,552.3
2819	Industrial inorganic chemicals	36.1	3,465.9

MARKET TRENDS

In addition to demanding constant power to ensure continual operations, the chemical industry requires backup power to ensure reliability of operation and safe shutdown in the event of a power interruption. According to site security guidelines for the U.S. chemical industry developed by industry groups, it is recommended that chemical facilities secure utilities including communications (telephone and computer), water, sewer, and gas from a security standpoint as well as a safety and operations standpoint. These guidelines note that key resources such as control centers, rack rooms, computer servers, and telecommunications equipment may warrant a backup power source, such as a generator.[167] The EPA has also conducted outreach to the chemical industry regarding prevention of chemical accidents caused by electric power outages, and recommends the installation of backup power supplies and services if there is critical equipment that needs to operate to ensure the safe state of the process or work area. EPA suggests that services such as emergency pumps, lighting, alarms, and instruments and controls, particularly computer operated distributed control systems (DCS), may need to operate using backup power generators or UPS systems. According to EPA, steam or diesel driven pumps should be considered to maintain critical flows while a process is shutting down or otherwise dealing with a power outage.[168]

About one-fifth of electricity used by the chemical industry as a whole is produced on-site, primarily by means of cogeneration.[169] The chemical industry is one of the largest cogenerators in the manufacturing sector, second only to pulp and paper mills. The chemical industry has steadily increased its cogeneration capacity. The chlor-alkali and sodium chlorate sectors of chemical manufacturing also produce significant quantities of by-product hydrogen, which is often used on-site as fuel for power generation, offsetting requirements and costs for natural gas. Excess quantities of by-product hydrogen are also sometimes sold (e.g., to gas purification/distribution companies or petroleum refineries), or vented as a waste. More recently, several companies have investigated the use of by-product hydrogen in PEM fuel cells installed on-site.

[166] Eto, J., J. Koomey, B. Lehman, N. Martin, E. Mills, C. Webber, and E. Worrell. 2001. Scoping Study on Trends in the Economic Value of Electricity Reliability to the U.S. Economy. LBNL-47911. Available at http://eetd.lbl.gov/emills/PUBS/PDF/LBNL_47911.pdf [Accessed December 13, 2006].

[167] American Chemistry Council, Chlorine Institute, Inc., Synthetic Organic Chemical Manufacturers Association. 2001. Site Security Guidelines for the U.S. Chemical Industry. Available at http://www.chlorineinstitute.org/Files/PDFs/SecurityguidanceACC1.pdf [Accessed September 2006].

[168] EPA. 2001. Chemical Accidents from Electric Power Outages. EPA-550-F-01-010. Available at http://yosemite.epa.gov/oswer/Ceppoweb.nsf/vwResourcesByFilename/power.pdf/$File/power.pdf [Accessed September 2006].

[169] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Chemicals Industry Analysis Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/chemicals/index.html [Accessed September 2006].

Chlor-Alkali Market Trends

The demand for both caustic and chlorine saw a general decline in recent years.[170] This was largely attributed to high natural gas prices, which eliminated the cost advantages of U.S. chlor-alkali manufacturers. For example, Pioneer, which has been idling its 225,000 ton per year plant in Tacoma, Washington, since March 2002, announced that it will not resume production because it was unable to obtain reasonably priced power.[171] Other reasons for reductions in the demand for chlorine cited in the literature include: decreases in the use of chlorine in the pulp and paper industry as a bleaching agent (in response to environmental pressures to reduce chlorinated organic substances in wastewater effluents),[172] and decreases during the 1998 to 2002 period in the overall demand growth for chlorine in the manufacture of organic chemicals (largely due to process changes in ethylene dichloride/polyvinyl chloride, or EDC/PVC, manufacture).[173]

In 2004, however, there was a reversal of this declining trend with a strong demand for chlorine (largely due to China's enormous growth), a general rebounding of the global economy, and a lack of new capacity.[174] Growth for chlorine and caustic through 2006 (the forecast period) were projected to be 2 and 1.4 % per annum, respectively.[175,176] In a recent electrochemical industry update,[177] construction of new facilities in the northwest U.S. was reported (Equapac is building a 75,000 ton per year plant in Longview, WA; Ineos Chlor and Equa-Chlor have started work on a 80,000 ton per year plant in Longview, WA, using Ineos Membrane electrolyze technology).

Sodium Chlorate Market Trends

An analysis by the Innovation Group (TIG)[178] notes that in the U.S. through 2001, sodium chlorate market trends were largely driven by the 1998 U.S. EPA ruling that addressed concerns about chlorine dioxins and organic halides in pulp mill effluents; the ruling stated that chlorine could be replaced with chlorine dioxide, which is produced from sodium chlorate. Until April 2001, the deadline for implementing the substitute technology, the conversion to elemental chlorine free (ECF) bleaching was a key demand driver in increasing the sodium chlorate market. The mature markets and competitive situation of North America in the paper and pulp industries indicated that consumption of sodium chlorate is expected to be relatively stagnant from 2004 to 2009.[179]

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[170] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[171] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[172] Schlag, S. and K. Yagi. 2005. Chemical Economics Handbook Program - CEH Report: Sodium Chlorate. Available at http://www.sriconsulting.com/CEH/Public/Reports/732.1000/ [Accessed September 2006].
[173] The Innovation Group (TIG). 2003. Chemical Profile for Chlorine. Available at http://www.the-innovation-group.com/ChemProfiles/Chlorine.htm [Accessed June 2006].
[174] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[175] The Innovation Group (TIG). 2003. Chemical Profile for Chlorine. Available at http://www.the-innovation-group.com/ChemProfiles/Chlorine.htm [Accessed June 2006].
[176] The Innovation Group (TIG). 2003. Chemical Profile for Caustic Soda. Available at http://www.the-innovation-group.com/ChemProfiles/Caustic%20Soda.htm [Accessed June 2006].
[177] Srinivasan, V., P. Arora, and P. Ramadass. 2006. Report on the Electrolytic Industries for the Year 2004. J. Electrochem. Soc. 153(4): K1-K14.
[178] The Innovation Group (TIG). 2004. Chemical Profile for Sodium Chlorate. Available at http://www.the-innovation-group.com/ChemProfiles/Sodium%20Chlorate.htm [Accessed June 2006].
[179] Schlag, S. and K. Yagi. 2005. Chemical Economics Handbook Program - CEH Report: Sodium Chlorate. Available at http://www.sriconsulting.com/CEH/Public/Reports/732.1000/ [Accessed September 2006].

Fuel Cell Activity in the Chlor-Alkali Market Segment

As mentioned previously, hydrogen gas produced as a by-product of the chlor-alkali electrolytic cell process is often captured and burned as a fuel in on-site power stations (e.g., power for caustic soda drying/concentration). Excess hydrogen can also be used in the manufacture of hydrochloric acid, or compressed and sold as a product. Several projects have investigated potential applications of by-product hydrogen from the chlor-alkali industry to PEM fuel cell power generation, although none identified were specifically cited as being for backup power applications. Projects are being pursued both in the U.S. and internationally.

Dow Chemical and General Motors are currently collaborating on the installation of a large-scale PEM system to produce electricity (up to 35 MW), using hydrogen produced as a by-product from chlorine production at a Freeport, Texas, facility.[180] The Freeport facility of Dow Chemical is one of the largest chlor-alkali sites in the country, producing about 3,240 thousand short tons of chlorine per year (using diaphragm and membrane processes) and 3,564 thousand short tons of sodium hydroxide per year.[181] The project will provide valuable information regarding the viability of fuel cells in process industries using by-product hydrogen.

NedStack Fuel Cell Technology (Arnhem, The Netherlands) is working with Azko Nobel chlor-alkali facilities at Delfzijl and Rotterdam Harbor in the Netherlands in a project supported by the Dutch Ministry of Economic Affairs through its Energy Innovation Program. The project involves construction of a 20 MW PEM fuel cell power plant with a system life of 175,000 hours, and cost of € 250/kW and 0.01 €/kWh.[182] To date, a durable stack has been developed and tested in a pilot plant, a 100 kW module has been tested and is ready for installation in the Akzo Nobel plant in Delfzijl, and it is expected that 1 MW systems will be available in early 2007.

In 2005, Nuvera Fuel Cells, Inc., an international developer of multi-fuel reforming and PEM fuel cell technology, and UHDENORA SpA, a world developer and supplier of electrochemical plants for the production of chlorine and caustic soda, announced that they will develop a modular fuel cell system designed to increase the eco-efficiency of chlor-alkali plants.[183] According to the agreement, Nuvera and UHDENORA will engage in a three-phase joint initiative aimed at developing a rugged base-load system capable of reducing a plant's power consumption by approximately 20%.[184] The new system will be capable of converting the available hydrogen into DC current, delivering high-efficiency electricity. The system is also being designed to integrate safely and reliably with chlor-alkali electrolyzers, avoiding any interference with ongoing plant production. The companies began initial testing of the fuel cell system in May 2005.

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[180] The Dow Chemical Company. 2006. Fuel Cell Program. Available at: http://www.dow.com/commitments/studies/fuelcell/ and http://www.eere.energy.gov/industry/bestpractices/energymatters/articles.cfm/article_id=233 [Accessed September 2006].
[181] SRI Consulting. 2006. Directory of Chemical Producers. Available at http://www.sriconsulting.com/DCP [Accessed June 2006].
[182] NedStack Fuel Cell Technology B.V. 2006. PEM Power Plant: Stationary Power Generation with By-Product Hydrogen. Presented at Fuel Cell 2006, Raleigh-Durham, North Carolina. Available at http://www.fuelcell-magazine.com/PresentationsPDF/Nedstack06.pdf [Accessed September 2006].
[183] PR Newswire Europe Ltd. 2005. UHDENORA, Nuvera to Develop Advanced Energy Saving Systems for the Electrochemical Industry. Available at http://www.prnewswire.co.uk/cgi/news/release?id=139540 [Accessed September 2006].
[184] Cross, J., A. Maggiore, and G. Sibilia. 2005. PEM Technology for the Chlor-Alkali Industry. Presented at the 2005 Fuel Cell Seminar, November 18, 2005. Available at http://www.fuelcellseminar.com/pdf/2005/Friday-Nov18/Cross_James_573.PDF [Accessed September 2006].

Fuel Cell Activity in the Sodium Chlorate Market Segment
In Vancouver, Canada, a fuel cell demonstration project[185,186] is currently being conducted involving the use of waste by-product hydrogen from a sodium chlorate manufacturing plant. Although the electricity generated by PEM fuel cells in this project will not be directly used by the sodium chlorate facility itself, the project demonstrates that sodium chlorate plants have the potential to provide an important supply of low-cost hydrogen to support the commercialization of fuel cell and other hydrogen-based technologies.

MARKET SEGMENT ANALYSIS

Overall, nine organizations from the chlor-alkali industry and seven organizations from the sodium chlorate industry were contacted. As several of the contacts were unable to provide all the detail requested by the survey, interviews were conducted to gather information on general trends and potential for application of PEM fuel cells in their market segment. Nine organizations participated in the interview. In addition, two organizations that participated in the interview also provided completed surveys. Seven representatives declined to answer the survey or participate in the interview, and indicated that there were no feasible applications for fuel cells at their facilities. Information received from the surveys will be summarized first, followed by the information received from the interviews.

Survey Summary

Of the two organizations that responded to the survey, one was large (> 3,000 employees) and one was small (< 500 employees). Both responses were received from the energy managers at these facilities. According to these respondents, functions that required backup power included computers, instruments, vibration monitors, fire eyes, motors, and drives with process facilities as well as emergency equipment needed to shut down the manufacturing plant.

Of the two respondents, one respondent had one to two partial outages in the past year, which lasted less than 60 seconds, while the other had three outages that lasted 4 hours or longer. Both respondents indicated that any level of disruption without backup power was very disruptive. Primary potential impacts of power outages were disruptions in production, disruptions in distribution, and implementation of emergency management plans. Both users indicated that they used a combination of batteries, UPS systems, and generators to provide backup power to their facilities. One respondent reported that backup power was being supplied by one 1 MW diesel generator, multiple UPS systems for control system backup, and battery backups for main switchgear control power.

In selecting a backup power system, respondents stated that reliability, start-up time, fuel availability, emissions, and good experience with this type of system in the past were very important factors. Capital cost was less of a concern to one respondent than the aforementioned factors. Both respondents were very satisfied with the current performance of their backup systems. Respondents were particularly satisfied with reliability, fuel availability, and other

[185] Natural Resources Canada. 2006. New Project Supports Advancement of Hydrogen Fuel Cell Technology for Lift Trucks - Hydrogenics, GM and NMHG to Strengthen Collaboration. Available at http://www.nrcan.gc.ca/es/etb/ctfca/NewsReleases_e.html [Accessed September 2006].
[186] Government of Canada Newsroom. 2005. Minister Emerson Announces $12.2 Million Contribution to Advance Hydrogen Economy. Available at http://news.gc.ca/cfmx/view/en/index.jsp?articleid=174809&keyword=IWHUP&keyword=IWHUP& [Accessed September 2006].

critical performance categories. One respondent was dissatisfied with the capital costs of his 1 MW generator system. Neither of the respondents had considered alternatives for their smaller backup needs. Both respondents had heard of PEM fuel cells for backup power. However, neither had considered them as a viable alterative because of their high capital costs. One respondent indicated they would purchase PEM fuel cells based on a track record of others using them and the energy efficiency of PEM fuel cells as compared to other competing alternatives. Both respondents indicated that government incentives were taken into consideration when making purchasing decisions. Respondents indicated that capital purchase decisions are made on the basis of return on investment. One respondent indicated that they also considered capital costs and payback period.

Interview Summary

Representatives in the electrochemical industry (including chlor-alkali and sodium chlorate manufacturers) indicated that backup power needs are generally met in this sector. Interview participants indicated that technologies being used to meet backup power requirements include UPS systems (five facilities), batteries (five facilities), and/or diesel generators (four facilities). In two cases, interviewees indicated that the need for backup power was generally limited at their facilities due to a high level of power redundancy (e.g., self-sufficient power cogeneration on-site, plus grid backup).

Backup power for operational systems usually demands large amounts of energy and needs are typically met via multiple levels of power redundancy (e.g., multiple grid sources, co-generation). Backup power for control systems and other small critical applications are usually met via diesel generators, UPS or other battery systems. Another interviewee indicated that the power demands of most operations-level systems were likely beyond the capabilities of fuel cells, but that fuel cell technologies could be applied in some operations with smaller power draw (on the order of 20 kW) and small critical operations, such as control systems.

Regarding the durations and impacts of outages, one interviewee indicated that power outages were on the order of nanoseconds, and one indicated that power outages lasted 4 hours or longer. One interviewee indicated that no disruptive power outages had occurred at their facility due to a high level of power supply redundancy.

All interviewees responding in this area indicated that they were generally very satisfied with their current backup power technologies. No interviewees indicated specific concerns regarding their current backup power systems. Some interviewees reported testing fuel cells for supplemental power systems, but no interviewees had considered fuel cells for backup power applications.

Information was not provided by industry regarding potential opportunities for future procurement of new backup power systems. However, there were a number of concerns regarding the use of PEM fuel cells and of hydrogen in backup power applications. Regarding perceptions of PEM fuel cells as backup power and the use of hydrogen as a fuel source, interviewees indicated that by-product hydrogen is already commonly used as a fuel in the electrochemical industry. The majority (6 facilities) indicated that their facility generated a large portion of their process power through cogeneration; excess by-product hydrogen from the chlor-

alkali process was cited in most of these cases (5 facilities) as being an important source of fuel for power cogeneration. Excess by-product hydrogen that was not used by facilities for power cogeneration (or that exceeded what was needed for power cogeneration at the facility) was also reported by interviewees to be sold to gas liquifiers/distributors (2 facilities); at one facility excess hydrogen was vented to the atmosphere. Three interviewees indicated that fuel cells using by-product hydrogen would only be feasible for generating supplemental power, unless hydrogen storage technologies were implemented for backup power.

Three interviewees indicated that they had considered and tested PEM fuel cells for converting excess process hydrogen into supplemental DC power for the process, but not for backup power uses. After testing, none of the facilities opted to install fuel cells due to lack of economic feasibility. The majority of interviewees (five facilities) indicated that they did not consider PEM fuel cells to be a cost effective option at this time due to high initial capital investment and the higher value that they currently receive for their by-product hydrogen (as a fuel source for on-site power cogeneration, or as a sold commodity). Two interviewees indicated that PEM fuel cells could possibly be more economically feasible at remote/isolated facilities with lack of access to grid power or that otherwise had stranded hydrogen due to market deficiencies. One interviewee indicated that PEM fuel cells had not been considered for critical power backup at this time because the reliability of fuel cell systems was unknown and they had proven technologies already in place.

Two interviewees cited the need for government (financial) incentives to drive the adoption of fuel cell technologies.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Based on analysis of the chlor-alkali and sodium chlorate market segments, the chemical manufacturing sector is not an attractive near-term market opportunity for PEM fuel cells. Initial opportunities for PEM fuel cells in this market segment are likely to be grid parallel or grid independent applications utilizing the hydrogen available on-site for generating supplementary power for facility operation, and not backup power applications. Success in grid parallel and grid independent applications is likely, only if performance issues (increased power size, durability and efficiency) and capital costs can be addressed.

There are potential benefits of pursuing application of PEM fuel cells in this market sector; for instance, codes, standards, and procedures for handling hydrogen are better established than in residential or commercial applications. The potential to convert excess hydrogen into useful energy on-site is attractive, and (as demonstrated by the recent agreement between General Motors and Dow Chemical) there appears to be market interest in pursuing such an opportunity. However, primary research indicates that electrochemical companies already use excess hydrogen as fuel for steam/heat cogeneration or other process functions (e.g., dryers) in their manufacturing operations, and realize significant cost savings by doing so. The market also currently favors the sale of any excess by-product or waste hydrogen to gas liquefiers for purification and distribution or to petroleum refineries for use in the hydrocracking process; many such facilities are co-located to facilitate this arrangement. Conversations with representatives in the electrochemical industry indicated that use of by-product hydrogen in PEM fuel cell applications is, in general, not considered economically competitive at this time. In

addition, present performance and cost characteristics of PEM fuel cells do not appear to meet user requirements.

For backup power applications, control systems backup is the best fit for PEM fuel cells. The chemical manufacturing segment presently uses UPS systems, batteries, and generators to provide backup for control systems. No apparent drivers for switching backup power sources at a control systems level were identified. Marketing research indicates that users in this segment are very satisfied with their present technologies. Since most facilities have redundant power sources, these backup systems often provide a second or even third level of protection, so there is limited interest in alternatives. Users select backup power systems based on various factors including capital costs, reliability, fuel availability, and a track record of others using them. Users in this segment are aware of PEM fuel cells for backup power; however, high capital costs and lack of reliability data are barriers to adoption.

Lack of technology fit, cost barriers, and other barriers, including low growth in the chlor-alkali market segment and stagnant growth in the sodium chlorate market segment, suggest that the chemical manufacturing segment does not offer compelling value for PEM fuel cells in the near term.

RESEARCH SUMMARY:
COMPUTER AND ELECTRONIC EQUIPMENT MANUFACTURERS

MARKET SEGMENT DESCRIPTION

The computer and electronics sector includes the manufacturing and distribution of a wide variety of electronic equipment, including computers and computer components, electronic storage devices, and other electrical components. Table e-1 identifies the SIC and NAICS classifications for the computer and electronics sectors.

Table e-1. SIC and NAICS Codes for Computer and Electronic Equipment Manufacturing.

2-Digit SIC Codes	35 – Industrial and commercial machinery and computer equipment
	36 – Electronic, electrical equipment and components, except computer equipment
4-Digit SIC Codes	3571 – Electronic computers
	3572 – Computer storage devices
	3575 – Computer terminals
	3577 – Computer peripheral equipment, not elsewhere classified (nec)
	3578 – Calculating and accounting equipment
	3579 – Office machines, nec
	3651 – Household audio and video equipment
	3661 – Telephone and telegraph apparatus
	3663 – Radio and television communications equipment
	3669 – Communications equipment, nec
	3671 – Electron tubes
	3672 – Printed circuit boards
	3674 – Semiconductors and related devices
	3675 – Electronic capacitors
	3676 – Electronic resistors
	3677 – Electronic coils and transformers
	3678 – Electronic connectors
	3679 – Electronic components, nec
NAICS Codes	333311 – Automatic vending machine manufacturing
	333313 – Office machinery manufacturing
	334111 – Electronic computer manufacturing
	334112 – Computer storage device manufacturing
	334113 – Computer terminal manufacturing
	334119 – Other computer peripheral equipment manufacturing
	334210 – Telephone apparatus manufacturing
	334220 – Radio and television broadcasting and wireless communications equipment manufacturing
	334290 – Other communications equipment manufacturing
	334310 – Audio and video equipment manufacturing
	334411 – Electron tube manufacturing
	334412 – Bare printed circuit board manufacturing
	334413 – Semiconductor and related device manufacturing
	334414 – Electronic capacitor manufacturing
	334415 – Electronic resistor manufacturing
	334416 – Electronic coil, transformer, and other inductor manufacturing
	334417 – Electronic connector manufacturing
	334418 – Printed circuit assembly (electronic assembly) manufacturing
	334613 – Magnetic and optical recording media manufacturing

The largest industry segments (by dollar volume) are the production of electronic computers and semiconductors. Electronic computers are machines that: store processing programs and data; are programmable; perform arithmetical computations; and are able to modify their own execution by logical decision during the processing run. Equipment that incorporates computers for functions such as measuring, displaying, or controlling process variables are classified with the end product (and not included here). The electronic computers segment includes electronic computers, computers (digital, analog, or hybrid), mainframe computers, minicomputers, and personal computers (microcomputers).

The computer and electronics sector includes establishments primarily engaged in manufacturing semiconductors and related solid-state devices. Important products of this business are semiconductor diodes and stacks, including rectifiers, integrated microcircuits (semiconductor networks), transistors, solar cells, and light sensing and emitting semiconductor (solid-state) devices.

Backup power is used in the manufacture of computers and electronics to prevent power outages and blackouts and also to prevent voltage dips and sags by supplying a constant flow of premium power. Manufacturing requires a constant flow of high quality power – voltage sags can negatively impact manufacturing operations as much as power outages.[187,188] The computer and electronics sector uses backup power for manufacturing equipment control systems, air compressors and ventilation systems, clean rooms, data centers, and R&D centers – equipment support and computer systems.

The two primary backup power technologies that are used in computer and electronic manufacturing are diesel generators and conventional UPS battery systems. Conventional UPS battery systems provide 90 to 94% efficiency. UPS units offer the benefit of speed in providing backup power; this is important when a typical outage lasts less than 0.1 second.[189] When the utility grid has a disturbance, UPS units can take as little as 2 to 4 milliseconds to recover, protecting manufacturing operations before damage is done. Other technologies being marketed to the manufacturing sectors include microturbines, flywheel power systems, and ultracapacitors.

MARKET SIZE

The computer industry (SIC Code 3571) includes an estimated 2,278 U.S. establishments and employs 90,762 people. Total annual sales in this industry are $196,557.41 million; average sales per establishment are $116.40 million. The semiconductor industry includes an estimated 2,706 U.S. establishments and employs 216,488 people. Total annual sales in this industry are $131,430.70 million; average sales per establishment are $67.50 million. Table e-2 illustrates the overall size of the computer and electronics industry.

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[187] Deepak, D., R. Schneider, W. Brumsickle, D. Trungale, and T. Grant. 2002. Impact of Voltage Sag Correction in Critical Manufacturing Applications. Available at http://www.softswitch.com/docs/PQA%202002%20DySC.pdf [Accessed June 2006].
[188] Seymour, E., A. Pratt, R. Heckman, and D. Powell. 2004. Fabs Can Ride through Voltage Sags with Power-quality Targets. Solid State Technologies: International Magazine for Semiconductor Manufacturing. Available at www.advenergy.com/en/upload/File/Reprints/40340-144%20(Fabs%20can%20ride%20volt%20sags).pdf [Accessed June 2006].
[189] Sorkin, A. 2005. UPS: For When the Grid Goes Down. Distributed Energy, the Journal for Onsite Power Solutions. Available at http://www.distributedenergy.com/de_0511_ups.html [Accessed June 2006].

Table e-2. Number of Businesses in Various Computer and Electronic Equipment Manufacturing Sectors.[190]

SIC Code	SIC Description	Number of Businesses	Average Sales (Million $)	Total Sales (Million $)
3571	Electronic computers	2,278	116.4	196,557.4
3572	Computer storage devices	663	87.6	39,259
3575	Computer terminals	528	17	7,818.4
3577	Computer peripheral equipment, nec	2,363	45.5	86,622
3578	Calculating and accounting equipment	511	12.6	4,894.1
3579	Office machines, nec	618	22.7	9,382.1
3651	Household AV equipment	2,504	5.6	12,775
3661	Telephone and telegraph apparatus	1,610	35.1	38,428.9
3663	Radio and TV communications equipment	3,218	34	87,596.3
3669	Communications equipment, nec	1,436	11.3	13,005.7
3671	Electron tubes	125	7.1	728.2
3672	Printed circuit boards	1,716	31.8	46,205
3674	Semiconductors and related devices	2,706	67.5	131,430.7
3675	Electronic capacitors	154	26.6	3,109.5
3676	Electronic resistors	117	48.5	3,789.9
3677	Electronic coils and transformers	519	3.6	1,553.3
3678	Electronic connectors	455	64.9	20,953.8
3679	Electronic components, nec	4,395	4.9	18,768.4
	Total	**25,916**	**62.7**	**722,877.7**

In many cases, sellers (distributors and suppliers) of computers and electronics are not necessarily the manufacturers. Often, if a company retains management and operations of manufacturing, the manufacturing activities are located in Asia. China, Taiwan, and Singapore are among the common computers and electronics manufacturing countries. Key contract manufacturing companies include: Motorola, Sanmina SCI Corporation, Lenovo Group Limited, Solectron Corporation, Flextronics International Ltd, Jabil Circuit Inc, Celestica Inc., SYNNEX Corporation, and Kimball International Inc.

The rising cost of power is a concern among manufacturers. Due in part to rising power costs, Intel moved chipmaking operations from California to Ireland, New Mexico, and Arizona.[191] Some companies retain manufacturing operations in the U.S., but power costs are a driver for many businesses to move or outsource manufacturing overseas. Manufacturing services are often outsourced by companies such as HP and Compaq to contract manufacturers such as Sanmina, Jabil Circuit, and Lenovo. Larger computer and electronic companies who have manufacturing operations in the U.S. include: Apple Computer, Ariba, Advanced Micro Devices Inc., Cisco Systems, HP, Intel, Juniper Networks, Oracle Corporation, Sun Microsystems, and Texas Instruments.

Despite the U.S. trend toward outsourcing manufacturing operations to Asia, there is still some growth in domestic computer and electronic manufacturing. For example, in San Francisco, the electronic and computer manufacturing sector ballooned from a 6.1% share of Bay Area gross

[190] Dun and Bradstreet. Zapdata industry report. Available at www.zapdata.com [Accessed June 2006].
[191] Society of Manufacturing Engineers. 2001. Coping in California. Available at http://www.sme.org/cgi-bin/get-press.pl?&&20012443&GP&&SME& [Accessed June 2006].

domestic product (GDP) in 1994 to a 10.3% share in 2000 (in the middle of the dot-com bubble). It has since settled down to 6.9%.[192]

MARKET TRENDS

High-tech businesses are particularly vulnerable to power outages and blackouts due to the high cost of downtime and the need for an uninterrupted flow of high quality electricity in manufacturing (99.99999% reliability). Therefore, both power availability and power quality in electronics manufacturing have a significant effect on the quality and cost of electronic devices.

This has been cited in a number of manufacturing areas, including semiconductor manufacturing, PCB assembly, and system-level assembly. Due to the delicate manufacturing process, the semiconductor industry is particularly sensitive to power fluctuations. Power problems can cause large financial losses because of lost product and deferred production, costing the high-tech manufacturing sector anywhere from $30 billion to $119 billion every year.[193] Estimates suggest that the cost of downtime is approximately $0.5 million per hour in the electronics sector, and $1.3 million per hour in the information technology sector.[194] Power disturbances cost U.S. firms an estimated $30 billion annually in lost productivity and manufacturing processes. During the California energy crisis and blackouts in 2000, economists were projecting potential impacts of $75 million up to $100 million in Silicon Valley. One company noted that a 3-hr blackout cost $1 million per hour. In addition to loss of revenue and productivity, other consequences may include lost customers, decreased customer loyalty, non-compliance with regulatory requirements, legal implications, missing key audit requirements, loss of competitive advantage, and bad public image.

Some companies have been investigating small, modular energy generation and storage systems that can provide backup power during outages, hedge against energy price spikes, eliminate power quality problems, mitigate future emissions costs, and contribute to grid stability. There seems to be a growing market demand for smaller scale, fuel-flexible energy systems that can be deployed close to the point of use. A variety of products, including "Hybrid" and "SANUPS" units, are being developed that moderate voltage spikes and dips.

MGE UPS Systems, Inc. announced that MGE China is showcasing the first environmentally friendly fuel cell UPS in China for manufacturing and computer networking applications. The 3kVA UPS is powered by Ballard Power Systems' Nexa RM Series fuel cell modules and provides mission-critical process applications with extended run-time during power failures. This system has also been used in a project demonstrating the use of a fuel cell as a backup power source for an apartment building in New York.[195]

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[192] Bay Area Economic Forum. 2006. The Innovation Economy: Protecting the Talent Advantage. Available at http://www.bayeconfor.org/pdf/BAEP_February06web.pdf [Accessed June 2006].

[193] Electric Power Research Institute (EPRI). 1999. Electricity Technology Roadmap: 1999 Summary and Synthesis. Palo Alto, CA, EPRI.

[194] META Group, Inc. 2000. Quantifying Performance Loss: IT Performance Engineering and Measurement Strategies. Available at http://www.metagroup.com/us/displayArticle.do?oid=18750 [Accessed June 2006].

[195] MGE UPS Systems, Inc. 2004. MGE China Showcases Ballard® Fuel Cell Solution for Long Duration Backup Power – First Environmentally Friendly UPS in China to Provide Hours of Power Backup for Industrial and Networking Applications. Available at http://www.mgeups.com/news/pr/prus.htm?pr=71 [Accessed June 2006].

Environmental concerns are a driver for this industry to adopt alternative energy technologies. High-tech manufacturing may have interior emissions limitations due to building or manufacturing codes. Additionally, many manufacturing facilities are located in areas with emissions regulations that limit the use of diesel generators. For example, due to pollution caused by emergency diesel generators, these can be used a maximum of 200 hours per year in California. The Bay Area Air Quality Management District forbids turning on generators while the power is on. This ability to start generators only after the power goes off prohibits their use as an uninterrupted source of electricity.[196]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for PEM fuel cells in the computer and electronics manufacturing industry, computer and electronics manufacturing and distribution firms were contacted: 47 organizations were contacted, and four complete survey responses were received. In addition, three brief interviews in lieu of responses to survey questions were conducted. Eleven organizations declined to answer, indicating that this information was confidential. Of these responses, three respondents were from small electronics manufacturing and distribution firms, while one respondent represented the semiconductor manufacturing division of a large computer and electronics company.

Respondents indicated that backup power was used for computer systems, emergency lighting, exhaust fans, life safety systems, and some manufacturing applications. The most critical applications requiring backup power were IT, manufacturing, exhaust fans, and life safety systems. Responses received from smaller manufacturers indicated a limited need for backup power, while larger manufacturers considered backup power to be more important. Two manufactures reported experiencing blackouts of < 60 seconds, of unknown frequency. Only one manufacturer knew the frequency at which power outages occurred but noted that this information was confidential, as any outage (or even a voltage sag) can cause manufacturing disruptions; the respondent indicated that outages would be very disruptive. Three of the four manufactures noted that blackouts of any duration (< 60 seconds to > 4 hours) would be disruptive to very disruptive. Two respondents indicated that, although they do not typically experience disruptions, they had experienced several in the last month. One indicated that, although exact information is confidential, such disruptions are rare. All respondents indicated that power outages could result in disruptions of production and/or distribution.

Three of the four respondents use UPS units to provide backup power; one of these uses batteries and generators as well. One respondent uses a natural gas generator. Sizes of backup units varied; one respondent uses UPS units of < 1 kW, while another uses units greater than 250 kW, with approximately 400 kW of UPS power/batteries per facility. Gas and diesel generators ranged from 35 to > 700 kW.

Respondents indicated that reliability was the most important factor in selecting a source for backup power. Two mentioned that fuel cost and availability were also important factors. Three of the four respondents indicated that the performance of their current backup system was very good. One did not respond but indicated that emissions from generators and maintenance on

[196] Bay Area Economic Forum. 2006. The Innovation Economy: Protecting the Talent Advantage. Available at http://www.bayeconfor.org/pdf/BAEP_February06web.pdf [Accessed June 2006].

UPS units were a concern. Of the respondents, three indicated that the reliability of current systems was good to very good, and that fuel availability and start up time were very good.

None of the respondents saw a growing need for backup power in this market, and one indicated that demand would continue for some time at its current rate.

One of the four respondents had considered alternatives to their current mode of operation. One larger manufacturing company had considered PEM fuel cells as a potential source of backup power. This respondent had no concerns with the use of hydrogen as a fuel; however, the respondent did not believe that PEM fuel cells could favorably compete with current alternatives due to high costs. The respondent indicated that dissatisfaction with the current mode of backup power, energy efficiency of PEM fuel cells, environmental concerns, availability of government incentives, and a positive track record of others using PEM fuel cells could be potential drivers for adoption. Their decision to purchase would be made by engineering representatives from different manufacturing sites, and would be based on return on investment. Other respondents from smaller companies made capital decisions based on other factors, including initial capital cost, payback period, and need.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The opportunity for PEM fuel cells in this segment appears to be limited in the near-term. The computer and electronics manufacturing sector requires a consistent flow of high-quality power. The industry is extremely sensitive to blackouts and voltage sags, and there is a high cost associated with downtime. However, while the computer and electronics industries are large, many of the manufacturing functions are being outsourced overseas, and there does not appear to be a high growth rate of manufacturing operations in U.S. The potential fit for PEM fuel cells in this market segment is as backup power for specific computer systems, control systems, and emergency lighting in the near term. Facilities, however, require larger capacity backup technology than currently available PEM fuel cell units can supply. Limited information was gathered from surveys on the requirements for backup power in clean-rooms and manufacturing operations, as this information is considered confidential.

Environmental drivers are forcing manufacturing plants to consider alternatives to diesel generators. However, at this time, the size and durability of PEM fuel cells limit them from being considered as a suitable alternative. Manufacturers have introduced several products to address short outages and power quality problems. While users may be interested in protecting their networks from power quality problems, it does not appear that users are actively looking for alternatives to provide support for longer outages. Users seem very satisfied with their current backup power systems.

Marketing research did not identify a compelling value proposition for PEM fuel cells in this market segment. While no apparent barriers to PEM fuel cell adoption exist, it is likely that adoption will be driven by the reliability, quick start-up time, and capital and lifecycle costs of PEM fuel cells as compared to existing alternatives.

RESEARCH SUMMARY:
DATA CENTERS

MARKET SEGMENT DESCRIPTION

Nearly every medium-sized or larger company has some kind of data center that runs the applications that handle the core business and data necessary for the operation of the business. Data center services may be provided internally by an organization or bought from outside vendors. This market segment includes establishments primarily engaged in providing on-site management and operation of computer and data processing facilities on a contract or fee basis. These types of companies include data network operators, Internet and online services providers (e.g., web hosting services and co-location centers), and managed network services.

This analysis considers the potential for direct hydrogen PEM fuel cells for data center backup power. Table f-1 identifies the SIC and NAICS codes associated with this market segment.

Table f-1. Relevant SIC and NAICS Codes for Data Center Services.

2-Digit SIC Code	73 – Business services
4-Digit SIC Code	7376 – Computer facilities management services
NAICS Code	541513 – Computer facilities management services

A data center houses electronic equipment for the purpose of processing data for critical operations. Equipment housed in a data center typically includes critical computer systems and associated components as well as environmental controls (e.g., air conditioning, fire suppression), redundant/backup power supply, Internet and network connections, and security functions. Servers are the main form of equipment in a data center, often placed in racks of cabinets lined in single rows with corridors between them.

Data centers require reliable power for maximum network uptime. Backup power is a critical requirement of a data center in order to protect data and maximize uptime. Power loss, even for a few seconds, incurs high interruption costs for data centers and Internet service providers.[197] Power disruptions can result in data corruption, burned circuit boards, component damage, file corruption, and lost customers.[198] Studies suggest that U.S. industry interruption costs associated with system downtime average $1 million per hour.[199]

Backup power is typically provided by UPS and/or diesel generators. A Cisco Systems white paper recommends the following:[200]

- Multiple physically separate connections to public power grid substations
- Continuous power supply with backup UPS systems, with fuel (48 hours worth) for UPS-generators kept on the premises.

[197] Brown, A.S. 2003. Despite optimistic forecasts and steady progress in technology, widespread use of this alternative power source may still be more futuristic than realistic. necdigest™. Available at http://www.nfpa.org/itemDetail.asp?categoryID=561&itemID=18405&URL=Publications/necdigest/necdigest%20Magazine/necdigest®%20archives/Fall%202003/Fuel%20Cells&cookie%5Ftest=1 [Accessed July 2006].
[198] Pacific Northwest National Laboratory (PNNL). 2002. Electrical Power Interruption Cost Estimates for Individual Industries, Sectors, and U.S. Economy (PNNL-13797). Prepared for the U.S. Department of Energy under Contract DE-AC06-76RL01830.
[199] META Group, Inc. 2000. Quantifying Performance Loss: IT Performance Engineering and Measurement Strategies. Available at http://www.esolutionsgroup.ca/services/network_data.shtml [Accessed December 2006].
[200] Cisco Systems, Inc. 2004. White Paper Data Center: Best Practices for Security and Performance.

Traditional backup power sources for data centers include battery-based UPS systems and diesel generators. Secondary research indicates that these systems are typically large (1 to 2 MW) with an on-site fuel supply in case of extended outages (72 hours). Some data centers also have multiple power connections to the public grid for redundancy. For example, WestHost Inc., whose primary business is web hosting, has battery backup and 750 kV diesel generators with an underground fuel tank holding a 3 to 5 day supply of fuel to power its data center. Another web hosting service, AppSite, maintains a backup power system that includes two 2 MW generators, and 72 hours of backup fuel.

A number of other examples likewise indicate that data centers minimize the chance of power outage through backup systems designed with redundancy of power sources using diesel generators, battery-powered UPS, multiple grid power feeders, and a 72+ hour fuel supply.

MARKET SIZE

Larger companies may have several data centers, and large cities have data center buildings located in secure locations close to telecommunications services. Factors such as the rapid growth of the web, the increase in the use of networks to help geographically dispersed teams, and increasing server power have led to rapid growth in data centers and in their energy use.[201]

Potential fuel cell users in this market sector include hospitals and banks with large data center needs, as well as data center service providers like Sun Microsystems, Intel, Cisco, and others.

According to a survey of IT executives, companies are consolidating and centralizing data centers.[202] Data centers are being consolidated into a few central locations with increased capacity. More than half of all data centers are expected to expand or relocate by 2010.[203] As part of disaster recovery plans, companies are setting up secondary data centers. At the same time, companies are searching for ways to reduce their data center operating costs. These trends raise new issues for backup power.

The trend to centralize and consolidate has also caused an increased demand for servers (increasing at an average rate of 11% per year) and storage (increasing at a median rate of 22% per year), which brings greater demands for cooling in densely packed data centers.[204] As data centers increase capacity, heat output increases. Power and cooling are key issues of concern for data centers. The Green Grid, an association of IT professionals, has been formed to seek to lower the overall consumption of power in data centers around the globe.

Table f-2 provides market size statistics for SIC Code 7376, Computer Facilities Management Services.

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[201] Research News. 2006. Energy-Efficient Direct-Current-Powering Technology Reduces Energy Use in Data Centers By Up to 20 Percent. Available at http://www.lbl.gov/Science-Articles/Archive/EETD-DC-power.html [Accessed June 2006].
[202] Antonopoulos, A. M. 2006. The Four Main Data Center Trends. Network World. Available at http://www.networkworld.com/newsletters/datacenter/2006/0515datacenter1.html [Accessed June 2006].
[203] Data Center Knowledge. 2006. Five Predictions: Relocations and Outsourcing. Available at http://www.datacenterknowledge.com/archives/2006/03.html [Accessed June 2006].
[204] Mears, J. 2006. Consolidation and Growth – Trends in the New Data Center. Network World. Available at http://www.networkworld.com/weblogs/datacenter/012169.html [Accessed June 2006].

Table f-2. Market Size Statistics – Industry: Computer Facilities Management (SIC Code 7376).

Estimated Number of U.S. Establishments:	790
Number of People Employed in this Industry:	14,160
Total Annual Sales in this Industry:	$16,930.90 million
Average Number of Employees Per Establishment:	19
Average Sales Per Establishment:	$25.30 million

Source: www.zapdata.com, accessed June 2006.

MARKET TRENDS

Data communication applications worldwide spent an estimated $371.4 million on stationary lead-acid batteries in 2003, approximately 26% of the stationary lead-acid battery market. An annual growth rate of 9.3% is forecast through 2010, bringing estimated revenues from data communications' demand for lead-acid batteries to $693.2 million in 2010. The demand for stationary lead-acid batteries in the data center market segment is predicted to increase, threatening alternative competing backup power technologies (including UPS systems powered by fuel cells).[205]

However, there have been several fuel cell projects in this sector. In 2002, Chevron Energy Solutions installed a 200 kW phosphoric acid fuel cell (PAFC) at its ChevronTexaco data center in San Ramon, California.[206] The fuel cell, from UTC Power, supports critical data and retail transaction systems. It is designed to provide power to these critical systems without interruption in case of a power outage.[207]

Similar to the fuel cell installed at Chevron's San Ramon data center, a 200 kW PAFC from UTC Power supplies direct energy to a computer system center in Brazil. Likewise, a UTC Power 200 kW PAFC was installed in 1997 at a Hamilton Sundstrand data center in Connecticut. Three 200 kW PAFCs from UTC Power were installed in an office building in Fresno, California, in May 2004. The fuel cells provide power for computer server rooms, communications, building security, and other functions. In November 2000, two 200 kW PAFCs were installed at Ramapo College in Mahwah, New Jersey, to provide direct power and thermal energy to a dormitory and computer center.[208]

The primary driver for Chevron, in adopting a fuel cell at its San Ramon data center, was learning. They wanted to gain direct experience with stationary fuel cell technology and be able to evaluate the differences between fuel cells and generators and between fuel cells and UPS systems. Though not the case with Chevron, cost can be a factor in choosing a backup power source, but incentives (e.g., grants and rebates) could help make fuel cell projects cost competitive with other technologies.[209]

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[205] Frost & Sullivan Inc. 2004. World Stationary Lead Acid Battery Markets.
[206] Research Reports International. 2004. Distributed Generation Case Studies, 3rd Edition.
[207] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[208] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[209] Research Reports International. 2004. Distributed Generation Case Studies, 3rd Edition.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct hydrogen PEM fuel cells as backup power for data centers, seven data centers were contacted, and two responses were received.

Responses were received from one small data center service provider and from a data center operated by and for a large science and technology organization. Respondents indicated that backup power was used for servers, air-conditioning, lighting, telephone switching, and data center specific network switches. One respondent indicated that servers were the most critical applications and required continuous backup power. Respondents reported that they had experienced approximately two power outages in the past year. One respondent indicated that the outages lasted less than 60 seconds, while the other cited outages of approximately 3 to 5 minutes. Respondents indicated that any length of outage would be highly disruptive. One respondent indicated that an outage could result in a security breach and implementation of emergency management plans. Respondents stated that backup power was provided by both UPS systems and diesel generators. Sizes of backup power systems varied and were based on the type of application supported. Systems could be less than 5 kW to over 250 kW.

Respondents identified reliability, capital cost, lifetime of the unit, start-up time, ease of use, and fuel availability as very important factors in selecting a backup power system. Both respondents were fairly satisfied with their current backup power systems. One respondent indicated that they had no generator backup, and long outages could severely impact their operations. Respondents were split on the growing need for backup power in their market segment. One respondent had considered alternatives to their current mode of operation. Neither had considered PEM fuel cells as a smaller backup power solution. Decisions to purchase PEM fuel cells were made on the basis of initial capital cost and business justification. One respondent stated that government incentives were not considered in making purchasing decisions, and the other did not know if government incentives were considered.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

PEM fuel cells provide the benefits of low or zero emissions, high efficiency and reliability, siting flexibility, scalability, and ease of maintenance. Secondary research indicates that fuel cells can be reliable and efficient alternatives for mission critical applications such as data centers.[210] In addition, the size and projected growth of this market sector offers an attractive opportunity for PEM fuel cells. Users in this market segment appear to be fairly satisfied with their current mode of operation and there appears to be little interest in alternatives. No external drivers for pushing adoption of alternatives were identified in this market segment.

Marketing research did not identify a compelling value proposition for PEM fuel cells in this market segment. Near-term opportunities for PEM fuel cells will be as replacements to small battery systems, UPS systems, and generators. PEM fuel cells will have to compete with more established alternatives in this market segment and it is likely that small size, high capital costs, and lack of reliability data will limit application in the near-term.

[210] Gangi, J. 2004. Fuel Cells: Providing Customer Value Today. Distributed Energy, the Journal for Onsite Power Solutions. Available at http://www.distributedenergy.com/de_0411_fuel.html [Accessed June 2006].

RESEARCH SUMMARY:
ELECTRIC UTILITY SUBSTATIONS

MARKET SEGMENT DESCRIPTION

Electric utilities include establishments engaged in the generation, transmission, and/or distribution of electric energy for sale. This analysis considers the potential for PEM fuel cells for backup power of critical functions at electric utility substations. Table g-1 identifies the SIC and NAICS codes associated with this market segment.

Table g-1. Relevant SIC and NAICS Codes for Electric Utilities.

2-Digit SIC Code	49 – Electric, gas, and sanitary services
4-Digit SIC Code	4911 – Electric services
NAICS Code	221112 – Fossil fuel electric power generation

The electric industry commonly uses standard indices to track and benchmark reliability performance. These indices are termed CAIDI (Customer Average Interruption Duration Index), SAIDI (System Average Interruption Duration Index), and SAIFI (System Average Interruption Frequency Index). CAIDI measures average outage duration if an outage (greater than 1 minute) is experienced (i.e., average restoration time). SAIDI measures average outage duration per customer, and SAIFI measures how often a customer can expect to experience an outage. The indices are defined over a fixed time period, typically a year, and can be measured over an entire electric distribution system or over smaller portions of a system.[211] An industry benchmarking survey reported the CAIDI average as 320 minutes (5.3 hours), the SAIDI average as 95 minutes (1.6 hours), and the SAIFI average as 1.2 interruptions per customer.[212,213] The survey benchmarked reliability statistics with nearly 100 electric utilities across the nation.

Secondary research indicates that there is a need for standby or emergency power at battery substations to provide power to switching components and substation control equipment during AC power outages. Backup power is also needed for supervisory, monitoring, and indication functions at substations. Presently, there are more than 100,000 substation battery installations in the U.S.[214] Most battery strings employed for substation backup power are 120V DC, and typical loads are 5 to 30 amps.[215]

The dominant technology for substation backup technology is a vented, also called flooded, lead-acid battery. Typical heavy-duty flooded lead-acid battery banks provide 8 hours of backup to serve critical loads.[216] Vented lead-acid batteries are reported to generally meet the 15 to 20 year

[211] Rothwell, J. 2004. The Reliability Triangle. We Energies. Available at http://tdworld.com/mag/power_reliability_triangle/index.html [Accessed June 2006].
[212] Edmond Electric. 2006. System Reliability. Available at http://www.edmondok.com/Electric/elec_reliability.html [Accessed June 2006].
[213] City of Georgetown Texas. 2006. Reliability Stats. Available at http://www.georgetown.org/departments/gus/electric/reliabilitystats.php [Accessed June 2006].
[214] Eckroad, S., T. Key, and H. Kamath. 2004. Assessment of Alternatives to Lead-Acid Batteries for Substations. Available at http://www.battcon.com/PapersFinal2004/KamathPaper2004.pdf [Accessed December 2006].
[215] Davis, D. 2005. Fuel Cells: A Look at the Future for OSP and Substation Backup Power. Presentation at Advancements in Battery Technology & Power Management 2005.
[216] Electric Power Research Institute (EPRI). 2006. Alternatives to Substation Batteries. Available at http://www.epriweb.com/public/000000000001009083.pdf [Accessed June 2006].

life requirements of backup battery systems. Although maintenance routines are well-established, resources are needed to maintain and monitor lead-acid batteries.
A survey of electric utility practices found that valve-regulated lead-acid batteries are used significantly but that these are typically being replaced with vented lead-acid systems. Nickel-cadmium (NiCd) batteries are also used at a small number (5%) of installations.[217]

MARKET SIZE

Table g-2 provides market size statistics for SIC Code 4911, Electric Services. There are an estimated 9,404 establishments in the U.S. electric services industry, which generate total annual sales of $759,569.5 million, or an average of $180.5 million per establishment.

Table g-2. Number of Businesses in Electric Services Industry (4911).

SIC Code	SIC Description	Number of Businesses	Average Sales (Million $)	Total Sales (Million $)
4911-0000	Electric services	5,251	181,516	132,378.703
4911-9900	Electric services, nec	202	3,881	2,391.1
4911-9901	Distribution, electric power	1,642	85,107	110,555.102
4911-9902	Generation, electric power	2,119	176,364	502,420.906
4911-9903	Transmission, electric power	190	10,143	11,823.7
	Total	**9,404**	**457,011**	**759,569.5**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Utilities worldwide spent an estimated $124.5 million on stationary lead-acid batteries in 2003; a moderate but stable 2.9% annual growth rate is predicted from 2000 to 2010. In 2003, utilities purchased 8.6% of 840.4 million stationary lead-acid batteries shipped worldwide, compared to other end-user applications. This percentage is expected to decline to 6.7% by 2010.[218]

Potential fuel cell users in this sector include DTE Energy, WE Energies, First Energy, Duke Energy (formerly Cinergy), American Electric Power (AEP), Avista Corporation, ConEdison, Minnesota Power, Mississippi Power Company, Pacific Gas & Electric, Southern California Edison, Sierra Pacific, TXU Energy, and others.

MARKET TRENDS

State mandates for renewable energy, such as those in California and New York, help drive the use of fuel cells and other alternatives. However, the lack of a regulatory policy encouraging alternative energy in most states has slowed the process of fuel cell adoption in the utility industry.[219]

An industry survey showed moderate interest in trying new technologies for backup power systems. Eckroad et al. analyzed alternatives to lead-acid batteries, including fuel cells, in electric utility substations.[220] A number of obstacles to fuel cell adoption remain, such as the need for supplemental power due to a lack of instantaneous response time, relatively untested

[217] Eckroad, S., T. Key, and H. Kamath. 2004. Assessment of Alternatives to Lead-Acid Batteries for Substations. Available at http://www.battcon.com/PapersFinal2004/KamathPaper2004.pdf [Accessed December 2006].
[218] Frost & Sullivan, Inc.. 2004. World Stationary Lead Acid Battery Markets.
[219] Stern, G.M. 2006. The Coming Fuel Cell Revolution. EnergyBiz Magazine. Available at http://energycentral.fileburst.com/EnergyBizOnline/2006-2-mar-apr/Fuel_Cell0306.pdf [Accessed June 2006].
[220] Eckroad, S., T. Key, and H. Kamath. 2004. Assessment of Alternatives to Lead-Acid Batteries for Substations. Available at http://www.battcon.com/PapersFinal2004/KamathPaper2004.pdf [Accessed December 2006].

performance, and additional refueling required. The authors concluded that any alternative technologies are years away from a significant level of market acceptance.
PEM fuel cells show potential for replacing conventional lead-acid batteries in backup energy systems. The cost of PEM fuel cells is roughly the same as traditional battery backup power.[221,222] The main advantage is that PEM fuel cells can provide power indefinitely, provided that hydrogen fuel is supplied. Fuel cells also offer the advantage of being scalable, and eliminating costly battery maintenance and replacement. PEM fuel cells can also be used to maintain batteries at full charge during outages, in preparation for relay/breaker closure once power is restored. This reduces the need for personnel to be dispatched during power outages. The smaller space requirement needed for fuel cells alleviates space shortages. PEM fuel cells have the ability to withstand extreme environmental conditions, eliminating the need for the environmentally controlled spaces that lead-acid batteries require to protect them from harsh weather conditions.

Several barriers to adoption of PEM fuel cell technology for backup power applications exist in this marketplace. A barrier to adopting PEM fuel cells is that they may need to be paired with complementary technology (e.g., batteries) to facilitate instantaneous response required for substation backup power. Another disadvantage of fuel cells in substation backup power applications is that they are relatively untested (i.e., 2- to 3-year demonstrated performance), although fuel cells are increasingly being demonstrated as alternative or supplementary backup power solutions at electric substations. Since PEM fuel cells are a relatively new technology whose reliability is still unproven, electric utilities are cautious in adopting fuel cells widely. Furthermore, capital costs for PEM fuel cells for substation backup can range from $15,000 to $50,000, making it unaffordable for some utilities. Additional challenges, such as delivering a hydrogen fuel supply and developing siting guidelines that facilitate the use of hydrogen and ensure safety, are being resolved.

In May 2005, Connecticut's Public Utilities Commission announced an agreement to conduct a 1-month demonstration of a Proton Energy Systems 15 kW regenerative fuel cell at an electric substation in Wallingford, Connecticut, next to Proton Energy Systems' office.[223] In Vancouver, Washington, Bonneville Power Administration has operated a ReliOn Independence 1000 PEM fuel cell at its Ross substation since April of 2004.[224] In 2001, Detroit Edison, which owns 14% of PlugPower, tested a PlugPower PEM fuel cell for backup power at a substation in Michigan. The hydrogen fuel cell served as a replacement for control batteries. Following the success of that pilot test, Detroit Edison proceeded to install a 5 kW GenCore direct hydrogen fuel cell, in parallel with the batteries, at one of its 600 substations.[225] In 2003 and 2004, ReliOn (under the

[221] Stern, G.M. 2006. The Coming Fuel Cell Revolution. EnergyBiz Magazine. Available at http://energycentral.fileburst.com/EnergyBizOnline/2006-2-mar-apr/Fuel_Cell0306.pdf [Accessed June 2006].
[222] Egbert, S.T. 2005. Raising the Bar on Substation Backup Power. Utility Automation & Engineering T&D. Available at http://uaelp.pennnet.com/articles/article_display.cfm?Section=ARCHI&C=Feat&ARTICLE_ID=243623&KEYWORDS=raising%20the%20bar&p=22 [Accessed June 2006].
[223] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[224] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[225] Stern, G.M. 2006. The Coming Fuel Cell Revolution. EnergyBiz Magazine. Available at http://energycentral.fileburst.com/EnergyBizOnline/2006-2-mar-apr/Fuel_Cell0306.pdf [Accessed June 2006].

former name Avista Labs) installed fuel cells at a substation in the northwestern U.S. to provide backup power for substation protection and control equipment.[226]

In May 2006, the Electric Power Research Institute (EPRI) issued a call for utilities to participate in a project to demonstrate and evaluate alternative technologies to traditional substation batteries.[227] Fuel cells are one of the alternative technologies to be tested as backup power at a host utility. The project will provide installation and design experience, field data, and lifecycle cost analysis to inform an evaluation of alternatives to lead-acid batteries.

MARKET SEGMENT ANALYSIS

Fourteen electric utilities were contacted to further determine requirements for backup power and the potential for application of fuel cells. Five interviews were conducted, and two responses were received from large electric utility companies. One was a large diversified energy company involved in the development and management of energy related businesses and services. The other company is involved in electric generation, transmission, and distribution. Functions typically requiring backup power, as identified by respondents, include substations and telecommunication sites. Critical backup power applications at substations include power control networks and relay protection at the substation. Respondents indicated that the impacts of power outages were minimal because critical systems are supported by redundant backup power systems. In case of backup power system failure, impacts can be devastating and could result in the implementation of emergency management plans and potentially losses in distribution.

Backup power is currently provided by batteries. The size of batteries used varies from 15 to 30 kW to over 250 kW. The number of backup power systems used varied significantly between users. One respondent reported approximately 1,000 backup power units. Systems were either nominal 48V consisting of two 24V lead-acid batteries or nominal 120V consisting of two 60V lead-acid batteries. When asked to rate the importance of various factors in selecting a backup power system, respondents identified reliability, annual operating and maintenance costs, start-up time, ease of use, fuel availability, and good experience with this type of system in the past as very important. Both respondents rated the performance of their current backup power systems as very good. One respondent elaborated that despite the good performance of battery systems, they are difficult to use, need extensive maintenance, and need to be located in vented rooms. Respondents rated the reliability, capital cost, lifetime, start-up time, ease of use, and fuel availability as very good for their current systems.

Both respondents indicated that they did not see a growing need for backup power in the next three years. Both respondents indicated that they had considered alternatives to batteries including fuel cells and natural gas and diesel fueled generators to provide extended run time. Both respondents were aware of PEM fuel cells for backup power. One respondent indicated that they had tested fuel cells and may consider installing fuel cells systems as backup to batteries to save cost and space in cities like New York. Batteries would serve as primary backup in case the grid went down and would then transfer load to the fuel cell. Both

[226] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[227] Electric Power Research Institute (EPRI). 2006. Alternatives to Substation Batteries. Available at http://www.epriweb.com/public/000000000001009083.pdf [Accessed June 2006].

respondents indicated that PEM fuel cells do not compete favorably with their existing backup power systems today but could in the future. Both respondents indicated that they were not concerned about using hydrogen as a fuel. One respondent indicated that they had concerns with the regulatory code written for battery backup, which specifies where the backup unit must be located (15 feet away from exposed switch gear), and noted that this may be a deterrent to the use of fuel cells. One respondent indicated that electric utilities were conservative and were not willing to adopt unproven technology. Both respondents indicated that incentives and the track record of others using PEM fuel cells would be important drivers for adopting the technology.

Respondents indicated that capital purchase decisions were made on the basis of initial capital cost and payback period. One respondent indicated that they took return on investment into consideration as well. One respondent indicated that lower budgets and the increasing cost of fuel were also important decision drivers.

Utilities with an interest in fuel cell technology were more willing (than other companies) to participate in interview discussions. Three utilities contacted, reported having tested fuel cells. One noted that the main barriers to adopting fuel cells are high cost and low performance. One utility had investigated the potential for using fuel cells to supplement battery backup at a substation, including receiving a vendor demonstration. The utility determined that fuel cells did not meet their requirements, citing cost as a factor in that decision.

Two utilities interviewed reported that they have no backup power at their substations. They have multiple feeds and switching arrangements that provide continuous power in case of outages. One utility also has a 10VA mobile transformer on a trailer that can be used in cases where they cannot switch to another substation.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

PEM fuel cells are well-suited for backup power applications at electric utility substations. However, electric utilities appear to be very satisfied with the performance of current backup power technologies. Electric utility respondents in this analysis indicated that power outages are not as disruptive to electric utility substation operations, primarily due to the availability of redundant power sources as well as reliable backup power sources that can maintain service or can facilitate relay breaker closing until AC power is restored. However, the threat of extended outages, as experienced in recent years during the Northeast blackout of 2003, and Hurricanes Rita and Katrina, has raised questions about the backup capacity of traditional batteries used for backup power. Electric utilities are investigating alternative sources to supply extended runtime to their critical sites as well as their remote sites. Characteristics desired by users in this market segment are high reliability, quick start-up time, wide fuel availability, and good experience with this type of system in the past.

Marketing research indicates that utilities are aware of PEM fuel cells, and recognize the advantages of PEM fuel cells over incumbent technologies. Despite this awareness, electric utilities appear to be slow adopters of PEM fuel cell technology. A few utilities have explored the possibility of using PEM fuel cells and have considered them as supplements to existing battery backup or as battery rechargers at substations. Users remain concerned about reliability, start-up time, lifetime, and capital cost of PEM fuel cells for backup power.

As users are fairly satisfied with current technologies, there is no significant driver for switching in this segment. Adoption of PEM fuel cells by users in this market segment is dependent on a track record of others using them. Furthermore, users in this market segment also appear to be price sensitive as capital purchase decisions are based on initial capital cost and the availability of government incentives. It is likely that in the near term, adoption will be limited to feasibility testing at remote substation sites or at substation sites where backup power systems are costly to maintain, until users are convinced of the reliability of PEM fuel cells for their application.

RESEARCH SUMMARY:
FOOD MANUFACTURING INDUSTRY

MARKET SEGMENT DESCRIPTION

The food manufacturing industry includes firms and associated establishments that manufacture or process foods and beverages for human consumption. It also includes other related products such as manufactured ice, chewing gum, vegetable and animal fats and oils, and prepared feeds for animals and fowl. Two areas – industries that use hydrogen, and industries that specialize in frozen foods – were selected for in-depth examination. Table h-1 lists the SIC and NAICS codes selected for this analysis.

One area of focus was on industries that use hydrogen, such as in the manufacture of edible fats and oils. It was assumed that fuel cell users who already use hydrogen may have infrastructure in place to facilitate the supply of hydrogen for backup power. Additionally, employees would be accustomed to working with hydrogen and would require minimal education and training. This segment includes starch and vegetable fats and oils manufacturing. Industries are engaged in one or more of the following: (1) wet milling corn and vegetables; (2) crushing oilseeds and tree nuts; (3) refining and/or blending vegetable oils; (4) manufacturing shortening and margarine; and (5) blending purchased animal fats with vegetable fats.

The other area of focus was on industries that specialize in frozen foods. The frozen food segment was chosen because it uses freezers and other equipment with large power requirements and high consequences if the equipment does not function properly or if there is a lack of power. This can extend to one or more of the following: fresh and frozen seafood processing, frozen fruits and vegetables processing, and ice cream and frozen dessert manufacturing.

Table h-1. Selected SIC and NAICS Codes for Food Manufacturing.

2-Digit SIC Code	20 – Food and kindred products
4-Digit SIC Codes	2024 – Ice cream and frozen desserts 2037 – Frozen fruits and vegetables 2038 – Frozen specialties, not elsewhere classified (nec) 2046 – Wet corn milling (refining purchased oil) 2074 – Cottonseed oil mills (processing purchased cottonseed oil) 2075 – Soybean oil mills (processing purchased soybean oil) 2076 – Vegetable oil mills, except corn, cottonseed, and soybean 2077 – Animal and marine fats and oils (fresh and frozen marine fats and oils) 2079 – Shortening, table oils, margarine, and other edible fats and oils, nec 2092 – Prepared fresh or frozen fish and seafood 2097 – Manufactured ice
NAICS Codes	311221 – Wet corn milling 311222 – Soybean processing 311223 – Other oilseed processing 311225 – Fats and oils refining and blending 311411 – Frozen fruit, juice, and vegetable manufacturing 311412 – Specialty food manufacturing 311520 – Ice cream and frozen dessert manufacturing 311712 – Fresh and frozen seafood processing

MARKET SIZE

The food processing and beverage industry accounts for about one-sixth of the U.S. manufacturing sector's activity.[228] In 2001, food and beverage manufacturing plants accounted for 13% of the value of shipments from all U.S. manufacturing plants. There are large numbers of food processing establishments (plants) in the U.S. – almost 29,000 owned by about 22,000 companies, according to the Census of Manufacturers.[229]

Generally, food processors (e.g., Tyson Foods (meats), Dairy Farmers of America (dairy products), and Tate & Lyle (sweeteners, sugar)) are located near farms, and specialize in one or two food segments. Many food industries are consolidating. As shown in Table h-2 below, overall the industry has increased the number of establishments, but the USDA reports that this gain primarily reflects increases in a few selected industries (e.g., salsa making) where the number of small producers has dramatically increased.

Table h-2. Consolidation of Businesses in the Food Manufacturing Industry.

Industry	Number of Businesses		
	1992	1997	Change
Meat	3,242	3,164	-78
Dairy	2,024	1,834	-190
Fruits and Vegetables	2,052	2,117	65
Grain Mill Products	2,618	2,531	-87
Bakery Products	3,152	3,384	232
Sugar	1,129	1,259	130
Fats and Oils	540	519	-21
Beverages	2,064	2,243	179
Other Prepared Foods	3,984	4,784	800
Total Food	**20,805**	**21,835**	**1,030**

Source: Census of Manufacturers, as cited in Harris, J., Kaufman, P., Martinez, S., and C. Price. 2002. The U.S. Food Marketing System, 2002. USDA/ERS. Agricultural Economic Report No. (AER811) Available at: http://www.ers.usda.gov/publications/aer811/ or http://www.ers.usda.gov/publications/aer811/aer811c.pdf. Accessed September 2006.

Food processing plants are located throughout the United States. The County Business Patterns (CBP) reports that, in 2000, California had the most food manufacturing plants (4,252), while New York (2,227) and Texas (1,739) were also leading food manufacturing states.[230]

Table h-3 characterizes the market for edible fats and oils. There are an estimated 183 establishments in this industry, employing over 7,783 people, and generating annual sales of $3,972.90 million. Key companies in this sector include: Bunge Limited, Cargill Foods, Cargill Soy Protein Solutions, and Cargill Industrial Oils & Lubricants.

Table h-4 characterizes the market for fresh or frozen fish and seafood. There are an estimated 555 establishments in this industry, employing over 22,336 people, and generating annual sales of $4,489 million. Key companies in this sector include: Icelandic USA, Inc., and American Seafoods Group, LLC.

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[228] Huang, K. 2003. Food Manufacturing Productivity and its Economic Implications. Available at http://www.ers.usda.gov/publications/tb1905/ [Accessed September 2006].
[229] U.S. Department of Agriculture, Economic Research Service. 2005. Food Market Structures: Food and Beverage Manufacturing. Available at http://www.ers.usda.gov/Briefing/FoodMarketStructures/processing.htm [Accessed September 2006].
[230] U.S. Department of Agriculture, Economic Research Service. 2005. Food Market Structures: Food and Beverage Manufacturing. Available at http://www.ers.usda.gov/Briefing/FoodMarketStructures/processing.htm [Accessed September 2006].

Table h-5 characterizes the market for ice cream and frozen desserts. There are an estimated 1,132 establishments in this industry, employing over 25,370 people, and generating annual sales of $5,354.20 million.

Table h-3. Number of Businesses in the Edible Fats and Oils Industry (2079).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2079-0000	Edible fats and oils	44	1,900	352.5
2079-0100	Margarine and margarine oils	1	100	63.5
2079-0102	Margarine-butter blends	3	13	1
2079-0103	Margarine, including imitation	6	979	77.3
2079-0104	Nut margarine	3	310	186.2
2079-0200	Shortening and other solid edible fats	6	556	23.2
2079-0201	Compound shortenings	4	526	99.6
2079-0203	Vegetable shortenings (except corn oil)	3	487	669.2
2079-9901	Cooking oils, except corn: vegetable refined	20	477	811.6
2079-9902	Cottonseed oil, refined: not made in cottonseed oil mills	1	6	2
2079-9903	Edible oil products, except corn oil	18	1,016	203.1
2079-9904	Oil, hydrogenated: edible	4	201	1,336.8
2079-9905	Oil, partially hydrogenated: edible	1	1	0.1
2079-9906	Olive oil	48	269	86.6
2079-9907	Peanut oil, refined: not made in peanut oil mills	1	7	1
2079-9908	Salad oils, except corn: vegetable refined	5	62	6.5
2079-9909	Soybean oil, refined: not made in soybean oil mills	7	400	14
2079-9910	Vegetable refined oils (except corn oil)	8	428	38.8
	Total	**183**	**7,738**	**3,972.9**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Table h-4. Number of Businesses in the Fresh or Frozen Seafood Industry (2092).

SIC	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2092-0000	Fresh or frozen packaged fish	207	8,173	920.5
2092-0100	Fresh or frozen fish or seafood chowders, soups, and stews	19	284	43.8
2092-0101	Chowders, fish and seafood: frozen	5	18	5.2
2092-0102	Soups, fish and seafood: frozen	1	1	0.2
2092-0200	Prepared fish or other seafood cakes and sticks	8	63	14.8
2092-0201	Crabcakes, frozen	5	30	23.9
2092-0203	Fishcakes, frozen	2	16	1.3
2092-9901	Crab meat, fresh: packaged in nonsealed containers	26	629	70.7
2092-9902	Crabmeat, frozen	9	155	166.1
2092-9903	Fish fillets	1	200	N/A
2092-9904	Fish, fresh: prepared	51	3,016	515.9
2092-9905	Fish, frozen: prepared	16	1,047	532.9
2092-9906	Seafoods, fresh: prepared	93	3,451	464.8
2092-9907	Seafoods, frozen: prepared	49	3,076	1,163.7
2092-9908	Shellfish, fresh: shucked and packed in	18	749	57.3

	nonsealed containers			
2092-9909	Shellfish, frozen: prepared	8	434	374.5
2092-9910	Shrimp, fresh: prepared	24	764	77.2
2092-9911	Shrimp, frozen: prepared	13	230	56.2
	Total	**555**	**22,336**	**4,489**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Table h-5. Number of Businesses in the Frozen Ice Cream and Dessert Industry (2024).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2024-0000	Ice cream and frozen deserts	674	12,950	3,054.1
2024-0100	Ice cream and ice milk	79	2,294	824.9
2024-0101	Ice cream, bulk	118	2,495	254.8
2024-0102	Ice cream, packaged: molded, on sticks, etc.	78	4,782	1,055.8
2024-0103	Ice milk, bulk	2	44	4.2
2024-0104	Ice milk, packaged: molded, on sticks, etc.	1	11	0.8
2024-0200	Dairy based frozen desserts	30	643	55.4
2024-0201	Custard, frozen	28	373	24.1
2024-0203	Sherbets, dairy based	1	0	N/A
2024-0204	Spumoni	1	3	0.5
2024-0205	Yogurt desserts, frozen	18	332	34.8
2024-0300	Nondairy based frozen desserts	13	431	11.1
2024-0301	Fruit pops, frozen	13	332	33.1
2024-0303	Ices, flavored (frozen dessert)	58	470	40.5
2024-0304	Juice pops, frozen	7	139	8.7
2024-0306	Rice-based desserts, frozen	1	4	5
2024-0307	Sorbets, non-dairy based	4	19	6.5
2024-0308	Tofu desserts, frozen	6	48	20
	Total	**1,132**	**25,370**	**5,434.2**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Table h-6 characterizes the market for frozen fruits and vegetables. These are establishments primarily engaged in freezing fruits, fruit juices, and vegetables, and which also produce important by-products such as fresh or dried citrus pulp. There are an estimated 299 establishments in this industry, employing over 29,807 people, and generating annual sales of $7,801.4 million.

Table h-7 characterizes the market for frozen specialties, which includes establishments primarily engaged in manufacturing frozen food specialties, not elsewhere classified, such as frozen dinners and frozen pizza. There are an estimated 613 establishments in this industry, employing over 41,447 people, and generating annual sales of $8,242.3 million.

Table h-6. Number of Businesses in the Frozen Fruits and Vegetables Market Industry (2037).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2037-0000	Frozen fruits and vegetables	80	4,439	469.9
2037-0100	Frozen fruits and vegetables	22	4,764	661
2037-0101	Citrus pulp, dried	2	11	1.7
2037-0102	Fruits, quick frozen and cold pack (frozen)	38	3,347	1,205.3
2037-0103	Potato products, quick frozen and cold pack	24	4,581	3,654.9
2037-0104	Vegetables, quick frozen & cold pack, excl. potato products	43	7,701	924
2037-0200	Fruit juices	50	2,332	382.3
2037-0201	Fruit juice concentrates, frozen	29	1,847	412.1
2037-0202	Fruit juices, frozen	11	785	90.1
	Total	**299**	**29,807**	**7,801.4**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Table h-7. Number of Businesses in the Frozen Specialties Market Industry (2038).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2038-0000	Frozen specialties, nec	270	22,503	4,224.4
2038-9901	Breakfasts, frozen and packaged	12	239	18.2
2038-9902	Dinners, frozen and packaged	33	4,473	518.3
2038-9903	Ethnic foods, nec, frozen	111	4,823	474.1
2038-9905	Lunches, frozen and packaged	5	114	2.2
2038-9906	Pizza, frozen	114	7,042	2,934.4
2038-9907	Snacks, incl. onion rings, cheese sticks, etc.	47	835	29.9
2038-9908	Soups, frozen	12	685	24
2038-9909	Spaghetti and meatballs, frozen	1	6	0.4
2038-9910	Waffles, frozen	7	277	16.5
2038-9911	Whipped topping, frozen	1	450	N/A
	Total	**613**	**41,447**	**8,242.3**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Table h-8 characterizes the market for manufactured ice, which addresses establishments primarily engaged in producing ice for sale. There are an estimated 616 establishments in this industry, employing over 6,757 people, and generating annual sales of $837 million.

Table h-8. Number of Businesses in the Manufactured Ice Market Industry (2097).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
2097-0000	Manufactured ice	466	4,876	592.4
2097-9901	Block ice	72	990	128.1
2097-9902	Ice cubes	78	891	116.5
	Total	**616**	**6,757**	**837**

Sales figures are in millions. Source: www.zapdata.com. Accessed September 2006.

Total sales of frozen foods in the U.S. have continued to climb over the past several years, reaching more than $29.2 billion in 2003, 1.6% higher than in 2002. The frozen entrée category continues to be the largest within the frozen food market with more than $3.67 billion in annual sales. The frozen meat/seafood category and the hand-held entrées (non-breakfast) experienced the largest growth from 2002 to 2003, with sales of the meat/seafood category increasing by

8.4% and the hand-held entrées increasing by 7.9%. Juices/drinks experienced the largest decline within the frozen food market, with sales decreasing 13.2% from 2002 to 2003.[231]

Industry trends indicate that the growth in demand for frozen foods will continue. A survey conducted by the National Restaurant Association found that 96% of restaurant owners said they will use frozen food for their table service operations, while 100% will use frozen food for their quick service operations.

MARKET TRENDS

Refrigeration equipment is a major consumer of energy for certain sectors of the food industry. According to a 2001 market assessment, the engine-driven refrigeration market is growing, promising lower operating costs and enhanced reliability.[232] Engine-driven systems are often used for capacity expansions, particularly when expensive transformer upgrades may be required. The longer operating hours of refrigeration applications improve the economics of engine-driven equipment, especially when heat recovery is employed.

Figure h-1 presents refrigeration applications in sub-sectors of the food industry for small and large capacity refrigeration compressors. Primary applications include dairies, food processing, meatpacking, and refrigerated warehouses. In industries like frozen fish processing, processors may be found offshore on large factory ships. Many processors function as isolated facilities; the development of a dedicated on-site power source, such as a fuel-cell powered technology, is a potential consideration.

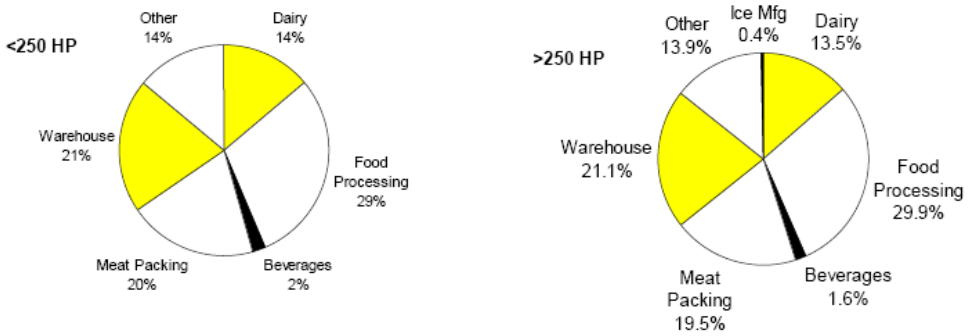

Figure h-1. Refrigeration Applications in Sub-sectors of the Food Industry.

Source: Onsite Energy Corporation for Oak Ridge National Laboratory for U.S. Department of Energy. 2001. Assessment of On-Site Power Opportunities in the Industrial Sector. Final Report, Contract No. 85X-TA008V.

Research has also indicated that the food processing sector represents an important market for on-site power generation and in particular for systems less than 50 MW in capacity. The food industry has had a peak steam draw of 53 million lbs per hour; it also has many small operations that use packaged boilers producing less than 25,000 lbs per hour. Energy end use is primarily for material handling, cooking, freezing, and refrigeration; more than $3.2 billion was spent on

[231] American Frozen Food Institute. 2006. Industry at a Glance. Available at http://www.affi.com/factstat-glance.asp [Accessed September 2006].
[232] Onsite Energy Corporation for Oak Ridge National Laboratory for U.S. Department of Energy. 2001. Assessment of On-Site Power Opportunities in the Industrial Sector. Final Report, Contract No. 85X-TA008V.

electricity in 1994. Since almost half of all the energy input is used for generating steam, CHP is also being pursued as an option for power supply. The most notable CHP opportunities in the food processing sector include meat preparation and packing, flour and grains, poultry, malt beverages, and fruit/vegetables processing and freezing processes.[233] CHP is well-positioned in this industry, operating in certain areas with a high potential for fuel cells, and would be a serious competitor in this market.

Although no fuel cell activity was identified in the food manufacturing sectors of focus for this analysis, a fuel cell project was identified at a bakery facility in Connecticut.[234] In response to a 2002 Connecticut Clean Energy Fund (CCEF) program designed to accelerate fuel cell commercialization, two fuel cells have been installed at the Pepperidge Farm bakery in Bloomfield, Connecticut. The project was designed to install commercially ready fuel cells in high-value applications to evaluate benefits, feasibility, and viability of use. Pepperidge Farm is partnering with FuelCell Energy Inc., which is providing a 250 kW direct fuel cell power plant to the bakery facility. The power plant will provide approximately 20% of the facility's base power.[235]

MARKET SEGMENT ANALYSIS

Three companies in the frozen foods sector were contacted; each indicated that there was no need for backup power in this industry.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Limited information was available on the requirements for backup power in this market segment. Research indicates that this market does not have significant demand for sources of backup power supply. Some on-site generation is being supplied, primarily through CHP; however, neither primary nor secondary research indicated substantial near-term growth in the backup power market in this sector. It is likely that PEM fuel cells can be utilized as battery and UPS system replacements. Lack of near-term growth and minimal industry interest suggest that this is not a potential near-term market for PEM fuel cells.

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[233] Onsite Energy Corporation for Oak Ridge National Laboratory for U.S. Department of Energy. 2001. Assessment of On-Site Power Opportunities in the Industrial Sector. Final Report, Contract No. 85X-TA008V.
[234] Food Processing Technology. 2006. Pepperidge Farm Bakery Plant, Bloomfield, CT, USA. Available at http://www.foodprocessing-technology.com/projects/pepperidge/ [Accessed September 2006].
[235] Fuel Cells Today. 2005. Fuel Cell Energy to Provide DFC Power Plant to Pepperidge Farm. Available at http://findarticles.com/p/articles/mi_m0OXF/is_2005_March_16/ai_n13454077.%20Accessed%20September%2029 [Accessed September 2006].

RESEARCH SUMMARY:
FEDERAL AGENCIES

MARKET SEGMENT DESCRIPTION

Federal agencies are considered to be the largest single energy consumer in the U. S. Energy used in federal buildings in 2004 accounted for 35.4% of the total federal energy bill. The federal government owns/operates over 500,000 buildings, including 422,000 housing structures (for the military) and 51,000 non-residential buildings. In fiscal year 2000, approximately $4 billion was spent on energy to heat, cool, light, and conduct operations in those 500,000 plus federal buildings. The DoD appears to be the largest consumer of energy in federal buildings (FY2004), accounting for 61.2% of total energy use in federal buildings and occupying 65.3% (FY2004) of the total floor space in federal buildings.[236]

While federal agencies are more likely to adopt grid parallel and grid independent sources of power due to their high energy needs, backup power may be needed for critical applications. The intent of this analysis, which focuses on a subset of potential federal users, was to identify applications and needs for backup power, as well as backup power trends, within these agencies. This particular subset of federal users was selected for two main reasons: (1) these agencies were deemed likely to have backup power needs, and (2) ample information was publicly available on the roles and activities of these agencies. Specific agencies that were considered for this analysis, along with their associated primary SIC and NAICS classifications, are provided in Table i-1. Table i-2 presents the primary roles of each agency selected for this analysis.

Table i-1. SIC and NAICS Codes for Selected Federal Agencies.

Agency	2-Digit SIC Code	4-Digit SIC Code(s)	NAICS Code(s)
DHS	97 – National security and international affairs	9711 – National security	928110 – National security
DOE	49 – Electric, gas and sanitary services	4911 – Electric services 4931 – Electric and other services combined 4955 – Hazardous waste management	213112 – Support activities for oil and gas operations 22112 – Electric power transmission, control, and distribution 221121 – Electric bulk power transmission and control 541620 – Environmental consulting services 541690 – Other scientific and technical consulting services 921190 – Other general government support 924110 – Administration of air and water resource and solid waste management programs
DOI	95 - Administration of environmental quality	9512 – Land, mineral, and wildlife conservation	924120 – Administration of conservation programs

[236] U.S. Department of Energy. 2006. 2006 Buildings Energy Data Book. Available at http://buildingsdatabook.eere.energy.gov/ [Accessed October 16, 2006].

Agency	2-Digit SIC Code	4-Digit SIC Code(s)	NAICS Code(s)
	and housing programs		
EPA	96 – Administration of economic programs	9631 – Regulation, administration of utilities	926130 – Regulation and administration of communications, electric, gas, and other utilities
FAA	45 – Transportation by air	4581 – Airports, flying fields, & services	488111 – Air traffic control
FCC	96 – Administration of economic programs	9621 – Regulation, administration of utilities	926130 – Regulation and administration of communications, electric, gas, and other utilities
FEMA	92 – Justice, public order and safety	9229 – Public order and safety, nec	922190 – Other justice, public order, and safety activities
FHWA	96 – Administration of economic programs	9621 – Regulation, administration of transportation	926120 – Regulation and administration of transportation programs
GSA	91 – Executive, legislative & general government, except finance	9199 – General government, nec	921190 – Other general government support
NASA	37 – Transportation equipment	3761 – Guided missiles and space vehicles	336414 – Guided missile and space vehicle manufacturing
NRC	96 – Administration of economic programs	9631 – Regulation, administration of utilities	926130 – Regulation and administration of communications, electric, gas, and other utilities
NWS	99 – Nonclassifiable establishments	9999 – Nonclassifiable establishments	921190 – Other general government support
USCG	92 – Justice, public order and safety	9229 – Public order and safety, nec	922120 – Police protection 926150 – Regulation, licensing, and inspection of miscellaneous commercial sectors 928110 – National security
USDA	96 – Administration of economic programs	9641 – Regulation of agricultural marketing	926140 – Regulation of agricultural marketing and commodities
USPS	43 – United States Postal Service	4311 – U.S. Postal Service	491110 – Postal service

nec - not elsewhere classified

Table i-2. Primary Roles of Selected Federal Agencies.

Agency	Description of Agency
DHS	This agency provides investigative and protective services intended to prevent attacks on the United States. Created in the wake of the 9/11 terrorist attacks, DHS includes units devoted to domestic nuclear detection, intelligence and analysis, management, operations coordination, policy, preparedness, and science and technology.
DOE	DOE's mission is to advance the national, economic, and energy security of the U.S.; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex. In support of this mission, the DOE has four primary goals: apply advanced science and nuclear technology to the nation's defense, promote a diverse supply of environmentally safe energy, conduct scientific research, and dispose of high-level radioactive waste.
DOI	The DOI manages one out of every 5 acres of land in the U.S. and is comprised of eight bureaus, including the National Park Service, U.S. Fish and Wildlife Service, and Bureau of Reclamation (BOR). The BOR was established in 1902 to construct dams, power plants, and canals throughout the western U.S.
EPA	This agency develops and enforces environmental policy and regulations throughout the country. Besides working to ensure compliance with federal environmental rules, the agency provides support for state environmental protection efforts. In addition, the EPA conducts research on environmental issues through a network of laboratories.
FAA	The FAA is responsible for overseeing air transportation in the United States. FAA focuses on air transportation safety, including the enforcement of safety standards for aircraft manufacturing, operation, and maintenance. It also manages air traffic in the U.S. through a network of towers at the nation's airports. It maintains radar systems, communication equipment, and air traffic security systems.
FCC	The FCC regulates interstate and international communications by radio, television, wire, satellite, and cable. The Communications Act of 1934 established the FCC as an independent US government agency directly responsible to Congress. Its jurisdiction covers the 50 states, the District of Columbia, and US possessions.
FEMA (part of DHS)	This agency is charged with building and supporting the nation's emergency management system. FEMA leads federal efforts to prepare for, respond to, and recover from disasters that overwhelm state and local resources.
FHWA	Part of the U.S. Department of Transportation (DOT), the FHWA offers funding and technical support for the construction and preservation of highways across the nation. FHWA's budget provides support for local and state governments, as well as national parks, national forests, Indian lands, and other federally-owned land.
GSA	In addition to acting as the government's landlord in obtaining office space for the federal workforce, the GSA also supplies equipment, telecommunications, and information technology products to its customer agencies. It carries out its mission through the Federal Technology Service, Federal Supply Service, Public Buildings Service, and regional offices throughout the country.
NASA	NASA is responsible for the public space program of the U.S., as well as long-term civilian and military aerospace research. Today, NASA conducts its work in four principle areas: 1) Aeronautics: providing new flight technologies that improve our ability to explore and which have practical applications on Earth; 2) Exploration Systems: creating new capabilities for, human and robotic exploration; 3) Science: exploring the Earth, moon, Mars and beyond; and 4) Space Operations: providing critical technologies for much of the rest of NASA through the space shuttle, the International Space Station, and mission support.
NRC	This agency oversees the civilian use of nuclear materials. Its regulatory oversight encompasses three primary components: commercial electric-power generation reactors and research/test reactors; nuclear materials in medical, industrial, and academic settings; and nuclear waste disposal.

Agency	Description of Agency
NWS	The NWS produces climate, hydrologic, and weather forecasts and warnings for the United States. Its mission also includes forecasting to protect life and property and to enhance the national economy. The NWS is now part of the Department of Commerce's National Oceanic & Atmospheric Administration (NOAA).
USCG (part of DHS)	The USCG guards the public, the environment, and the economic and security interests of the U.S. Its primary roles consist of promoting maritime safety; supporting national defense; providing maritime security; protecting natural resources; and facilitating maritime transport, commerce, and recreation.
USDA	Founded in 1862 by Abraham Lincoln, the USDA oversees a host of matters related to the nation's agricultural industries and food supply. Among many other functions, it provides training and scientific resources for farmers, monitors food safety, operates the Forest Service, and aids federal decision-making processes related to agricultural regulations and trade policies.
USPS	The USPS is responsible for handling cards, letters, and packages mailed throughout the United States. This independent government agency, which relies on postage and fees to fund its operations, delivers more than 210 billion pieces of mail a year to approximately 144 million addresses.

Source of agency information: Hoovers, Inc., fact sheets obtained from http://premium.hoovers.com.

At least one energy-dependent function is critical to many, if not all, of the agencies identified for this analysis: communications. Communications are critical both internally (e.g., radio towers that enable FEMA agents to remain in contact during a natural disaster or electronics that permit conversations between the space shuttle and earth-bound NASA technicians) and externally (e.g., equipment and radio towers that enable communication between air traffic control personnel and pilots). Maintaining communications to support the responsibilities described in Table i-2 requires that equipment and facilities remain operational at all times.

To support communications and other key functions, it appears that all federal agencies have a need for backup power for small- as well as large-scale applications (> 250 kW). In addition, specific backup power applications have been identified for particular agencies, as summarized below:

FAA

The FAA is responsible for a number of activities designed to ensure the safety and efficient operation of civil aviation. The FAA operates a network of airport towers, air route traffic control centers, and flight service stations. Using these facilities, the agency develops air traffic rules, assigns the use of airspace, and controls air traffic. Also, the FAA installs, operates, and maintains facilities that use visual and electronic aids to support air navigation. Critical air traffic control and air navigation systems include voice and data communications equipment, radar facilities, computer systems, and visual display equipment at flight service stations.[237]

[237] Federal Aviation Administration. 2005. What We Do. Available at http://www.faa.gov/about/mission/activities/ [Accessed October 2006].

NRC

Backup power is necessary to maintain functionality of the NRC's public notification sirens in the event of a nuclear emergency; however, the agency does not yet have backup systems in place at many critical locations. As of 2005, only 27% of the NRC's 62 nuclear power emergency planning zones were prepared to remain fully operational in the absence of grid power.

In 2005, interest groups and local governments filed a public petition requesting that the NRC enforce battery backup requirements for vital emergency notification equipment so that the public can be promptly notified of a radiological emergency in the event of an accident or act of terrorism. The petition stated that grid failures due to lightning, hurricanes, ice storms, earthquakes, and mechanical failures in the electricity distribution system routinely cause a loss of power to community alerting systems near nuclear power stations. The petition requested that the sirens be supported with chargeable battery backup systems, preferably powered by photovoltaic solar arrays so as to ensure siren operation for the duration of any emergency. Supplements to the petition identified existing examples of solar-powered sirens at remote locations and requested retrofitting of entire siren systems with battery backup power. Despite the fact that relatively few of its emergency planning zones are equipped to function in the event of a power loss, the NRC denied the public petition.

In its denial of the petition, the NRC did not dispute the fact that many siren systems surrounding nuclear power stations would fail in the event of a radiological release coinciding with a power blackout. However, the agency's current emergency plan relies upon "local route notifications" wherein first responders (police and fire department personnel, etc.) travel in emergency vehicles through neighborhoods within ten-mile emergency planning zones and communicate instructions to residents using bullhorns.[238] Nevertheless, it appears that PEM fuel cells could be used in lieu of battery systems, should NRC eventually decide that all of its emergency siren systems should be equipped with backup power.

NWS

The NOAA Weather Radio (NWR) All Hazards is a nationwide network of radio stations broadcasting continuous weather information directly from a nearby National Weather Service (NWS) office. NWR is an "All Hazards" radio network, making it a single source for comprehensive weather and emergency information. NWR broadcasts NWS warnings, watches, forecasts, and other hazard information 24 hours per day. In conjunction with federal, state, and local emergency managers and other public officials, NWR also broadcasts warnings and post-event information for all types of hazards – including natural (e.g., earthquakes or avalanches), environmental (e.g., chemical releases or oil spills), and public safety (e.g., AMBER alerts or 911 Telephone outages).[239] Ensuring that NWR remains functional through the use of redundant transmitters and backup power was identified in a 2004 internal memorandum as a key priority

[238] Nuclear Information and Resource Service. 2005. NRC denies public petition for battery back up power to emergency sirens: Nuclear accident notification systems broadly vulnerable to grid power failures. Available at http://www.nirs.org/press/05-20-2005/1 [Accessed October 2006].

[239] NOAA, National Weather Service. 2006. NOAA Weather Radio All Hazards. Available at http://www.weather.gov/nwr/ [Accessed October 2006].

for the NWS from FY2007 through FY2011.[240] NWR is a prime example of a potential communication-related application for PEM fuel cells.

USCG

The USCG is responsible for operating and maintaining remote communications stations, radio navigation stations, weather stations, lighthouses, and lighted structures with audible warning signals to aid in navigation. Often, these sites draw power from older or unreliable power sources, which are costly to repair and frequently out-of-service.[241] Some of these sites are in environmentally-sensitive areas, and in many instances, historical or spatial restrictions limit the use of solar panels. The USCG appears to have a need for PEM fuel cells in lieu of older power sources and innovative but impractical solutions such as solar panels.

Backup power to federal agency activities, like those described above, is commonly supplied through diesel generators and/or batteries. Diesel generators are generally used for large, energy-intensive applications. Batteries are commonly used for smaller applications. For examples of specific backup power systems at various organizations, with a summary of primary research surveys and interviews, refer to the Market Segment Analysis section..

MARKET SIZE

The federal government spent $7.4 billion to consume 1 quadrillion Btu of site-delivered (end use) energy in 2000.[242] However, energy consumption in government buildings dropped 23% between 1985 and 2000 due to better energy management.[243] Detailed statistics on the amount of backup power consumed at federal facilities were not found.

Each federal agency included in this analysis is associated with distinctive sites and critical energy applications for which PEM fuel cells may be suitable. Limited information was available on the number of sites of application. Details on the number of facilities operated by various federal users are shown below, which may give some insight on the size of the various federal users.

DHS

Twenty-two federal agencies were combined to form the DHS. DHS components include the USCG, FEMA, the Secret Service, and the Transportation Security Administration. Due to this diversity, DHS-related facilities vary widely in size and are located throughout the U.S.

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[240] Johnson, D.L. 2004. FY07-FY11 Program Baseline Assessment: NWS Priorities. *Memorandum from D.L. Johnson to Mission Goal Team Leads and Program Managers*. Available at http://www.nws.noaa.gov/com/files/fy07-11_nws_priorities.pdf [Accessed October 2006].

[241] D'Entremont, J. 2001. Coast Guard looks at fuel cells as a new energy source: Cape Henry lights the way. Lighthouse Digest June 2001: 20.

[242] U.S. Department of Energy. 2006. Federal Energy Management Program. Available at http://www1.eere.energy.gov/femp/ [Accessed October 2006].

[243] The Alliance to Save Energy. 2005. Topics. Available at http://www.ase.org/section/topic [Accessed October 2006].

DOE
In addition to DOE Headquarters in Washington, D.C., the DOE operates approximately 14 regional operations offices that oversee activities in support of the missions assigned to the Department.[244] Also, the DOE owns 21 national laboratories and technology centers throughout the country, which employ more than 30,000 scientists and engineers.[245]

DOI
The DOI, through its Bureau of Reclamation (BOR), is the largest water distributor in the country. In total, the DOI provides water to 31 million citizens through 820 dams and reservoirs.[246] BOR also operates 58 hydroelectric power plants, which serve 6 million households. BOR has deployed multiple backup power systems at these plants to provide emergency power to systems such as plant protection, controls, security, communications, and lighting.

EPA
EPA occupies approximately 190 offices and laboratories nationwide. Approximately 57 of these are classified as large facilities (i.e., greater than 20,000 gross square feet in area): they include 29 major laboratory facilities, 10 regional offices, 6 large program offices, and 12 headquarters office buildings. The rest of EPA's facilities are smaller, special-purpose buildings and project offices scattered throughout the U.S. EPA facilities are owned by the Agency, owned or leased by the GSA and assigned to EPA, or leased directly by EPA.[247]

FAA
According the Central Intelligence Agency's World Factbook, there are currently 14,858 airports in the U.S.[248] As described above, the FAA is responsible for maintaining air traffic safety and facilitating air navigation at each of these facilities. Additionally, the FAA operates nine regional offices, one aeronautical center, one technical center, and field offices in each state and in several foreign countries.[249]

FCC
There are six operating bureaus and ten staff offices within the FCC.[250]

FEMA
FEMA, a component of DHS, has more than 2,600 full-time employees. They work at FEMA headquarters in Washington D.C., at regional and area offices across the country, the Mount Weather Emergency Operations Center, and the National Emergency Training Center in

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[244] U.S. Department of Energy. 2006. Operations offices. Available at http://www.doe.gov/organization/opsoffices.htm [Accessed October 2006].
[245] U.S. Department of Energy. 2006. National Laboratories and Technology Centers. Available at http://www.doe.gov/organization/labs-techcenters.htm [Accessed October 2006].
[246] U.S. Department of the Interior. 2006. Homepage. Available at http://www.doi.gov/ [Accessed October 2006].
[247] U.S. Environmental Protection Agency. 2006. EPA facilities. Available at http://www.epa.gov/greeningepa/facilities/index.htm#labs [Accessed October 2006].
[248] U.S. Central Intelligence Agency. 2006. Field Listing – Airports. The World Factbook. Available at https://www.cia.gov/cia/publications/factbook/fields/2053.html [Accessed October 2006].
[249] Federal Aviation Administration. 2006. Offices. Available at http://www.faa.gov/about/office_org/ [Accessed October 2006].
[250] Federal Communications Commission (FCC). 2006. About the FCC. Available at http://www.fcc.gov/aboutus.html [Accessed October 2006].

Emmitsburg, Maryland. FEMA also has nearly 4,000 standby disaster assistance employees who are available for deployment after disasters. FEMA often works in partnership with other organizations that are part of the nation's emergency management system.[251]

FHWA

FHWA consists of a headquarters office in Washington, DC; a division office in each State (including four metropolitan offices), the District of Columbia, and Puerto Rico; a resource center (with four locations); and three Federal Lands Highway division offices.[252]

GSA

GSA's management oversight covers $500 billion in federal assets, including approximately 8,300 buildings and 170,000 vehicles, and technology programs totaling more than $100 million. GSA National Headquarters is located in Washington D.C. Its 11 regional offices are located in Boston, Massachusetts; New York, New York; Philadelphia, Pennsylvania; Atlanta, Georgia; Chicago, Illinois; Kansas City, Missouri; Fort Worth, Texas; Denver, Colorado; San Francisco, California; Auburn, Washington; and Washington, D.C.[253]

NASA

NASA Headquarters in Washington, D.C. provides overall guidance and direction to the Agency, while 10 field centers and a variety of installations conduct the day-to-day work in laboratories, on airfields, in wind tunnels, and in control rooms.[254]

NRC

The NRC regulates commercial nuclear power plants that generate electricity. Currently, 104 nuclear power plants are licensed to operate in the United States. These plants generate about 20% of the nation's electrical power.[255] In addition, the NRC has four remote regional offices, located in larger cities, which operate as "command-and-control" centers by maintaining computer systems and communications with the power plants. These four offices are located in Philadelphia, Pennsylvania; Chicago, Illinois; Arlington, Texas; and Atlanta, Georgia.[256]

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[251] Federal Emergency Management Agency (FEMA). 2006. About FEMA. Available at http://www.fema.gov/about/index.shtm [Accessed October 2006].

[252] U.S. Department of Transportation, Federal Highway Administration. 2006. Contacts. Available at http://www.fhwa.dot.gov/whoweare/contacts.htm [Accessed October 2006].

[253] U.S. General Services Administration (GSA). 2005. GSA regions overview. Available at http://www.gsa.gov/Portal/gsa/ep/channelView.do?pageTypeId=8199&channelPage=/ep/channel/gsaOverview.jsp&channelId=-13362 [Accessed October 2006].

[254] National Aeronautics and Space Administration (NASA). 2006. NASA sites. Available at http://www.nasa.gov/about/sites/index.html [Accessed October 2006].

[255] U.S. Nuclear Regulatory Commission. 2006. Power reactors. Available at http://www.nrc.gov/reactors/power.html [Accessed October 2006].

[256] U.S. Nuclear Regulatory Commission. 2006. Region I. Available at http://www.nrc.gov/who-we-are/organization/rifuncdesc.html#funcdesc [Accessed October 2006].

NWS

The NWS has approximately 20 Central Weather Service offices; approximately 45 specialized data gathering and forecast centers; 10 regional headquarters and administrative support centers; and dozens of regional weather offices spread throughout the country.[257] Furthermore, NWS has approximately 884 Automated Surface Observing Systems (ASOS) sites.[258] There are 940 NOAA NWR transmitters, covering all 50 states, adjacent coastal waters, and U.S. territories.[259]

USCG

The USCG operates several hundred remote communications stations, radio navigation stations, weather stations, and lighted navigational aid (e.g., lighthouse) stations.[260]

USDA

In addition to USDA Headquarters in Washington, D.C., the Department maintains USDA Service Centers throughout the U.S. Each of these Service Centers serves a fairly limited geographic region (e.g., a county or metropolitan area) and is designed to be a one-stop resource for the services provided by three USDA agencies: the Farm Service Agency, the Natural Resources Conservation Service, and Rural Development. Each U.S. state and territory contains multiple USDA Service Centers; some states may contain dozens.[261]

USPS

The USPS operates an estimated 26,958 establishments in the U.S., employing over 709,000 individuals.[262]

MARKET TRENDS

The federal government is the largest energy consumer in the United States, with new mandates to meet increased demand, reduce peak operating costs, enhance energy security, and improve the reliability of electric power generation through the use of distributed generation (DG) and CHP technologies.[263] Recent federal mandates, including the Energy Policy Act of 2005 (EPAct 2005)[264] and Executive Order 13123,[265] require energy reduction and "greening initiatives" for federal operations. Individual federal agencies also may have internal goals for reducing energy costs and consumption.

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[257] NOAA, National Weather Service. 2005. NWS organization. Available at http://www.weather.gov/organization.php?task=cwsu.php#task [Accessed October 2006].
[258] Personal Communication between Rachel Sell (Battelle) and Tony Leonardo (National Weather Service), June 2006.
[259] NOAA, National Weather Service. 2006. NOAA Weather Radio All Hazards. Available at http://www.weather.gov/nwr/ [Accessed October 2006].
[260] U.S. Coast Guard Research and Development Center. 2003. Cape Henry Lighthouse Fuel Cell Evaluation, Final Report. Report No. CG-D-05-03. Available at www.rdc.uscg.gov/Reports/2003/CGD0503Report.pdf [Accessed October 2006].
[261] United States Department of Agriculture. 2006. USDA Service Center Locator. Available at http://offices.sc.egov.usda.gov/locator/app?service=action/1/CountyMap/1/NavBar.HomeLink [Accessed October 2006].
[262] Dun and Bradstreet. 2006. Zapdata industry report: U.S. Postal Service (4311). Available at http://www.zapdata.com [Last Accessed October 2006].
[263] United States Combined Heat & Power (CHP) Association. 2006. CHP market studies. Available at http://uschpa.admgt.com/markets.htm#dist [Accessed October 2006].
[264] The Library of Congress. 2005. H.R.6: Energy Policy Act of 2005. Available at http://thomas.loc.gov/cgi-bin/query/F?c109:6:./temp/~c109idTQ7y:e790842 [Accessed October 2006].
[265] U.S. Department of Energy, CEQ NEPAnet. 1999. Executive Order 13123. Available at http://ceq.eh.doe.gov/nepa/regs/eos/eo13123.html [Accessed October 2006].

EPAct 2005 contains numerous provisions related to the use of clean, efficient, and renewable energy sources, including fuel cells, which affect federal agencies. Section 783 of the Act (Federal Procurement of Stationary, Portable, and Micro Fuel Cells) requires the head of any federal agency that uses electrical power from stationary, portable, or microportable devices to lease or purchase a fuel cell to meet certain energy savings goals, provided that the agency head is able to identify an appropriately efficient and reliable fuel cell to meet the agency's needs. The cost of leasing or purchasing stationary, portable, and microportable fuel cells is to be paid or shared by the DOE, in cooperation with the Hydrogen and Fuel Cell Technical Task Force and the Technical Advisory Committee. The DOE may use the GSA or other vendors to ensure cost-effective fuel cell purchases or lease arrangements.[266]

Executive Order 13123, passed in 1999, calls upon federal agencies to improve the energy efficiency of their buildings, promote the use of renewable energy, and reduce greenhouse gas emissions. This Order requires greater use of renewable energy by implementing renewable energy projects and by purchasing electricity from renewable sources. The goal for new renewable energy use by the federal government was set at 1,384 gigawatt-hours (GWh) by 2005. In 2003, federal agencies reported that they were purchasing or producing over 600 GWh of new renewable energy, or over 40% of that goal. The Order also requires federal facilities to achieve a 30 % reduction in greenhouse gas emissions by 2010, compared to 1990 levels. By FY 2001, carbon emissions from energy used in non-exempt federal facilities declined 19.4% compared to the 1990 base year. The federal government exceeded the 20% reduction goal established for FY 2000, relative to the 1985 base year. More recently in 2001, agencies reduced their gross square foot energy consumption by more than 23%, relative to the base. The government also saved more than $1.3 billion in 2001, on a constant dollar basis, relative to 1985, in reduced energy bills, much of which can be attributed to energy efficiency improvements.[267]

EPA is one example of a federal agency that has been working diligently to reduce its actual energy use, decrease its water use, and increase its green power purchases as it moves forward to meet Executive Order 13123 goals. Due to its green power purchases, EPA reduced its reported FY 2005 energy consumption by approximately 40% from its FY 1990 baseline, helping the Agency to far exceed its goal of a 20% reduction. DOE reporting guidelines allow agencies to net out green power purchases from reported energy consumption; without the green power credit, EPA's actual FY 2005 energy consumption was only 1.2 % below the baseline). EPA is nearing completion on multiple commissioning projects and mechanical equipment upgrades at its largest energy-using facilities and expects substantial energy consumption reductions to be reported in FY 2006. In meeting its future energy reduction goals, EPA expects to have a better balance between energy use reductions and green power purchases.[268]

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[266] The Library of Congress. 2005. H.R.6: Energy Policy Act of 2005. Available at http://thomas.loc.gov/cgi-bin/query/F?c109:6:./temp/~c109idTQ7y:e790842 [Accessed October 2006].
[267] Garman, D.K. 2003. Testimony of David K. Garman, Assistant Secretary, Energy Efficiency and Renewable Energy, Before the House Committee on Government Reform – Energy Efficiency Improvements in Federal Buildings and Vehicles. Available at http://www1.eere.energy.gov/office_eere/congressional_test_0312_203.html [Accessed October 2006].
[268] U.S. Environmental Protection Agency. 2006. Greening EPA: Results and Projections. Available at http://www.epa.gov/greeningepa/energy/results.htm [Accessed October 2006].

While fuel cells have not been widely adopted by federal agencies, several federal agencies have begun demonstrating fuel cell systems. Examples of fuel cell installation and demonstration activities at federal agencies are presented below.

DOI

The DOI's Bureau of Reclamation operates 58 hydroelectric power plants and has multiple backup power systems deployed at these plants to provide emergency power to systems such as plant protection, controls, security, communications, and lighting. In 2003, the BOR's Hydroelectric Research and Technical Services Group investigated backup power sources for use at BOR plants and determined that PEM fuel cell technology was the best choice for one of the Bureau's sites in Colorado.[269] Prior to this evaluation, all the DC backup power needs at the BOR had been met by batteries and/or engine-driven generators.[270]

A PEM fuel cell system was installed in October 2003 at the Pole Hill Power Plant near Loveland, Colorado, to replace an existing battery bank of 48V-DC batteries at a communication site. This site was selected because the existing battery bank was scheduled for replacement.[271] The site had extreme temperature ranges during the year (-25º C to 40º C), which demonstrated the fuel cell system's ability to operate in harsh environments. It was specified that the system should be able to provide extended backup power for up to 3 days of continuous operation. Testing continued for 3 months and was cycled 50 times, for a total run time of approximately 25 hours.

At the conclusion of this demonstration, the BOR concluded that it would not recommend the use of PEM fuel cells for primary or vital systems, such as power plant control and protection power, until a proven track record of performance is established. Instead, the BOR would consider the use of fuel cells for less critical systems, such as communications and monitoring systems. The BOR is considering additional sites for future PEM fuel cell applications and is planning to monitor the existing fuel cell system for 5 years, with completion of the project expected in fiscal year 2008.[272]

EPA

The mission of EPA's National Vehicle and Fuel Emissions Laboratory (NVFEL), operating since 1971 in Ann Arbor, Michigan, is to advance clean vehicle fuels and technologies. As part of major project to replace its aging and obsolete heating, ventilation, and air conditioning (HVAC) system with an energy-efficient alternative, NVFEL incorporated a 200 kW PAFC fuel cell into the initial design of the new HVAC system. The fuel cell's electrical and thermal outputs are connected to primary electrical and heating systems. The fuel cell serves part of the

[269] Myers, N. and J. DeHaan. 2005. Fuel Cells: Will Fuel Cells Be Replacing Batteries at Your Facility? Presented at the Battcon Conference, May 2005. Bureau of Reclamation Hydroelectric Research and Technical Services Group, Denver, CO.
[270] U.S. Department of Energy, Federal Energy Management Program. 2005. Fuel Cells in Backup Power Applications. Technology Installation Review, DOE/EE-0310. Available at http://www1.eere.energy.gov/femp/pdfs/hydrogenfc_tir.pdf [Accessed October 2006].
[271] U.S. Department of Energy, Federal Energy Management Program. 2005. Fuel Cells in Backup Power Applications. Technology Installation Review, DOE/EE-0310. Available at http://www1.eere.energy.gov/femp/pdfs/hydrogenfc_tir.pdf [Accessed October 2006].
[272] U.S. Department of Energy, Federal Energy Management Program. 2005. Fuel Cells in Backup Power Applications. Technology Installation Review, DOE/EE-0310. Available at http://www1.eere.energy.gov/femp/pdfs/hydrogenfc_tir.pdf [Accessed October 2006].

base load of the facility, reducing electrical demand by nearly 200 kW. The new system became fully operational in March of 2001.[273]

FAA

In 2003, a 3 kW ReliOn PEM fuel cell unit (consisting of six smaller 500-W modular fuel cells) was installed at McChord Air Force Base in Tacoma, Washington. Sponsored by Construction Engineering Research Lab (CERL), a division of the U.S. Army Engineer Research and Development Center (ERDC), the fuel cells were installed as part of a 1-year demonstration project (through April 2004). The fuel cell system, which ran on unpressurized, industrial-grade hydrogen, backed up communications for an FAA radar system.[274] As part of the demonstration, the PEM fuel cell system responded to a loss in power and supplied backup power to a load bank located at an FAA-owned and operated radio transmitter and receiver (RTR) site. Over the demonstration period, the system was monitored for over 8,800 hours and accumulated over 1,100 successful starts, for a total system run time of 419 hours.[275]

NASA

NASA has been involved in fuel cell research and development for several niche applications. NASA's Glenn Research Center conducts research in energy storage technologies, including fuel cells, regenerative fuel cells, batteries, and flywheels, and has recently adopted PEM fuel cells. The Center conducted technology advancement programs on the Gemini PEM fuel cell and the Apollo alkaline fuel cell. It was responsible for advancing and qualifying primary fuel cell power technology for the Space Shuttle's onboard power system. It also developed the technology and supported advanced development activities for the alkaline fuel cells used in the Apollo missions and the Space Shuttle. The Center leads development of modular PEM fuel cell stack technology for use in Launch Vehicles. This technology provides increased peak-to-nominal power capability and improved reliability. Glenn is also leading the effort to evaluate and develop fuel cell and regenerative fuel cell energy storage systems for missions with long eclipse periods, such as Lunar/Mars bases, unmanned aerial vehicles, and high-altitude balloons. Totally passive components are the focus of this effort to minimize the weight, improve the energy density, and maximize the reliability of these systems.[276]

In 2005 Teledyne Energy Systems, Inc., engineered a PEM fuel cell power plant and delivered it to NASA's Glenn Research Center for testing in the Center's state-of-the-art fuel cell test facility. This fuel cell was noted to be the first high-fidelity, 12 kW PEM fuel cell hardware for space applications evaluated in a spaceflight-like environment.[277,278]

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[273] U.S. Environmental Protection Agency/U.S. Department of Energy. 2002. Laboratories for the 21st Century: Case Studies. The U.S. Environmental Protection Agency's National Vehicle and Fuel Emissions Laboratory, Ann Arbor, Michigan. Available at http://www.epa.gov/lab21gov/pdf/cs_nvfel_508.pdf [Accessed October 2006].

[274] Fuel Cells 2000. 2005. McChord Air Force Base, FAA radio transmitter-repeaters. Available at http://www.fuelcells.org/db/project.php?id=634 [Accessed October 2006].

[275] U.S. Department of Energy, Federal Energy Management Program. 2005. Fuel Cells in Backup Power Applications. Technology Installation Review, DOE/EE-0310. Available at http://www1.eere.energy.gov/femp/pdfs/hydrogenfc_tir.pdf [Accessed October 2006].

[276] National Aeronautics and Space Administration (NASA). 2006. NASA Glenn Research Center - Exploration Systems. Available at http://www.nasa.gov/centers/glenn/projects/exploration.html [Accessed October 2006].

[277] No author. 2006. NASA Fuel Cell Undergoing Tests. Fuel Cell Today (January 5, 2006). Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,7011,00.html [Accessed October 2006].

[278] Teledyne Technologies Incorporated. 2005. Teledyne delivers 12 kW PEM fuel cell power plant to NASA. Available at http://www.investquest.com/iq/t/tdy/ne/news/tdy080905pem.htm [Accessed October 2006].

USCG

The USCG began investigating the use of fuel cells in 1998 in an effort to meet energy objectives that called for a 20% reduction in facility energy costs from 1995 levels by 2005. The objectives further mandated that USCG minimize the use of petroleum fuels in all its facilities and platforms.[279] With funding from the Green Power Initiative of the Renewable Energy Trust (administered by the Massachusetts Technology Collaborative), DoD's Climate Change Fuel Cell Program, and Key-Span Energy, the USCG Research and Development Center installed one of the first fuel cells in the New England region in 2003. This fuel cell, a 250 kW FuelCell Energy Model DFC 300, is located at the USCG Air Station Cape Cod in Bourne, Massachusetts. Air Station Cape Cod is one of the largest USCG air stations on the East Coast, providing support for both fixed-wing aircraft and helicopters for search and rescue, maritime law enforcement operations, and other missions.

In addition to electric power, the Air Station Cape Cod fuel cell provides heat for domestic hot water for barracks and an associated galley and, at full 250 kW design output, has the potential to provide space heating for the entire building. In its first 12 months of operation (2003 to 2004), the fuel cell averaged an operating availability of 96.2% above its first year's expected design availability, producing a total of 1,392 megawatt-hours of electricity. Over the same year, approximately 1,832 million Btu of recovered heat was utilized for domestic hot water use, offsetting the purchase of nearly 26.3 million cubic feet of natural gas and resulting in a total net savings of almost $24,000 in operating expenses. Demonstrating a key benefit of fuel cell technology, in 2003 the fuel cell provided emergency power to the barracks and galley during several short grid outages, and in September 2003 was operated in a totally grid-independent mode as a precaution against potential grid power loss during a hurricane.[280] Air Station Cape Cod intends to operate the fuel cell as long as the economics are favorable.[281]

Another USCG-affiliated fuel cell demonstration took place at the Cape Henry Lighthouse in Virginia Beach, Virginia, in 2002. As noted above, the USCG operates several hundred remote communications, navigation, and weather stations with limited access to reliable, efficient power sources. Over the past few years, low-power fuel cell systems have emerged as a potential option in the suite of remote power technologies. To assess the potential of fuel cells in an operational marine environment, the USCG Research and Development Center installed and demonstrated a 3 kW, direct methanol fuel cell at the Cape Henry Lighthouse.

The Cape Henry installation was placed into service in March of 2002 and ran for approximately 6 months. Performance data such as fuel consumption, power output, and reliability were collected and compared with conventional energy technologies. An evaluation of costs, safety, training, fuel logistics, and other factors was conducted to assess the potential for future use of

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[279] U.S. Department of Energy, Federal Energy Management Program. 2005. U.S. Coast Guard Air Station Cape Cod demonstrates successful fuel cell. FEMP Focus – Summer 2005. Available at http://www.eere.energy.gov/femp/newsevents/fempfocus_article.cfm/news_id=9327 [Accessed October 2006].

[280] U.S. Department of Energy, Federal Energy Management Program. 2005. U.S. Coast Guard Air Station Cape Cod demonstrates successful fuel cell. FEMP Focus – Summer 2005. Available at http://www.eere.energy.gov/femp/newsevents/fempfocus_article.cfm/news_id=9327 [Accessed October 2006].

[281] U.S. Department of Energy, Federal Energy Management Program. 2004. Fuel Cell Demonstration at the U.S. Coast Guard Air Station Cape Cod. Case Study PNNL-SA-42044, August 2004. Available at http://www1.eere.energy.gov/femp/pdfs/fuel_cell_cs.pdf [Accessed October 2006].

fuel cells at other Coast Guard operational sites. Results of this demonstration were mixed, as several problems with fuel supply and overheating were observed. However, the technology appears to have significant promise and should be closely monitored by the USCG as manufacturers introduce more reliable systems.[282]

USPS

While no evidence was found to suggest that USPS has installed fuel cells for backup power, the agency has begun testing hydrogen fuel cell-powered vehicles. In September 2006 the USPS announced that it had agreed to extend a program with General Motors for another year of testing GM HydroGen3 minivans in Washington, DC, and Irvine, CA. The USPS already boasts 37,000 alternative-fuel vehicles in its fleet.[283]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells as backup power for federal agencies, several agency representatives were contacted. In total, 13 federal agencies were contacted, seven responses were received, and nine interviews were conducted. A detailed summary of the contacts made and responses received from each agency is presented below.

DHS

Two DHS officials were contacted. No responses were received.

DOE

Three DOE national laboratories were contacted (Idaho, Brookhaven, and Lawrence Livermore National Laboratories). One complete survey response was received, and one interview was conducted.

The survey respondent identified a need for backup power for life safety systems (i.e., emergency lights, fire protection, and security), programmatic data protection, computer protection, and hospital certification. Life safety systems were cited as the most important application requiring backup power. The respondent's facility employs over 32 fixed emergency generators and numerous battery backup and UPS systems; systems range in size from < 5 kW to 1 MW. Four of the fixed generators are < 50 kW and support life safety needs in smaller facilities. The facility also utilizes a number of small portable generators in the 5 to 50 kW range that can be moved around the site to support various power needs during planned or forced power outages. UPS systems are typically owned by individual scientific departments in various locations around the site. The majority of these support data protection and allow the orderly shutdown of computer equipment in the event of a power outage.

The survey respondent indicated the frequency and impact of grid power outages at the national laboratory. Approximately four partial outages (lasting < 1 second) had occurred in the past year. Even short outages can be very disruptive to the national laboratory, if their large research machines are on-line. In the middle of winter, an extended outage could be devastating due to freeze damage. An estimated one to two grid power outages occur each year that are considered

[282] U.S. Coast Guard Research and Development Center. 2003. Cape Henry Lighthouse Fuel Cell Evaluation, Final Report. Report No. CG-D-05-03. Available at www.rdc.uscg.gov/Reports/2003/CGD0503Report.pdf [Accessed October 2006].
[283] Hoovers, Inc. 2006. United States Postal Service fact sheet. Available at http://premium.hoovers.com/ [Accessed October 2006].

very disruptive. Possible consequences of power outages include: loss of lives, security breaches, implementation of emergency management plans, and disruptions in production.

The survey respondent indicated the importance of various factors in selecting a backup power system. The respondent cited reliability, ease of use use/maintenance, and good experience with a system as the most important factors in selecting a backup power system.

The survey respondent rated the overall performance of their current backup power systems as very good. The respondent indicated the greatest satisfaction with the following aspects of their current backup power systems: fuel availability, ease of use/maintenance, lifetime of the unit, and reliability. To ensure the performance and reliability of their emergency generators (to start and perform as required), the national laboratory conducts an extensive preventive maintenance program and testing program. The performance of UPS system is less certain because each department or division owns its own units and usually relies on outside services for maintenance.

The survey respondent anticipated a growing need for backup power among federal agencies in the next three years. However, the respondent had not considered alternatives to their current backup power systems and was not aware of PEM fuel cells as a backup power source.

The survey respondent reported that capital purchase decisions are made on the basis of need, funding availability, and priority. Purchasing decisions for backup power systems are made by the plant engineering division manager.

One national laboratory interviewed for this analysis reported using diesel generators for backup power and UPS systems for emergencies.

FAA

One FAA official was contacted in fiscal year 2006. No response was received from this individual. In fiscal year 2005, an individual from the FAA was contacted for information on the potential for PEM fuel cells at their facilities. Feedback received then is summarized below.

The FAA representative contacted in 2005 reported that FAA was a partner with DoD in a PEM fuel cell demonstration at a U.S. Air Force Base. Six 3 kW hydrogen fuel cells were installed in March 2002 and operated for 391 hours, providing backup power at a Radio Transmit and Receive (RTR) site. Specific loads powered included building lighting, building bay doors, and the building local area network (LAN) switch.

The respondent indicated that environmental concerns were very important in influencing the FAA's decision to conduct a PEM fuel cell demonstration. The respondent identified the following critical issues for the fuel cell application: reliability, start-up time, usability, and durability for use in an outdoor enclosure in a remote location.

The respondent reported that cost plays a role in influencing the decision to purchase fuel cells but that reliability, power quality, and durability (life) of a system are more important. The respondent noted that the reliability of fuel cells is an important benefit that affects the

purchasing decision. The respondent indicated that downtime of an RTR site can have a significant impact at larger airports, costing up to $1 million per day.

The respondent discussed other alternative technologies for backup power and indicated that photovoltaic and wind power would be considered as alternatives to batteries. The respondent commented that generators and batteries are expensive and indicated a desire to move away from these systems due to the maintenance required. The respondent reported that capital purchasing decisions are made using centralized energy management.

The respondent reported that the FAA was very pleased with the performance of the fuel cell system and has purchased additional fuel cell systems for installation at other sites. The fuel cells were easy to use, and remote monitoring facilitated maintenance of the system.

When asked to identify the primary barriers that impede wide-scale commercialization of PEM fuel cells, the respondent indicated that the most important barriers were the durability of PEM fuel cells and the need for a reformer. The respondent also identified the following as important barriers to wide-scale commercialization of PEM fuel cells: balance of plant issues, fuel supply, service infrastructure, lack of storage technologies, lack of national policy on fuel cells, national/state/local incentives for adoption, lack of funding for development, and lack of a champion for fuel cell commercialization.

FEMA

State agencies affiliated with FEMA were contacted as part of the Emergency Response market segment. No federal FEMA officials were contacted.

DOT

One DOT official was contacted. One interview was completed.

The interviewee commented on sources of power used at DOT facilities. The government has set goals for increasing the percentage of renewable energy used at government facilities. Currently, 0.9% of power used at DOT facilities is renewable energy, a considerable portion of which is geothermal energy. The interviewee also noted that DOT does not own many of its buildings but rents or uses GSA space.

The interviewee was not aware of PEM fuel cells as a source of backup power and did not anticipate that PEM fuel cells would be considered at government facilities because their percent use is presently very low. However, with incentives, the interviewee expected PEM fuel cells to be considered as an alternative backup power source. The interviewee cited radar as one application of backup power.

NASA

Five NASA officials were contacted. One complete survey response was received, and one interview was conducted.

The survey respondent represented a NASA research center with critical backup power needs for research, operations, communication, and data collection and storage. The facility utilizes

batteries, UPS systems, and diesel and propane generators for backup power. These systems range in size from < 5 kW to > 250 kW. Based on the size and diverse nature of the work performed at the research center, there is no typical size of backup power system.

The survey respondent reported one to two power outages across the entire lab in the past year, and four to six in isolated areas. These power outages were estimated to last from 1 second to 2 hours. The respondent indicated that any power outage, whether 1 second or 4 hours in duration, would be very disruptive without backup power. The respondent estimated that one grid power outage that is considered very disruptive occurs each year. Potential consequences of power outages at the respondent's facility include: implementation of emergency management plans, disruptions in production, disruptions in distribution, and loss of research data.

The survey respondent rated the overall performance of their current backup power systems as very good. The respondent indicated the greatest satisfaction with the following aspects of their current backup power systems: reliability, capital cost, lifetime of the unit, annual operating cost (fuel and maintenance), start-up time, and fuel availability. The respondent noted concerns with the reliability of their current backup power systems and operating costs for a sufficient amount of standby power.

The survey respondent rated the importance of several factors in selecting a new backup power system. Reliability, capital cost, lifetime of the unit, annual operating cost (fuel and maintenance), emissions, start-up time, ease of use/maintenance, and fuel availability were all considered very important factors in selecting a backup power system. Good experience with a system was considered less important than the above factors. The respondent cited reliability, capital cost, annual operating cost, and ease of use/maintenance as the most important.

The survey respondent reported that capital purchase decisions for backup power systems are made on the basis of initial capital cost, payback period, and return on investment. Government incentives are not considered in making a purchasing decision. Purchasing decisions for backup power systems are made by high- and low-voltage power system managers.

The survey respondent anticipated a growing need for backup power among federal agencies in the next 3 years. The respondent agreed to be contacted again for further information.

The survey respondent was aware of PEM fuel cells as a source of backup power and had considered fuel cells as an alternative. However, the respondent felt that the capital cost of fuel cells was still too high for them to compete favorably with their existing backup power systems. The respondent also cited concerns about using hydrogen as a fuel. The respondent identified factors that would drive a decision to purchase PEM fuel cells, including: the cost of not having electricity, or having a power failure; dissatisfaction with the current mode of backup power; energy efficiency of PEM fuel cells as compared to alternatives; environmental concerns; and a track record of others using the PEM fuel cell system.

An interview was also conducted with a representative of the NASA Johnson Space Center. The interviewee commented on NASA's present use of fuel cells and potential opportunities for the use of PEM fuel cells in the near future. Currently, NASA is primarily interested in the use of

fuel cells on spacecraft and is working to certify them under various conditions of use. NASA has returned to using alkaline fuel cells that were used in the Apollo flights and expects to use them on future missions as well. PEM fuel cells are one of various energy technologies used on-board the spacecraft. NASA is considering the capture of hydrogen from rocket propellant for use in PEM fuel cells; however, this is presently just a proposal to conduct research.

The interviewee noted that NASA has also shown interest in using PEM fuel cell vehicles at various sites, and one 2-week test using a fuel cell vehicle was conducted. NASA would consider converting fleets to fuel cell vehicles, if funding were available. Terrestrial applications of PEM fuel cells for backup power exist; however, these are lower priority and are greatly dependent on the availability of funds.

The interviewee discussed potential drivers for the adoption of PEM fuel cells. The interviewee stated that mandates are necessary to drive PEM fuel cell adoption. Budgets are tight, particularly for more expensive, unproven alternatives without clear benefits. No funding is presently available for fuel cell development. The interviewee could recall only one mandate from 1976 for NASA to assist in the understanding of the science behind fuel cells. The interviewee expected the recent increase in the price of gasoline to drive mandates (with funding support) for fuel cells.

NRC

Two NRC officials were contacted. One interview was conducted.

The interviewee described backup power at the approximately 104 nuclear power plants operating in the U.S. A nuclear plant typically has multiple, large emergency diesel generators on site for emergency power. For example, one plant has five separate 4,400 kW units. Nuclear power plants have some backup power needs for communications and security issues, which are normally fed from the emergency diesel generators, but might have a need for an independent backup power source. Nuclear plants also employ dedicated battery circuits (battery banks). The main reason for backup power at nuclear power plants is safety, to control plant shutdown, and to keep the plant cool. There are a myriad of regulatory requirements to meet that driver.

The interviewee commented on potential applications for PEM fuel cells at nuclear power plants. He suggested that fuel cells could possibly replace the following current battery applications:

- Emergency power for communications (e.g., walkie talkies recharged by fuel cells in lieu of batteries)
- Emergency instrumentation and control equipment used during loss of power (to monitor the reactor)
- The interviewee was uncertain about the backup power source for emergency sirens. He speculated that it was tied to the battery backup for instrumentation and control equipment.

The interviewee estimated that each nuclear plant has five vital batteries that offer potential for fuel cell technology (i.e., replacement by a fuel cell). Each battery could provide emergency

power of approximately 700 amps in the first minute, < 500 amps in the first 30 minutes, and 300 amps for up to 6 hours.

The interviewee explained that NRC is the regulator, not the operator, of nuclear power plants. NRC is responsible for assuring that nuclear power plants operate safely and meet federal regulations, but NRC does not purchase or maintain backup power units for nuclear power plants. NRC has four remote regional offices (similar to command and control centers), located in large U.S. cities, and maintains communication with nuclear power plants. The interviewee was not aware of fuel cells being used at NRC offices.

Purchases of backup power systems for nuclear power plants are made by plant operators, not NRC. There are about 12 or 24 operators for the approximately 100 plants in the U.S. Fairly large corporations operate a number of nuclear sites. The interviewee cited Entergy as an example. Entergy operates 11 nuclear units at nine plant sites in seven states.

NWS

One NWS official was contacted. One complete response was received.

The respondent described the primary drivers for backup power to support the maintenance of weather data collection platforms and weather data dissemination. Hurricane Isabel (2003), Hurricane Charley (2004), and Hurricanes Katrina and Rita (2005) resulted in an identified need for an uninterrupted supply of meteorological and climatologic data. Two mission-critical weather systems were identified as vulnerable to failure during severe weather events (i.e., 40+ mph winds, tropical cyclones, winter storms, and local thunderstorms). This vulnerability was due to commercial and telecommunication outages.

The respondent indicated the frequency and impact of power outages at Automated Surface Observing System (ASOS) sites (owned by NWS and FAA) and NWS NOAA weather radio (NWR) sites. Each site may experience several minor power outages annually. Outages caused by severe weather events occur approximately once a year. Outages lasting from 1 second to 4 hours are not uncommon. Outages of 1 second duration are not considered disruptive; however, longer outages (e.g., 1 to 4 hours) are very disruptive. The respondent indicated that power outages could result in loss of lives, disruptions in distribution (of data), and loss of data.

ASOS sites currently have UPS systems to address the temporary short-term loss of grid power. The UPS system is capable of supplying backup AC power under full load for a minimum of 10 minutes. The primary purposes of the UPS system, as identified by the respondent, are to provide uninterrupted operation during minor power outages and fluctuations, to filter facility power (i.e., during power surges), and to allow uniform (orderly) shutdown of an ASOS in a prolonged power outage. In its current configuration, the UPS is not designed to sustain operations for prolonged power outages, and backup engine generators are needed.

NWR locations currently do not have UPS units to address the short-term loss of grid or have the ability to filter facility power. Backup engine generators are needed for NWR sites.

To address the deficiencies identified above, the respondent reported that NWS is currently procuring 238 backup power generators in the 11 to 12 kW range and 40 generators in the 20 to 22 kW range. The generators will be liquid propane vapor compatible engine generators or hydrogen fuel cells that convert liquid propane vapor to hydrogen gas. Both types of systems must meet the standard for stationary engine generators (UL 2200).

The respondent rated the importance of several factors in selecting a backup power system. Reliability, capital cost, lifetime of the unit, annual operating cost (fuel and maintenance), emissions, start-up time, ease of use/maintenance, and fuel availability were all considered very important factors in selecting a backup power system. The respondent cited reliability, lifetime, and capital cost as the most important factors.

The respondent was not very well satisfied with the performance of the agency's existing backup power systems. ASOS sites do not currently have a UPS that can provide 10 minutes of backup power, and NWR sites do not have NWR-owned UPS units; some NWR sites are supported by non-NWS-owned standby generators. The respondent rated the reliability, annual operating cost (fuel and maintenance), emissions, start-up time, and fuel availability of existing backup power units as very good; capital cost, lifetime of the unit, and ease of use/maintenance were rated not so good.

The respondent was aware of PEM fuel cells as a source of backup power but did not think they were likely to compete favorably with existing backup power systems due to cost. The respondent did not have any concerns with using hydrogen as a fuel. The respondent identified several factors that would drive a decision to purchase PEM fuel cells for backup power, including the cost of not having electricity, or having a power failure; dissatisfaction with the current mode of backup power; energy efficiency of PEM fuel cells as compared to alternatives; environmental concerns; availability of government incentives; and track record of others using the PEM fuel cell system.
The respondent provided information on the capital purchase decision process within NOAA. Many factors contribute to government procurement decisions, including initial capital cost, payback period, and return on investment. Government incentives are also considered in making a purchasing decision. Purchasing decisions for backup power systems are made by the chief of the maintenance branch.

USCG (part of DHS)

Two USCG officials were contacted. One complete response was received, and one interview was conducted.

The respondent represented an island Integrated Support Command facility whose primary functions are search and rescue and law enforcement. The respondent identified a need for backup power to operational units, such as telephones, computers, and other equipment needed for lifesaving operations. The most critical applications requiring backup power were cited as security communication and computers. Specifically, the facility's communication center (CommCenter) is a critical application that requires backup power to be able to respond to off-shore emergency calls (up to 500 miles) and provide alerts in case of terrorist threats.

The respondent indicated the frequency and impact of power outages at the island facility. One outage had occurred in the first 5 months of 2006. The facility experienced four to five outages in 2005, including a failure of the high-voltage line running through the island, which caused a loss of power to the entire island for a few hours. A typical outage lasts between 5 minutes and 1 hour. The respondent reported that outages lasting greater than 1 hour would be highly disruptive without backup power; an estimated one to four power outages that are considered disruptive occur each year. Outages at the facility could potentially result in loss of lives, security breaches, decreased ability to implement emergency management plans, and other disruptions (e.g., sewage removal).

Backup power for the facility is currently provided by batteries, six diesel generators, and three main UPS units. In addition, each computer server has its own UPS unit for backup power (individual computers do not have backup power). Diesel generators support telephones and computers as well as a sewage lift station on the island. A UPS unit (100 to 250 kW) can provide backup power to the facility's CommCenter for 10 minutes.

The respondent rated the importance of several factors in selecting a backup power system. Capital cost, lifetime of the unit, emissions, and start-up time were considered important factors; reliability, annual operating cost, ease of use/maintenance, fuel availability, and good experience with a system were not as important. The respondent cited lifetime of the unit, emissions, and start-up time as the most important factors in selecting a backup power system.

The respondent rated the overall performance of existing backup power systems as very good, although there were concerns noted with maintenance (i.e., finding parts for old machinery). The respondent also indicated a desire to replace diesel generators with an alternate source of backup power.

The respondent was not aware of PEM fuel cells as source of backup power, but has considered a waste heat system fueled by propane as an alternate backup power source. The respondent did not have concerns about using hydrogen as a fuel. The respondent identified potential applications for alternative backup power sources in the 5 to 30 kW power range, the relevant size range for PEM fuel cells. Backup power for security lighting and camera systems on the island, comprised of two circuits of 17 kW each, may be candidate applications for fuel cells.

The respondent anticipated a growing need for backup power in the next 3 years but was not certain of the size of the potential market for PEM fuel cells (i.e., the total number of USCG facilities that would have smaller backup power needs).
The respondent provided information on the procurement process at the USCG facility. Capital purchase decisions are made on the basis of return on investment and other future energy savings, in addition to lifetime of the unit; maintenance costs are not considered in making purchase decisions (to the dismay of the respondent). Capital purchase decisions are made by the Civil Engineering Unit.

The interviewee commented on a 3 kW fuel cell installed at a USCG lighthouse. The USCG considered the potential for fuel cell power at remote applications, and based upon the lighthouse

installation, concluded that fuel cell technology was not ready for Coast Guard installations due to cost, maintainability, and other factors.

USDA

Two USDA officials were contacted. One interview was completed.

The interviewee was not aware of fuel cells being used at USDA facilities but mentioned that USDA is considering renewable energy in the form of ethanol and wind. The interviewee noted that USDA facilities are leased, and the lessor may make the purchasing decisions for backup power systems. The interviewee was uncertain whether current backup power systems consisted of generators or other sources.

EPA

Twenty EPA officials were contacted. Three completed responses were received from three EPA research laboratory facilities, and two interviews were conducted with EPA staff.

Respondents reported critical business operations requiring backup power. All three respondents identified computer operations; two identified critical laboratory equipment (e.g., for analysis, refrigeration, and storage); two identified emergency operations or life safety functions; and one identified security.

Respondents reported that between one and six power outages had occurred in the past year. These outages typically lasted less than 3 minutes, but respondents indicated that all outages (whether 1 second or 4 hours) would be very disruptive. Power outages could potentially result in loss of lives, security breaches, implementation of emergency management plans, or disruptions in production at respondents' facilities.

Two respondents use batteries, UPS systems, and generators for backup power. One respondent could not provide details of EPA's backup power system due to security considerations. Both respondents reported using a diesel emergency power generator (one of size 375 kW, and the other 1,200 kW), one to three UPS units approximately 50 kW and larger, and numerous local UPS units. One respondent also reported using a 200 kW PAFC (connected in parallel) for backup power, but noted that it may be decommissioned due to operational costs, parts availability, and reliability.

Respondents were asked to rate the importance of various factors in selecting a backup power system. All three respondents rated reliability, lifetime of the unit, start-up time, and fuel availability as very important factors; two respondents also cited capital cost, emissions, and ease of use/maintenance as very important factors in selecting a backup power system. Good experience with a system was considered important by all three respondents. Annual operating cost was considered important or very important by two respondents, but not so important by one respondent. When asked to identify the three most important factors in selecting a backup power system, respondents cited reliability (two respondents), annual operating cost (one respondent), capital cost (one respondent), lifetime of the unit (one respondent), and ease of use/maintenance (one respondent).

Respondents commented on the performance of their current backup power systems. One respondent rated the performance of the facility's current backup power systems as very good and noted no concerns. Another respondent indicated concerns with the facility's backup diesel generator, including its reliability, emissions, and parts availability; start-up time was also not considered very good.

Respondents varied in their opinions of whether the need for backup power would increase in the next three years. Two respondents anticipated a growing need for backup power among federal research laboratories, and one did not.

Two respondents had considered alternative sources of backup power, including photovoltaic and solid oxide fuel cells, bi-fuel, and co-generation. Two respondents were aware of PEM fuel cells as a power source for backup power applications. Two respondents stated that PEM fuel cells were not likely to compete with existing backup power systems because of high capital costs. However, one respondent commented that EPA's mandate to utilize innovative technology may justify the higher operating and capital costs of fuel cells. One respondent indicated that a decision to purchase PEM fuel cells would be driven by dissatisfaction with the current mode of backup power, energy efficiency of PEM fuel cells as compared to alternatives, environmental concerns, and availability of government incentives.

Respondents commented on the capital purchase decision process in their organizations. Two reported that decisions are made on the basis of initial capital cost and payback period. One respondent indicated that capital purchase decisions are made on the basis of payback period and return on investment. One respondent noted that interaction and installation with existing equipment are also considered. Two respondents indicated that government incentives were considered in making a purchasing decision, while one respondent indicated that they were not. All three respondents reported that procurement decisions are a consolidated effort involving several individuals. At one respondent's facility, an independent analysis is sought before a purchase is initiated.

An interview was conducted with EPA representatives to discuss potential applications for fuel cells at EPA facilities and drivers for adoption. EPA has considered adopting alternative power technologies for new buildings and laboratories and expressed an interest in fuel cells. Drivers for fuel cell adoption at EPA facilities include: a desire to increase the use of alternative technologies, and growth in the number of EPA facilities. However, the size of current PEM fuel cell products may limit adoption.

One EPA division interviewed in this analysis reported having no backup power (UPS or generators).

USPS

One USPS official was contacted. No response was received.

GSA

Two GSA officials were contacted. One interview was completed.

An interview was conducted with a large federal facility participating in a 5 kW PEM fuel cell demonstration project. In an effort to pursue alternative energy sources, the fuel cell was installed as a backup generator (in place of a gasoline-powered generator) for the facility's telecommunications system.

The interviewee noted that the facility's telecommunications system was the only application that currently provides an opportunity for PEM fuel cells. No other applications fit the size range and have a steady load. The interviewee expected that PEM fuel cells could be adopted at other GSA facilities where applications offer the right fit.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

As large consumers of electricity, there is significant potential for the application of PEM fuel cells in grid parallel, grid independent, and backup power applications. Furthermore, federal users are interested in alternative technologies that can reduce their energy consumption and help meet their energy efficiency goals. Primary drivers for adoption of energy alternatives are the commitment to energy efficiency, environmental concerns, interest in novel technologies, and commitment to energy security. While users in this sector are primarily looking for ways to offset their grid electricity consumption, there has also been some interest in alternative technologies to increase reliability and runtime for backup power applications. Federal users including FAA, USCG, BOR, and NOAA have even considered PEM fuel cells as alternatives. While these users are satisfied with the performance of PEM fuel cell technologies there is some dissatisfaction with the capital costs of the systems.

Legal directives such as EPAct 2005 and Executive Order 13123 are likely to drive the long-term use of alternative energy sources such as PEM fuel cells. Also, primary research indicates that some agencies would welcome alternatives to current energy technologies, such as diesel generators, due to emissions and other concerns. Marketing research also suggests that, due to cost, reliability, and durability issues, it is likely that PEM fuel cells will be adopted in the near term by government users in backup power applications.

The early opportunities for PEM fuel cells in the federal market segment are with those users that require reliable backup power to support their communications infrastructure. The FAA, USCG, and NOAA are particularly good candidates as they are looking for alternatives to support communication at remote locations, are looking for alternatives to generators, or are interested in alternatives that can provide longer runtimes. While there is significant interest in alternatives, for most federal users, capital expenditure on facility related infrastructure is low priority unless mandated at this time. With shrinking budgets federal agencies find it difficult to budget and finance energy investments. In the near term, it is likely that the availability of funding will drive the adoption of PEM fuel cells with federal users.

RESEARCH SUMMARY:
GROCERY STORES

MARKET SEGMENT DESCRIPTION

This market segment encompasses stores commonly known as supermarkets, food stores, and grocery stores, primarily engaged in the retail sale of a wide range of food products, including canned and frozen foods; dry goods, such as tea, coffee, spices, sugar, and flour; fresh fruits and vegetables; and fresh and prepared meats, fish, and poultry. Table j-1 identifies the SIC and NAICS classifications that cover this market segment.

Table j-1. SIC and NAICS Codes for Grocery Stores.

2-Digit SIC Code	54 – Food stores
4-Digit SIC Code	5411 – Grocery stores
NAICS Code	445110 – Supermarkets and other grocery (except convenience) stores

This market was considered for the application of fuel cells because of the size of the market, the need for constant, reliable power to maintain food quality, especially for refrigerated or frozen items, and the often 24/7 nature of the business. Secondary research indicates that backup power is most directly needed for emergency lighting, refrigerator and freezer cases, and point of sale cash registers.

There are no standards or requirements mandating the use of backup power in grocery stores, so the decision is made on a chain-by-chain or store-by-store basis. Some grocery chains choose to only supply backup power to stores located in areas with unreliable grid power or that often experience outages due to adverse weather such as icy conditions in the north or hurricanes in the south. Smaller stores and specialty stores often have no backup power and merely close when power outages occur.

Backup power, when supplied, is usually in the form of generators with some additional help from UPS systems in computer equipment. Information on the size of typical backup systems in grocery stores is limited to anecdotal evidence. Publix Grocery stores, a chain located primarily in the southern U.S. states, recently announced a plan to use backup generators in its hurricane-zone stores.[284,285] Following the 2004 hurricanes (including Hurricane Wilma) that cut access to power and spoiled over $60 million dollars worth of goods, Publix is spending $100 million to install 500 kW generators at every store in hurricane-prone areas. The company's plans are to install 400 stationary and mobile generators in hurricane-prone store locations and 175 quick-connecting docking stations in stores in lower-probability hurricane areas.

[284] Gray Television Group, Inc. 2006. Publix put backup generators at its hurricane zone stores. Available at http://www.wjhg.com/home/headlines/2919421.html [Accessed September 2006].
[285] Publix Asset Management Company. 2006. Publix Purchases Generators as Part of Business Recovery Plan. Available at http://www.publix.com/about/newsroom/NewsReleaseItem.do?newsReleaseItemPK=1857 [Accessed September 2006].

MARKET SIZE

Current data on the grocery store market are provided below. SIC Code 5411, covering the grocery store industry, is represented by Table j-2. These statistics indicate that there are an estimated 164,981 grocery establishments in the U.S. These establishments employ over 2.6 million individuals and are responsible for total annual sales exceeding $620 billion.

Table j-2. Number of Businesses in Grocery Stores Industry (5411).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
5411-0000	Grocery stores	59,292	618,113	85,798.797
5411-0100	Supermarkets	5,109	166,975	62,614.199
5411-0101	Supermarkets, chain	10,643	914,078	344,044.406
5411-0102	Supermarkets, greater than 100,000 square feet (hypermarket)	123	15,300	1,502
5411-0103	Supermarkets, independent	2,187	90,411	14,608.1
5411-0104	Supermarkets, 55,000 - 65,000 square feet (superstore)	31	3,187	1,417.7
5411-0105	Supermarkets, 66,000 - 99,000 square feet	24	1,710	2,533.2
5411-0200	Convenience stores	31,144	162,652	17,620.801
5411-0201	Convenience stores, chain	17,307	141,496	36,581.699
5411-0202	Convenience stores, independent	11,420	62,315	9,343
5411-9901	Cooperative food stores	399	7,355	898
5411-9902	Delicatessen stores	7,810	39,351	3,169.9
5411-9903	Frozen food and freezer plans, except meat	160	2,343	159.6
5411-9904	Grocery stores, chain	2,304	152,417	16,334
5411-9905	Grocery stores, independent	17,028	225,731	26,391.801
	Total	**164,981**	**2,603,434**	**623,017.188**

Sales figures are in millions. Source: www.zapdata.com, accessed September 2006.

Grocery stores have very low net profit margins, traditionally barely 3% of sales, and must move a large number of goods.[286] Various factors are cited as contributing to the slim profit margins, including the perishable nature of a large portion of a grocer's stock, fierce competition from low price, non-traditional competitors (including warehouse clubs and dollar stores), mature markets, steep start-up costs, and antitrust limitations. The supermarket industry is relatively mature, and not projected to grow substantially, although there may be a growth in the demand for backup power, as indicated by Publix's recent investment in generators.

Supermarkets and grocery stores consume large amounts of energy, consuming more electricity per square foot than any other type of commercial building.[287] Grocery stores spend approximately $4.1 billion annually on electricity alone in the United States and Canada. On average, the annual utility bill for a supermarket is roughly equal to its profit. For a major chain, efficiency improvements that cut energy costs by 10 % could be worth tens of millions of dollars.

[286] Hoovers, Inc. 2006. Industry Record: Grocery Retail. Available at http://premium.hoovers.com/subscribe/ind/overview.xhtml?HICID=1535 [Accessed September 2006].
[287] E Source. 1998. E Briefing: Highlights of reports issued under E SOURCE's supplemental research services. EB-98-2. Available at http://www.esource.com/members/e_cd/pdfs/EB9802.pdf [Accessed September 2006].

MARKET TRENDS

No evidence of fuel cell activity in the U.S. grocery market segment could be identified; however, certain players in the grocery industry are showing increased interest in alternative energy sources.

One natural foods chain, Whole Foods, recently announced their plan to use wind power, and become the largest buyer of wind energy credits in North America.[288] It plans to purchase credits equal to 100% of its projected energy use for 2006, making Whole Foods the only Fortune 500 company to purchase renewable energy credits to offset 100% of its electricity use. One credit represents one megawatt-hour of electricity from renewable sources.

Specialty and organic markets such as Whole Foods are becoming increasingly popular, and traditional grocery stores are offering more specialty foods and organic products in addition to their traditional fare. This move, as well as the move to the use of renewable energy resources, is part of a larger movement by all Fortune 500 companies trying to project a "greener" image.[289] Although there are no regulatory drivers to promote the use of alternative energy sources, or to institute backup power systems, grocery companies are responding to public demand for improved environmental performance. Image enhancement is one of the most common benefits reported by ENERGY STAR participants. Image maintenance as a responsible corporate citizen through improved energy efficiency often minimizes community opposition to opening new stores. Once stores are opened, a positive environmental image contributes to increased sales and enhanced community relations.[290]

MARKET SEGMENT ANALYSIS

Twenty-seven grocery stores or related retail food organizations were contacted to further determine requirements for backup power and the potential for application of PEM fuel cells in the supermarket sector. Five informal interviews were conducted, with three additional complete responses to the survey. Three survey responses were collected representing a large grocery chain, a warehouse club, and a natural foods and specialty foods chain. In addition, three smaller specialized food chains were interviewed but did not complete the survey.

From the interviews conducted, it was noted that the smaller, niche stores tend not to have backup power, while larger grocery stores have at least partial backup and often full backup in areas with grid unreliability or a history of more common power outages (i.e., with the potential for greater loss of income). One smaller store decided against installing backup generators due to the cost of installing transfer switches in existing stores and the capital cost of procuring generators. All the smaller stores indicated that in the instance of extended power outages in which power was not restored in a matter of minutes, the stores were simply closed. In these stores, if keeping food cold during an outage is a concern, then the stores arrange for delivery of dry ice. One interviewee, the Director of Energy Management of a large chain of stores, indicated that the company had installed either generators or battery backup systems in all its

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[288] Horovitz, B. 2006. Whole Foods Goes With the Wind. USA Today (January 9, 2006). Available at http://www.usatoday.com/money/industries/food/2006-01-09-whole-foods-usat_x.htm [Accessed September 2006].
[289] Horovitz, B. 2006. Whole Foods Goes With the Wind. USA Today (January 9, 2006). Available at http://www.usatoday.com/money/industries/food/2006-01-09-whole-foods-usat_x.htm [Accessed September 2006].
[290] Innovest Strategic Value Advisors, Inc. 2002. Energy Efficiency & Investor Returns: The Retail Food Sector. Available at http://files.harc.edu/Sites/GulfcoastCHP/Publications/EnergyEfficiencyRetailFood.pdf [Accessed September 2006].

stores to power emergency lighting and emergency management controllers. New generators installed are typically 50 kW in size, with some older units in the 25 kW size range. The interviewee indicated that looking across stores, power outages were less than 1% of total run time. Most stores were fairly satisfied with grid electricity, except in certain areas with power availability issues like Southern California. The interviewee identified the frozen and refrigerated products section within the grocery store as most severely impacted by power outages. Backup power primarily relies on the use of generators and UPS systems that are easy to operate by the various personnel within the stores. Grocery store respondents noted an interest in renewable and environmentally friendly alternative power sources but indicated that cost would be an issue in widespread adoption.

Of the three survey respondents, two were large grocery chains and one was a large grocery and retail chain. Respondents indicated that backup power was used to power complete store operations in certain high-risk markets like Florida. Respondents indicated that the functions most critical to their business operations include refrigeration, point of sale, and emergency lighting.

One respondent indicated that they had experienced approximately 37 grid outages at their facility in the past 12 months, while the other two respondents indicated they did not keep track of such information. Two large grocery store representatives noted that outages typically lasted from a few seconds to several hours. One respondent noted that outages could last days in Florida and Louisiana. Two respondents indicated that outages longer than 1 hour were very disruptive. All three respondents indicated that power loss results in the implementation of emergency management plans and disruptions in production and distribution.

All three respondents indicated they had either batteries or generators for backup power. One large retail and grocery chain indicated they had generators at only 5% of their facilities and in most cases did not have backup power. The size of backup power systems used in low-risk stores ranged from 15 to 60 kW to over 250 kW for one large grocery store. The same large grocery store indicated that they had systems > 1 MW. Backup power systems used by the large retail and grocery store were sized from 5 to 15 kW to over 250 kW. The respondent from this large retail and grocery store indicated that the company had 450 UPS systems at 9 kW and 50 generators at 50 kW at each facility. One respondent, who noted that each of the company's stores had approximately 139 backup systems, indicated that the size of the systems was not readily available.

All three respondents identified reliability and fuel availability as the most important factors is selecting a backup power system. Respondents also identified lifetime of unit, ease of use, and good experience with the type of system as important factors. Capital cost was identified as a very important factor by only one respondent. All three respondents who use some form of backup power indicated that their systems were good. One respondent indicated that backup systems currently in place were a maintenance problem. Only two respondents provided information on the performance of their backup power systems. Respondents indicated that fuel availability, ease of use, annual operating cost, start-up time, and lifetime of unit were very good. They also indicated that reliability, capital cost, and operation and maintenance costs were good.

Two respondents indicated that they envisioned a growing need for backup power in their sector. One respondent had considered alternatives like solar, wind turbines, and fuel cells for backup power. Another respondent had not considered alternatives for backup power but had briefly installed a microturbine for testing. All three respondents had heard of PEM fuel cells; however, only two had heard of them for backup power. All three respondents indicated that they did not think that PEM fuel cells would compete favorably with existing technologies. They identified the fact that systems are very expensive, high lifecycle costs, and lack of fuel as factors that would impact adoption. One respondent had concerns of using hydrogen as a fuel. Factors cited that would drive decisions to adopt PEM fuel cells included the energy efficiency of PEM fuel cells compared to alternatives, environmental concerns, availability of government incentives, and track records of others using PEM fuel cells. Two respondents indicated that decisions to procure backup power systems were made based on return on investment. One noted that decisions were made based on initial capital cost and payback period. One respondent indicated that decisions were also made based on grid vulnerability. Two respondents indicated that they would consider government incentives when making a purchase decision.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The grocery industry, particularly the emerging specialty and organic market segment, has an interest in environmentally friendly energy alternatives, including in fuel cells. There is potential for application of PEM fuel cells at high-risk stores as replacements to smaller generators (50 kW). No regulatory market drivers that impact a need for backup power or the consideration of environmentally friendly alternatives were identified in this market segment. The market opportunity for PEM fuel cells will be limited to sensitive energy markets prone to energy outages like the gulf coast. However, market indications show that grocery stores have very small profit margins with which to invest in expensive alternatives like fuel cells. Cost is a significant barrier for an industry with low profit margins. Furthermore, fuel availability is a critical factor for making purchasing decisions in this sector. As a result it is likely that the grocery market segment will be a potential mid-term market opportunity when capital cost and fuel availability can be addressed.

RESEARCH SUMMARY:
HOSPITALS

MARKET SEGMENT DESCRIPTION

The healthcare market sector includes various establishments involved in all aspects of care for individuals. These establishments include hospitals, rehabilitation and long-term care facilities, psychiatric facilities, surgical facilities, urgent care operations, and retirement care centers. Table k-1 identifies the SIC and NAICS codes for the healthcare industry. While there are a wide variety of healthcare specialties within this market sector, for the purposes of this discussion the focus is on hospitals as the primary candidate for potential fuel cell users. Other related healthcare markets provide similar care and have similar power concerns. It is assumed that a number of the same issues for backup power in the hospital market hold true in other healthcare facilities. Also, other health services may be part of a larger hospital system and form an integrated healthcare delivery network. Such an integrated network typically consists of several hospitals, nursing homes, home care agencies, hospices and ambulatory care units, and other affiliated healthcare entities.[291]

Table k-1. SIC and NAICS Codes for the Healthcare Industry.

2-Digit SIC Code	80 – Health services
4-Digit SIC Codes	8052 – Intermediate care facilities 8062 – General medical & surgical hospitals 8063 – Psychiatric hospitals 8069 – Specialty hospitals, excluding psychiatric
NAICS Codes	622110 – General medical and surgical hospitals 622210 – Psychiatric and substance abuse hospitals 622310 – Specialty (except psychiatric and substance abuse) hospitals 623110 – Nursing care facilities 623210 – Residential mental retardation facilities 623311 – Continuing care retirement communities

The healthcare sector requires critical power to support a wide variety of functions within a hospital campus. The reliability of the electrical power systems that serve hospitals is very important. Not only do power outages in the hospital industry cause potential for loss of revenue and an inconvenience to hospital staff and patients, but hospitals also provide a number of services for which reliable power is a necessity for the preservation of human life. These critical services include surgical, radiological, life support, intensive care, and emergency care.[292] Hospitals also contain a large amount of technical and diagnostic equipment that requires power. Furthermore, the trend in the U.S. healthcare system toward a standardized health information infrastructure for electronic medical records and computerized charting of patients means that, to access information necessary for the quality care of patients, power must constantly be supplied to the computer systems that contain the medical information.[293] In addition to these specialized needs, like many large building complexes, hospitals have a variety of typical power needs such

[291] Energy and Environmental Analysis, Inc. (Energy Nexus Group). 2003. Task 2.1 Report: National Account Sector Energy Profiles. Available at http://files.harc.edu/Sites/GulfCoastCHP/MarketAssessments/NationalAccountSectorEnergyProfiles.pdf [Accessed December 2006].
[292] Wikimedia Foundation, Inc. 2006. Hospital. Available at http://en.wikipedia.org/wiki/Hospitals [Accessed December 2006].
[293] Wikimedia Foundation, Inc. 2006. Health Informatics. Available at http://en.wikipedia.org/wiki/Medical_informatics [Accessed December 2006].

as heating, air conditioning and ventilation systems, computer systems, food service, laundry, and other services.

Hospitals are usually given priority status within the utilities infrastructure and are therefore one of the first to receive service for restoration of power during outages.[294] Still, power outages are a possibility, and there are state laws and national standards that require that hospitals and emergency services maintain a backup power supply. Hospitals must have emergency power testing programs in place to meet the requirements of the National Fire Protection Association (NFPA), as well as standards established by accreditation organizations such as the Joint Commission on Accreditation of Healthcare Organizations (JCAHO). The JCAHO operates voluntary accreditation programs for hospitals and other healthcare services and is responsible for certifying hospitals as having met the condition of participation required for reimbursement under the federal Medicare program.[295,296] The NFPA and JCAHO programs include requirements for generator load testing, also commonly known as 30%.[297]

In recent news, the JCAHO issued new requirements for emergency electrical power testing.[298] The Revised Standard EC.7.40 now requires organizations to test their emergency generators at least once every 36 months for a minimum of 4 continuous hours. This test is in addition to the current requirement to test emergency generators 12 times each year for 30 continuous minutes. This additional requirement is based on a new NFPA requirement designed to assure health care organizations that their emergency generators will operate during extended power outages. The new requirement is effective January 1, 2007, and organizations must have performed this test by July 1, 2007, in order to be in initial compliance. JCAHO stated that the revision is "based on recent briefings by experts and debriefing with organizations that have sustained extended electrical utility power outages."[299]

The NFPA and JCAHO mandate that all hospitals use emergency diesel generators to back up utility-supplied power. While these requirements ensure that hospitals regularly test emergency generator systems, they do not address the transitional gap between utility and generator power (or lag time until a diesel generator comes fully online).

MARKET SIZE

According to the latest statistics from the American Hospital Association,300 there are a total of 5,759 registered hospitals in the U.S. Table k-2 presents the breakdown of the types of hospitals reported by AHA.

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[294] Wikimedia Foundation, Inc. 2006. Hospital. Available at http://en.wikipedia.org/wiki/Hospitals [Accessed December 2006].
[295] Wikimedia Foundation, Inc. 2006. Hospital. Available at http://en.wikipedia.org/wiki/Hospitals [Accessed December 2006].
[296] American Society for Healthcare Engineering. 2006. Joint Commission on Accreditation of Healthcare Organizations. Available at http://www.ashe.org/ashe/codes/jcaho/index.html [Accessed December 2006].
[297] American Society for Healthcare Engineering. 2006. Managing Hospital Emergency Power Systems – Testing, Operation and Maintenance. Available at http://www.ashe.org/ashe/products/pubs/pdfs/mg2003stymiest.pdf [Accessed December 2006].
[298] American Society for Healthcare Engineering. 2006. Homepage. Available at http://www.ashe.org/ [Accessed December 2006].
[299] American Society for Healthcare Engineering. 2006. Advisories and Alerts. Available at http://www.ashe.org/ashe/codes/advisories/index.html [Accessed December 2006].
[300] American Hospital Association. 2006. Fast Facts on US Hospitals. Available at http://www.aha.org/aha/resource_center/fastfacts/fast_facts_US_hospitals.html [Accessed June 2006].

Table k-2. Types of Hospitals in the U.S., 2004.[301]

Type	Number
Number of U.S. community** hospitals	4,919
Number of nongovernment not-for-profit community hospitals	2,967
Number of investor-owned (for-profit) community hospitals	835
Number of state and local government community hospitals	1,117
Number of federal government hospitals	239
Number of nonfederal psychiatric hospitals	466
Number of nonfederal long term care hospitals	112
Number of hospital units of institutions (prison hospitals, college infirmaries, etc.)	23
Total Number of All U.S. Registered* Hospitals	**5,759**

Updated November 14, 2005.
**Registered hospitals* are those hospitals that meet AHA's criteria for registration as a hospital facility. Registered hospitals include AHA member hospitals as well as nonmember hospitals.
***Community hospitals* are defined as all nonfederal, short-term general, and other special hospitals. Other special hospitals include obstetrics and gynecology; eye, ear, nose, and throat; rehabilitation; orthopedic; and other individually described specialty services. Community hospitals include academic medical centers or other teaching hospitals if they are nonfederal short-term hospitals. Excluded are hospitals not accessible by the general public, such as prison hospitals or college infirmaries.

According to the most recent energy expenditure information from the U.S. Energy Information Administration (EIA)'s 2003 Commercial Buildings Energy Consumption Survey (CBECS), there are 129,000 U.S. buildings in the combined healthcare industry that account for 3,163 million square feet of total floorspace.[302] Table k-3 presents information on total electricity consumption and expenditures for the combined healthcare industry compared to all U.S. buildings.

Table k-3. Total Electricity Consumption and Expenditures in U.S. Buildings, 2003.[303]

	All Buildings* Using Electricity			Electricity Consumption			Electricity Expenditures
				Primary	Site		
	Number of Buildings (thousands)	Floorspace (million square feet)	Floorspace per Building (thousand square feet)	Total (trillion Btu)	Total (trillion Btu)	Total (billion kWh)	Total (million dollars)
All	4,404	63,307	14.4	9,168	3,037	890	69,032
Healthcare	129	3,163	24.6	748	248	73	4,882
Inpatient	8	1,905	241.4	539	178	52	3,198
Outpatient	121	1,258	10.4	209	69	20	1,684

Released: June 2006

MARKET TRENDS

The new requirements for emergency electrical power testing discussed above, combined with efforts to demonstrate fuel cells in the healthcare industry, are potentially important trends that could open the door for PEM fuel cells as a backup power source for hospitals.

[301] American Hospital Association. 2006. Fast Facts on US Hospitals. Available at http://www.aha.org/aha/resource_center/fastfacts/fast_facts_US_hospitals.html [Accessed June 2006].
[302] Energy Information Administration, Office of Energy Markets and End Use. 2006. Form EIA-871A of the 2003 Commercial Buildings Energy Consumption Survey. Available at http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set1/2003html/b1.html [Accessed December 2006].
[303] Energy Information Administration, Office of Energy Markets and End Use. 2006. Forms EIA-871A, C, and E of the 2003 Commercial Buildings Energy Consumption Survey. Available at http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set10/2003excel/c13.xls [Accessed December 2006].

No installations of PEM fuel cells for backup power at hospitals were found through secondary data. However, there have been several demonstrations of PAFCs at hospitals through the DoD PAFC Demonstration program. Most of these fuel cell installations (listed below) were grid parallel applications for peak-shaving or for quality power assurance, and several were set up to provide CHP.[304]

1. St. Francis Hospital in Hartford, Connecticut, installed a 200 kW PC25 PAFC natural gas fuel cell that provides power security to an operating room and is interconnected with the hospital's distribution and air conditioning system.
2. In December 2000, a 200 kW PAFC natural gas fuel cell was installed at North Central Bronx Hospital in Bronx, New York. The fuel cell supplies supplemental power and backup power. The installation was funded through the U.S. DoD Climate Change Fuel Cell Program.
3. In 1999, South County Hospital in Wakefield, Rhode Island, installed a 200 kW PC25 PAFC natural gas fuel cell. The fuel cell provides electricity and heat, produces one-third of the hospital's electricity during peak hours (saving $60,000 to $90,000/year), and also provides backup power for the hospital's critical loads.
4. In July 1997, a 200 kW PC25C PAFC natural gas fuel cell was installed at the Barksdale Air Force Base hospital in Bossier, Louisiana. The fuel cell, which operated until October 2002, was grid connected; total estimated thermal utilization was approximately 90%.
5. Edwards Air Force Base hospital in Palmdale, California, demonstrated a 200 kW PC25C PAFC natural gas fuel cell from July 1997 to July 2002. The fuel cell was grid connected and produced a high grade thermal output that was utilized by a space heating loop. Total estimated thermal utilization was approximately 23%.
6. A natural gas 200 kW PC25C PAFC was installed at Laughlin Air Force Base Hospital in Del Rio, Texas, from September 1997 until November 2002. The installation was part of the U.S. DoD PAFC Demonstration Program. The fuel cell was grid connected at an existing electrical transformer (no emergency backup). Thermal output was utilized by a space heat/cool reheat loop and domestic hot water (DHW) loop; estimated thermal utilization was approximately 75%.
7. A 200 kW PC25C PAFC natural gas fuel cell was installed at the Jacksonville, Arkansas, Little Rock Air Force Base hospital from October 1997 until December 2000. The installation was part of the DoD PAFC Demonstration Program. The fuel cell was grid connected at an electrical panel, and thermal output was used by a space conditioning recirculation loop. Total estimated thermal utilization was approximately 85%.
8. In another DoD PAFC Demonstration Program installation, a 200 kW PC25B PAFC natural gas fuel cell was installed at the Twentynine Palms Marine Corp Base Naval Hospital in Twentynine Palms, California. Use of the natural gas fuel cell lasted from June 1996 to May 2000. The fuel cell was grid connected at an existing subpanel. However, a grid independent connection was established at a new electrical subpanel. Thermal output was utilized by DHW loops with an estimated thermal utilization of 60%.
9. At the Naval Air Station Naval Hospital in Jacksonville, Florida, a 200 kW PC25C PAFC natural gas fuel cell was installed from April 1997 to April 2002 as part of the DoD PAFC Demonstration Program. The fuel cell was grid connected at an existing electrical panel

[304] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Accessed December 2006].

(no emergency backup), and thermal output was utilized by a DHW loop with an estimated thermal utilization of 56%.

10. Another 200 kW PC25C PAFC natural gas fuel cell was installed at the Marine Corp Base Camp Pendleton Naval Hospital in Oceanside, California, from October 1995 to January 2002. The installation was part of the DoD PAFC Demonstration Program. The fuel cell was grid connected at an existing panel. Thermal output was utilized for DHW storage with thermal utilization estimated at 75%.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells, 35 healthcare organizations were contacted. Many organizations expressed interest; five survey responses were received, and two interviews were conducted.

Responses were received from two large and three medium-sized hospitals. Four respondents in this category were government hospitals. Respondents indicated that backup power in hospitals was required for a variety of applications including life support equipment, critical equipment, life safety equipment, communications systems, blood bank refrigerators, urgent care areas, emergency lighting, and specific zones within the facility. Respondents indicated that all backup power applications were critical to their business operations. Two hospitals indicated that life support equipment and medical equipment were especially critical applications requiring backup power.

In terms of number of power outages during the past year, responses varied among respondents. Two respondents reported two outages, and one reported experiencing six to ten outages. One respondent indicated that no outages occurred but they experienced numerous power sags. Respondents indicated that power interruptions lasted from < 60 seconds to over 4 hours. Respondents rated the impact of power interruptions and indicated that short interruptions were disruptive but extended interruptions (greater than 1 hour) were very disruptive. In the past year, one respondent had experienced two very disruptive power outages. According to respondents, power outages at hospitals can result in implementation of emergency management plans, loss of life, and security breach.

Backup power is currently supplied through a combination of UPS, batteries, and generators. One respondent indicated that they also have alternate feeds from the grid to ensure continuous and reliable power. The size of backup systems used by respondents varied from < 5 kW to over 1MW. Respondents rated reliability, start-up time, ease of use, fuel availability, and good experience with system in the past as the most important factors in selecting a backup power system. Four respondents rated their current backup power systems as very good, while one respondent did not provide an answer. All five respondents reported very high levels of satisfaction with various performance factors of their current systems, including reliability, start-up time, capital cost, operation and maintenance costs, lifetime, annual operating costs, emissions, ease of use, and fuel availability.

Respondents were split on the potential for growth in backup power requirements for hospitals. Two respondents anticipated a growing need, while two respondents did not. None of the respondents had considered alternative sources of backup power. Only two respondents had

heard of PEM fuel cells as a backup power source, and both believed that PEM fuel cells could compete favorably with existing backup power systems. Of these two respondents, one was concerned about using hydrogen as a fuel source.

Respondents indicated that a combination of factors would drive their decision to purchase PEM fuel cells, including the cost of not having electricity, energy efficiency of PEM fuel cells compared to alternatives, track record of others using PEM fuel cells, environmental concerns, and government incentives. Four respondents indicated that capital purchase decisions were made on the basis of initial capital costs. Two respondents also indicated that decisions were made based on equipment reliability. One respondent indicated that certification requirements, life safety, and support needs were considered in making a purchasing decision. Only one respondent indicated that they considered government incentives when making purchasing decisions. Respondents reported that decisions to procure systems were typically made by engineers.

Interviewees indicated that backup power is provided in three main areas: critical (which includes surgeries, patient care, ventilators, and other essential care to preserve life), life safety (which includes emergency and other lighting, lighting of exit signs), and equipment (which supports other hospital facilities, including the air handler and emergency elevators).

Interviewees indicated that power outages were not a major problem for their hospital complexes, but backup power is a requirement for accreditation. Backup power is supplied primarily through the use of diesel and natural gas generators, with support from some UPS systems. Alternatives such as fuel cells had not been widely investigated by interviewees, and little was known about them. Because generators are required and are tested regularly, interview respondents have not had a compelling reason to seek alternative energy sources for backup power.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Based on this analysis, hospitals are not thought to represent a near-term opportunity for PEM fuel cells. Hospitals currently use generators and UPS systems to meet their backup power requirements and do not appear to be dissatisfied with the performance of their existing systems. It also appears that a substantial part of their backup power needs are met with large systems, beyond the current capacity of PEM fuel cells. While there is some experience with fuel cells in this sector, demonstration projects have focused on providing baseload power to healthcare facilities using PAFC systems; research indicates that none of these have employed PEM fuel cells.

At the same time, the landscape for backup power in the healthcare sector is changing. New accreditation standards are expected to change the way backup power is used, as it increases annual operating time associated with testing backup systems. If PEM fuel cells can be demonstrated to provide an economic or performance advantage over existing systems in smaller power output, niche applications, this could spur interest in PEM systems as these increased operating requirements are implemented. The size of the market and the backup power demand for at least some applications with lower power output requirements are promising market characteristics. Even though past fuel cell projects in this sector have focused on baseload

power, such demonstrations may help develop user confidence in fuel cell use as a viable power source in this sector. Changes in this market should be monitored as it may represent a viable mid-term market for PEM fuel cells.

RESEARCH SUMMARY:
METALS PROCESSING AND REFINING

MARKET SEGMENT DESCRIPTION

The metal refining and processing market segment includes the processing and refining of aluminum, steel, and other metals. Metal refining and processing addresses a variety of activities, including: foundry operations (including for aluminum and steel), metal production (aluminum, steel, and other products), casting (including die casting), extruding, rolling and drawing, and wire drawing. Table l-1 identifies the SIC and NAICS codes associated with this market segment.

Table l-1. Relevant SIC and NAICS Codes for Metals Processing and Refining.

2-Digit SIC Code	33 – Primary metal industries
4-Digit SIC Codes	3312 – Blast furnaces and steel mills 3313 – Electrometallurgical products 3315 – Steel wire and related products 3316 – Cold finishing of steel shapes 3317 – Steel pipe and tubes 3321 – Gray and ductile iron foundries 3322 – Malleable iron foundries 3324 – Steel investment foundries 3325 – Steel foundries, not elsewhere classified (nec) 3331 – Primary copper 3334 – Primary aluminum 3339 – Primary nonferrous metals, nec 3341 – Secondary nonferrous metals 3351 – Copper rolling and drawing 3353 – Aluminum sheet, plate, and foil 3354 – Aluminum extruded products 3355 – Aluminum rolling and drawing, nec 3356 – Nonferrous rolling and drawing, nec 3357 – Nonferrous wiredrawing and insulating 3363 – Aluminum die-castings 3364 – Nonferrous die-castings except aluminum 3365 – Aluminum foundries 3366 – Copper foundries 3369 – Nonferrous foundries, nec 3398 – Metal heat treating 3399 – Primary metal products
NAICS Codes	324199 – All other petroleum and coal products manufacturing 331111 – Iron and steel mills 331112 – Electrometallurgical ferroalloy product manufacturing 331210 – Iron and steel pipe and tube manufacturing from purchased steel 331221 – Rolled steel shape manufacturing 331222 – Steel wire drawing 331312 – Primary aluminum production 331314 – Secondary smelting and alloying of aluminum 331315 – Aluminum sheet, plate, and foil manufacturing 331316 – Aluminum extruded product manufacturing 331319 – Other aluminum rolling and drawing 331411 – Primary smelting and refining of copper 331419 – Primary smelting and refining of nonferrous metal (except copper

	and aluminum) 331421 – Copper rolling, drawing, and extruding 331422 – Copper wire (except mechanical) drawing 331423 – Secondary smelting, refining, and alloying of copper 331491 – Nonferrous metal (except copper and aluminum) rolling, drawing, and extruding 331492 – Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum) 331511 – Iron foundries 331512 – Steel investment foundries 331513 – Steel foundries (except investment) 331521 – Aluminum die-casting foundries 331522 – Nonferrous (except aluminum) die-casting foundries 331524 – Aluminum foundries (except die-casting) 331525 – Copper foundries (except die-casting) 331528 – Other nonferrous foundries (except die-casting) 332618 – Other fabricated wire product manufacturing 332811 – Metal heat treating 332813 – Electroplating, plating, polishing, anodizing and coloring

Metal Casting

Die casting is an old process of injecting molten metal into a steel die under high pressure. The metal, aluminum, zinc, magnesium, or sometimes copper, is held under pressure until it solidifies into a net shape metal part. In modern applications, using computerized controls, die casters produce precision and high-strength products at a rapid rate.

Metal casting plays a critical role in the success of U.S. manufacturing through the production of high quality castings. Castings are used in 90% of all finished manufactured products. Die casting, which produces over one-third of all metal castings, is an important segment of the larger metal casting industry. Over 500 die casters manufacture thousands of non-ferrous castings for applications in automotive, computer, medical, and other industries. Die casters contribute over $7.3 billion to the nation's economy annually and provide over 63,000 jobs directly and indirectly. While larger firms are world leaders, 58% of these companies have fewer than 100 employees. The average power requirements of a metal casting plant are in the 1 MW range.

Steel Mills/Steel Products

Those facilities included in the steel products sector tend to be slightly smaller, both in terms of their power demand and average number of employees, and have slightly lower load factors. The steel mills sub-industry includes large integrated steel mills and smaller "mini-mills." The average power requirements for steel mills are in the 50 MW range, and for steel products, in the 3 to 4 MW range.[305] Large power consumption equipment in steel mills includes blast furnaces, electric arc furnaces, and coke plants.

[305] Arthur D. Little, Inc. 2000. Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications. Volume I (Main Text). Final Report to Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.

Primary Aluminum and Aluminum Refining
Aluminum originates as an oxide called alumina, and because aluminum itself does not occur in nature as a metal, the processing of aluminum requires electricity to extract. The aluminum industry can be broken down into two distinct sub-industries: primary aluminum and aluminum products. Within the aluminum industry, the dominant differences between the two sub-industries are facility size (in terms of megawatts used). Primary aluminum production facilities have power requirements over 100 MW, while aluminum products plants have power requirements around 4 to 5 MW.

The U.S. aluminum industry is the world's largest producer of primary aluminum, annually producing about $39.1 billion in products and exports. The U.S. industry operates over 300 plants in 35 states, produces more than 23 billion lbs of metal annually, and employs over 145,000 people. Aluminum products include castings, extrusions, mill products, and other aluminum fabricated products. Top markets for the industry are transportation, beverage cans, packaging, and building construction.

Backup Power
A constant flow of power is important to ensure full utilization of the production facilities described above. Blackouts and/or loss of power can impact production and company performance, creating delays in filling demand. Blackouts can also cause equipment failures; for instance, blackouts in foundries can inflict permanent damage on furnaces, pots (used to pour metal), and other equipment. Longer power outages are often of greater concern. As a result, backup power is used for a variety of applications in metals refining and processing. These include:

- **Foundry and Furnaces** – Heating, melting, and extracting metal require very high temperatures. These establishments are primarily engaged in: manufacturing hot metal, pig iron, and silvery pig iron from iron ore and iron and steel scrap; converting pig iron, scrap iron, and scrap steel into steel; and hot-rolling iron and steel into basic shapes, such as plates, sheets, strips, rods, bars, and tubing. This area also includes merchant blast furnaces and by-product or beehive coke ovens.
- **Automation and Robotics** – For instance, the pots pouring metal in foundry operations need to be controlled and maintained at certain temperatures.
- **Processing and Controllers** – Some furnaces are controlled by a computerized system that permits control capabilities and a variety of energy management strategies. Documentation includes a variety of operating logs and specific event recording such as power failure, missing energy pulses, tap changes, and load shedding and restoring. This may also include plant shutdown in the case of power outages.
- **Casting** – Cast metals require processes for melting, grinding, and coating systems, as well as automation for pouring and molding, and cooling systems (to keep wax molds cool).

Several technologies are currently being used to provide backup power in the metals industry, including gas turbine and diesel generators, UPS systems, and gas-powered flywheels. Energy-intensive process industries, including steel mills, may use generators during emergency outages and natural disasters, or to supplement grid power. A variety of options, including

aeroderivative gas turbine generation (up to 22 MW) and linked 1 MW diesel systems are used for additional power supplies. UPS systems are used for backup power in metal refining.

MARKET SIZE

Table l-2 presents the size of various market segments in the metals processing and refining industry.

Table l-2. Number of Businesses in Metals Processing and Refining Market Segments.[306]

SIC Code	Industry Segment	Type	Number of Businesses	Total Sales ($M)
3312	Blast furnaces and steel mills	Steel mills	2,513	94,669.10
3313	Electrometallurgical products	Steel products	86	2,556.70
3315	Steel wire and related products	Steel Products	843	4,507.40
3316	Cold finishing of steel shapes	Steel products	242	9,081.20
3317	Steel pipe and tubes	Steel products	565	10,512.60
3321	Gray and ductile iron foundries	Metal casting	597	8,407.70
3322	Malleable iron foundries	Metal casting	30	67.90
3324	Steel investment foundries	Metal casting	221	4,872.80
3325	Steel foundries, nec	Metal casting	462	3,835.30
3331	Primary copper	Other	46	174.20
3334	Primary aluminum	Primary aluminum	183	8,142.00
3339	Primary nonferrous metals, nec	Other	264	2,823.90
3341	Secondary nonferrous metals	Other	373	10,135.80
3351	Copper rolling and drawing	Other	208	9,564.90
3353	Aluminum sheet, plate, and foil	Aluminum products	216	30,311.70
3354	Aluminum extruded products	Aluminum products	392	6,928.70
3355	Aluminum rolling and drawing, nec	Aluminum products	186	2,756.40
3356	Nonferrous rolling and drawing, nec	Other	303	4,662.50
3357	Nonferrous wiredrawing and insulating	Other	602	19,921.00
3363	Aluminum die-castings	Metal casting	395	9,015.30
3364	Nonferrous die-castings except Aluminum	Metal casting	255	913.90
3365	Aluminum foundries	Metal casting	565	3,005.10
3366	Copper foundries	Metal casting	422	1,904.30
3369	Nonferrous foundries, nec	Metal casting	325	1,086.70
3398	Metal heat treating	Other	778	1,571.30
3399	Primary metal products	Other	551	2,068.90

A report by Arthur D. Little, Inc. assesses the backup power market for metals refining and processing. The report estimates the fraction of power demand within each industry that is likely to be installed as backup power (see Table l-3).

[306] Dun and Bradstreet. 2006. Zapdata Industry Report. Available at http://www.zapdata.com [Accessed July 2000].

Table l-3. Estimated Demand for Backup Power Generation Equipment.[307]

Industry	Dominant Backup Power Needs	Estimated Backup*	Total Power Demand
Primary Aluminum	Shutdown, extraction processes	30%	8,500 MW
Aluminum Products	Shutdown	5%	1,000 MW
Metal Casting	Shutdown	5%	2,000 MW
Steel Mills	Shutdown, pumps	10%	5,700 MW
Steel Products	Shutdown	5%	1,500 MW

*Estimated percentage of total power demand.

In addition to the backup power needs in Table l-3, backup power sources, such as UPS, are used to provide premium power to the industries listed in Table l-4 below.

Table l-4. Dominant Premium Power Needs.[308]

Industry	Dominant Premium Power Needs	Assumed Premium Power*
Primary Aluminum	Controls (UPS)	1%
Aluminum Products	Controls (UPS)	5%
Steel Mills	Controls (UPS), avoided grid penalties	5%
Steel Products	Controls (UPS)	1%

*Estimated percentage of total power demand.

MARKET TRENDS

The industry is concerned about the cost and reliability of grid power, and companies are investigating options for both backup and on-site power (e.g., distributed, off-grid).[309] Particularly in California, companies have been looking to build on-site power, as grid power is not particularly reliable. On-site power can be isolated from the grid so that it can act as backup power if necessary. Other states are investigating on-site power as well. A key driver for investments in on-site power will be the cost of outside power. At $0.07 per kW, on-site power is less attractive; however, when grid power was $0.23 per kW, on-site power was highly attractive. Currently, grid power costs are hovering around $0.14 to $0.15 per kW; therefore, the decision to build on-site power depends on how much power a facility requires, economies of scale, the economics of the power source, and other factors.

One fuel cell demonstration project is taking place in the metalworking industry. In 2005, the California Cast Metals Association (CCMA), TST Inc., Alliance Power, Otto H. Rosentreter Company, Southern California Gas Company, FuelCell Energy, and South Coast Air Quality Management District teamed up to site 500 kW fuel cells (two DFC300 systems that run on natural gas) at an industrial metalworking facility to provide baseload power. The project also includes the installation of four 60 kW Capstone microturbines to work in conjunction with the fuel cells. The fuel cells were able to provide 300 kW of power during Southern California's rolling blackouts in June 2006.

[307] Arthur D. Little, Inc. 2000. Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications. Volume I (Main Text). Final Report to Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.
[308] Arthur D. Little, Inc. 2000. Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications. Volume I (Main Text). Final Report to Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.
[309] American Society of Mechanical Engineers. 2000. Rent-a-power plant. Mechanical Engineering (June).

Changes in the industry may affect the need for backup power. It has been suggested that U.S. operations are shifting from manufacturing to service and management. While output continues to rise, the number of die casting businesses and employees has fallen across North America. One study of end-use markets showed an expansion in casting shipments for 2004 with considerable gains in aluminum and steel. The study forecasts that demand for casting would rebound in 2004 and in subsequent years; while imports would rise to new highs and keep the expansion of shipments by domestic foundries at modest levels. However, other studies indicate that the number of die-casting businesses in North America will continue to fall, and that by 2013, the industry expects total employment to decline by as much as 40%. Die casting businesses are reacting to these trends in a number of ways, such as forming global partnerships and finding lower-cost off-shore sources for tooling.[310]

Pressure facing industry from environmental regulations may influence the need for backup power as well. For instance, a failure in the UPS, and subsequent failure of the backup systems at an alumina refinery plant, caused a cloud of fly-ash to be released. This created a breach in license operations, due to an infringement of clean air regulations. EPA has begun work on the development of area source emission standards for iron and steel foundries that could include all facilities not covered by the Iron & Steel Maximum Achievable Control Technology (MACT) requirements finalized in 2004. It is possible that these standards could spur the use of backup power to avoid compliance breaches resulting from power outages.

MARKET SEGMENT ANALYSIS

In the metals refining and processing industry, 11 companies were contacted, and four responses were received. Of the respondents, two were small metal soldering and manufacturing companies, one was a large steel foundry and manufacturing company, and one was a professional association representing foundry operations and die casting.

Two respondents reported that they use backup power, and the professional association indicated that a large portion of their constituents use backup power. Critical functions include heating metals pots on manufacturing lines and cooling wax molds used for casting metal. Backup power for computers and automation was also considered important.

Respondents indicated that they had experienced one to six blackouts in the previous year. Manufacturing facilities noted blackouts lasting from < 60 seconds up to 1 hour; additionally, rolling blackouts had triggered longer power outages ranging from 1 to 4 hours. Companies indicated that disruptions of less than 3 minutes were minimally disruptive, while disruptions greater than 1 hour were considered very disruptive. Three companies indicated that they had experienced one to two disruptive power outages over the last year. All companies indicated that disruptive power outages could result in disruption of production and distribution. Other potential impacts of power outages included equipment damage and safety hazards.

Two respondents (one large manufacturing company and one professional organization) indicated that the primary source of backup power was diesel and natural gas generators, with sizes ranging from 30 to 150 kW. One manufacturing company reported using UPS units of < 5 kW. Respondents typically had one to two backup power units per facility. Respondents

[310] North American Die Casting Association. 2005. U.S. Die Casting Industry Fact Sheet: Manufacturing & Die Casting Statistics.

unanimously indicated that reliability was a very important attribute of backup power; two respondents indicated that other very important attributes included start-up time and ease of use. Capital cost and fuel availability were also considered important. All respondents who currently use backup power indicated that the performance of their current backup power system was good to very good; no concerns were noted. When asked to rate current backup systems, three respondents indicated that fuel availability was very good, two noted that reliability was very good, and two noted that start-up time was very good. Capital cost and operation and maintenance costs were considered to be good to very good by all respondents. Of the four respondents, only the professional association anticipated a growing need for backup power, indicating that, while about 0.5% of the market is currently using backup power, this would increase to 10% over the next 3 years.

Only one of the four respondents was aware of PEM fuel cells as a potential source of backup power; this respondent indicated that PEM fuel cells would favorably compete with other forms of backup power. The respondent also believed that PEM fuel cells could be excellent for providing base load power for facilities, although a fuel cell in the range of 250 kW could be used to provide backup power as well. Factors cited as potentially driving the adoption of PEM fuel cells included the cost of not having electricity (i.e., the cost of a power failure), dissatisfaction with the current mode of backup power, and the energy efficiency of PEM fuel cells as compared to alternatives. Most did not know what criteria would be used to purchase new backup power units, or who would make such decisions, although one respondent indicated that it was based on initial capital cost.

POTENTIAL OPPPORTUNITIES FOR PEM FUEL CELLS

There are numerous applications for backup power in the metals processing and refining market segment. Backup power units currently being used range in size from < 5 kW to 250 kW. While the market size is attractive, it is unclear whether there is sufficient growth potential to support this sector as a target market for fuel cell backup power. There are numerous, highly distributed facilities in this industry each with their own backup power needs. The overall demand for backup power in aluminum, steel, and metal casting is estimated to be 5 to 30% of overall power requirements; metal refining and processing facilities typically require 5 to 20 MW per facility. The potential market for backup power for blast furnaces and steel mills alone could range as high as 3,750 MW to 15,000 MW. However, the U.S. metals refining and processing market is slowly shrinking as businesses move overseas. Primary research seems to suggest low domestic growth potential for backup power in this industry.

Users in this market segment are interested in alternatives as reliability to operations is a necessity. Although respondents did not consider environmental factors to be a key driver for the purchase of a backup power system, regulatory requirements concerning emissions from this industry are becoming more stringent. While PEM fuel cells offer no distinct advantage over low-wattage UPS units in terms of emissions, they do offer this advantage over diesel-powered generators. Initial capital cost of alternatives also appears to be a factor when selecting and purchasing a backup power system in this market segment. This may impact the potential for adoption of PEM fuel cells in the near term.

It appears that in the near term, PEM fuel cells may be considered as replacements to UPSs and small diesel generators. This market will be limited in the near term as adoption of PEM fuel cells in the metals refining and processing industry will depend on several factors, including the competitiveness of PEM fuel cells with existing technologies, the reliability of PEM fuel cells, and the impact of environmental regulations on demand for backup power sources in this sector.

RESEARCH SUMMARY:
MINING

MARKET SEGMENT DESCRIPTION

The mining industry includes SIC Codes 12 and 10 for coal and metal mining companies. This does not include those facilities involved in oil and gas exploration and production, or mining of non-metals (e.g., gravel). Table m-1 identifies the SIC and NAICS classifications that represent coal and metal mining.

Table m-1. SIC and NAICS Codes for Coal and Metal Mining.

2-Digit SIC Codes	12 – Coal mining 10 – Metal mining
4-Digit SIC Codes	1222 – Bituminous coal underground mining 1231 – Anthracite mining (hard coal) 1241 – Coal mining services 1011 – Iron ores 1021 – Copper ores 1031 – Lead and zinc ores 1041 – Gold ores 1044 – Silver ores 1061 – Ferroalloy ores, except vanadium 1081 – Metal mining services 1094 – Uranium-radium-vanadium ores 1099 – Miscellaneous metal ores, not elsewhere classified (includes platinum)
NAICS Codes	21211 – Coal mining 212112 – Bituminous coal underground mining 212210 – Iron ore mining 212234 – Copper ore and nickel ore mining 212231 – Lead ore and zinc ore mining 212221 – Gold ore mining 212222 – Silver ore mining 213114 – Support activities for metal mining 212291 – Uranium-radium-vanadium ore mining 212299 – All other metal ore mining

Mining companies use backup power to support several functions at mine sites. According to a recent study by Arthur D. Little, backup power is a critical need, integral to normal operation in the mining industry.[311] Safety, pumping, and shutdown concerns are the primary drivers behind the demand for backup power in this industry. The greatest need for backup power may be in underground mines where human lives are at risk when systems fail. Functions often supported with backup power in mines include:

- Ventilation systems
- Hoists, for getting people out of mines

[311] Arthur D. Little, Inc. 2000. Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications. Volume I (Main Text). Final Report to Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.

- Communications devices, such as telephones and signaling devices (must contain a backup power supply to be approved for use in coal mines)
- Emergency lighting
- Mine pumps.

Total power demand for the mining industry is estimated at 18,000 MW, with the average facility size estimated to be 2 MW. The fraction of this power demand that is likely to be installed as backup power is estimated at 10%. This suggests that backup power requirements for an average facility would be about 200 kW.[312]

Currently, diesel generators are the primary source of backup power for mines. There is not usually a need for UPS systems, except for monitoring systems, which are used in some mines to monitor carbon monoxide and methane levels, and to detect heat or fire.

The U.S. Mine Safety and Health Administration (MSHA) administers safety and health standards that govern the nation's mines. As part of MSHA's escape and evacuation planning requirements for underground mines, each mine is required to provide a statement of availability of emergency power, telecommunications, and ventilation.

MARKET SIZE

Assuming a total power demand for the industry of 18,000 MW, and an estimated 10 % of which is likely to be installed as backup power (based on figures provided in the Arthur D. Little study), the total demand for backup power in the mining industry might be estimated at 1,800 MW.

Data on the overall mining industry size, including the number of businesses operating in each subsector, are presented in Tables m-2, m-3, and m-4 below. It should be noted that some mining companies operate across multiple subsectors and therefore may be included in more than one of the tables below.

[312] Arthur D. Little, Inc. 2000. Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications. Volume I (Main Text). Final Report to Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.

Table m-2. Number of Businesses in Bituminous Coal and Lignite-Surface Mining Industry (1221).[313]

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
1221-0000	Bituminous coal and lignite-surface mining	300	13,510	9,065.8
1221-0100	Bituminous coal surface mining	132	6,067	5,922.7
1221-0101	Auger mining, bituminous	25	261	29.4
1221-0102	Culm bank mining	2	5	0.6
1221-0103	Strip mining, bituminous	129	3,520	1,015.8
1221-0104	Strip mining, lignite	8	74	37.7
1221-0105	Surface mining, bituminous, nec	86	7,430	9,129.7
1221-0106	Surface mining, lignite, nec	9	1,037	272.5
1221-0200	Bituminous coal and lignite loading and preparation	13	155	754.6
1221-0201	Coal preparation plant, bituminous or lignite	60	3,238	611.5
1221-0202	Unit train loading facility, bituminous or lignite	8	161	15.6
	Total	**772**	**35,458**	**26,855.9**

*Sales figures are in millions.

Table m-3. Number of Businesses in Underground Coal Mining Industry (1222).[314]

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
1222-0000	Bituminous coal-underground mining	268	17,320	15,878
1222-9901	Underground mining, semianthracite	1	100	12.8
1222-9902	Underground mining, semibituminous	6	113	165.5
1222-9903	Underground mining, subbituminous	12	1,489	233.6
	Total	**287**	**19,022**	**16,289.9**

*Sales figures are in millions.

Table m-4. Number of Businesses in Metals Industry (1011, 1021, 1031, 1041, 1044, 1061, 1094, 1099).[315]

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
Iron Ores				
1011-0000	Iron ores	29	1,637	55.9
1011-0100	Iron ore mining	31	2,598	2,147.6
1011-0101	Open pit iron ore mining, nec**	5	2,036	24.7
1011-0102	Open pit taconite mining	4	1,308	0.5
1011-0103	Underground iron ore mining	3	19	2.6
1011-0200	Iron ore preparation	4	18	0.3
1011-0201	Iron ore beneficiating	3	12	0.9
1011-0202	Iron ore pelletizing	4	16	33.8
	Subtotal	**83**	**7,644**	**2,266.2**
Copper Ores				
1021-0000	Copper ores	45	2,101	346.6
1021-0100	Copper ore mining and preparation	21	3,857	13,079.4
1021-0101	Copper ore milling and preparation	5	935	2.8
1021-0102	Open pit copper ore mining	17	2,407	3,184.6
1021-0103	Underground copper ore mining	5	950	428.3
	Subtotal	**93**	**10,250**	**17,041.699**

[313] Dun and Bradstreet. 2006. Zapdata industry report. Available at http://www.zapdata.com [Accessed May 2006].
[314] Dun and Bradstreet. 2006. Zapdata industry report. Available at http://www.zapdata.com [Accessed May 2006].
[315] Dun and Bradstreet. 2006. Zapdata industry report. Available at http://www.zapdata.com [Accessed May 2006].

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
Lead and Zinc Ores				
1031-0000	Lead and zinc ores	15	1,063	3.5
1031-0100	Lead ores mining	9	1,297	1,231
1031-0101	Cerussite mining	1	2	0.3
1031-0200	Zinc ores mining	6	351	42.8
1031-0203	Willemite mining	1	1	0.2
	Subtotal	**32**	**2,714**	**1,277.8**
Gold Ores				
1041-0000	Gold ores	122	8,501	1,079.1
1041-0100	Gold ores mining	130	3,924	5,172.9
1041-0101	Open pit gold mining	24	902	211.9
1041-0102	Placer gold mining	20	233	11.6
1041-0103	Underground gold mining	31	573	46.5
1041-0200	Gold ores processing	8	17	1.8
1041-0201	Gold bullion production	3	10	1.2
1041-0202	Gold ore milling	7	45	6
1041-0203	Gold recovery from tailings	3	20	5.2
	Subtotal	**348**	**14,225**	**6,536.4**
Silver Ores				
1044-0000	Silver ores	13	308	15.2
1044-0100	Silver ores mining	5	323	1.1
1044-0101	Open pit silver mining	1	3	0.1
1044-0102	Placer silver mining	2	23	9.7
1044-0103	Underground silver mining	3	7	0.2
1044-0200	Silver ores processing	3	5	0.2
1044-0202	Silver ore milling	3	8	0.2
1044-0203	Silver recovery from tailings	8	20	1.8
	Subtotal	**38**	**697**	**28.5**
Ferroalloy Ores, Except Vanadium				
1061-0000	Ferroalloy ores, except vanadium	7	433	86.8
1061-0200	Manganese ores mining	1	2	0.2
1061-0300	Molybdenum ores mining	10	1,119	276
1061-0400	Tungsten ores mining	3	8	4.8
1061-9901	Cobalt ore mining	1	2	0.3
1061-9902	Columbite mining	2	7	1
1061-9904	Huebnerite mining	1	12	1.7
1061-9905	Nickel ore mining	3	7	0.8
	Subtotal	**28**	**1,590**	**371.6**
Uranium-radium-vanadium Ores				
1094-0000	Uranium-radium-vanadium ores	14	257	100
1094-9903	Radium ore mining, nec	1	5	0.1
1094-9905	Uranium ore mining, nec	37	551	1,653.9
1094-9906	Vanadium ore mining, nec	1	0	N/A
	Subtotal	**53**	**813**	**1,754**
Metal Ores, nec				
1099-0000	Metal ores, nec	19	62	5.9
1099-0100	Aluminum and beryllium ores mining	2	8	0.7
1099-0101	Aluminum ore mining	14	205	94.5
1099-0102	Bauxite mining	10	285	543.7
1099-0104	Beryllium ore mining	2	1,863	196.8

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
1099-0200	Palladium group ores mining	3	1,266	507.8
1099-0300	Platinum group ores mining	2	6	0.8
1099-0400	Rare-earth ores mining	3	23	2
1099-0501	Rutile mining	1	9	0.9
1099-0502	Titaniferous-magnetite mining	1	1	0.1
1099-0503	Titanium ore mining	1	10	1.1
1099-9904	Mercury ore mining	1	4	0.4
1099-9906	Thorium ore mining	1	4	N/A
	Subtotal	**60**	**3,746**	**1,354.6**

*Sales figures are in millions.

MARKET TRENDS

The demand for backup power in the mining industry is expected to increase in future years, in light of recent mining crises that have drawn national attention. For example, the Sago Mine Explosion, which occurred on January 2, 2006, has heightened awareness of the need for appropriate underground mine rescue equipment and technology.316 In underground mines, lives may be at stake when critical systems for ventilation, evacuation, and communications fail.

Title 30 of the Code of Federal Regulations (CFR) establishes rules that support the use of emergency power equipment in underground mines. Regulations established under 30 CFR § 57.11053 require mine operators to provide copies of their escape and evacuation plans to MSHA, which must be reviewed and updated at least once every 6 months. Among other requirements, the plan must include "a statement of the availability of emergency communication and transportation facilities, emergency power and ventilation and location of rescue personnel and equipment."[317] While emergency power sources are not required for escape hoists, a regulation under 30 CFR § 57.19111 requires that either fixed ladders be provided that reach as near the shaft of the mine, or "an escape hoist powered by an emergency power source shall be provided."

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells to provide backup power in mining operations, three mining companies were contacted, and one response was received. One MSHA representative also participated in a brief interview.

The single respondent organization was a medium-sized platinum mining company. The company uses limited backup power, which supplies a communications system and personnel hoist, in its mines. The company does not provide backup power for its ventilation system because it would require 3 MW of power. The respondent considered the most important applications of backup power in mines to be pumping (in mines with the potential for flooding and thus the need to ensure that the mine does not flood in case of a power failure), communications systems, and escape hoisting. The respondent reported that the consequences of power outages include loss of life, disruptions in production, and disruptions in distribution.

[316] Mine Safety and Health Administration. 2006. Sago Mine Information Single Source Page. Available at http://www.msha.gov/sagomine/sagomine.asp [Accessed August 2006].
[317] Mine Safety and Health Administration. 2006. Title 30 Code of Federal Regulations. 30 CFR § 57.11053 Escape and evacuation plans. Available at http://www.msha.gov/30cfr/57.11053.htm [Accessed October 2006].

The respondent estimated that the company has experienced two power failures during the past year, and they have had a few planned outages. One unplanned outage lasted 12 hours, and another lasted more than 24 hours. The respondent indicated that any outages > 1 second are considered very disruptive. A power failure trips all electronic systems (e.g., the hoist), and many need to be restarted, a process which can take up to several hours.

The company currently uses diesel generators to meet its backup power requirements. One of the company's mines utilizes two 2-MW generators, which is sufficient power for the entire mine operation. A second mine utilizes one 750 kW generator.

The respondent identified reliability, emissions, ease of use, and past experience with the system as very important factors in making a decision to purchase a backup power system. Of these, the respondent considered reliability and emissions to be the most important factors.

Reliability and emissions are the primary concerns the company has with the performance of its current backup power systems. Although the company has had some issues with failure of its backup power systems to start when needed, the respondent indicated that the company is fairly satisfied with the performance of its current backup power systems. Favorable characteristics of the company's current backup power systems, as indicated by the respondent, are ease of use, operation and maintenance costs, and fuel availability.

The respondent expects to see growth in the future demand for backup power in the mining sector. Because of the Sago Mine disaster, the respondent reported that the federal government is expected to promulgate new requirements for backup power at the nation's mines.

The respondent stated that the company has not considered alternatives to diesel generators for backup power (other than larger sized systems). The company is familiar with PEM fuel cells and believes that PEM fuel cells will compete for backup power in this industry at some point, though the respondent did not indicate a timeframe.

The respondent did not have any concerns with the use of hydrogen as a fuel, primarily due to the company's past experience with an experimental hydrogen-powered vehicle. The company performed a field test with a Zero Emission Utility Solution (ZEUS), developed by the National Institute for Occupational Safety and Health (NIOSH), in 2004. The respondent noted that, while he personally did not have concerns with a hydrogen-powered vehicle, some employees of the company were concerned about safety.

The respondent stated that capital purchase decisions in this company were made based on a return on investment assessment. Government incentives are considered in capital purchase decisions.

The respondent agreed to be contacted again for further information.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Limited information was available to assess the potential for PEM fuel cells as a backup power source in the mining industry. Based on secondary research, PEM fuel cells appear to fit the size requirements for backup power at typical mines. However, the single data point in this analysis suggests that PEM fuel cells would be too small to provide adequate backup power. Current PEM products for backup power could meet the lower estimate for power size requirements described in the Arthur D. Little study (200 kW) but not the higher estimate provided by the mining company interviewed for this analysis (2 MW).

The primary value proposition that PEM fuel cells offer over the current technology is the opportunity to reduce emissions in a sector where diesel emissions are very closely monitored and regulated. PEM fuel cells offer clean emissions as well as reliability, factors which were valued over cost and other factors by the respondent interviewed in this analysis. In addition, new safety regulations being discussed may increase requirements for backup power in the mining sector.

RESEARCH SUMMARY:
NATIONAL AND STATE PARKS

MARKET SEGMENT DESCRIPTION

A national or state park is a reserve of land that is typically protected from human development and environmental alteration. National or state parks typically consist of spacious areas known for their exceptional scenic or natural characteristics; these areas often have significant ecological, geological, archeological, historical, recreational, or other such values. The federal government generally is responsible for the administration of national parks, while state or local governments are responsible for operating and maintaining state parks. State parks are often, but not always, smaller than national parks. This analysis considers the potential for PEM fuel cells for backup power at national and state park facilities. Table n-1 identifies the primary SIC and NAICS classifications associated with this market segment.

Table n-1. SIC and NAICS Codes for National and State Parks.

2-Digit SIC Code	95 – Administration of environmental quality and housing programs
4-Digit SIC Code	9512 – Land, mineral, and wildlife conservation
NAICS Code	712190 – Nature parks and other similar institutions

National and state parks do have a need for backup power. These parks have education and resort facilities that need to sustain lodge operations in the event of power supply interruption to provide services such as heating, ventilation, and air conditioning systems, electricity, water supplies (both for drinking and fire protection), kitchen services, and lighting. Parks have campground and visitor facilities, stores with retail point-of-sale systems, and computerized central reservation systems that also require power. Park facilities often are located in remote areas, and providing utility power to these facilities can be difficult. Above-ground power lines may be prohibited because of their aesthetic impacts, and below-ground power line easements are difficult to obtain in some parks. As a result, many parks use generators not only for backup power but for their primary power supply, as well.[318]

Backup power is presently provided by diesel and propane generators, photovoltaic array systems, and battery backup technologies.[319]

MARKET SIZE

Current market size data for national and state parks are provided below. Table n-2 provides data on the primary SIC code related to national and state parks (9512 - Land, Mineral, and Wildlife Conservation). Because parks offer forestry services, SIC codes that are likely to be associated with national or state parks include 0851 (Forestry services). Market information on these related SIC codes is provided in Table n-3; note that only a small portion of the organizations associated with these services could reasonably be expected to work in national or state park facilities. In Tables n-2 and n-3, only those eight-digit SIC specialties deemed relevant to national and states parks are shown.

[318] National Park Service. 2003. Greening the National Park Service: Greening Case Studies. Available at http://www.nps.gov/renew/case.htm [Accessed July 2006].
[319] National Park Service. 2003. Greening the National Park Service: Greening Case Studies. Available at http://www.nps.gov/renew/case.htm [Accessed July 2006].

Table n-2. Number of Potential Users – Industry: Land, Mineral, and Wildlife Conservation (9512).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
9512-0000	Land, mineral, and wildlife conservation	4,955	137,204	1
9512-0200	Land conservation agencies	1,048	39,442	0.2
9512-0201	Land management agency, government	448	16,152	N/A
9512-0400	Land, mineral, and wildlife conservation, level of government	4	419	N/A
9512-0401	Land, mineral, and wildlife conservation, federal government	20	295	N/A
9512-0402	Land, mineral, and wildlife conservation, state government	110	631	N/A
9512-0403	Land, mineral, and wildlife conservation, county government	79	402	N/A
9512-0404	Land, mineral, and wildlife conservation, local government	72	698	N/A
9512-9901	Conservation and stabilization agency, government	153	2,900	0.8
9512-9902	Recreational program administration, government	3,151	57,520	1
	Total	**10,040**	**255,663**	**3**

Sales figures are in millions. Source: www.zapdata.com, accessed July 2006.

Table n-3. Number of Potential Users – Industry: Forestry Services (0851).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
0851-0000	Forestry services	3,387	15,250	578.5
0851-0100	Forest management services	461	2,353	115.3
0851-9901	Fire fighting services, forest	760	4,642	197.5
0851-9902	Fire prevention services, forest	212	1,337	46.8
	Total	**4,820**	**23,582**	**938.1**

Sales figures are in millions. Source: www.zapdata.com, accessed July 2006.

The National Park Service (NPS) is the federal agency responsible for administration of national parks. The NPS, which partners with other governments and private organizations to manage its land, oversees approximately 390 units within the National Park System; these units include national parks, national monuments, national historic sites, national recreation areas, national rivers, national battlefields, and national scenic trails. The National Park System covers over 84 million acres of land in the United States and its territories.[320]

National and state parks generate revenues primarily through fees collected from visitors but also receive funding from federal and state governments. The most popular NPS units in 2005 include Blue Ridge Parkway (nearly 18,000,000 recreational visits), Golden Gate National Recreation Area (over 13,000,000 recreational visits), and Great Smoky Mountains National Park (over 9,000,000 recreational visits).[321] In FY 2005, the NPS earned approximately $287,715,000 in revenue derived from the public and $52,949,000 in revenue from federal sources. The total cost of services provided by the NPS for FY 2005 was $3,000,536,000.[322]

[320] U.S. Department of the Interior, National Park Service. 2005. Annual Report: Fiscal Year 2005. Available at http://www.doi.gov/pfm/annrept/nps_05_par.pdf [Accessed July 2006].
[321] National Park Service, Public Use Statistics Office. 2005. 2006 Statistical Abstract. Available at http://www2.nature.nps.gov/stats/abst2005.pdf [Accessed July 2006].
[322] U.S. Department of the Interior, National Park Service. 2005. Annual Report: Fiscal Year 2005. Available at http://www.doi.gov/pfm/annrept/nps_05_par.pdf [Accessed July 2006].

State parks, though typically smaller in size, are much more plentiful than national parks and are also heavily utilized. There were 5,842 state park areas in 2004, comprising over 13 million acres.[323] State parks represent less than 2% of the property devoted to outdoor recreation nationwide but host nearly 30% of all visitors at state and federal outdoor recreation areas. In 2001, 735 million people reported visiting state parks. There are multiple facilities that may require primary and/or backup power at these parks. The following statistics, compiled by the National Association of State Park Directors, characterize the state park industry in 2004 by summarizing key features and activities reported by all state parks during that year:[324]

- 208,849 campsites ranging from primitive to multiple hookups
- 6,492 cabins and cottages
- 124 lodges (with 6,865 rooms) in 25 states
- 129 golf courses
- 48 ski slopes
- 309 marinas
- 293 swimming pools
- 99 stable operations
- $345.7 million spent on capital improvements and land acquisition
- $690.9 million expended for capital expenditures
- Average share of the state budget: 0.24%.

Both national and state parks maintain large work forces. The NPS has approximately 20,000 direct employees. In 2004, state parks employed 20,603 full-time personnel and an additional 33,295 part-time and seasonal personnel.[325]

MARKET TRENDS

Efforts are underway to replace fossil fuel-based power sources in parks with alternative energy sources.[326,327] Existing technologies, particularly diesel generators, are being replaced by environmentally friendly alternatives such as photovoltaic and wind-based technologies. No information was found on performance or user satisfaction; however, wind technologies have been identified as ideally suited for use in the National Park System.[328,329]

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[323] The National Association of State Park Directors. 2004. State Park Facts. Available at http://isu1.indstate.edu/naspd/statistics_sub.asp [Accessed July 2006].
[324] The National Association of State Park Directors. 2004. State Park Facts. Available at http://isu1.indstate.edu/naspd/statistics_sub.asp [Accessed July 2006].
[325] The National Association of State Park Directors. 2004. State Park Facts. Available at http://isu1.indstate.edu/naspd/statistics_sub.asp [Accessed July 2006].
[326] National Park Service. 2003. Greening the National Park Service: Greening Case Studies. Available at http://www.nps.gov/renew/case.htm [Accessed July 2006].
[327] U.S. Department of the Interior. 2004. Statement of Joseph Alston, Superintendent of Grand Canyon National Park, National Park Service, Before the House Resources Subcommittee on National Parks, Recreation and Public Lands of the House Committee on Resources, on the Use of Hydrogen Fuel Cell Technology in the National Park System. Available at http://www.doi.gov/ocl/2004/FuelCell.htm [Accessed July 2006].
[328] U.S. Department of Energy, National Renewable Energy Laboratory. 1998. New Wind Energy Technologies Are Cost-Effective in Federal Applications. DOE/GO-10098-583. Available at http://www1.eere.energy.gov/femp/pdfs/WindTF.pdf [Accessed July 2006].
[329] Xanterra Parks & Resorts. 2006. Renewable Energy. Available at http://www.xanterra.com/Renewable-Energy-378.html [Accessed July 2006].

Anthony Eggert, Associate Research Director of the Hydrogen Pathways Research Program at the University of California-Davis Institute of Transportation Studies, testified before the House Hearing on the Use of Hydrogen Fuel Cell Technology in the National Park Service on May 15, 2004.[330] In his testimony, Mr. Eggert cites a number of benefits and challenges associated with the demonstration of hydrogen and fuel cell technologies within the NPS. Benefits include the high visibility of NPS properties to national and international visitors; the ability to replace heavily polluting diesel generators with technologies that have substantially lower pollutant emissions; and the management structure of the NPS, which includes a highly trained workforce. Challenges include the absence of an inexpensive hydrogen feedstock due to the lack of natural gas pipelines into many parks and strict construction, siting, and permitting controls that would make developing a new hydrogen infrastructure difficult. [331]

The NPS has a vested interest in environmental programs. Through its Green Energy Parks Program, the NPS has initiated many efforts to foster environmental stewardship throughout the National Park System. Several hydrogen fuel cell systems have been installed at various units within the National Park System, as summarized below, and numerous other fuel cell initiatives have been planned:[332]

- The first pure hydrogen fuel cell was installed in 1999 at Golden Gate National Recreation Area's Kirby Cove Campground. The 0.5 kW system was fairly reliable, and when coupled with a solar photovoltaic system, provided clean electricity to a trailer site reserved for an NPS volunteer campground host. When the services of a campground host were deemed no longer necessary, the fuel cell system was removed.[333]
- Experiments have been conducted with PEM fuel cells to power various functions at the Golden Gate National Recreation Area and Yellowstone and Yosemite National Parks.[334]
- Opened in May of 2004, the Exit Glacier Nature Center at Kenai Fjords National Park is powered by a 5 kW, solid-oxide fuel cell. The remote Nature Center is not served by utility power, and park officials had previously relied on diesel generators for electricity. The fuel cell, which runs on hydrogen generated by propane, is used to flush toilets, power videos and other interactive exhibits, and provide heat.[335]
- In 2002, a 4.5 kW hydrogen fuel cell was demonstrated at the west entrance of Yellowstone National Park. The system was used to heat offices and power entrance kiosks; however, the system was later removed from the park after being deemed too difficult to maintain.[336]

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[330] Eggert, A. 2004. Hearing on the Use of Hydrogen Fuel Cell Technology in the National Park Service. Available at http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1067&context=itsdavis. [Accessed July 2006.[

[331] Eggert, A. 2004. Hearing on the Use of Hydrogen Fuel Cell Technology in the National Park Service. Available at http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1067&context=itsdavis. [Accessed July 2006.[

[332] National Parks Conservation Association. 2004. Alternate Fuel Source Tapped at Kenai Fjords. Available at http://www.npca.org/magazine/2004/fall/news3.html. [Accessed July 2006.]

[333] U.S. Department of the Interior. 2004. Statement of Joseph Alston, Superintendent of Grand Canyon National Park, National Park Service, Before the House Resources Subcommittee on National Parks, Recreation and Public Lands of the House Committee on Resources, on the Use of Hydrogen Fuel Cell Technology in the National Park System. Available at http://www.doi.gov/ocl/2004/FuelCell.htm. [Accessed July 2006.]

[334] National Parks Conservation Association. 2004. Alternate Fuel Source Tapped at Kenai Fjords. Available at http://www.npca.org/magazine/2004/fall/news3.html. [Accessed July 2006.]

[335] National Parks Conservation Association. 2004. Alternate Fuel Source Tapped at Kenai Fjords. Available at http://www.npca.org/magazine/2004/fall/news3.html. [Accessed July 2006.]

[336] National Parks Conservation Association. 2004. Alternate Fuel Source Tapped at Kenai Fjords. Available at http://www.npca.org/magazine/2004/fall/news3.html. [Accessed July 2006.]

MARKET SEGMENT ANALYSIS

Twenty-five individuals affiliated with state or national parks were contacted in an attempt to gather information on requirements for backup power and the potential for fuel cell use in national and state parks. Two interviews were conducted, and one complete survey response was received. Interviewees were enthusiastic about the potential use of fuel cells and the opportunity to test them as an alternative, environmentally friendly, energy source. Interviewees also expressed enthusiasm over the opportunity to educate the public on new alternative energy sources that help protect natural resources and aid in reducing emissions. Various park services use fuel cells for backup power and even for prime power in more remote locations.

One completed survey was received from a regional energy manager serving 60 national parks and 7 state parks. The respondent indicated that backup power was required for museums and curatorial centers, waste water treatment, utility water systems, fire protection, radio and telephone systems, dispatch centers, fire/rescue/law enforcement operations, hospitality, housing and administrative units onsite. The respondent indicated that power outages were not as disruptive but could result in loss of drinking water and release of sewage. The respondent indicated that backup power was currently being met through generators, which vary in size depending on the application, but range from 5 kW to > 250 kW. The respondent indicated that reliability, emissions, lifetime of unit, and good experience with this type of system in the past were the most important factors when selecting a backup power system. The respondent's primary concerns regarding current systems were emissions and the high cost of owning and operating the systems. The respondent had considered alternatives, including propane, for diesel generators. The respondent was aware of PEM fuel cells for backup power but was skeptical of their performance. The respondent had no concerns about hydrogen as a fuel and cited the primary drivers for purchasing fuel cells as: environmental concerns, government incentives, and a track record of others using them. The respondent indicated that a variety of factors were considered when making purchasing decisions, including initial capital costs, payback period, and return on investment.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Both state and national parks seem to have significant interest in the installation of alternative technologies, including fuel cells. Users in this market segment are considering alternatives to diesel generators, and are looking for environmental friendly alternatives. While the market is small and growth is limited, there is potential for application of PEM fuel cells at various sites within the national park system (e.g. remote lodging facilities, communication systems). While users are interested in alternatives, the primary barrier is likely to be the cost of the systems. Park budgets are tight, and existing fuel cell installations have been sponsored by other agencies and programs. National parks are currently weathering a funding crisis, with the NPS reported to be under-funded by as much as $600 million per year. National park advocacy groups indicate that the parks are getting just two-thirds of the funding they need, leading to severe staffing shortages and deteriorating park facilities.[337] Without outside funding, there is little chance that park systems could afford such installations on their own in the near-term, given their extreme budget constraints. Adoption in NPS will be dependent on availability of funds and will likely be a mid-term opportunity.

[337] Lovgren, S. 2004. U.S. National Parks Told to Quietly Cut Services. National Geographic News. Available at http://news.nationalgeographic.com/news/2004/03/0319_040319_parks.html [Accessed July 2006].

RESEARCH SUMMARY:
ORIGINAL EQUIPMENT MANUFACTURERS (OEMs) AND SUPPLIERS

MARKET SEGMENT DESCRIPTION

The original equipment manufacturing (OEMs) and supply industry includes the manufacture and supply of a range of transportation-related equipment. This analysis focuses primarily on the manufacture and assembly of motor vehicles and car bodies. OEMs and suppliers include establishments primarily engaged in manufacturing or assembling complete passenger automobiles, trucks, commercial cars and buses, and special purpose motor vehicles which are for highway use. It also includes the manufacture and supply of chassis and passenger car bodies, as well as various parts and accessories. Other transportation-related equipment manufacturing (not specifically addressed in this report) includes aerospace vehicles, railroads, ships, and boats as well as motorcycles and armored cars. Table o-1 identifies the SIC and NAICS classifications that cover original equipment manufacturers and suppliers.

Table o-1. SIC and NAICS Codes for Original Equipment Manufacturers and Suppliers.

2-Digit SIC Code	37 – Transportation equipment
4-Digit SIC Code	3711 – Motor vehicles and car bodies
NAICS Code	336111 – Automobile manufacturing

The U.S. is the world's largest marketplace for motor vehicles because of the size and affluence of its population. According to the U.S. Department of Transportation, approximately 230 million motor vehicles - nearly 136 million automobiles, 95 million trucks, and 777,000 buses were registered in the United States in 2003.

In 2004, about 9,400 establishments manufactured motor vehicles and parts; these ranged from small parts plants with only a few workers to huge assembly plants that employ thousands. Table o-2 below shows that 68.9% of establishments in the industry manufactured motor vehicle parts including, electrical and electronic equipment; gasoline engines and parts; brake systems; seating and interior trim; steering and suspension components; transmission and power train parts; air-conditioners; and motor vehicle stampings, such as fenders, tops, body parts, trim, and molding. Other establishments specialized in manufacturing truck trailers; motor homes; travel trailers; campers; and car, truck, and bus bodies placed on separately purchased chassis.[338]

Globalization of the industry has boosted competition among U.S. motor vehicle manufacturers, prompting innovations in product design and in the manufacturing process. Manufacturers have rapidly designed and produced new models aimed at niches in the market. Firms also must be fast and flexible in implementing new production techniques, such as replacing traditional assembly lines with modern systems using computers, robots, and interchangeable platforms. Plants designed for production flexibility put resources in the right place at the right time, allowing manufacturers to shift to new models quickly and efficiently.

[338] Bureau of Labor Statistics, U.S. Department of Labor. 2006. Career Guide to Industries, 2006-07 Edition, Motor Vehicle and Parts Manufacturing. Available at http://www.bls.gov/oco/cg/cgs012.htm [Accessed May 2006].

MARKET SIZE

Table o-2 characterizes the market for OEMs and suppliers for the manufacture of motor vehicles and car bodies. There are an estimated 2,022 establishments in the U.S., employing 280,242 people. Total annual sales in this industry are $457,793.4 million, with average sales per establishment of $273.0 million.

Table o-2. Number of OEMS and Suppliers – Manufacture of Motor Vehicles and Car Bodies (3711).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3711-0000	Motor vehicles and car bodies	465	89,024	41,892.602
3711-0100	Automobile assembly, including specialty automobiles	619	115,225	388,082.188
3711-0101	Ambulances (motor vehicles), assembly of	47	1,958	216.1
3711-0102	Automobile bodies, passenger car, not including engine, etc.	122	8,212	138.8
3711-0103	Cars, armored, assembly of	31	393	144
3711-0104	Cars, electric, assembly of	26	114	20.1
3711-0105	Chassis, motor vehicle	123	6,040	1,476.4
3711-0106	Hearses (motor vehicles), assembly of	6	273	105.8
3711-0107	Patrol wagons (motor vehicles), assembly of	3	77	8.1
3711-0108	Station wagons (motor vehicles), assembly of	1	1	0.1
3711-0109	Taxicabs, assembly of	10	41	3.7
3711-0200	Truck and tractor truck assembly	80	20,901	17,351.4
3711-0201	Motor trucks, except off-highway, assembly of	12	11,336	632.3
3711-0202	Truck tractors for highway use, assembly of	27	2,330	2,226.8
3711-0203	Trucks, pickup, assembly of	37	3,134	10.4
3711-0300	Military motor vehicle assembly	30	826	1,972.7
3711-0301	Amphibian motor vehicles, assembly of	3	51	12.6
3711-0302	Personnel carriers (motor vehicles), assembly of	17	82	6.7
3711-0303	Reconnaissance cars, assembly of	6	22	1.8
3711-0304	Scout cars (motor vehicles), assembly of	5	70	0.4
3711-0305	Universal carriers, military, assembly of	1	2	0.1
3711-0400	Bus and other large specialty vehicle assembly	30	1,576	128.2
3711-0401	Brooms, powered (motor vehicles), assembly of	3	18	1.8
3711-0402	Buses, all types, assembly of	67	8,903	1,816.1
3711-0403	Fire department vehicles (motor vehicles), assembly of	84	5,009	875.5
3711-0404	Mobile lounges (motor vehicle), assembly of	10	157	8.8
3711-0405	Motor buses, except trackless trollies, assembly of	6	1,652	270.4
3711-0406	Motor homes, self contained, assembly of	20	1,034	132.5
3711-0407	Road oilers (motor vehicles), assembly of	2	8	0.7
3711-0408	Snow plows (motor vehicles), assembly of	34	587	42.7
3711-0410	Street sprinklers and sweepers (motor vehicles), assembly of	15	769	164.7
3711-0411	Wreckers (tow truck), assembly of	80	417	48.8
	Total	**2,022**	**280,242**	**457,793.406**

Sales figures are in millions. Source: www.zapdata, accessed September 2006.

Motor vehicle assembly plants use energy throughout the plant for many different end-uses. The main energy types used on-site are electricity, steam, gas, and compressed air. Total energy expenditures in the transportation equipment manufacturing industry as a whole (NAICS Code

336) were estimated at $3.6 billion in 1999.[339] In vehicle assembly plants categorized in SIC Code 3711, about $700 million is spent on energy. An estimated two-thirds of the budget for assembly plants is spent on electricity.[340] Electricity use in vehicle assembly plants has increased over time from 8.6 terawatt hours (TWh) in 1987 to 10 TWh in 1995, while the average specific electricity consumption per car has decreased from almost 1000 kW hours per car in 1987 to 860 kW hours per car in 1995. However, there are large variations among individual plants.[341]

Table o-3 provides an estimate of the typical electricity end-use distribution in vehicle assembly plants, based on studies of such plants in the U.S. About 70% of all electricity is used in motors to drive different pieces of equipment in the plant.

Table o-3. Distribution of Electricity Use in Vehicle Assembly Plants.[342]

End-Use	Share of Electricity Use (%)	Estimated Electricity Consumption in 1995 (kW Hours/Car)	Average Electricity Applied in Analyses in this Study (kW Hours/Car)
HVAC	11-20%	95-170	160
Paint Systems (e.g., Fans)	27-50%	230-320	260
Lighting	15-16%	130-140	130
Compressed Air	9-14%	80-120	120
Materials Handling/Tools	7-8%	60-70	60
Metal Forming	2-9%	20-80	30
Welding	9-11%	80-95	80
Miscellaneous	4-5%	35-45	20
Total	**100%**	**730-1040**	**100%**

According to the EIA,[343] net demand for electricity in 2002 for transportation equipment (NAICS 336) was 27,700 million kW hours. Secondary data on the proportion of total energy use typically supported with backup power was not available.

MARKET TRENDS

The impact of unscheduled downtime from power outages in this sector can be significant, as was underscored by the August 2003 blackout. Power outages affected automotive manufacturers and suppliers throughout the United States and Canada and resulted in an estimated production loss of 35,000 vehicles, the temporary layoff of more than 100,000 workers, and more than $1 billion in lost wages and production.[344]

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[339] U.S. Census, U.S. Department of Commerce. 2000. Annual Survey of Manufacturers, various years. Available at http://www.census.gov/econ/overview/ma0300.html [Accessed December 2006].
[340] Berkeley National Laboratory. 2003. Energy Efficiency Improvement and Cost Savings Opportunities for the Vehicle Assembly Industry: an ENERGY STAR® Guide for Energy and Plant Managers.
[341] U.S. Census, U.S. Department of Commerce. 2000. Annual Survey of Manufacturers, various years. Available at http://www.census.gov/econ/overview/ma0300.html [Accessed December 2006].
[342] Berkeley National Laboratory. 2003. Energy Efficiency Improvement and Cost Savings Opportunities for the Vehicle Assembly Industry: an ENERGY STAR® Guide for Energy and Plant Managers.
[343] Energy Information Administration. 2002. Manufacturing energy consumption survey. Available at http://www.eia.doe.gov/emeu/mecs/contents.html [Accessed December 2006].
[344] Portal Publishing Ltd. 2004. Automotive Industry Action Group's crisis management process could save millions. Available at http://www.continuitycentral.com/news0910.htm [Accessed September 2006].

According to The Electricity Consumers Resource Council,[345] at least 70 auto and parts plants and several offices were shut down by the August 14, 2003, blackout. General Motors Corporation reported that the blackout affected approximately 47,000 employees at 19 manufacturing facilities and three parts warehouses in Michigan, Ohio, and Ontario. The Ford Motor Company reported that 23 of Ford's 44 plants in North America were shut down, as were numerous office, engineering, and product development facilities in southeastern Michigan. Other facilities were affected by disruptions in parts supply lines. At Ford's casting plant in Brook Park, Ohio, the outage caused molten metal to cool and solidify inside one of the plant's furnaces. The company reported that a week would be required to clean and rebuild the furnace.

The North American operating units of DaimlerChrysler AG lost production at 14 of its 31 plants. Six of those were assembly plants with paint shops. All the vehicles that were moving through the paint shop at the time of the outage had to be scrapped. The company reported that, in total, 10,000 vehicles had to be scrapped. A number of other manufacturing and assembly plants were affected as a result of the blackout, including Honda Motor Company's assembly plant in Alliston, Ontario, Delphi's Flint East Manufacturing Complex, and several of Neff-Perkins Company's manufacturing plants. Specific operations affected by the blackouts include presses, air conditioning units, and painting machines.

As illustrated by the power outages experienced in August 2003, OEMs and suppliers typically do not maintain backup power for all manufacturing and assembly processes. Short interruptions in production can usually be made up by running overtime, and larger manufacturers keep approximately 2 months worth of inventory in dealer lots. However, longer unplanned plant shutdowns have a direct impact on earnings, since automakers book revenues when a vehicle is built.

The industry uses some backup power technologies. Diesel generators appear to be a common type of backup system. Honda, for example, has two diesel generators (a 200 kW and 500 kW) in one of its plants and uses diesel generators for backup power in all North American locations. Some motor vehicle manufacturers buy power from other facilities for backup; others maintain their own power plants, which generate electricity from coal or natural gas.

The industry has also investigated fuel cell technology, although not for backup power applications. Ford Motor Company completed testing in 2003 on a 5 kW solid oxide fuel cell at the Dearborn Assembly Plant in Michigan. The fuel cell system utilized hydrogen gas from the plant's vehicle paint shop (supplemented with natural gas) to provide electricity and heat for the facility. In 2001, Ford installed a 200 kW PAFC at its North American Premier Automotive Group headquarters in Irvine, California. The fuel cell, fueled by natural gas, provided 25 % of the building's electricity and hot water.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells among OEMs and suppliers, 39 companies were contacted, and two responses were received. One respondent represented a

[345] The Electricity Consumers Resource Council. 2004. The Economic Impacts of the August 2003 Blackout. Available at http://www.elcon.org/Documents/EconomicImpactsOfAugust2003Blackout.pdf [Accessed May 2006].

large engine machining manufacturing plant, while the other was a small manufacturer of oxygen sensors.

Respondents reported that backup power was required for all machining operations and lighting, computer servers, and basic utilities. Of these operations, respondents typically indicated that machining operations and computer servers were the most critical functions. However, a number of manufacturers, including some who declined to take the survey, indicated that backup power systems are not feasible for their manufacturing processes due to the magnitude of power requirements.

The large engine machining manufacturer had experienced five power outages in the last 12 months; three of these outages were weather related, and two were related to problems with the power company. All five outages lasted less than 3 seconds, and all outages were considered very disruptive. The small oxygen sensor manufacturer experienced approximately four outages in the last 12 months, lasting 60 seconds on average. This respondent stated that outages lasting 1 second were minimally disruptive, 3-minute outages were moderately disruptive, and outages lasting 1 hour or more were very disruptive. Both respondents noted that power outages resulted in disruptions in production; one respondent also stated that power outages resulted in implementation of emergency management plans and disruptions in distribution.

Respondents indicated that backup power requirements are being met through UPS systems and generators. The large manufacturer has multiple backup power systems, including one 5 kW, two 50 kW, one 10 kW, one 15 kW, and one 50 kW. The small manufacturer indicated that it has two diesel generators, one of 200 kW and one of 500 kW.

Both respondents indicated that important characteristics to consider in selecting a backup power system were reliability and startup time. One respondent also stated that emissions, ease of use, fuel availability, and reliability were other critical decision factors.

When asked to rate the performance of their current backup power systems, respondents indicated that reliability, lifetime of the unit, and fuel availability were generally good. One respondent stated that ease of use, capital cost, and startup time were good, while annual operating costs and emissions of the current system were not very good. The other respondent indicated that capital cost, annual operating cost, startup time, and ease of use were not very good.

Neither survey respondent anticipated a growing need for backup power in this market; nor had they considered alternatives to current backup power systems. Neither respondent had heard of PEM fuel cells.

One respondent stated that purchase decisions for backup power systems are based on the payback period of the investment, but that government incentives are considered; the other respondent stated that decisions were made based on return on investment and that government incentives are not considered.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Potential applications for backup power by OEMs and suppliers include computer servers, machining operations, emergency lighting, and basic utilities. These applications consume a small portion (< 30%) of the power required for automotive manufacture and supply. Based on limited data, users appear to have a high level of satisfaction with current backup power systems, which include UPS systems and generators ranging from 5 kW to 500 kW. While PEM fuel cell systems may be adequately sized to meet some of these backup power needs (e.g. emergency lighting), respondents lacked familiarity with PEM fuel cells and did not express interest in pursuing new or alternative technologies.

Power requirements for large, automated applications such as molten metal furnaces and continuous flow assembly lines are too large to be accommodated by current PEM fuel cell technology. Additionally, despite the negative impact of extended power outages on OEMs and suppliers, there is little indication that companies are vigorously pursuing strategies to provide more backup power.

There eventually may be opportunities PEM fuel cells to provide backup power in small, niche applications; companies who are actively pursuing PEM fuel cell technology for vehicle applications could potentially be willing adopters of stationary PEM fuel cells for demonstration purposes. However, there do not appear to be any strong drivers for the use of PEM fuel cells as a backup power source in near term.

RESEARCH SUMMARY:
PETROLEUM REFINERIES

MARKET SEGMENT DESCRIPTION

This market segment comprises establishments primarily engaged in refining crude petroleum into refined petroleum. This market segment was examined because the process of oil refining produces and utilizes hydrogen gas, and can potentially provide a more economical source of hydrogen. Other applications in the oil and gas market like backup power for offshore oil rigs (unmanned platforms) and protection of pipelines are not discussed here. This market segment includes firms engaged in producing gasoline, kerosene, distillate fuel oils, residual fuel oils, aliphatic and aromatic chemicals, and lubricants, through fractionation or straight distillation of crude oil, redistillation of unfinished petroleum derivatives, cracking, or other processes. Table p-1 identifies the SIC and NAICS classifications for petroleum refining.

Table p-1. SIC and NAICS Codes for Petroleum Refining.

2-Digit SIC Code	29 – Petroleum refining and related industries
4-Digit SIC Code	2911 – Petroleum refining
NAICS Code	324110 – Petroleum refineries

The major products of the petroleum refining sector are transportation fuels, but its products are also used in other energy applications and as feedstock for the chemical industries (e.g., solvents, xylene, styrene). Refinery operations fall into five major categories that involve separation, cracking, rearrangement, and blending of hydrocarbons. Table p-2 lists major petroleum refining processes.

Table p-2. Major Petroleum Refining Processes.[346]

Category	Major Technologies
Topping (Separation of Crude Oil)	Atmospheric distillation Vacuum distillation Solvent deasphalting
Thermal and Catalytic Cracking	Delayed coking Fluid coking/flexicoking Visbreaking Catalytic cracking Catalytic hydrocracking
Combination/Rearrangement of Hydrocarbons	Alkylation Catalytic reforming Polymerization Isomerization Ethers manufacture
Treating	Catalytic hydrotreating/hydroprocessing Sweetening/sulfur removal Gas treatment
Specialty Product Manufacture	Lube oil Grease Asphalt

[346] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Petroleum Analysis Industry Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/petroleum/tech.html [Accessed June 2006].

Potential areas of application within the refinery are for supervisory control and data acquisition (SCADA) systems, mainframe computers controlling manufacturing and data center operations, emergency lighting, and alarm systems.

MARKET SIZE

The U.S. petroleum refining industry is the largest in the world and processes approximately one quarter of all crude oil globally. There were approximately 149 petroleum refineries around the U.S. as of January 2006,[347] employing over 65,000 employees.[348] The number of refineries has declined significantly from 205 in 1990.

The U.S. refining industry produces a mix of products with a total value exceeding $151 billion. According to the EIA,[349] total U.S. petroleum product consumption declined by 77,000 billion barrels per day (bbl/d), or 0.4%, in 2005. Higher prices and the impact of hurricanes on liquefied petroleum gases and petrochemical feedstocks drove this decline in consumption. In 2006 and 2007, petroleum consumption is projected to increase by 0.9% and 2.1%, respectively. However, several refineries are still shut down or are operating at reduced rates because of hurricane damage. Petroleum refineries are located in 33 states, but the largest number of refineries is found on the Gulf Coast, followed by California, New Jersey, and Alaska.[350] The size of the U.S. petroleum refining market based on the number of adopters is provided in Table p-3. Statistics are provided for specialty segments within the industry. A total of 1,536 establishments generate annual sales of $617,199 million.

Table p-3. Number of Businesses in Petroleum Refining Industry (2911).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
2911-0000	Petroleum refining	776	63,035	586,018.625
2911-0100	Gases and liquefied petroleum gases	72	1,163	3,151.5
2911-0101	Gas, refinery	86	5,721	24,126.6
2911-0102	Liquefied petroleum gases, LPG	11	161	17
2911-0200	Light distillates	2	415	295.3
2911-0201	Alkylates	2	4	7.3
2911-0202	Gasoline blending plants	23	359	582.2
2911-0203	Jet fuels	24	458	387.9
2911-0204	Kerosene	1	1	0.1
2911-0206	Solvents	24	195	349
2911-0300	Intermediate distillates	1	3	0.3
2911-0301	Acid oil	2	17	0.1
2911-0302	Diesel fuels	87	362	58
2911-0303	Oils, fuel	132	2,037	247.7
2911-0304	Oils, illuminating	4	24	2.7
2911-0305	Oils, partly refined: sold for rerunning	8	498	6.8

[347] As of January 2006, seven refineries had idle distillation units. The large increase in idle capacity as of 1/1/2006 compared to the prior year is due primarily to the continuing impact from Hurricanes Katrina and Rita that kept BP-Texas City (437,000 bbls/cd), ConocoPhillips-Alliance (247,000 bbls/cd), and Murphy-Meraux (120,000 bbls/cd) idle. [Energy Information Administration (EIA), Form EIA-820, Annual Refinery Report.]

[348] Worrell, E. and C. Galitsky. 2005. Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries: An ENERGY STAR® Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory.

[349] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Short-Term Energy Outlook. Available at http://www.eia.doe.gov/emeu/steo/pub/ [Accessed December 2006].

[350] Worrell, E. and C. Galitsky. 2005. Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries: An ENERGY STAR® Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory.

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
2911-0306	Still oil	2	12	1.6
2911-0400	Heavy distillates	1	9	0.9
2911-0401	Mineral jelly	2	4	0.4
2911-0402	Mineral oils, natural	14	95	6.5
2911-0403	Mineral waxes, natural	6	139	1.6
2911-0404	Oils, lubricating	41	1,008	555.3
2911-0405	Paraffin wax	8	87	2.6
2911-0500	Residues	2	4	3
2911-0501	Asphalt or asphaltic materials, made in refineries	35	576	615.9
2911-0502	Coke, petroleum	12	636	256.4
2911-0503	Greases, lubricating	7	52	14.4
2911-0504	Petrolatums, nonmedicinal	3	265	N/A
2911-0505	Road materials, bituminous	5	37	3.1
2911-0506	Road oils	6	43	8
2911-0600	Aromatic chemical products	59	1,557	57.1
2911-0601	Benzene, made in refineries	1	1	0.1
2911-0700	Nonaromatic chemical products	10	36	3.5
2911-0702	Fuel additives	55	1,225	400.7
2911-9901	Fractionation products of crude petroleum, hydrocarbons, nec	12	69	17.5
	Total	**1,536**	**80,308**	**617,199.375**

Note: Not all establishments have a specialty. Sales figures are in millions.
Source: Dun and Bradstreet. Industry Reports www.zapdata.com, accessed June 2006.

U.S. petroleum refineries are operated by 59 companies.[351] Although there are a relatively large number of independent companies in the U.S. refining industry, the majority of the refining capacity is operated by a small number of multi-national or national oil processing companies. The largest companies (as of January 2003) include: ConocoPhilips, ExxonMobil, BP, Valero, ChevronTexaco, Marathon Ashland, and Shell, which combined represent 59% of crude distillation unit (CDU) capacity. Table p-4 lists the top-producing facilities as of January 2005.

Table p-4. Top 10 U.S. Petroleum Refineries, by Operable Atmospheric Crude Oil Distillation Capacity (Barrels per Calendar Day) as of January 1, 2005.[352]

Rank	Company Name	State	Site	Barrels Per Day
1	ExxonMobil Refining & Supply Co	Texas	Baytown	557,000
2	ExxonMobil Refining & Supply Co	Louisiana	Baton Rouge	493,500
3	Bp Products North America Inc	Texas	Texas City	437,000
4	Bp Products North America Inc	Indiana	Whiting	410,000
5	ExxonMobil Refining & Supply Co	Texas	Beaumont	348,500
6	Sunoco Inc (R&M)	Pennsylvania	Philadelphia	335,000
7	Deer Park Refining Ltd Partnership	Texas	Deer Park	333,700
8	Chevron USA Inc	Mississippi	Pascagoula	325,000
9	Citgo Petroleum Corp	Louisiana	Lake Charles	324,300

[351] Worrell, E. and C. Galitsky. 2005. Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries: An ENERGY STAR® Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory.
[352] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. U.S. Refineries Operable Atmospheric Crude Oil Distillation Capacity (Barrels per Calendar Day). Available at http://www.eia.doe.gov/neic/rankings/refineries.htm [Accessed June 2006].

Rank	Company Name	State	Site	Barrels Per Day
10	Conoco Phillips	Illinois	Wood River	306,000

Petroleum refining is the most energy-intensive manufacturing industry in the U.S. and accounts for about 7.5% of total U.S. energy consumption.[353] The petroleum refining industry uses energy both to supply heat and power for plant operations and as a raw material for the production of petrochemicals and other non-fuel products.

Petroleum refineries are also one of the largest users of hydrogen. Refineries use hydrogen in processes such as hydrocracking (simultaneously breaking down large hydrocarbons and adding hydrogen), hydrotreating (adding hydrogen), catalyst regeneration, desulfurization, and heavy oil upgrading.

Refineries spend typically 50% of cash operating costs (i.e., excluding capital costs and depreciation) on energy, making energy a major cost factor and also an important opportunity for cost reduction.[354] Energy consumption increased from 5,762 trillion Btu in 1991 to 7,130 Btu in 1998.[355] Refinery gas, natural gas, and petroleum coke account for the largest shares of energy use. Energy use is also a major source of emissions in the refinery industry, making energy efficiency improvement an attractive opportunity to reduce emissions and operating costs. The petroleum industry produces about 32% of electricity onsite, primarily by means of cogeneration.[356] The refining industry is the third largest cogenerator in the manufacturing sector. The amount of electricity consumed as backup power is unknown.

MARKET TRENDS

Rotating power outages (i.e., rolling blackouts) in California have the potential to impact refinery operations and could potentially influence demand for backup or supplementary power. In 2001, EIA conducted a study of the impact of power outages on California petroleum refineries and natural gas supply in response to a 2001 California Public Utilities Commission ruling that utilities must include transmission level customers (like refineries) in rotating outages.[357] The survey study found that the potential impact of rotating electrical outages on individual California refineries ranged from minimal to severe. About one-fourth of the refining capacity in California is protected from electrical outages either because of sufficient cogeneration capacity within the refinery or because it is in an electric utility service area that is not expected to be subject to rotating electrical outages (e.g., in the Los Angeles Department of Water and Power service area). The rest of the refineries could be forced to either reduce operating rates or shut down completely during an electricity outage if it should affect their supply of electricity.[358] According to the EIA study, about 40 % of the California refining capacity has some

[353] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Petroleum Analysis Industry Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/petroleum/tech.html [Accessed June 2006].
[354] Worrell, E. and C. Galitsky. 2005. Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries: An ENERGY STAR® Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory.
[355] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Petroleum Analysis Industry Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/petroleum/tech.html [Accessed June 2006].
[356] Worrell, E. and C. Galitsky. 2005. Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries: An ENERGY STAR® Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory.
[357] Energy Information Administration. 2001. Electricity Shortage in California: Issues for Petroleum and Natural Gas Supply. Available at http://www.eia.doe.gov/emeu/steo/pub/special/california/june01article/carefinery.html [Accessed June 2006].
[358] Energy Information Administration. 2001. Electricity Shortage in California: Issues for Petroleum and Natural Gas Supply. Available at http://www.eia.doe.gov/emeu/steo/pub/special/california/june01article/carefinery.html [Accessed June 2006].

cogeneration capabilities, but not enough to keep operating at full rates. Processing rates at these refineries would need to be reduced by up to 30 % or selected units shut down in order to continue operating during an electrical outage. Returning to full production after a scheduled shutdown can take up to several days, so the period of reduced production would potentially be longer than the period of the electrical outage. Finally, up to 27 % of the California refining capacity is expected to be forced to shut down completely during a rotating electrical outage should it occur in their block. It takes a refinery 1 to 2 weeks to return to full operating rates following a forced emergency shutdown.

Regarding the susceptibility of a refineries' hydrogen supply, the EIA study also found that most refineries are self-sufficient in their hydrogen supply and produce it within the refinery by the reforming unit. However, several California refineries were found to produce additional hydrogen from natural gas, and several reported receiving hydrogen from outside the refinery. A temporary loss of outside hydrogen supply would require storing untreated product until hydrogen was restored. Longer disruptions would require cutbacks in refinery production rates. However, outside hydrogen supply is not expected to be a significant refinery risk issue in California because the major hydrogen producer is in the Los Angeles area and has a cogeneration plant that is likely to be protected from disruption.[359]

The EIA also recently conducted an analysis of the impact of Gulf Coast hurricanes on the petroleum industry. EIA estimates that at the height of the refinery outages (September 22 to 25, 2005), as much as 4.9 million barrels per day of refining capacity (nearly 29 % of U.S. refining capacity and over 60 % of refining capacity in the Gulf Coast region) were shut down. Some of the shutdowns were precautionary, ahead of the storms, but several refineries were damaged extensively, thus keeping them shut down for a relatively long time. For example, as of October 10, 2005, more than 2 million barrels per day of refining capacity were still shut down.[360]

One potential driver for increased backup power at petroleum refineries is the Gasoline for America's Security Act of 2005, passed in the wake of Hurricanes Katrina and Rita.[361,362] Section 203 of the bill requires an assessment of the adequacy of backup power capacity, and the need for any additional capacity, to provide for continued operation during emergencies. This requirement applies to crude oil or refined petroleum product pipeline facilities that are significant to the nation's supply needs and are located in areas that have historically been subject to higher incidents of natural disasters, such as the Gulf Coast, where the petroleum refining industry is concentrated.

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[359] Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. 2006. Petroleum Analysis Industry Brief. Available at http://www.eia.doe.gov/emeu/mecs/iab98/petroleum/onsite.html [Accessed June 2006].
[360] Energy Information Administration. 2006. The Impact of Tropical Cyclones on Gulf of Mexico Crude Oil and Natural Gas Production. Available at http://www.eia.doe.gov/emeu/steo/pub/pdf/hurricanes.pdf [Accessed June 2006].
[361] THOMAS (Library of Congress). 2006. Gasoline for America's Security Act of 2005. Available at http://thomas.loc.gov/cgi-bin/bdquery/z?d109:HR03893:@@@L&summ2=m& [Accessed December 2006].
[362] The Committee on Energy and Commerce. 2006. Gasoline for America's Security Act of 2005. Available at http://energycommerce.house.gov/108/news/Gas_Bill.pdf; http://energycommerce.house.gov/108/Markups/09282005markup1659.htm; and http://energycommerce.house.gov/108/News/09262005_1661.htm#Related [Accessed December 2006].

To date, no U.S. petroleum refineries have adopted fuel cell technologies. However, an oil refinery in Japan has installed a 1 kW PEM fuel cell.[363] Lawrence Livermore National Laboratory[364] has investigated the use of a direct carbon fuel cell and a SOFC that use by-products of petroleum refining. Advantages of this system are a significant decrease in carbon dioxide emissions and reduced power costs.

A few other industry trends could influence opportunities for fuel cells in the petroleum refining industry. Recently, facilities in this sector have announced plans to increase their on-site capacity for generating hydrogen. For example, in April 2006 Linde Gas LLC announced plans to build and operate an on-site hydrogen steam methane reformer at the Shell Chemical LP plant in Mobile, Alabama. From this facility, Linde will supply industrial-grade hydrogen facilitating gas oil hydrotreating by Shell at Mobile. The scheduled start-up for the Linde facility is November 2007. This latest contract represents Linde's fourth on-site hydrogen generation plant serving the North American marketplace.[365] Similarly, Chicago Bridge & Iron Company (CB&I) recently reported that they had been awarded a $40 million contract by a major U.S. refiner to supply a large-scale hydrogen plant for one of its refineries located in Texas. Delivery of the plant is scheduled for summer 2007.[366] Such developments could potentially result in a more economical fuel source for PEM fuel cell systems sited at refineries.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells, 10 petroleum refining companies were contacted. Two responses were received. One respondent was a large company (> 3000 employees) and one respondent was a medium sized company (500 to 3000 employees). Typical operations that require backup power as identified by respondents include SCADA, mainframe computing hardware, emergency lighting and alarm systems. Neither respondent was able to report the exact number of outages experienced in the past 12 months. They indicated that grid reliability varied significantly by location. Both respondents indicated that without backup power any outage would be highly disruptive and could result in disruptions in production and distribution. Users used a combination of UPSs, batteries, and generators to provide backup power. One respondent also uses a 250 kW PAFC to support data center operations. The size of the backup systems ranged from < 5 kW to > 2000 kW. The most important user requirements when selecting a backup power system are reliability, start-up time, emissions, fuel availability, and good experience with system in the past. Respondents indicated that performance of their systems were good, and reported no specific concerns. Respondents did identify a growing need for backup power. Only one of two respondents had considered alternatives, including fuel cells. This user has a pre-existing PAFC installation and is familiar with fuel cells. The user indicated satisfaction with the performance of their system but was dissatisfied with operations and maintenance requirements and associated costs of the PAFC system. Neither user was

[363] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Updated October 2005; accessed June 14, 2006].
[364] Steinberg, M., J. F. Cooper, and N. Cherepy. 2002. High Efficiency Direct Carbon and Hydrogen Fuel Cells for Fossil Fuel Power Generation. DOE, Lawrence Livermore National Laboratory. Available at http://www.llnl.gov/tid/lof/documents/pdf/242935.pdf [Accessed June 2006].
[365] Linde Gas. 2006. News. Available at http://www.us.lindegas.com/international/web/lg/us/likelgus.nsf/docbyalias/news_shell [Accessed June 2006].
[366] Chicago Bridge & Iron (CB&I) Company N.V. 2006. CB&I to Supply Large Hydrogen Plant for Refinery in Texas. Available at http://www.cbi.com/ir/release.aspx?releaseid=192318 [Accessed December 2006].

particularly concerned about hydrogen as a fuel. Both respondents indicated that government incentives were considered when making purchasing decisions.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

This market was examined to determine opportunities for PEM fuel cells in backup power only. Like the chemical industry, petroleum refineries are large producers of hydrogen gas and have large energy requirements, making them potential candidates for application of PEM fuel cells in grid parallel and grid independent applications. However, one potential barrier to the application of fuel cells in the petroleum industry for these applications is the already high expenses associated with hydrogen production or purchase. Hydrogen is used in the refinery in large quantities for processes such as hydrocrackers and desulfurization using hydrotreaters. Adopting PEM fuel cells may require the additional purchase or production of sufficient quality hydrogen. In order to determine if PEM fuel cells show value for these applications, this added cost of purchasing hydrogen fuel would need to be compared to the energy cost savings resulting from fuel cells' improved efficiency over grid electricity or other power sources.

The industry is highly sensitive to power outages, and reliability requirements for backup power technologies are very high. While the impact of Hurricanes Katrina and Rita may increase demand for sustained backup power capacity in the event of natural disasters that strike petroleum refineries, the potential size of the petroleum refinery market is small relative to other industries (149 operating refineries in 2006). Due to the need for reliable power, refineries have built in redundancy to ensure a continuous power supply. Backup power at an operational level is provided through alternate grid lines, large generators, and turbines. At a control systems level, backup power is provided through batteries and UPS systems. Due to limited power size and durability, PEM fuel cells are not likely to be adopted in the near term for operational level backup. Early applications for PEM fuel cells for backup power may be limited to specific applications like communications support and emergency lighting.

Marketing research indicates that users are fairly satisfied with current technologies and alternatives have been considered only to a limited extent. It appears that there is only a limited understanding of PEM fuel cells for backup power in this market segment. As users emphasize reliability, start-up time, fuel availability, and good experience with the system as factors that would influence them when selecting a backup system, it is likely that PEM fuel cells will not be adopted in the near term.

RESEARCH SUMMARY: PHARMACEUTICALS

MARKET SEGMENT DESCRIPTION

This market segment comprises establishments primarily engaged in the manufacture of in-vivo diagnostic substances and pharmaceutical preparations (except biological) intended for internal and external consumption in dose forms, such as ampoules, tablets, capsules, vials, ointments, powders, solutions, and suspensions.[367] Products of this industry include pharmaceutical preparations promoted primarily to the dental, medical, or veterinary professions, and pharmaceutical preparations promoted primarily to the public.

This analysis considers the potential for PEM fuel cells for backup power at pharmaceutical manufacturing facilities. Table q-1 identifies the SIC and NAICS codes associated with this market segment.

Table q-1. SIC and NAICS Codes for Pharmaceutical Manufacturing.

2-Digit SIC Code	28 – Chemicals and allied products
4-Digit SIC Code	2834 – Pharmaceutical preparations
NAICS Code	325412 – Pharmaceutical preparation manufacturing

There is a need for continuous power and reliable backup power for the production, storage, and testing of drug products. A constant, reliable supply of electricity – 99.999 reliability – is necessary for operations.

In manufacturing pharmaceutical products, strict adherence to quality assurance is critical to ensure that the product is manufactured correctly. Exact requirements for specifications and dosage must be met. To meet these requirements, reliable power is needed during the production process to ensure that precise quality control processes are followed and all production parameters are monitored and recorded.[368] Losses of power during critical production steps can result in failed batches that must be discarded. Revenue losses of $1 million per hour of downtime are reported for the pharmaceutical industry.[369]

For storage and testing facilities, backup power is needed for stability chambers in the event of power failures. Temperature and humidity within each chamber must be continually monitored and documented with an automatic chart recorder or electronic monitoring system. Extended exposure to significantly changed temperature or humidity can put significant stress on the samples, and can lead to inaccurate or failing results. Therefore, it is essential that the temperature and humidity within each stability storage unit be closely monitored and the chambers be re-validated routinely.[370]

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[367] U.S. Census Bureau. 2006. North American Industry Classification System (NAICS) 2002. Available at http://www.census.gov/epcd/www/naics.html [Accessed December 2006].
[368] Pentadyne Power Corporation. 2006. Case Study: Multinational Pharmaceutical Company Depends on Pentadyne's DC Flywheel to Keep Data Center Operations Up and Running. Available at http://www.pentadyne.com/Power%20Protection%20for%20Pharmaceutical%20Applications.pdf [Accessed December 15, 2006].
[369] META Group, Inc. 2000. Quantifying Performance Loss: IT Performance Engineering and Measurement Strategies. Available at http://www.esolutionsgroup.ca/services/network_data.shtml [Accessed December 2006].
[370] Pharmatek Laboratories, Inc. 2004. Press Release: Pharmatek Expands Pharmaceutical Stability Storage and Testing Services. Available at http://www.pharmatek.com/pdf/021004_press.pdf [Accessed December 2006].

Traditional backup power sources for pharmaceutical companies include battery-based UPS systems and diesel generators. Another option that can be used in combination with backup generators is a DC flywheel power system. The flywheel power system can provide bridging power to the backup generators when a power outage occurs. While the flywheel system is compatible with the UPS system, the flywheel requires low maintenance, saves space, and provides high reliability as an alternative to UPS battery banks.[371]

A vaccine manufacturer experiencing frequent power interruptions elected to install a 2200 kVA PureWave UPS system combined with a backup generator. The combination provides 100% protection from power outages, a critical requirement for the vaccine production process. The PureWave UPS system provides 30 seconds of backup power at full load and 60 seconds at half-load. For longer outages, the UPS system transfers the load to the backup generator and then back to the utility feeder when power is restored. The PureWave UPS system allows room for expansion and does not require an air-conditioned room.[372]

MARKET SIZE

Hoover's, Incorporated reports approximately 700 pharmaceutical manufacturing companies in the U.S. (NAICS Code 325412). The top 10 companies, by sales, are listed in Table q-2.

Table q-2. Top 10 U.S. Pharmaceutical Manufacturing Companies, by Sales.[373]

Company Name	Location	Sales ($ mil)
Cardinal Health, Inc.	Dublin, OH	74,910.7
The Procter & Gamble Company	Cincinnati, OH	56,741.0
Pfizer Inc	New York, NY	51,298.0
Johnson & Johnson	New Brunswick, NJ	50,514.0
Tyco International Ltd.	Princeton, NJ	39,727.0
Abbott Laboratories	Abbott Park, IL	22,337.8
Merck & Co., Inc.	Whitehouse Station, NJ	22,011.9
3M Company	St. Paul, MN	21,167.0
Bristol- Myers Squibb Company	New York, NY	19,207.0
Wyeth	Madison, NJ	18,755.8

No secondary data were available on the total market for backup power in the pharmaceutical industry.

MARKET TRENDS

Secondary research identified one fuel cell demonstration project in the pharmaceutical industry in a grid parallel application; there are no known fuel cell demonstrations in backup power applications for this sector.

In 2002, Merck installed a fuel cell at its Rahway, New Jersey, facility, making it the first pharmaceutical company in the U.S. to adopt fuel cell technology.[374] The 200 kW PAFC,

[371] Pentadyne Power Corporation. 2006. Case Study: Multinational Pharmaceutical Company Depends on Pentadyne's DC Flywheel to Keep Data Center Operations Up and Running. Available at http://www.pentadyne.com/Power%20Protection%20for%20Pharmaceutical%20Applications.pdf [Accessed December 2006].
[372] S&C Electric Company. 2004. PureWave UPS System Provides a "Shot in the Arm" to Pharmaceutical Manufacturer. Case Study 653-1002, September 13, 2004.
[373] Hoovers, Inc. 2006. Industry fact sheets. Available at http://premium.hoovers.com/ [Accessed July 2006].

developed by United Technologies Corp., provides supplemental power for manufacturing and research operations at the 210 acre Merck complex in Rahway. The installation was initiated as a 4 year demonstration program. The project was made possible by funding incentives from the New Jersey Clean Energy Program and the DoD Climate Change Program.

A few pharmaceutical companies participate in U.S. EPA's Climate Leaders program, including Pfizer, Johnson & Johnson, and Baxter International, Inc. As partners in the Climate Leaders program, these companies have taken steps to reduce U.S. greenhouse gas emissions by reducing energy consumption. Pfizer is beginning to investigate renewable energy sources as an alternative to fossil fuel use. The company has installed a photovoltaic system at a facility in Germany and plans to continue to seek opportunities to implement clean energy technologies in the future.[375]

MARKET SEGMENT ANALYSIS

Approximately 15 pharmaceutical companies were contacted to further determine requirements for backup power and the potential for application of fuel cells. Obtaining responses from pharmaceutical companies proved difficult; no responses to surveys were received.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Based on secondary data analysis, it is difficult to assess the potential for PEM fuel cells to meet backup power for pharmaceutical manufacturing companies. The industry does have promising characteristics, such as a strong demand for backup power due to the high cost of unscheduled downtime. Recent energy-related trends in this sector are also encouraging, including Merck's fuel cell demonstration project and industry involvement in the EPA's Climate Leaders program, which is exploring alternatives to fossil fuels.

However, additional data from end users is required to adequately assess the mid- to long-term potential for fuel cell technology in this sector. Specifically, information on the current backup power systems used, specific applications they support, and user satisfaction with these systems needs to be better understood.

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[374] Merck. 2002. Merck Installs Cutting Edge Fuel Cell Technology. Available at http://www.merck.com/about/feature_story/11112002_fuel_cell.html [Accessed December 2006].
[375] U.S. EPA. 2006. Climate Leaders. Available at http://www.epa.gov/climateleaders/ [Accessed December 2006].

RESEARCH SUMMARY:
RAILWAYS

MARKET SEGMENT DESCRIPTION

Railways are used by various industries for short- and long-range transportation of goods and materials; they are also used for short- and long-range passenger transportation. Line-haul rail provides freight transportation and passenger transportation over longer distances, while subway and transit rail provide local and suburban transit. Subway and transit rail furnish mass passenger transportation over regular routes and on regular schedules, with operations confined principally to a municipality, contiguous municipalities, or a municipality and its suburban areas. A sector that provides critical support to railways is the switching and terminal operations industry. This industry includes establishments primarily engaged in the furnishing of terminal facilities for rail passenger or freight traffic for line-haul service, and in the movement of railroad cars between terminal yards, industrial sidings, and other local sites. Terminal companies do not necessarily operate any vehicles but may operate the stations and terminals. Table r-1 lists the SIC and NAICS classifications associated with railways.

Table r-1. SIC and NAICS Codes for Railways.

2-Digit SIC Codes	40 – Railroad transportation 41 – Local, suburban transit & interurban highway passenger transport
4-Digit SIC Codes	4011 – Railroads, line-haul operating 4013 – Switching and terminal services 4111 – Local and suburban transit
NAICS Codes	482111 – Line-haul railroads 482112 – Short line railroads 485112 – Commuter rail systems 485119 – Other urban transit systems 488210 – Support activities for rail transportation

Railways use backup power for a variety of applications; secondary research indicated that the most important application was backup power for signal and crossing mechanisms, particularly for freight railroads. Primary research also revealed that subway and transit rail use backup power technologies to provide power for railway coaches and on-train applications such as doors and lighting. The primary technology used to provide backup power in the railways sector is batteries.

Typical applications of backup power in the railway sector include the following:

- Signals and Crossing Guard Mechanisms – This includes active warning devices, interlocking and control points, and crosses interconnected with traffic signals. Current backup used/required is a 12 to 16V battery system for the controls, lights, and gate at active warning intersections.
- Coach Backup Power – Emergency backup power for railway coaches (passenger quarters). Coach backup power typically uses NiCd batteries, which provide 3 to 5 hours of backup life.
- Mass Transit Backup – Emergency backup power for mass transit and electric locomotives (electromotive units, or EMUs). This includes metro systems (underground,

elevated, and ground-level), rapid suburban rail networks, tramways, automatic shuttles, and buses. Backup systems provide buffer power for on-board systems, such as door opening or braking, as well as backup power for other onboard systems such as air conditioning and lighting. Backup times typically required are between 20 and 90 minutes; NiCd batteries are currently the primary backup power source.

- On-site Communications – This includes railway station/terminal communications, computer equipment, and telephone switches and air conditioning in order to maintain safe and timely operations.

MARKET SIZE

Table r-2 presents market statistics on the railway sector. Only the eight-digit SIC Code specialties relevant to railways are shown. There are approximately 2,800 U.S. establishments involved in line-haul rail operations (SIC Code 4011), employing over 98,000 individuals in electric railroads, interurban railways, and steam railroads. The terminal and switching services industry (SIC Code 4013) includes nearly 700 establishments and employs almost 23,000 individuals. With total sales of over $3.4 billion, the local and suburban transit market (SIC Code 4111) comprises approximately 4 % of total sales in the railway sector.[376]

Table r-2. Number of Businesses Associated with Railroad Operation – Industries: Railroads, Line-haul Operating (4011), Switching and Terminal Services (4013), and Local and Suburban Transit (4111).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
4011-0000	Railroads, line-haul operating	2,644	93,322	83,517.797
4011-9901	Electric railroads	40	476	223.6
4011-9902	Interurban railways	96	4,384	2,933.9
4011-9903	Steam railroads	14	169	15
4013-0000	Switching and terminal services	445	12,033	751.3
4013-9901	Belt line railroads	8	170	55
4013-9902	Logging railroads	12	50	3.5
4013-9903	Railroad switching	100	2,692	373.4
4013-9904	Railroad terminals	129	8,010	71.8
4111-0400	Passenger rail transportation	77	1,760	139.4
4111-0401	Commuter rail passenger operation	29	11,165	1,410.9
4111-0402	Local railway passenger operation	49	2,115	266.3
4111-0403	Subway operation	38	5,555	1,573.4
4111-9902	Elevated railway operation	8	131	19
	Total	**3,689**	**142,032**	**91,354**

Sales figures are in millions. Source: www.zapdata.com, accessed September 2006.

The key players in line-haul rail operations are the large railroad companies, which include the main passenger railway, Amtrak, as well as freight railways, such as CSX, Union Pacific, and Burlington Northern Santa Fe (BNSF). Other key players in the railway market include active warning device/signal manufacturers, such as Digicon, Safetran, Union Switch and Signal, and Western-Cullen-Hays; the Association of American Railroads; AREMA (American Railway Engineering and Maintenance-of-Way Association); Departments of Transportation; and the Federal Railroad Administration.

[376] Dun and Bradstreet. 2006. Zapdata industry report. Available at http://www.zapdata.com [Accessed September 2006].

Freight Rail: Backup Power for Signal and Crossing Guard Mechanisms
The market size for backup power for signal and crossing guard mechanisms in the U.S. freight and passenger line-haul rail market can be characterized by the following statistics:[377]

- Total railroad crossings – 253,000
- Active crossings (crossings with warning devices) – 65,000
- Crossings interconnected with traffic signals – 9,000
- Interlocking/control points – 5,000
- On-site backup – 2,800 (number of sites)
- Units less than 15 kW – 1,375 (annual sales volume in units)
- For units < 15 kW – priced $4,000 to $6,000 per unit, $4 to 8 million in sales.

Railroads invest a substantial amount of time and resources into improving rail safety, including ensuring safe crossings. For instance, Union Pacific averages about 400 diagnostic (signal crossing improvement) projects annually on its 23-state system.[378] BNSF spent approximately $36 million in 2005 on grade-crossing signal maintenance and repair, which includes inspection of gates, lights, and backup power sources.[379]

Subway and Transit Rail: Backup Power for Rail Coaches, On-board Lights, etc.
Local and suburban transit rail is primarily comprised of public transit systems. Large metropolitan areas often have significant investments in rail systems such as subways. Cities with railways of significant size include:

- New York City – Metropolitan Transportation Authority (MTA)
- Chicago – Chicago Transit Authority (CTA)
- Washington, DC – Washington Metropolitan Area Transit Authority (WMATA)
- San Francisco – Bay Area Rapid Transit (BART)
- Boston – Massachusetts Bay Transportation Authority (MBTA)
- Atlanta – Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Philadelphia – Southeastern Pennsylvania Transportation Authority (SEPTA)
- Miami – Miami-Dade Transit Service
- Cleveland – Greater Cleveland Regional Transit Authority
- Los Angeles – Los Angeles County Metropolitan Transportation Authority (MTA)
- Baltimore – Maryland Mass Transit Administration (MTA)

The New York City Department of Transportation (NYCDOT) has been considering adding battery backup to signals at critical intersections. Substations convert as many as 27,000 V of power-plant electricity for use in the subway.[380] Alternating current (AC) operates signals, station and tunnel lighting, ventilation, and miscellaneous line equipment. Direct current (DC) operates trains and auxiliary equipment, such as water pumps and emergency lighting. As a

[377] Ducker Worldwide, Inc. 2002. Market Opportunity Assessment for Long Term Standby Gensets in the United States. Market assessment provided for Battelle Memorial Institute by Ducker Worldwide Inc.
[378] Union Pacific Railroad. 2003. Who Decides Where Railroad Crossings Are Located? Available at http://www.uprr.com/newsinfo/railroad/2003/1216_install.shtml [Accessed September 2006].
[379] Burlington Northern Santa Fe Railway. 2006. Grade Crossing Safety. Available at http://www.santaferailway.com/communities/pdf/4_GradeCrossingSafety.pdf [Accessed September 2006].
[380] Metropolitan Transportation Authority. 2006. Subways. Available at http://mta.info/nyct/facts/ffsubway.htm [Accessed September 2006].

point of reference, the NYC Transit subway system uses enough power annually to light the City of Buffalo for a year. In the subway system, backup power is required for functions such as lighting and ventilation, as well as signals. Not all intersections require backup power. The following statistics indicate the size of the NYC subway system:[381]

- NYC has 11,600 signalized intersections
- NYC Transit Department of Signals operates 6,700 trains
- 11,646 track circuits and 11,000 automatic train stops
- 12,080 wayside signals (which are being converting to LCD displays)
- 361 storage batteries
- NYC Transit track and infrastructure (annual) budget
    - Operating (maintenance): $116 million
    - Capital: $150 million.

MARKET TRENDS

Overall industry growth in the railway sector is flat. Additionally, railways are attempting to close unnecessary crossings (e.g., Union Pacific has closed more than 1,000 in the last four years; BNSF has closed 3,000 in the last six years[382]). Railways are also developing systems in addition to signals to help prevent accidents due to broken or faulty crossing and grade signals. Alaska Railroad is developing a Collision Avoidance System (CAS), which is a computer-based network designed to prevent train-to-train collisions, among other functions.[383] The DOT is incorporating sensors, computers, and digital communications into "Intelligent Railroad Systems" for train control (including braking, grade-crossing warnings, and planning). The impact of these systems on the need for backup power is unclear; however, they may signify some reduction in the need for signals. Still, some growth projections for backup power applications, particularly in signals and crossings applications, are healthy, given that certain measures are taken to educate and promote backup power in the railroad segment.[384]

A number of factors are driving the need for backup power in the railways industry. One driver for backup power in locomotives is to maintain low-cost operations and high customer satisfaction. Storms and heavy weather can cause commercial power outages, producing extensive signal damage and disrupting rail operations. Some railroads are using geographic information systems (GIS) and weather forecasting to prepare for outages; however, backup power is still considered critical. A power outage in the northeast U.S. recently interrupted Amtrak transit service, stranding thousands of rush-hour commuters in hot tunnels.[385]

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[381] No author. 2004. 100 years of subway signals. Railway Age 205(6). Available at http://www.findarticles.com/p/articles/mi_m1215/is_6_205/ai_n6134827/pg_1 [Accessed September 2006].
[382] Burlington Northern Santa Fe Railway. 2006. Grade Crossing Safety. Available at http://www.santaferailway.com/communities/pdf/4_GradeCrossingSafety.pdf [Accessed September 2006].
[383] No author. 2004. CBTC under way in Alaska. Railway Age 205(1). Available at http://www.findarticles.com/p/articles/mi_m1215/is_1_205/ai_112985914 [Accessed September 2006].
[384] Ducker Worldwide, Inc. 2002. Market Opportunity Assessment for Long Term Standby Gensets in the United States. Market assessment provided for Battelle Memorial Institute by Ducker Worldwide Inc.
[385] King, L. 2006. Amtrak presses its probe of massive rail power outage. The Philadelphia Inquirer (May 27, 2006). Available at http://www.railserve.com/railnews/newsjump.cgi?http://www.philly.com/mld/inquirer/news/local/states/pennsylvania/counties/bucks_county/14679078.htm [Accessed September 2006].

Power interruptions to Canadian National's communications equipment and intermodal operations have caused major disruptions in shipping schedules.[386] Any delays at the yard can quickly ripple throughout the entire rail network, costing the railroad thousands of dollars in penalties for late deliveries. However, when Canadian Pacific recently experienced a power outage, emergency backup power allowed it to continue railway operations uninterrupted.[387]

More important than inconveniences and disruptions to services, backup power for signals and crossings is required for safety. CSX has received two fines of over $225,000 in the last several years related to signal failure as a cause of crossing accidents.[388,389] Although railroads have standards and long-standing legislation for backup power at signal crossings, highway traffic signals do not currently utilize any backup power device.[390] Due to train/car accidents, there is recent legislation regarding the need for backup power at rail crossings where traffic signals are interconnected; such legislation may increase the market for backup power in rail and associated segments.[391]

Future legislation/regulations could help promote the use of backup power for traffic signal/railroad interconnections. The Federal Transit Authority and the Federal Railroad Administration, as well as railroad companies, are key decision-makers in establishing new railway crossings.[392] Regulators and stakeholders, such as the Federal Transit Authority and the Federal Railroad Administration, will have an impact on the need and standards for backup power.

In addition to backup power for locomotives, signals, and crossings, backup power for communication equipment and computers used in railway operations is important. During the 2003 blackout that affected the northeastern U.S. and Canada, transportation agencies learned to keep low-tech phones on hand in case of a power outage. Other agencies realized, during an extended outage in August, that computer equipment supported by backup generators would require air conditioning to maintain a safe operating temperature.[393]

There have been a limited number of fuel cell demonstration projects in this sector, and some interest in developing a fuel cell-powered train. In February 2005, New York Power Authority installed two 200 kW PAFCs in the Grand Central train station terminal. The fuel cell uses natural gas to produce hot water used in restaurants and hotels. In 2006, New York Power Authority is slated to install a 200 kW PAFC in a subway maintenance facility in Corona. The PAFC will generate electricity for railway maintenance and cleaning equipment, and will be able

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[386] Judge, T. 2004. Weathering the Storms. Railway Age 205 (10): 20.
[387] Judge, T. 2004. Weathering the Storms. Railway Age 205 (10): 20.
[388] No author. 2006. Cracking down on crossing safety: FRA fines CSXT $227,000 for fatal warning system failure at New York grade crossing. Progressive Railroading.Com. Available at http://www.progressiverailroading.com/freightnews/article.asp?id=8354 [Accessed October 2006].
[389] No author. 2005. CSX agrees to improve railroad crossing safety. The Business Review (March 7, 2005). Available at http://www.bizjournals.com/albany/stories/2005/03/07/daily7.html [Accessed October 2006].
[390] Ducker Worldwide, Inc. 2002. Market Opportunity Assessment for Long Term Standby Gensets in the United States. Market assessment provided for Battelle Memorial Institute by Ducker Worldwide Inc.
[391] Ducker Worldwide, Inc. 2002. Market Opportunity Assessment for Long Term Standby Gensets in the United States. Market assessment provided for Battelle Memorial Institute by Ducker Worldwide Inc.
[392] Union Pacific Railroad. 2003. Who Decides Where Railroad Crossings Are Located? Available at http://www.uprr.com/newsinfo/railroad/2003/1216_install.shtml [Accessed September 2006].
[393] Judge, T. 2004. Weathering the Storms. Railway Age 205 (10): 20.

to operate as a standalone generator during a grid power outage.[394] An international consortium, led by Vehicle Projects LLC of Denver, is developing a 1 MW fuel cell-powered locomotive. The five-year project began in May 2003 to develop and demonstrate the first fuel cell-powered locomotive for military and commercial railway applications.[395] However, there have been no fuel cell demonstrations in backup power applications in the railroad sector.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in the railroad industry, 26 individuals were contacted, and six responses were received. Of the six respondents, three were large freight railways (two from the same company), one was a medium-sized freight railway, and one was a small freight railway. One respondent was a large consulting firm that supports suburban and local transit. Respondents indicated that applications for backup power include signals and crossings, bridges, emergency communication, and emergency lighting. All respondents indicated that signals and crossings were critical. The local transit railway indicated that emergency communication and lighting were also critical.

Participants indicated difficulty in determining the frequency and duration of blackouts. One indicated that the severity of a blackout depended on circumstances (e.g., if a train is approaching a crossing). Three companies indicated that outages of longer durations (i.e., > 1 hour) would have a more severe impact than those of shorter durations (i.e., < 1 hour). One company indicated that power outages of all durations were extremely disruptive. On average, companies experienced anywhere from one to ten disruptive power outages per year. Companies indicated that the most significant impact of power outages is on distribution and production, but that safety (in terms of the potential for lost lives) is also a key consideration.

Respondents used a wide variety of technologies from sizes of < 5 kW to > 250 kW to provide backup power. All respondents indicated that they use batteries. The following technologies were also used by two or more organizations: backup generators, solar cells, UPS units, and wind power. Respondents had one-to-two backup units per signal, crossing, or station. The overall number of backup units depended on the size of the company and the number of signals and crossings it maintains. All respondents indicated that reliability was a critical factor in backup power systems. Other critical factors noted to be important were: start-up time (identified by four respondents), lifetime of the unit (identified by three respondents), and ease of use (identified by two respondents). Five of the six respondents indicated that the performance of their current backup systems was very good; one did not address the issue of performance. Concerns regarding current backup systems included high capital cost and lack of reliability.

When asked to rate current backup systems compared to alternatives, five respondents rated reliability as good; one rated reliability as very good. Start-up time was rated good by two respondents and very good by four. Respondents rated the lifetime of their backup units as fair to good; they rated ease of use as good to very good.

All respondents anticipated a growing need for backup power in the railroad industry. Three of the six respondents had considered alternatives to their current backup power systems; among

[394] No author. 2004. Rail experts press for cash to fund research into fuel-cell locomotives. Professional Engineering 17(8): 6.
[395] No author. 2004. Rail experts press for cash to fund research into fuel-cell locomotives. Professional Engineering 17(8): 6.

the alternatives considered were diesel and propane generators and flywheel systems. Two of the six had heard of PEM fuel cells as a means of supplying backup power. While neither of these two thought that PEM fuel cells would be able to successfully compete against alternatives, they indicated that the factors driving adoption would be: energy efficiency, environmental benefits, positive demonstration projects, price, and availability of government incentives.

One respondent indicated that the decision to purchase backup systems is based on initial capital cost; three indicated that it is based on payback period, and one indicated that it is based on return on investment. Incentives are usually considered when they are offered. Purchase decisions for backup signal power are made by the signals departments or other individuals with engineering expertise. Standards departments are often consulted as well.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Within the railroad industry, backup power for signals and crossings represents the most critical application area. While the industry as a whole may not be large, the number of signals and crossings distributed across U.S. railroad and suburban transit systems is significant. PEM fuel cell products are considered as a good fit with user requirements for this application and in this industry. They are expected to meet user requirements for high reliability, quick start-up time, and ease-of-use. Additionally, the small power size requirements for signal and crossing applications fit will with commercially available PEM fuel cells.

Significant market growth is not projected for either line-haul or transit rail; it is expected that the market size, particularly for transit rail, will remain steady. However, regulatory requirements may drive increased interest in backup power for both line-haul and transit rail. PEM fuel cells may offer advantages in reliability and durability in harsh climates over current backup sources (primarily batteries), but cost is expected to be a barrier to market adoption in this segment. Additionally, the railway industry has been characterized as having a "high willingness to work with new products"[396] and may offer a potential market for PEM fuel cells.

[396] Ducker Worldwide, Inc. 2002. Market Opportunity Assessment for Long Term Standby Gensets in the United States. Market assessment provided for Battelle Memorial Institute by Ducker Worldwide Inc.

RESEARCH SUMMARY:
SKI RESORTS

MARKET SEGMENT DESCRIPTION

The ski resort industry comprises establishments primarily engaged in providing short-term lodging as well as alpine recreational activities, including downhill skiing, cross-country skiing, Telemark skiing, snowboarding, etc. In addition, the establishments in this industry may offer services such as food and beverage services, recreational services, conference rooms and convention services, spa facilities, ski and snowboard lessons, snow-making and grooming operations, shopping and other retail services, ski-lift and tramway transportation, laundry services, and parking. Table s-1 identifies the primary SIC and NAICS codes associated with this market segment.

Table s-1. SIC and NAICS Codes Associated with Ski Resorts.

2-Digit SIC Codes	79 – Amusement and recreation services
4-Digit SIC Codes	7999 – Amusement and recreation, not elsewhere classified
NAICS Code	713920 – Skiing facilities

A report prepared by Spirae Inc. and The Brendle Group provides a summary of energy use for ski area operations.[397] The report notes that while the bulk of the energy use at ski areas is associated with driving the motors that operate chair lifts and the air compressors and water pumps used in snow making, various other ski resort facilities also require electricity, including lodges, restaurants, shops, ticket sales offices, maintenance facilities, and others. These facilities use electricity not only for lighting, cooking, and operating HVAC fans, pumps, and other equipment, but also for space and water heating during much of the operating season.

Ski resort operations require constant power. Hospitality and lodging provide services on a constant basis; recreational facilities typically operate during daytime hours; while maintenance activities, such as snow-making, occur primarily at night. Operating chair lifts (daytime) and making snow (nighttime), consume the bulk of the energy at ski areas, which in some months can be on the order of 80 % or more.

The halting of the ski lift operations from power loss can result in the need to rescue passengers from lifts.[398,399] In those cases when power went out, backup generators were used to power the ski lifts so passengers could safely depart in a timely manner. Chair lift operations are required to have a backup source of power in order to evacuate passengers in case of an emergency. One New York ski resort uses a Prime Energy 1,500 kW generator system as a backup power source

[397] Spirae Inc. and The Brendle Group. 2004. The Role of Distributed Energy Resources in Optimizing Energy Use for Ski Area Operations. Final report, submitted to the Colorado Governor's Office of Energy Management and Conservation and the U.S. Department of Energy Denver Regional Office. Available at http://www.eere.energy.gov/de/pdfs/der_ski_areas.pdf [Accessed September 2006].
[398] No author. 1995. Power outage strands skiers. Milwaukee Sentinel (February 4, 1995). Available at http://www.findarticles.com/p/articles/mi_qn4208/is_19950204/ai_n10183939 [Accessed September 2006].
[399] Ski Press Media, Inc. 2004. Powder causes power outage in Telluride. Ski Press (March 3, 2004). Available at http://www.skipressworld.com/us/en/daily_news/2004/03/powder_causes_power_outage_in_telluride.html?cat=Resorts [Accessed September 2006].

for ski lift operations.[400] Numerous other resorts report the use of generators to use off-grid power sources and for load-shedding in order to reduce demand during peak periods.[401]

The predominant backup system used for ski lifts is a diesel engine connected via V-belts, chain, gear drive, or driveshaft to the speed-reducing gearbox.[402] Additionally, a few gasoline engines are used, typically on smaller lifts. Engine capacities, which tend to vary depending on the vertical gain and length of the lift as well as the chair spacing, range from relatively small (less than 50 HP or 37 kW) to well over 1,000 HP (746 kW), in one case exceeding 2,500 HP (1,864 kW). Well over one-third of the total lifts had backup systems rated at 100 HP (75 kW) or less, providing less than 5% of the total HP of all lifts. The large number of smaller chair lifts skews this value lower than might be expected; the average power rating is just over 250 HP (186 kW).

MARKET SIZE

Current data on the ski resort market are provided below. SIC Codes 7011 and 7999 covering ski resorts and ski resort activities, respectively, are represented in Table s-2. Only the eight digit SIC Code specialties relevant to ski resorts are shown.

Table s-2. Number of Companies Associated with Ski Resorts and Ski Resort Activities – Industry: Amusement and Recreation, nec (7999).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
7999-1119	Ski instruction	171	1,714	69.8
7999-1501	Aerial tramway or ski lift, amusement or scenic	84	4,172	245.9
7999-1510	Ski rental concession	227	2,061	109.8
	Total	**482**	**7,947**	**425.5**

Sales figures are in millions. Source: www.zapdata.com, accessed September 2006.

The National Ski Areas Association (NSAA) reports that 492 ski areas operated in the United States during the 2004/2005 ski season, according to its 2004/2005 Kottke National End of Season Survey.[403]

The breakdown of the 492 ski resorts by location is shown in Table s-3. With 50 ski areas in operation during the 2004/2005 season, Colorado leads the ski industry, followed by Michigan (44), Wisconsin (36), and Pennsylvania (35).

[400] Hull, P. 2004. Leasing power. Distributed Energy, the Journal for Onsite Power Solutions (May/June). Available at http://www.distributedenergy.com/de_0405_leasing.html [Accessed September 2006].
[401] National Ski Areas Association. 2006. Energy use for lifts. Available at http://www.nsaa.org/nsaa/environment/the_greenroom/index.asp?mode=greenroom&topic=T09 [Accessed September 2006].
[402] Spirae Inc. and The Brendle Group. 2004. The Role of Distributed Energy Resources in Optimizing Energy Use for Ski Area Operations. Final report, submitted to the Colorado Governor's Office of Energy Management and Conservation and the U.S. Department of Energy Denver Regional Office. Available at http://www.eere.energy.gov/de/pdfs/der_ski_areas.pdf [Accessed September 2006].
[403] National Ski Areas Association. 2005. 492 U.S. ski resorts in operation during 2004-2005 season. Available at http://www.nsaa.org/nsaa/press/2005/04-05-sa-number-history.pdf [Accessed September 2006].

Table s-3. Ski Areas Operating Per State.[404]

Alabama (1)	Massachusetts (15)	Ohio (6)
Alaska (9)	Michigan (44)	Oregon (13)
Arizona (4)	Minnesota (22)	Pennsylvania (35)
California (31)	Missouri (2)	Rhode Island (1)
Colorado (27)	Montana (16)	South Dakota (3)
Connecticut (6)	Nebraska (1)	Tennessee (1)
Georgia (1)	Nevada (4)	Utah (15)
Idaho (16)	New Hampshire (22)	Vermont (20)
Iowa (6)	New Jersey (3)	Virginia (3)
Illinois (5)	New Mexico (10)	Washington (13)
Indiana (4)	New York (50)	West Virginia (4)
Maine (20)	North Carolina (6)	Wisconsin (36)
Maryland (1)	North Dakota (6)	Wyoming (10)

Although the number of ski resorts has declined, the popularity of skiing and other winter sports seems to be increasing. The NSAA reports that five of the six best seasons on record have all occurred in the past six years, and that ski visits are up in all regions. Preliminary estimates for the NSAA's Kottke End of the Season Report show that national skier visits for the 2005/2006 season set an all-time record of 58.8 million visits, an increase of 3.3% from 2004/2005, and 2% higher than the previous record set in 2002/03.[405] Visits to the Pacific West, which contributed an increase of nearly 1.3 million visits, contributed to the record-setting season. Specifically, the Pacific Northwest rebounded from one of its worst seasons on record last season and shows an estimated 125% increase. The Rocky Mountain region, the largest of the five NSAA regions, registered a gain of 5.8%, or over 1.1 million additional visits over the previous record set in 2004/2005. Both the Southeast and Midwest regions also reported solid visitation in 2005/2006, contributing estimated increases of 6.1% and 3.4%, respectively, in comparison to 2004/2005.

MARKET TRENDS

As noted above, the ski industry is heavily dependent on electricity for its primary business operations.[406] This analysis provides evidence that the ski industry is moving toward a more environmentally conscious business model. A key driver is the fact that many people visit ski areas to experience the natural beauty of resort surroundings (i.e., they desire an environment free of noise and noxious emissions). Such visitors also tend to place a high priority on environmental concerns.

One example of industry's shift in environmental awareness is the development and adoption of an Environmental Charter, commonly referred to as "Sustainable Slopes," which provides guidance to resorts on the "greening" of all aspects of operations.[407] This Charter consists of 21 best practices for ski area owners and operators and focuses on various topics, including water conservation, fish and wildlife habitat protection, energy conservation, waste reduction, and air

[404] National Ski Areas Association. 2005. Ski areas operating per state. Available at http://www.nsaa.org/nsaa/press/0506/04-05-sa-per-state.pdf [Accessed September 2006].
[405] National Ski Areas Association. 2006. Preliminary Kottke Report indicates 2005/06 skier visits hit all-time record. Available at http://www.nsaa.org/nsaa/press/2006/PreliminaryReportKottke06.asp [Accessed September 2006].
[406] Spirae Inc. and The Brendle Group. 2004. The Role of Distributed Energy Resources in Optimizing Energy Use for Ski Area Operations. Final report, submitted to the Colorado Governor's Office of Energy Management and Conservation and the U.S. Department of Energy Denver Regional Office. Available at http://www.eere.energy.gov/de/pdfs/der_ski_areas.pdf [Accessed September 2006].
[407] National Ski Areas Association. 2006. Sustainable Slopes: The environmental charter for ski areas. Available at http://www.nsaa.org/nsaa/environment/sustainable_slopes/Charter.pdf [Accessed September 2006].

quality. According to the 2006 Sustainable Slopes Annual Report, 180 resorts have endorsed the Environmental Charter since its adoption in June 2000, representing over 75 % of the ski resorts nationally (based on skier/snowboarder visits).[408]

An example of the industry's efforts to mitigate impacts of climate change is the Keep Winter Cool campaign.[409] Recognizing the potentially disastrous effects of climate change upon the earth's systems and its bottom line, the ski resort industry has adopted a climate change policy. Keep Winter Cool is a partnership between the Natural Resources Defense Council and NSAA, and its goals are to raise visibility and public understanding of global warming and to spotlight existing opportunities to start addressing the issue.

The ski industry's focus on environmental concerns could be a compelling driver for fuel cell use in this market segment. However, no evidence was found to suggest that fuel cells are currently being used in any U.S. ski resorts. The Spirae Inc./Brendle Group report indicates that while fuel cells in the ski industry are a promising concept they are still cost-prohibitive. The analysis cites several challenging cost barriers associated with fuel cells, including: membrane technology development; platinum loading; and the sheer number of cells, and thus separate component layers of precision-fabricated materials, that must be stacked up to provide adequate power for most applications.[410] The report also explores limitations associated with other energy alternatives, such as diesel generators, batteries, and wind turbines.

MARKET SEGMENT ANALYSIS

Twenty ski resorts, associations, and resort operators were contacted to try to gather information on requirements for backup power and the potential for fuel cell use in ski resorts. One complete survey response was received.

According to the one survey response, backup power is provided for lift operations. It was indicated that power outages do not pose a significant problem; however, longer interruptions of power to ski lifts are of greater concern than shorter outages. Diesel and propane generators serve as the sole source of backup power; each lift in operation at the resort has its own generator for backup power.

Reliability, start up time, and emissions were cited by the respondent as the most important factors guiding the choice of backup power. The respondent indicated that resort personnel are highly satisfied with the use of generators for backup power. The resort representative indicated they had not considered alternatives to their current backup power sources and, while they were aware of PEM fuel cells as backup power sources, they did not think PEM fuel cells were currently a viable alternative due to high costs.

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[408] National Ski Areas Association. 2006. Ski industry releases annual environmental report. Available at http://www.nsaa.org/nsaa/press/2006/SkiIndustryReleasesAnnualEnvironmentalReport.asp [Accessed September 2006].
[409] National Ski Areas Association. 2006. Keep Winter Cool campaign. Available at http://www.nsaa.org/nsaa/environment/climate_change/keep_winter_cool.asp [Accessed September 2006].
[410] Spirae Inc. and The Brendle Group. 2004. The Role of Distributed Energy Resources in Optimizing Energy Use for Ski Area Operations. Final report, submitted to the Colorado Governor's Office of Energy Management and Conservation and the U.S. Department of Energy Denver Regional Office. Available at http://www.eere.energy.gov/de/pdfs/der_ski_areas.pdf [Accessed September 2006].

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Regulatory requirements directing the use of backup power for chair lift operations is a key driver of the demand for backup power in the ski industry. PEM fuel cells appear to be a good size fit with industry requirements for backup power. It is also expected that the industry would welcome the opportunity to eliminate diesel emissions from its operations in light of the industry's efforts to manage its environmental impacts and appeal to its environmentally conscious customers. However, the market size is small. Approximately one-third of chair lifts require backup systems of 75 kW or smaller. Assuming the roughly 500 ski areas in the U.S. have at least a two small chair lifts, the potential market would be over 1000 units.

In addition, other barriers exist to the adoption of PEM fuel cells. Ski resort owners and operators have indicated that cost would be a significant barrier. The lack of understanding about PEM fuel cell performance in cold climates could also present a potential barrier. Furthermore, ski resorts appear to be generally satisfied with generators as their primary backup power source and are thought to be unlikely to switch without significant incentives. While encouraging, the real impact of recent industry "greening" efforts, such as the adoption of the Sustainable Slopes charter, is yet to be seen in terms of influencing capital investment decisions for power technologies.

RESEARCH SUMMARY:
WATER AND WASTEWATER TREATMENT

MARKET SEGMENT DESCRIPTION

Water treatment plants include establishments primarily engaged in distributing water for sale for domestic, commercial, and industrial use. Wastewater or sanitary sewage treatment plants include establishments primarily engaged in the collection and disposal of wastes released into a sewer system by residences, businesses, and industries in a community. This analysis considers the potential for PEM fuel cells for backup power in these market segments. The handling of storm water and other runoff is not included in this analysis. Table t-1 identifies the SIC and NAICS codes associated with water and sewage treatment plants.

Table t-1. SIC and NAICS Codes for Water and Wastewater Treatment Plants.

2-Digit SIC Code	49 – Electric, gas, and sanitary services
4-Digit SIC Codes	4952 – Sewerage systems
	4941 – Water supply
NAICS Codes	221320 – Sewage treatment facilities
	221310 – Water supply and irrigation systems

Secondary research indicates that there is a need for continuous power and reliable backup power at wastewater treatment plants and pumping stations, due to the problem of sewage overflow during a power outage.[411] Public water systems also have a need for backup power, in case of loss of electrical power, at the treatment plant to continue treating water and at pumping stations that distribute drinking water to customers. Backup power maintains operation of the SCADA or computer system that monitors and controls plant processes. At some plants, backup power is also required for emergency lights and communications.

Diesel-fueled generators (either leased or permanently installed) are typically used for backup power. In New York City, nearly all treatment plants are provided with backup generators to prevent sewage overflows in case of a power failure. However, the lag time before generators begin operating, in addition to the possibility of faulty or inoperable generators, can result in spilled sewage. Due to their size, diesel-fueled generators also require additional real estate at the pump station.[412]

UPS systems may also be used in combination with generators to provide backup power at water and wastewater treatment plants. Sometimes batteries and multiple power feeds from the local power company are utilized. Primary research gathered from water/wastewater treatment plants indicates that generators used for backup power range in size from approximately 15 kW to 1,000 kW.

[411] No author. 2006. Power Outage Unleashes Raw Sewage. Washington Post (May 20, 2006). Available at http://www.washingtonpost.com/wp-dyn/content/article/2006/05/19/AR2006051901595.html [Accessed June 2006].
[412] WaterTechONLINE. 2003. NYC officials: Wastewater a problem following blackout. Available at http://watertechonline.com/News.asp?mode=4&N_ID=42621 [Accessed March 2006].

MARKET SIZE

Hoover's, Incorporated reports approximately 50 wastewater treatment companies in the U.S. (SIC Code 4952). The top ten companies, by sales, are listed in Table t-2. The number of facilities, or sewage treatment plants (STPs) operated by these companies vary. No specific information on the exact number operated by each company could be located. U.S. EPA reports 16,255 wastewater treatment facilities in the U.S. in the year 2000.[413]

Table t-2. U.S. Wastewater Treatment Companies, by Sales.

Company Name	Location	Sales ($ mil)
Gold Kist Inc.	Atlanta, GA	2,304.30
South Carolina Public Service Authority	Moncks Corner, SC	1,151.00
Covanta Energy Corporation	Fairfield, NJ	700.4
Lower Colorado River Authority	Austin, TX	694.4
Orlando Utilities Commission	Orlando, FL	673.1
Knoxville Utilities Board	Knoxville, TN	525.6
Aqua America, Inc.	Bryn Mawr, PA	496.8
Washington Suburban Sanitary Commission	Laurel, MD	442.7
Public Utility District No. 1 of Clark County	Vancouver, WA	423.6
California Water Service Group	San Jose, CA	320.7

Source: Hoover's, Inc. 2006. Available at www.Hoovers.com. Accessed 6-27-06.

Hoover's, Incorporated reports 82 water distribution companies in the U.S. (SIC Code 4941). The top ten companies, by sales, are listed in Table t-3. The U.S. public water system consists of approximately 53,000 community water systems and 21,400 not-for-profit non-community water systems (e.g., schools, churches). Approximately 85% of the 53,000 community water systems are small systems serving 3,300 or fewer consumers. The remainder are large water systems (1,041 systems) serving greater than 50,000 people, and medium systems (7,638 systems) serving 3,301 to 50,000 people.[414]

Table t-3. Top Ten U.S. Water Treatment Companies, by Sales.

Company Name	Location	Sales ($ mil)
Wisconsin Energy Corporation	Milwaukee, WI	3,815.50
Salt River Project	Tempe, AZ	2,251.70
We Energies	Milwaukee, WI	2,147.50
Wisconsin Power and Light Company	Madison, WI	1,409.60
South Carolina Public Service Authority	Moncks Corner, SC	1,151.00
USFilter Water & Wastewater Systems	Warrendale, PA	720.7
Covanta Energy Corporation	Fairfield, NJ	700.4
Lower Colorado River Authority	Austin, TX	694.4
Orlando Utilities Commission	Orlando, FL	673.1
Knoxville Utilities Board	Knoxville, TN	525.6

Source: Hoover's, Inc. 2006. Available at www.Hoovers.com. Accessed June 2006.

[413] EPA. 2003. Clean Watersheds Needs Survey 2000: Report to Congress. EPA-832-R-03-001. Available at http://www.epa.gov/owm/mtb/cwns/2000rtc/toc.htm [Accessed December 2006].
[414] EPA. 2005. Drinking Water Needs Infrastructure Survey and Assessment: Third Report to Congress. EPA 916-R-05-001. Available at http://www.epa.gov/safewater/needssurvey/pdfs/2003/report_needssurvey_2003.pdf [Accessed December 2006].

MARKET TRENDS

A Drinking Water Infrastructure Needs Survey and Assessment, conducted by U.S. EPA in 2003, indicates that the nation's public water systems need to invest $276.8 billion over the next 20 years to ensure continued safe drinking water for consumers. Needs identified in the U.S. EPA survey include new infrastructure, as well as repair or replacement of deteriorating or inadequate water distribution infrastructure. Of the total needs identified in the survey, $2.3 billion is estimated for upgrades categorized as "Other," which includes emergency power generators among other projects.[415]

Medium and large community water systems represent the greatest need for improvement in EPA's Drinking Water Infrastructure Needs Survey and Assessment, with the total cost of improvements estimated at $103 billion and $123 billion, respectively. Capital investment costs, on a per-household basis, are expected to be significantly higher for smaller systems than for larger systems, which can spread the costs over a larger customer base; larger systems can also take advantage of economies of scale. The total estimated cost for improvements to smaller community water systems is $34 billion.[416]

EPA has also documented needed improvements for U.S. wastewater treatment facilities. EPA's 2000 Clean Water Needs Survey reports that much of the nation's wastewater treatment infrastructure has reached or is nearing the end of its design life. The report predicted, based on year 2000 data, that an estimated 1,687 new wastewater treatment facilities were needed, in addition to repair, replacement, or expansion of existing infrastructure.[417] The need for backup power was not specifically noted in EPA's survey.

No reports of PEM fuel cells being demonstrated for backup power at U.S. public water systems were found. Other fuel cells have been demonstrated at a number of facilities in the wastewater treatment market both in the U.S. and overseas. Ability to use anaerobic digester gas (ADG) generated on-site appears to offer a promising solution for meeting a facility's energy needs. Brief descriptions of fuel cell installations at wastewater treatment facilities are presented below. These installations predominantly provide primary electricity to the treatment plant, rather than backup power. Projects initiated in the 2003 to 2004 timeframe include:

- Two 250 kW direct fuel cell units providing electricity and heat for the El Estero Wastewater Treatment Facility in Santa Barbara, California
- A 250 kW direct fuel cell at Palmdale Water Reclamation Plant in Los Angeles, California
- Four 250 kW direct fuel cell modules (forming one 1 MW unit) at South Treatment Plant in Renton, Washington (two-year demonstration project)
- A 250 kW direct fuel cell at the Los Angeles Department of Water and Power (LADWP) Terminal Island wastewater treatment facility in San Pedro, California.[418]

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[415] EPA. 2005. Drinking Water Needs Infrastructure Survey and Assessment: Third Report to Congress. EPA 916-R-05-001. Available at http://www.epa.gov/safewater/needssurvey/pdfs/2003/report_needssurvey_2003.pdf [Accessed December 2006].
[416] EPA. 2005. Drinking Water Needs Infrastructure Survey and Assessment: Third Report to Congress. EPA 916-R-05-001. Available at http://www.epa.gov/safewater/needssurvey/pdfs/2003/report_needssurvey_2003.pdf [Accessed December 2006].
[417] EPA. 2003. Clean Watersheds Needs Survey 2000: Report to Congress. EPA-832-R-03-001. Available at http://www.epa.gov/owm/mtb/cwns/2000rtc/toc.htm [Accessed December 2006].
[418] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].

In 1997, the New York Power Authority (NYPA) installed a UTC Power 200 kW PAFC at the Westchester County Wastewater Treatment Plant in Yonkers, New York. This became the world's first commercial fuel cell to use ADG to produce electricity. Ultra-low emissions (carbon monoxide and sulfur oxide emissions less than 1 ppm, and nitrous oxides less than 0.37 ppm), combined with high efficiency and reliability, prompted the NYPA to purchase eight additional fuel cells, which have been installed at four New York City Department of Environmental Protection wastewater treatment facilities in Brooklyn, Staten Island, the Bronx, and Queens.[419] For example, two 200 kW PAFCs that utilize ADG have operated at Bowery Bay Wastewater Treatment Plant since 2002.[420]

From 1997 to 2002, the Deer Island Sewage Treatment Plant in Boston, Massachusetts, operated a 200 kW PAFC from UTC Power that utilized digester gas.[421]

The City of Portland, Oregon, tested a 200 kW PAFC in 1999 at Columbia Boulevard Waste Water Treatment Plant. The fuel cell provided heat and electricity to the facility, generating as much as 1.6 million kW hours per year. Also in 1999, two 200 kW PAFCs were tested at Las Virgenes Wastewater Treatment Plant in Calabasas, California. The fuel cells provided 99% of on-site electricity.[422]

MARKET SEGMENT ANALYSIS

Approximately 30 wastewater treatment plants were contacted to further determine requirements for backup power and the potential for application of fuel cells. Responses were received from three wastewater treatment facilities, three water distribution centers, and one engineering consulting firm that had experience with water and wastewater systems. All respondents surveyed were small and had less than 500 people on site. The respondent from the engineering consulting firm identified his facility as small, but it should be noted that the respondent is part of a large engineering consulting firm.

Responses from the water treatment facilities are presented separately from the wastewater treatment facilities. Responses from the engineering consulting firm are also summarized separately.

Water Treatment and Distribution Response Analysis

Respondents indicated that backup power was typically required for plant emergency lights, SCADA and communications systems, computer operations, water pump operations including low and high service pumps, chemical feed system, mixers, and filters. All three respondents indicated that SCADA and communications systems were critical to their operations. One respondent indicated that pumps, chemical feed systems, mixers, and filters were also critical to their operations.

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[419] Gangi, J. 2004. Fuel Cells: Providing Customer Value Today. Distributed Energy, the Journal for Onsite Power Solutions (November/December). Available at http://www.distributedenergy.com/de_0411_fuel.html [Accessed June 2006].
[420] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[421] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].
[422] Fuel Cells 2000. 2005. Worldwide Fuel Cell Installations. Available at http://www.fuelcells.org/info/charts/FCInstallationChart.pdf [Last updated October 2005; accessed June 2006].

Two respondents indicated that they had experienced outages over the past year. One respondent reported that ten outages lasted longer than one hour, while the other respondent had experienced three outages, two of which lasting less than 60 seconds and the other one lasting 3 to 5 minutes. Respondents indicated that power outages greater than 1 hour were very disruptive. They indicated that outages could result in loss of safe drinking water, disruptions in production and distribution, and in extreme cases where water is not available for fire protection, outages could result in lives lost.

Two respondents indicated that, to protect themselves from power outages, they relied on additional feeds from the electric utility. All three respondents indicated that they relied on UPS systems to backup their SCADA and computer systems, while they used generators for pumps and other critical applications. The size of systems used varies significantly among users, from 5 to 15 kW to over 750 kW. Respondents were asked to rate various factors that were most important to them in selecting backup power systems. Respondents indicated that reliability, start-up time, good experience, and fuel availability were the most important factors in selecting a backup power system. Respondents also identified lifetime of the unit and ease of use, and capital cost as other important decision factors. For backup power, respondents indicated that capital cost was less important than the aforementioned decision factors.

All three respondents were very satisfied with the current performance of their systems. One respondent was concerned about emissions from their diesel generators and also indicated that they were difficult to use. One respondent reported difficulty in transporting their backup power unit. Respondents rated their current backup systems on a variety of characteristics and identified reliability, operation and maintenance costs, lifetime of unit, annual operating costs, ease of use, and startup time as very good. Satisfaction with emissions ranked lower than all other characteristics.

Respondents were split on the growing need for backup power in their market segment. Only one respondent had considered alternatives and was investigating solar, wind, and fuel cell technologies. None of the respondents had heard of PEM fuel cells for backup power applications. Two respondents indicated that decisions to purchase were made on initial capital cost. One respondent indicated that they also considered return on investment. One respondent indicated that they made decisions based on environmental concerns. Two respondents indicated that they took government incentives into consideration when making purchasing decisions.

Wastewater Treatment Response Analysis

Respondents indicated that backup power was mainly required for operation of pumps, aeration blowers and mixers, clarifier drivers, digester blowers, wastewater processing equipment, and traveling bridges. All respondents experienced power outages. The number of outages varied from two to ten. Respondents indicated that longer outages were more disruptive. The length of outages typically varied from 3 to 5 minutes or 1 to 4 hours. Respondents indicated that outages could result in disruptions in distribution, loss of safe drinking water, and implementation of emergency management plans.

Backup power is typically supplied through UPS and generators. Size varies based on the application supported and ranges from 5 to 30 kW to over 250 kW. Respondents indicated that

reliability, capital cost, start-up time, ease of use, fuel availability, and good experience with the system were very important factors in selecting backup power products. Respondents were very satisfied with their current backup power systems and had no concerns about their operation. Respondents rated performance characteristics of their backup power systems, including reliability, annual operating costs, startup time, and fuel availability, as very good.

All three respondents indicated that there would be a growing need for backup power in their market segment. One respondent indicated that they had considered alternatives to their backup power systems and had explored the use of reclaimed landfill gas. None of the respondents had heard of PEM fuel cells for backup power.

Decision drivers for respondents to purchase PEM fuel cells include the availability of incentives, track record of others using the PEM fuel cell system, and the cost of not having electricity. Respondents indicated that purchase decisions were made based on initial capital cost, return on investment, and payback period.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Potential applications of PEM fuel cells in water and wastewater treatment facilities include backup power for pump stations, aeration blowers, SCADA systems, digester blowers, and other water/wastewater processes. Users appear to be fairly satisfied with their current mode of operation. There is limited interest in alternatives for backup power in the waste water and water treatment market segments. Users in the wastewater market segment are primarily interested in utilizing waste gas to provide additional power to support operations. Initial capital cost and track record of others using new technologies are important considerations for users in this market segment when adopting new technologies.

Despite limited user interest in backup power, several factors suggest that wastewater treatment plants may represent a favorable market for adopting PEM fuel cell technology. These include large market size (16,255 wastewater treatment facilities in the U.S.), industry's willingness to explore possibilities for fuel cell technologies, and industry's experience gained through fuel cell demonstrations at wastewater treatment plants. Furthermore, fuel cells offer a distinct advantage in areas with space limitations, such as New York City, where adequate property to house diesel-fueled generators is limited.[423] Noise and emissions from diesel generators at pump stations in predominantly residential areas also present problems. Aging wastewater treatment systems may be in need of a makeover that includes updating backup power. Such facilities may consider adopting fuel cells provided the technology is cost-competitive (over its useful lifetime) with traditional backup power sources.

Due to price sensitivity and limited user interest, water and wastewater utilities appear to represent a favorable mid-term market for PEM fuel cells. In the near-term field demonstrations in backup applications (e.g. for SCADA systems) will be a key factor in increasing user familiarity with the technology and building user confidence.

[423] WaterTechONLINE. 2003. NYC officials: Wastewater a problem following blackout. Available at http://watertechonline.com/News.asp?mode=4&N_ID=42621 [Accessed March 2006].

RESEARCH SUMMARY:
SPECIALTY VEHICLES – ELECTRIC BICYCLES AND SCOOTERS

MARKET SEGMENT DESCRIPTION

Electric bicycles are defined in the Consumer Product Safety Act (15 U.S.C. 2085(b)) as "a two- or three-wheeled vehicle with fully operable pedals and an electric motor of less than 750 W (1 HP), whose maximum speed on a paved level surface, when powered solely by such a motor while ridden by an operator who weighs 170 lbs, is less than 20 miles per hour (mph)."[424] Physically, electric bicycles resemble a standard bicycle to which an electric motor has been added to make pedaling easier for the rider. Electric bicycles are used as a convenient means of local transportation by people who wish to ride a bicycle but do not wish to do all the pedaling themselves.

The word "scooter" conjures different images to different people. The State of California defines a motorized scooter as "any two-wheeled device that has handlebars, is designed to be stood upon or sat upon by the operator, and is powered by an electric motor that is capable of propelling the device with or without human propulsion."[425] Vehicles powered by a source other than electrical power (e.g., a gasoline-powered two-stroke engine) are also classified as motorized scooters. This definition encompasses vehicles of various shapes and sizes. Some consider powered scooters to be motorized versions of the two-wheeled, stand-on scooters often ridden by children, which resemble a narrow skateboard with handlebars. Others use the term to describe the sit-down motorbikes (e.g., the "Vespa") popular in heavily congested cities outside the U.S. Still others consider three- or four-wheeled personal mobility devices used by elderly and handicapped individuals to be a type of scooter. Scooters used for personal mobility by elderly or handicapped people are covered briefly in the "Wheelchair" section of this report. All other types of scooters will be covered here. Table u-1 identifies the SIC and NAICS classifications that cover manufacturing of electric bicycles and scooters.

Table u-1. SIC and NAICS Codes for Bicycle and Scooter Manufacturing.

2-Digit SIC Code	37 – Transportation equipment
4-Digit SIC Code	3751 – Motorcycles, bicycles, and parts
NAICS Code	336991 – Motorcycle, bicycle, and parts manufacturing

In general, powered stand-on scooters are similar in design to the manual stand-on variety but may have larger wheels. Powered ride-on scooters (hereafter termed "motorscooters") resemble motorcycles but have a step-through frame on which the rider sits without straddling the engine. Motorscooters typically have smaller wheels (between 8 and 14 inches in diameter) than motorcycles, along with a small displacement (between 30 cc and 250 cc).[426] Gas-powered motorscooters are capable of traveling between 25 and 60 mph.[427] Most motorscooters have automatic transmissions and, until recently, air-cooled or water-cooled two-stroke engines.

[424] U.S. Department of Transportation. 2005. Two- and Three-Wheeled Vehicles. Federal Register 70 (114): 34810-34814.
[425] Los Alamitos Police Force. 2006. The LAW – Los AI Watch: Special Bulletin – Motorized Scooters & Mini-Motorcycles (Pocket Rockets). Available at http://www.losalamitospolice.org/040810_mini-bikes.pdf [Accessed June 2006].
[426] Wikimedia Foundation, Inc. 2006. Scooter (motorcycle). Available at http://en.wikipedia.org/wiki/Motorscooter [Accessed June 2006].
[427] GS MotorWorks. 2006. About Gas Scooters. Available at http://www.gsmotorworks.com/about_gas_scooters/c8/Riding_Life.html [Accessed June 2006].

However, more stringent emissions controls have resulted in a growing number of four-stroke motorscooter engines. Another recent trend is the development of larger motorscooters, otherwise known as Mega Scooters or maxi-scooters, with engines ranging in size from 250 cc to 650 cc.[428]

Motorized bicycles and scooters can be powered by battery-driven electric motors or gasoline engines. Various types of rechargeable batteries are used to power electric bicycles and scooters. By far, the most common battery type for vehicles sold in the U.S. is sealed lead-acid (SLA), followed by NiCd and NiMH. In Europe and Asia, NiCd and NiMH are used more commonly than lead batteries.[429]

As indicated above, electric bicycles are defined as having motors of less than 750 W (1 HP). Among the products offered by U.S. manufacturers, electric bicycles typically use 24V or 36V electric motors powered by various battery configurations (two or three 12V SLA or twenty 1.2V NiMH batteries); several 12V models are also available. The power range for bicycle motors generally runs from 200 W to 450 W, with 450 W motors being the most common among the products identified. Electric bicycles vary in weight from 40 to 120 lbs, with most in the 65 to 85 lb range. These bicycles typically range in price from $300 to $3,300,[430] though more costly high-performance models are available.

Battery-powered stand-on scooters tend to be slower, have smaller wheels, and cost less than gasoline-powered models.[431] Electric scooters offer a broader range of motors than bicycles, from 90 W, 12V systems to 1 kW, 36V motors. Typically, electric stand-on scooters are driven by 100 to 750 W DC motors, have an operating range of 8 to 20 miles, and weigh 20 to 100 lbs.[432] Scooters with motors of 500 W or greater are typically powered by 36V battery systems (three 12V SLAs), while motors sized at < 500 W tend to be powered by 24V systems (two 12V SLAs). The self-balancing Segway scooter, which runs on two 1.88 kW motors (one per wheel), can be powered by lithium-ion (Li-ion) or NiMH battery packs; specific battery sizes were not available on the manufacturer's website. Most powered stand-on scooters are imported from China and retail for $150 to $900.[433] However, some uniquely designed scooter products such as the Segway can cost in the neighborhood of $5,000. In 2003, sales of electric and gas-powered stand-on scooters were approximately equal.[434]

Most gasoline-powered scooters (both stand-on and motorscooters) are manufactured abroad. These vehicles are available with engines in the 22 to 50 cc range, capable of generating 1.2 to 4.2 HP (0.9 kW to 3.1 kW). Competition or "sport" models typically have the largest engines (> 3 HP/2.2 kW). Some gas stand-on scooters run on four-stroke engines, while others run on two-

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[428] Wikimedia Foundation, Inc. 2006. Scooter (motorcycle). Available at http://en.wikipedia.org/wiki/Motorscooter [Accessed June 2006].
[429] CycleElectric. 2002. Market Size for Two Wheelers. Available at http://www.cycleelectric.com/rsc/worldsales2003.pdf [Accessed June 2006].
[430] Benjamin, E. 2005. Light Electric Vehicle Propulsion. Available at http://www.cycleelectric.com/rsc/LEVPropulsion.ppt [Accessed June 2006].
[431] U.S. Consumer Product Safety Commission. 2005. Powered Scooters. Consumer Product Safety Review 10(2).
[432] Benjamin, E. 2005. Light Electric Vehicle Propulsion. Available at http://www.cycleelectric.com/rsc/LEVPropulsion.ppt [Accessed June 2006].
[433] Benjamin, E. 2005. Light Electric Vehicle Propulsion. Available at http://www.cycleelectric.com/rsc/LEVPropulsion.ppt [Accessed June 2006].
[434] U.S. Consumer Product Safety Commission. 2005. Powered Scooters. Consumer Product Safety Review 10(2).

stroke engines that are fueled by a mixture of oil and gasoline. Standard motorscooters are available with two-stroke or four-stroke engines ranging in size from 30 cc to 250 cc, though more powerful "maxi-scooters" have 250 cc to 650 cc engines.[435]

Electric bicycles, powered scooters, and motorscooters are used by individuals for recreational and commuting purposes. Manufacturers of electric bicycles and scooters are primarily headquartered outside the United States, with several notable exceptions (ZAP, Currie Technologies, Razor USA, and Segway Inc.). Electric bicycles are distributed through various channels, including bicycle shops, the internet, catalog retailers, electric vehicle specialists, mass merchants, sporting goods stores, power sports retailers, and direct purchases from the manufacturer. Scooters are distributed through some of the same channels (mass merchants, the internet, bicycle shops, sporting goods stores) but can also be purchased at flea markets, independent retailers, recreational vehicle (RV) dealers, golf cart retailers, and truck vendors.[436]

MARKET SIZE

Current data on the electric bicycle and powered scooter manufacturing market are provided below. SIC Code 3751, covering manufacturing of motorcycles, bicycles, and parts, is represented by Table u-2. Only the eight-digit SIC Code specialties relevant to electric bicycles and powered scooters are shown. Note that the category of "Bicycles and related parts" includes manufacturers of standard (i.e., non-motorized) bicycles.

Table u-2. Number of Electric Bicycle and Scooter Manufacturers – Industry: Motorcycles, Bicycles, and Parts (3751).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3751-0102	Motor scooters and parts	58	684	72.3
3751-0200	Bicycles and related parts	207	3,286	251.4
	Total	**265**	**3,970**	**323.7**

Sales figures are in millions. Source: www.zapdata.com, accessed 6/20/06.

The markets for electric bicycles and scooters are seeing modest growth in the U.S., though the domestic market still pales in comparison to the foreign market for these vehicles. Approximately 65,000 electric bicycles were expected to be sold in the U.S. in 2004, up from 45,000 in 2003. In contrast, in China 7,000,000 electric bikes were sold in 2004, up from 4,000,000 the previous year.[437]

CycleElectric is an international consulting group that tracks market trends for electric bicycles and electric scooters. This group predicts that the market for electric bicycles in the U.S. will eventually reach approximately 1.5 million vehicles per year and that the market for light electric scooters will eventually reach about 15 million vehicles per year.[438] However, no timeline is provided for these forecasts.

[435] Wikimedia Foundation, Inc. 2006. Scooter (motorcycle). Available at http://en.wikipedia.org/wiki/Motorscooter [Accessed June 2006].
[436] Benjamin, E. 2004. Market Trend and Regulation of E-Scooter and E-Bike in North America. Presentation for ITRI, Taiwan. Available at http://www.cycleelectricusa.com/rsc/USA.ppt [Accessed June 2006].
[437] Alvord, K. 2004. Plugged in: E-Bikes and Segways are slow to catch on—but rebates help. E: The Environmental Magazine (September/October). Available at http://www.findarticles.com/p/articles/mi_m1594/is_5_15/ai_n6335040/pg_2 [Accessed June 2006].
[438] Benjamin, E. 2004. Market Trend and Regulation of E-Scooter and E-Bike in North America. Presentation for ITRI, Taiwan. Available at http://www.cycleelectricusa.com/rsc/USA.ppt [Accessed June 2006].

Leading manufacturers of electric bicycles include Currie Technologies, Inc., and ZAP. Leading manufacturers of powered stand-on scooters include Razor USA LLC, The Apache Motor Company, and Segway LLC. Leading manufacturers of motorscooters include Vectrix Corporation; Piaggio & C., S.p.A.; Yamaha Motor Corporation; and American Honda Motor Co., Inc.

MARKET TRENDS

Some companies have begun integrating fuel cells into electric bicycles. As early as 2000, a bicycle powered by a PEM fuel cell was successfully tested by Manhattan Scientifics, Inc. The PEM fuel cell used in this bicycle had an energy density of 205 W per kg, nearly seven times the energy density of lead-acid batteries (30 W per kg) and over three times the energy density of NiMH batteries (60 W per kg). More recently, Masterflex AG recently supplied the German city of Herten with the world's first fleet of bicycles propelled by fuel cell systems.[439] These bicycles will be targeted to executive commuters, delivery services, and area tourists. The fuel cell system allows the bicycles to travel distances of 120 to 250 kilometers (75 to 155 miles), which greatly exceeds the distance achievable by electric bicycles on a single charge.[440]

There has also been fuel cell activity in the scooter market. Palcan Fuel Cells demonstrated a scooter powered by a 2 kW PEM fuel cell in 2003 (based on metal hydride hydrogen storage technology). This fuel cell was developed specifically for use in two- and three-wheeled vehicles used in European and Asian markets, including scooters and rickshaws.[441] Vectrix, a European scooter manufacturer with offices in Rhode Island and Massachusetts, has developed a maxi-scooter powered by a fuel cell-battery hybrid system. Protonex's 500 W fuel cell system continuously charges the vehicle's NiMH batteries and is supplemented by a regenerative braking system. Vectrix plans to launch the vehicle in European markets before making it available in the U.S.[442]

MARKET SEGMENT ANALYSIS

To help identify the market opportunities for direct PEM fuel cells in electric bicycles and scooters, three U.S. manufacturers of these vehicles were contacted. Because this is a highly distributed market, individual users were not contacted. It was deemed that responses from manufacturers would provide insight into user requirements. None of these manufacturers responded. Therefore, the following analysis of opportunities for PEM fuel cells is based solely on secondary research.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The market for scooters and electric bicycles is still an emerging one in the U.S.; however, several issues have been identified as being particularly important to consumers. These issues

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[439] No author. 2005. Masterflex receives first order for fuel cell bicycles. Fuel Cell Today. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,6836,00.html [Accessed June 2006].

[440] Bangkok Post. 2006. German develops fuel-cell bicycles. Fuel Cell Works. Available at http://www.fuelcellsworks.com/Supppage4340.html [Accessed June 2006].

[441] Shen, J. 2003. Palcan showcases the future with fuel cell powered scooter for global masses. Available at http://www.palcan.com/s/NewsReleases.asp?ReportID=63580 [Accessed June 2006].

[442] Green Car Congress. 2005. Vectrix readies its electric and fuel cell hybrid scooters for market. Available at http://www.greencarcongress.com/2005/03/vectrix_readies.html [Accessed June 2006].

are as follows: cost, noise, torque, reliability, weight, and efficiency.[443] It remains to be seen whether fuel cell-powered vehicles will be able to compete with relatively inexpensive electric and gas-powered vehicles from a cost perspective. Fuel cell-powered or fuel cell-electric hybrid vehicles may be more likely to compete based on other benefits. For example, PEM fuel cells are: 1) much quieter than ICE vehicles, 2) capable of exceptional performance over battery-powered vehicles in terms of power density, 3) lighter than purely battery-driven models, 4) more efficient, and 5) easier to maintain.[444] Furthermore, PEM fuel cells and other electric vehicles eliminate the significant environmental concerns associated with ICE emissions, particularly from the much more widely used two-stroke engines.[445]

While the market for scooters and electric bicycles is growing in the U.S., it is significantly smaller that in other parts of the world. Manufacturers of PEM fuel cell-powered systems are targeting the European and Asian markets in the near term. Also, because of the distributed nature of users of these vehicles, a highly distributed refueling architecture will be required to support widespread adoption in the U.S. For these reasons, the market for electric bicycles and scooters is not considered a likely near-term market for PEM fuel cells in the U.S.

[443] Benjamin, E. 2005. Light Electric Vehicle Propulsion. Available at http://www.cycleelectric.com/rsc/LEVPropulsion.ppt [Accessed June 2006].
[444] Parker Hannifin Corporation/Vectrix USA. 2004. The World's First Fuel Cell/Electric Hybrid Scooter. Available at http://www.parker.com/chomerics/Scooter-Brochure-10-04.pdf [Accessed June 2006].
[445] Shen, J. 2003. Palcan showcases the future with fuel cell powered scooter for global masses. Available at http://www.palcan.com/s/NewsReleases.asp?ReportID=63580 [Accessed June 2006].

RESEARCH SUMMARY:
SPECIALTY VEHICLES – COMMERCIAL SWEEPERS/SCRUBBERS

MARKET SEGMENT DESCRIPTION

Commercial sweepers and scrubbers are vehicles equipped with one or more broom, mop, or brush attachments for heavy-duty cleaning of industrial floors or pavement. These vehicles can be used indoors or outdoors. Walk-behind and ride-on sweepers and scrubbers are available in a wide variety of shapes and sizes. Smaller walk-behind models may resemble lawnmowers and weigh as little as ~100 lbs. The largest ride-on models, which may include a combination of sweeping and scrubbing functions, can weigh in excess of 7,000 lbs. Some models are equipped with wet/dry vacuums and/or squeegees for more aggressive cleaning and water extraction. Table v-1 identifies the SIC and NAICS classifications that cover manufacturing of commercial sweepers and scrubbers.

Table v-1. SIC and NAICS Codes for Commercial Sweeper/Scrubber Manufacturing.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Code	3589 – Service industry machinery, not elsewhere classified
NAICS Code	333319 – Other commercial and service industry machinery manufacturing

Commercial sweepers and scrubbers can be powered by gasoline, propane, CNG, or diesel ICEs, as well as electric batteries. Corded electric models are also available. Electric models typically have smaller engines with motors ranging in capacity from 0.5 HP (375 W) to 4.6 HP (3.5 kW). Variously sized (12V, 24V, and 36V) battery systems, comprised of sealed flooded, gel cell, or absorption glass mat (AGM) deep-cycle batteries are used. Both walk-behind and riding sweepers/scrubbers may have electric motors. ICEs are used primarily in riding sweepers and scrubbers, though one 2.5 to 4 HP (1.9 to 3 kW) gas-powered walk-behind sweeper was found. Among the commercially available riding products reviewed for this analysis, gasoline and propane engines ranged between 55 HP (41 kW) and 97 HP (72 kW). Diesel engines ranged between 37 HP (28 kW) and 65 HP (48.5 kW). Specifications for CNG engines were unavailable.

Pricing for commercial sweepers and scrubbers is extremely variable. Walk-behind machines typically are available for $4,000 to $11,000. Riding machines range between $11,000 and $93,000; however, many models (including combination sweepers/scrubbers) are available for under $25,000.[446]

MARKET SIZE

Current data on the size of the commercial sweeper/scrubber manufacturing market are provided below. SIC Code 3589, which covers manufacturing of these vehicles, is represented in Table v-2. Only those eight-digit SIC Code specialties relevant to sweeper and scrubber manufacturing are shown.

[446] Prices obtained from online retailer of commercial sweepers and scrubbers: Caliber Equipment, Inc. Available at http://www.caliberequipment.com/ [Accessed June 2006].

Table v-2. Number of Commercial Sweeper/Scrubber Manufacturers - Industry: Service Industry Machinery, Not Elsewhere Classified (3589).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3589-0200	Commercial cleaning equipment	175	3,991	1,042.9
3589-0202	Carpet sweepers, except household electric vacuum sweepers	11	437	49.1
3589-0203	Dirt sweeping units, industrial	32	520	57.1
3589-0205	Floor washing and polishing machines, commercial	47	1,015	205.1
3589-0207	Vacuum cleaners and sweepers, electric: industrial	83	2,962	604.8
	Total	**348**	**8,925**	**1,959**

Source: www.zapdata.com, accessed June 2006.

The user market for commercial sweepers and scrubbers encompasses any facility with a hard floor, as well as outdoor areas where clean surfaces are desired (e.g., amusement parks, sidewalks). A few common industrial applications for compact riding models include retail home centers, warehouses, manufacturing plants, airports, and distribution centers. Walk-behind models are best suited for use in office buildings, educational facilities, hotels, convention centers, convenience stores, and shopping malls, though they can also be used in airports and manufacturing plants.

Detailed information on commercial sweepers and scrubbers was provided in a 2005 EPA report on nonroad engines (see Table v-3). This report, which documented the source of nonroad engine population values in EPA's NONROAD emissions inventory model, provided the most recent population data available (termed "base year" data) for non-road engines in a wide range of vehicles and equipment. All data were obtained from Power Systems Research, an independent market research firm that surveyed engine manufacturers and users to derive its estimates. For commercial sweepers and scrubbers, the year 1998 was designated as the base year.[447]

Major sweeper/scrubber manufacturers include American-Lincoln; Nilfisk Advance, Inc.; Tennant Company; Tornado® Industries, Inc.; TYMCO; Elgin Sweeper Co.; and Factory Cat/RPS Corporation.

[447] EPA. 2005. Nonroad Engine Population Estimates. EPA420-R-05-022. Washington, DC, EPA Office of Transportation and Air Quality.

Table v-3. Total Population of Commercial Sweepers/Scrubbers in the United States in 1998.

Year	Equipment Description	Min HP	Max HP	Avg HP	U.S. Population
1998	2-Str Sweepers/Scrubbers	1	3	1.276	3,298
1998	4-Str Sweepers/Scrubbers	3	6	4.735	3,777
1998	4-Str Sweepers/Scrubbers	6	11	9,855	5,779
1998	4-Str Sweepers/Scrubbers	11	16	14.85	1,563
1998	4-Str Sweepers/Scrubbers	16	25	18.23	3,348
1998	4-Str Sweepers/Scrubbers	25	40	31.91	2,011
1998	4-Str Sweepers/Scrubbers	40	50	46	2,273
1998	4-Str Sweepers/Scrubbers	50	75	63.35	2,306
1998	4-Str Sweepers/Scrubbers	75	100	90	23
1998	4-Str Sweepers/Scrubbers	100	175	150.0	47
1998	4-Str Sweepers/Scrubbers	300	600	411.0	3
1998	LPG – Sweepers/Scrubbers	25	40	31	2,011
1998	LPG – Sweepers/Scrubbers	40	50	47	2,273
1998	LPG – Sweepers/Scrubbers	50	75	63.35	2,306
1998	LPG – Sweepers/Scrubbers	75	100	90	23
1998	LPG – Sweepers/Scrubbers	100	175	150	47
1998	LPG – Sweepers/Scrubbers	300	600	411	3
1998	CNG – Sweepers/Scrubbers	175	300	190	20
1998	Diesel – Sweepers/Scrubbers	3	6	5	302
1998	Diesel – Sweepers/Scrubbers	6	11	11	14
1998	Diesel – Sweepers/Scrubbers	11	16	13.65	1
1998	Diesel – Sweepers/Scrubbers	16	25	21.69	1,845
1998	Diesel – Sweepers/Scrubbers	25	40	34.83	4,436
1998	Diesel – Sweepers/Scrubbers	40	50	43.64	2,993
1998	Diesel – Sweepers/Scrubbers	50	75	60.81	2,898
1998	Diesel – Sweepers/Scrubbers	75	100	81.86	10,672
1998	Diesel – Sweepers/Scrubbers	100	175	134.3	11,984
1998	Diesel – Sweepers/Scrubbers	175	300	216.7	3,222
1998	Diesel – Sweepers/Scrubbers	300	600	363.8	55
Total Population					**69,533**

Source: Adapted from EPA, 2005. Nonroad Engine Population Estimates. Washington, DC: EPA Office of Transportation and Air Quality. EPA420-R-05-022.

MARKET TRENDS

Emissions from ICE-powered commercial sweepers and scrubbers are regulated by EPA and state agencies within the category of nonroad engines. As such, they would be subject to the new emissions standards recently proposed by EPA for nonroad diesel engines. These standards, to be implemented in phases between 2008 and 2014, will require diesel engine manufacturers to outfit new engines with advanced emission control technologies.[448] Also, the California Air Resources Board (CARB) has proposed to adopt more stringent emission standards and test procedures for large (> 25 HP or 19 kW), spark-ignited engines in various types of equipment, including forklifts, sweepers/scrubbers, industrial tow tractors, and ground support equipment.[449]

[448] U.S. Department of Transportation, Federal Aviation Administration. 2005. Aviation and Emissions - A Primer. Washington, DC, FAA Office of Environment and Energy.

[449] California Air Resources Board. 2006. Staff report: New emission standards, fleet requirements, and test procedures for forklifts and other industrial equipment. Available at http://www.arb.ca.gov/regact/lore2006/isor.pdf [Accessed June 2006].

As early as 1999, analysts predicted that cleaner electric sweepers and scrubbers would eventually capture much of the market from their ICE-powered counterparts.[450] All major scrubber/sweeper manufacturers offer electric models, and numerous manufacturers offer alternatively fueled (CNG or propane) vehicles, as well.

MARKET SEGMENT ANALYSIS

To help identify the market opportunities for direct PEM fuel cells in commercial sweepers and scrubbers, manufacturers of these vehicles were contacted. Because this is such a highly distributed market with varied applications, manufacturers were thought to be best-positioned to provide a comprehensive view of user applications and requirements. Five manufacturers were contacted, and three responses were received. All respondents were manufacturers of industrial sweepers and scrubbers; two noted that their companies offered additional products and services. One small, one medium, and one large company responded.

Product offerings varied among the manufacturers who responded. One offered only electric sweepers and scrubbers, while the other two offered both electric and ICE-powered models. One manufacturer offered ICE products fueled by diesel or gasoline, and the other offered diesel, gasoline, propane, and combination-fuel ICEs.

Regarding which user markets are most affected by product downtime, one manufacturer indicated that the impact is somewhat dependent on the size of the vehicle being used and its application. However, several markets were deemed particularly sensitive to downtime, including building service contractors; large manufacturing facilities with multiple shifts and complex operations; and heavy industrial applications (e.g., foundries and mining), which have concerns about the cleanliness of the environment and product contamination.

Two manufacturers addressed the O&M requirements associated with their products. According to one respondent, O&M requirements vary according to the products offered and the applications in which they are used. Battery-based vehicles require frequent charging (and swapping with charged batteries), as well as water level monitoring, watering, and venting. ICE-based products primarily need to be refueled, but maintenance and monitoring of engine hydraulics are also required.

There are safety concerns with both electric and ICE models, as noted by two of the manufacturers contacted. The use of batteries raises concerns over leaking and splattering of acid, as well as toxic emissions that are released when a battery is vented. To avoid these emissions and the risk of a battery leak, one large manufacturer is shifting to sealed gel cell batteries, even though they do not last as long as flooded lead-acid systems. According to one large manufacturer, ICE-powered sweepers and scrubbers raise concerns over emissions. A medium-sized manufacturer pointed out that material safety data sheets must be maintained for the fuels and other substances associated with ICEs.

[450] Moore, B. 1999. Follow the money – non-road electric vehicles. EV World. Available at http://www.evworld.com/archives/interviews2/krein.html [Accessed June 2006].

Of the three manufacturers contacted, only one (the largest) was aware of PEM fuel cells as a potential substitute for existing power sources. This manufacturer examines all new and emerging technologies and has just begun to consider the potential for fuel cells in its products. When evaluating new technologies, the manufacturer indicated that maximizing run-time is a critical issue, but other factors are important as well. For example, ICEs provide more power than batteries, but batteries offer lower emissions and noise levels. Regarding fuel cells, the manufacturer was not prepared to call them a viable alternative but noted that they may have potential. The respondent doubted that fuel cells would ever fully replace ICE products because ICEs offer much-needed power; however, fuel cells may compete with batteries or some ICE applications.

Sweeper/scrubber manufacturers were asked about potential drivers for and barriers to the successful adoption of fuel cells. Two manufacturers addressed potential barriers. The largest manufacturer identified customer acceptance as a potential barrier but added that customers are likely to accept a change when they can see that it works. The same manufacturer noted that significant research and development may be necessary to meet the engineering requirements of sweepers and scrubbers (e.g., the power source must drive the engine as well as the brushes, vacuum attachments, water tank, and other functions). A medium-sized manufacturer noted that fuel cell use would depend on cost and competitiveness with current products. Only one manufacturer (the largest) suggested potential drivers for fuel cell use. This manufacturer noted that key drivers would be environmental concerns (citing tremendous potential benefits) and extended run-time.

Only two manufacturers responded to a question inquiring whether their customers would be concerned over the use of hydrogen as a fuel. A medium-sized manufacturer indicated that its customers would not be concerned as long as hydrogen were widely available and appropriate demonstration projects were conducted. A large manufacturer indicated that its customers might have some concerns.

There was limited interest among those contacted in working with DOE to demonstrate PEM fuel cells. The small manufacturer was not interested and did not wish to be contacted again. The medium and large manufacturers indicated that they might be interested but would have to ask around within their organizations before providing a more definitive response. Both agreed to be contacted again.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

With the exception of one major manufacturer who is considering the potential for PEM fuel cells in its sweeper and scrubber vehicles, no evidence was found through secondary or primary research to suggest that commercial sweeper/scrubber manufacturers are actively pursuing fuel cells as alternative power sources for their vehicles. The need to comply with EPA's stricter emission standards for nonroad diesel engines and the need to minimize hazardous emissions, particularly in indoor environments, are thought to be prompting the move from ICE to electric vehicles. While this may provide an opportunity for PEM fuel cells to enter this market, it is important to note that batteries also meet these requirements and battery-powered sweepers/scrubbers are already available. PEM fuel cells would need to demonstrate a competitive advantage (cost or performance) with these existing battery products in order to be

viable within this market. In light of current lack of development activity with PEM fuel cells and the status of incumbent technologies, the sweepers and scrubbers are not considered a likely near-term market for PEM fuel cell-powered specialty vehicles.

RESEARCH SUMMARY:
SPECIALTY VEHICLES – ICE RESURFACERS

MARKET SEGMENT DESCRIPTION

An ice resurfacer is a motorized vehicle, shaped like an industrial truck or tractor, which is used to smooth the surface of an ice rink after activities such as figure skating or hockey. The machine was invented in 1949 by Frank J. Zamboni and is still manufactured by Frank J. Zamboni & Co., Inc.; as a result, ice resurfacers, regardless of their origin, are often referred to as "Zambonis." Prior to Zamboni's invention, resurfacing was conducted manually using hoses and scrapers.[451] Table w-1 identifies the SIC and NAICS classifications that cover manufacturing of ice resurfacers.

Table w-1. SIC and NAICS Codes for Ice Resurfacer Manufacturing.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Code	3559 – Special industry machinery, not elsewhere classified (nec)
NAICS Code	333298 – All other industrial machinery manufacturing

Many different sizes and shapes of ice resurfacers are available to accommodate differently sized ice rinks, though all perform similar functions. All resurfacers use a conditioner, or a large and very sharp metal blade, to shave the surface of the ice. Ice shavings are swept and picked up by augers attached to the machine. At this stage of the process, wash water may be sprayed onto the ice to remove foreign material that has fallen onto the ice surface. Behind the conditioner, a sprinkler pipe and mop spread clean water onto the ice to fill in residual grooves and form a smooth new surface. Generally, resurfacers are equipped with tanks to hold the clean water and wash water; an engine or motor to provide propulsion to the vehicle and hydraulic power to the conditioner, tanks, and augers; and a reservoir to collect shaved ice.[452]

Currently, there are only two manufacturers of ice resurfacers: Frank J. Zamboni & Co., headquartered in California, and Resurfice Corp., located in Ontario. Both Resurfice Corp. and Frank J. Zamboni & Co. offer battery-powered and ICE-powered ice resurfacers. Zamboni offers an electric resurfacer driven by a 17.5 HP (13 kW) electric motor, which is powered by a 510 amp-hour lead acid battery pack. Resurfice Corp.'s Olympia Cellect™ resurfacer is powered by 180 amp-hour, 144V NiCd batteries. The drive system for the Cellect™ is capable of 15 kW nominal power and 30 kW peak power. Resurfice Corp.'s ICE resurfacers are available with emission-controlled propane or natural gas engines. Frank J. Zamboni & Co.'s ICE products can be operated on unleaded gasoline, propane, diesel, or CNG.[453] Engine capacity information was not publicly available for Resurfice Corp.'s products; however, Zamboni's ICE-powered vehicles are driven by 4-cylinder, 63 HP (47 kW) engines.

ICE-powered resurfacers range in weight from 5,660 lbs to 9,420 lbs (empty) and from 7,040 lbs to 13,700 lbs (full of water). The average empty weight among the ICE products identified was 6,858 lbs, and the average filled weight was 9,175 lbs. Electric resurfacers weigh between 6,330

[451] Wikimedia Foundation, Inc. 2006. Ice resurfacer. Available at http://en.wikipedia.org/wiki/Ice_resurfacer [Accessed June 2006].
[452] Wikimedia Foundation, Inc. 2006. Ice resurfacer. Available at http://en.wikipedia.org/wiki/Ice_resurfacer [Accessed June 2006].
[453] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].

lbs and 9,750 lbs (empty) and between 7,905 lbs and 11,350 lbs (full of water). The average empty weight among the electric products was 7,687 lbs, and the average filled weight was 9,165 lbs.

Both Resurfice Corp. and Zamboni offer more ICE models than electric vehicles. Of the estimated 8,000 Zamboni machines sold in the past 50 years, only about 1,000 have been electric.[454] However, there are significant health and safety concerns associated with the use of ICE-powered vehicles indoors. Unless the ice rink is adequately ventilated, air quality within the rink can become quite poor due to carbon monoxide and nitrogen dioxide emissions from ice resurfacing vehicles, posing a health hazard to those inside the rink.[455]

Conventional ICE-powered ice resurfacers range in cost from roughly $55,000 to $80,000.[456] It has been estimated that electric resurfacers cost approximately 60% more than ICE-powered models.[457] Within the electric product line, NiCd units are about $18,000 more expensive than models powered by lead-acid batteries.[458] Although electric resurfacers are more expensive initially, they have lower maintenance and fuel costs than ICE models; furthermore, electric models do not require the installation and maintenance of expensive ventilation systems capable of handling ICE exhaust.[459]

MARKET SIZE

Users of ice resurfacers, as illustrated in Table v-3, are mainly captured within three SIC codes: 7941 (Professional Sports Clubs and Promoters), 7997 (Membership Sports and Recreation Clubs), and 7999 (Amusement and Recreation Services, Not Elsewhere Classified). Colleges, universities, and other schools that maintain ice rinks would also be considered part of the user market for ice resurfacers; these institutions are captured within SIC Codes 8221 (Colleges, Universities, and Professional Schools) and 8211 (Elementary and Secondary Schools). Only a small percentage of these academic institutions are expected to have ice rinks; however, data were not available to determine the exact number. In Tables w-2 and w-3, only the eight-digit SIC specialty categories deemed most relevant to ice resurfacer manufacturing and use are shown.

Table w-2. Number of Ice Resurfacer Manufacturers - Industry: Special Industry Machinery, Nec (3559).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3559-9941	Ice resurfacing machinery	2	46	4
	Total	**2**	**46**	**4**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

[454] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune, (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].
[455] Pelham, T., L.E. Holt, and M.A. Moss. 2002. Exposure to carbon monoxide and nitrogen dioxide in enclosed ice arenas. Occupational and Environmental Medicine 59: 224-233.
[456] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune, (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].
[457] Pelham, T., L.E. Holt, and M.A. Moss. 2002. Exposure to carbon monoxide and nitrogen dioxide in enclosed ice arenas. Occupational and Environmental Medicine 59: 224-233.
[458] Sharke, P. 2000. With built-in ice maker. Mechanical Engineering. Available at http://www.memagazine.org/backissues/dec00/features/withice/withice.html [Accessed June 2006].
[459] Pelham, T., L.E. Holt, and M.A. Moss. 2002. Exposure to carbon monoxide and nitrogen dioxide in enclosed ice arenas. Occupational and Environmental Medicine 59: 224-233.

Table w-3. **Number of Potential Ice Resurfacer Users - Industries: Sports Clubs, Managers, and Promoters (7941); Membership Sports and Recreation Clubs (7997); Amusement and Recreation, Nec (7999); Colleges and Universities (8221); Elementary and Secondary Schools (8211).**

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
7941-0000	Sports clubs, managers, and promoters	1,256	11,512	1,214.8
7941-0100	Professional and semi-professional sports clubs	138	1,622	225.6
7941-0104	Ice hockey club	137	2,839	452.3
7997-0000	Membership sports and recreation clubs	15,874	120,903	5,421.4
7997-0100	Ice sports	55	494	20
7997-0101	Curling club, membership	34	150	4.7
7997-0102	Hockey club, except professional and semi-professional	119	850	37.1
7999-0600	Skating rink operation services	1,226	9,404	269.8
7999-0601	Curling rinks	99	367	9.2
7999-0602	Ice skating rink operation	420	7,553	235.9
7999-1110	Hockey instruction school	188	1,017	33.8
7999-1118	Skating instruction, ice or roller	123	775	18.6
7999-1120	Sports instruction, schools and camps	638	3,920	191.9
7999-9910	Recreation center	3,972	40,022	923.5
8221-0000	Colleges and universities	7,175	548,984	22,464.801
8221-0100	Colleges and universities	1,226	94,625	6,431.7
8221-0101	College, except junior	1,327	236,245	26,440.4
8221-0102	University	7,730	1,231,983	154,037.094
8211-0000	Elementary and secondary schools	57,045	2,605,595	60,601.102
8211-0100	Catholic elementary and secondary schools	430	14,141	325.4
8211-0101	Catholic combined elementary and secondary school	242	9,335	241.7
8211-0103	Catholic junior high school	97	4,677	165.9
8211-0104	Catholic senior high school	477	29,091	820.8
8211-0200	Private elementary and secondary schools	2,398	62,836	2,933
8211-0205	Private combined elementary and secondary school	833	46,337	2,887.9
8211-0207	Private junior high school	195	9,587	514.3
8211-0208	Private senior high school	421	18,483	731.4
8211-0300	Public elementary and secondary schools	4,438	258,506	78,165.5
8211-0302	Public combined elementary and secondary school	2,026	92,468	17,098.1
8211-0304	Public junior high school	3,691	254,001	2,291
8211-0305	Public senior high school	5,477	449,520	11,471.6
8211-9903	High school, junior or senior, nec	2,427	163,936	5,388.7
8211-9906	Secondary school, nec	963	62,816	1,220.9
	Total	**122,897**	**6,394,594**	**403,290**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

MARKET TRENDS

There is significant concern over exhaust from ICE-powered ice resurfacers. Many arena officials are prohibiting the use of ICEs indoors.[460] As a result, both manufacturers of ice resurfacing vehicles offer electric models.

Resurfice Corp. partnered with ePower Synergies Inc. and the University of North Dakota's Energy and Environmental Research Center to create the "Ice Bear," a hydrogen fuel cell-powered ice resurfacer. The Ice Bear was touted as having the performance and convenience of a propane-powered unit, but without the associated pollution. The Ice Bear's developers are seeking supporters to fund production of additional models.[461] They are also working on the development of a portable hydrogen refueling station to accompany the Ice Bear.[462]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in ice resurfacers, both manufacturers and users of these vehicles were contacted. Neither of the two manufacturers responded. Similarly, three potential users were contacted, but no responses were received. Due to the lack of data from primary sources, the following analysis of potential opportunities for PEM fuel cells was based solely on secondary research.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The electric ice resurfacers on the market currently address the growing concern about vehicle emissions in indoor environments. Furthermore, battery power may be sufficient to generate the required level of performance, since ice resurfacers typically only have to work for shifts of 20 minutes or less (e.g., between hockey periods) to cover the entire ice rink surface. They are not subjected to repeated start-stop cycles; nor do they operate for 8-hour shifts like some other specialty vehicles.

The greatest obstacle to using hydrogen fuel cells in ice resurfacers may be cost. A prototype hydrogen-powered ice resurfacer recently developed through the collaboration between Resurfice Corp. and ePower Synergies Inc. costs $150,000, whereas a conventional Zamboni product costs only $80,000. In fact, the Frank J. Zamboni Co. evaluated the use of fuel cells in its products and concluded that the idea was cost prohibitive for its customers.[463] While the cost would come down as production scaled up, it seems unlikely that the cost reductions from economies of scale would close this gap in the next few years. Considering the cost disadvantage and the ability of battery-powered vehicles to effectively address user requirements, ice resurfacers are not considered a promising near-term market for PEM fuel cells.

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[460] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune, (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].
[461] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune, (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].
[462] Fuel Cell Today. 2005. Fuel Cell-Powered Ice Refinisher Arrives at the Home of 2010 Winter Olympics. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,6915,00.html [Accessed June 2006].
[463] Kolpack, D. 2005. Ice-resurfacing vehicle runs on hydrogen. The Bismarck Tribune, (November 8, 2005). Available at http://www.bismarcktribune.com/articles/2005/11/08/news/state/105186.txt [Accessed June 2006].

RESEARCH SUMMARY:
SPECIALTY VEHICLES – GOLF CARTS

MARKET SEGMENT DESCRIPTION

Golf carts are motorized, four-wheeled vehicles that were originally designed to transport golfers and their equipment on a golf course. Today, golf carts are used in a wide variety of applications (both on and off the golf course) to transport small numbers of people over short distances at relatively slow speeds (typically 12 to 15 mph maximum range).[464] Golf carts are typically configured to carry two or four passengers. They may be covered (e.g., with a canopy and windshield) or uncovered. Approximately half of the golf carts manufactured come with small gasoline engines, and the other half are electrically powered. Electric golf carts were the first mass-produced electric vehicles for private consumer use; they are used in many communities where pollution control, noise control, and safety for pedestrians and other carts (due to slow speeds) are prized attributes.[465] Table x-1 identifies the SIC and NAICS classifications that cover manufacturing of golf carts.

Table x-1. SIC and NAICS Codes for Golf Cart Manufacturing.

2-Digit SIC Code	37 – Transportation equipment (manufacturing)
4-Digit SIC Code	3799 – Transportation equipment, not elsewhere classified (nec)
NAICS Code	336999 – All other transportation equipment manufacturing

This analysis will focus on golf carts used on golf courses and in residential environments. When golf cart-like vehicles are modified for use in specialty applications (e.g., to transport personnel and/or equipment in commercial, industrial, and institutional environments), they are referred to as utility vehicles or personnel carriers, which are covered in separate sections of this report.

All major golf cart manufacturers offer two types of vehicles: carts powered by gasoline ICEs and carts powered by electric batteries. Among the products offered by all golf cart manufacturers identified for this analysis, gasoline engines ranged in capacity from 9 HP (6.7 kW) to 13 HP (9.7 kW), with 9 HP (6.7 kW) and 11.5 HP (8.6 kW) being the most common engine sizes available. Electric golf carts operate on either SLA deep-cycle batteries or sealed gel batteries. Variously sized electric motors and battery configurations are available. Motor capacities among the manufacturers identified ranged from 2.5 HP (1.9 kW) to 5 HP (3.7 kW); multiple products were available in the 3.2 to 3.5 HP (2.4 to 2.6 kW) range. Several golf carts operate using 48V battery systems (configured as four 12V, six 8V, or eight 6V batteries); others operate on 36V systems (six 6V batteries) or 42V systems (seven 6V batteries).

There are drawbacks to both ICE and battery power sources. ICE golf carts are louder than electric models and require routine maintenance (e.g., fluid changes, tune-ups) like any other ICE-powered vehicle. Also, ICE exhaust is associated with air pollution, which is particularly undesirable in air quality nonattainment areas. Batteries also have drawbacks and limitations. Among these are low energy density and cycle-life, compared to ICE vehicles, maintenance

[464] Wikimedia Foundation, Inc. 2006. Golf cart. Available at http://en.wikipedia.org/wiki/Golf_cart [Accessed June 2006].
[465] Wikimedia Foundation, Inc. 2006. Golf cart. Available at http://en.wikipedia.org/wiki/Golf_cart [Accessed June 2006].

(charging) requirements, and weight.[466] Also, the performance of batteries may be reduced on uphill climbs, and they must be recycled at the end of their functional life.

Golf carts generally cost under $10,000. Pricing for a new golf cart begins at approximately $4,000 for the most basic model. More typically, golf carts cost between $6,000 and $9,000. Luxury models with extras such as upgraded upholstery, lights, and special wheels can cost upwards of $10,000. Because purchase prices are so high, leasing of golf carts is common; 75% to 90% of all new golf carts are leased instead of sold. Most commonly, leasing occurs through fleet rentals to golf courses. Golf carts are typically purchased, rather than leased, when they are for personal use.[467]

MARKET SIZE

Current data on the number of adopters in the golf cart market are provided below. Golf cart manufacturers (covered by SIC Code 3799) are represented in Table x-2. Table x-3 characterizes the recreational (i.e., golf-related, non-residential) user market for golf carts in the U.S.; this table includes public golf courses (SIC Code 7992); members-only golf, country, and other recreational clubs (SIC Code 7997); and small golf courses (pitch-and-putt) and driving ranges, as well as other recreational facilities (SIC Code 7999). Note that Table x-3 does not represent all recreational uses for golf carts, just those related directly to the sport of golf. In Tables x-2 and x-3, only those eight-digit SIC specialties related to the manufacturing or use of golf carts are shown.

Table x-2. Number of Golf Cart Manufacturers - Industry: Transportation Equipment, Nec (3799).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3799-0204	Golf carts, powered	52	438	39.5
	Total	**52**	**438**	**39.5**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

[466] Cook, B. 1999. The Low-Speed EV Marketplace: Synopsis of Presentation Delivered at 1999 Non-Road Electric Vehicle Conference, Orlando, FL. Available at http://www.evworld.com/archives/conferences/epri99/bcook.html [Accessed June 2006].
[467] BuyerZone.com, Inc. 2006. Golf Carts Buyer's Guide: Utility vehicle and golf car pricing. Available at http://www.buyerzone.com/industrial/golf_carts/buyers_guide6.html [Accessed June 2006].

Table x-3. Number of Potential Golf Cart Users - Industries: Public Golf Courses (7992); Membership Sports and Recreation Clubs (7997); Amusement and Recreation, Nec (7999).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
7992-0000	Public golf courses	8,487	150,167	7,865.9
7997-9904	Country club, membership	3,543	143,905	10,270.1
7997-9906	Golf club, membership	3,080	83,928	3,935.7
7999-0200	Golf services and professionals	1,248	8,630	351.2
7999-0201	Golf cart, power, rental	89	676	37.1
7999-0202	Golf driving range	1,112	7,124	339.4
7999-0203	Golf professionals	270	1,838	73.2
7999-0204	Golf, pitch-n-putt	49	386	8.2
	Total	**17,878**	**396,654**	**22,881**

Note: Not all establishments have a specialty. Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Sales of golf carts, which represented a large share of the market for personal mobility vehicles in 2002 (see Table x-4), are expected to increase through 2012. Demand for golf carts from 1992 to 2012 (projected) is presented in Table x-5. As Table x-5 also indicates, the number of golf courses in the U.S. is expected to grow through 2012.

Table x-4. Demand for Personal Mobility Devices by Type, 2002 (Total of $780 million).

Item	%
Golf Carts	55
Utility Vehicles	15
In-Plant Personnel Carriers	13
Commercial Vehicles	8
Other Products	9

Source: Adapted from The Freedonia Group, Inc. 2005. Power Lawn & Garden Equipment to 2009. Report #1903.

Table x-5. Demand for Golf Carts and Other Personal Mobility Devices, 1992-2012.[468]

Item	1992	1997	2002	2007	2012
Number of Golf Courses (000's)	14.4	16.1	17.5	19.5	21.5
Sales of Golf Carts Per Course ($000's)	14	21	25	29	35
Golf Cart Sales ($millions)	202	333	430	575	750
% of Golf Cart Sales (of total below)	56.0	56.3	55.1	53.5	52.6
Sales of Other Personal Mobility Devices ($millions)	361	592	780	1075	1425

Source: Adapted from The Freedonia Group, Inc. 2005. Power Lawn & Garden Equipment to 2009. Report #1903.

In order to assess the market size, it is necessary to consider how many golf courses are operational in the United States. According to the National Golf Foundation (NGF) there were 16,057 facilities containing at least one golf course as of December 31, 2004. The states with the most golf facilities include: Florida (1,073), California (925), Texas (857), Michigan (852), and New York (822). It is estimated that a total of 150.5 new 18-hole equivalents came online across the U.S. in 2004, suggesting a growth rate of approximately 1% per year. However, in that same year there were 990.5 18-hole equivalent golf courses in the construction pipeline.[469] No data

[468] The Freedonia Group, Inc. 2005. Power Lawn & Garden Equipment to 2009. Report #1903. Cleveland, OH, The Freedonia Group, Inc.
[469] National Golf Foundation. 2006. Questions/FAQ's. Available at http://www.ngf.org/cgi/whofaqa.asp? [Accessed May 2006].

were available on the average number of golf carts per course, but it is estimated that golf carts number in the tens at smaller golf courses, and can be in the hundreds for larger courses.

Limited data were found on the current market for residential golf cart users. However, at least one major golf cart manufacturer has noted recent growth in its market for private golf carts.[470]

The leading golf cart manufacturers are Club Car, Inc.; E-Z-Go (a Textron Company); Yamaha Golf Car Company; and Columbia ParCar Corp.

MARKET TRENDS

Although golf cart manufacturers still offer both gas and electric models, secondary research suggests that electric golf carts are gaining ground over gasoline-powered models, both in golf and residential applications. This may be attributable to the high costs of gasoline and the fact that electric models are quieter and less polluting than ICE models. New clean air standards have forced some localities to plan replacement of gas-powered golf cart fleets with electric models.[471] Residential subdivisions are seeking permission for their residents to operate electric golf carts on city streets,[472] and even some larger cities have reported increased neighborhood use of electric golf carts by their residents.[473]

In recent years, manufacturers have predicted a shift in the golf cart market away from gas vehicles and toward electric vehicles for various reasons, including increasingly stringent environmental standards (e.g., air emissions and hazardous material permitting requirements).[474]

There also appears to be a growing interest in developing alternative energy sources to supplement and work in conjunction with the batteries in electric carts. For example, companies have developed photovoltaic roof panels for golf carts, which keep the batteries charged and significantly extend battery life. PowerLight Corporation's SunCaddy solar electric systems were used on a fleet of 60 golf carts at the Francis H. I'i Brown golf course in Hawaii.[475]

Several companies have investigated the potential for fuel cells to be used in golf carts and other golf applications. Most notably, Astris Energi Inc., a Canadian R&D firm that focuses on alkaline fuel cells, recently developed its second fuel cell-powered golf cart prototype. This vehicle, known as the FII, has been converted to run on an alkaline fuel cell generator instead of batteries, making it lighter (by 170 lbs.) than the standard, battery-powered golf cart and allowing it to run for 3 days between hydrogen refills (compared to 8 to 10 hours between battery charges).[476] Humboldt State University's Schatz Energy Research Center (SERC)

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[470] Milicia, J. 2005. Golf carts traveling onto city streets. Las Vegas Sun (June 20, 2005). Available at http://www.lasvegassun.com/sunbin/stories/nat-gen/2005/jun/20/062005781.html [Accessed June 2006].
[471] Lee Enterprises. 2006. City approves budget for golf, bocce projects. The Napa Valley Register (January 2006). Available at http://www.napavalleyregister.com/articles/2006/01/19/news/briefing/iq_3260327.txt [Accessed June 2006].
[472] Piotraschke, J. 2005. Town board might allow golf carts on subdivision's streets. Greeley Tribune (November 4, 2005). Available at http://www.greeleytrib.com/article/20051104/NEWS/111040087 [Accessed June 2006].
[473] Milicia, J. 2005. Golf carts traveling onto city streets. Las Vegas Sun (June 20, 2005). Available at http://www.lasvegassun.com/sunbin/stories/nat-gen/2005/jun/20/062005781.html [Accessed June 2006].
[474] Golf Car Catalog. 2002. Todd Sauey, President & CEO of Par Car. Available at http://www.golfcarcatalog.com/index.cfm?fuseaction=archive&step=3&archive_id=19 [Accessed June 2006].
[475] Golf Press Association. 2002. Fleet of Solar-Powered Golf Cars Shine in Hawaii. The Wire. Available at http://www.golftransactions.com/equipment/suncaddy011702.html [Accessed June 2006].
[476] Astris Energi Inc. 2006. FII – Alkaline Fuel Cell (AFC) Powered Golf Car. Fact Sheet. Available at http://www.astris.ca/PR/pdf/Astris-FIIGolfCar.pdf [Accessed June 2006].

developed three golf carts powered by 4kW PEM fuel cells. These golf carts have been used in Palm Desert, California, since 1996.[477] Other golf-related fuel cell activities include a cooperative effort between residential developer WCI Communities and Florida Power & Light Company. These organizations collaborated on a project to install a stationary hydrogen fuel cell manufactured by Plug Power at a golf club in Venice, Florida. This fuel cell was used to help charge the club's golf carts.[478]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in golf carts, both manufacturers and users of these vehicles were contacted. Various contacts within four companies that manufacture golf carts were contacted, and two responses were received. Similarly, four golf courses and two industry groups also were contacted, and one response was received from an industry group representative. No golf courses responded.

The two golf cart manufacturers – one a small company and one medium-sized with a large parent company – offer electric and gasoline ICE-powered golf carts. The small manufacturer also produces ICE vehicles for industrial and commercial use.

The manufacturers indicated that all of their markets, particularly golf courses and industrial fabrication plants (for the manufacturer that produces industrial vehicles) are sensitive to downtime. The industry representative did not address downtime, as he was unaware of any such issues regarding golf carts.

Sparse information was obtained regarding O&M requirements. The small manufacturer indicated that maintenance was required every 2 weeks for batteries and every 4 weeks for other electric vehicle components, compared to a minimum of every 4 weeks for ICE-based products. The medium-sized manufacturer indicated that charging was the only O&M requirement for electric vehicles and did not address O&M requirements for ICE vehicles.

No real safety concerns were noted by respondents. The small manufacturer noted that batteries have the potential to explode but that such an event is extremely rare. No safety concerns related to ICE vehicles were reported.

In general, the manufacturers who responded appeared to be satisfied with the performance of batteries. One manufacturer praised their energy efficiency. Another manufacturer expressed concerns over ICE vehicles, noting that their performance and reliability lagged behind those of battery vehicles.

One manufacturer and an industry association representative were aware of the potential for fuel cells to be used as alternatives to existing power sources. The manufacturer was unable to comment on whether or not fuel cells were being evaluated by the company; however, the respondent noted that price and fuel availability were key issues when considering any energy

[477] Fuel Cells 2000. 2006. Fuel Cell Specialty Vehicles. Available at http://www.fuelcells.org/basics/fct/specialty.html [Accessed June 2006].
[478] WCI Communities, Inc. 2004. Golfers to drive the hydrogen highway. Available at http://wci.wcicommunities.com/?pageID=press_releases_detail&siteID=1000&vid=1000&CID=1081348271828 [Accessed June 2006].

source. The manufacturer also pointed out that golf courses buy anywhere from 50 to 350 golf carts at a time, so there is the potential for widespread use if the technology were to be made available. The industry association representative noted that a Canadian company had already developed a fuel cell-powered golf cart and that other alternative energy sources (e.g., solar power) were being investigated.

Regarding whether their customers would be concerned over the use of hydrogen as a fuel, neither manufacturer believed this would be a problem from a safety perspective. One manufacturer stressed the need for hydrogen to be accessible and inexpensive in order for customers to use it.

Both manufacturers expressed some interest in working with DOE to demonstrate PEM fuel cells; one was more interested in providing a vehicle to DOE for R&D than in forming an ongoing partnership. Both manufacturers also agreed to be contacted again.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

ICE-powered golf carts appear to be losing ground to electric golf carts in both recreational and residential environments, particularly in areas where air pollution and noise are a concern. Battery-powered models are currently widely used, and batteries are generally considered to be inexpensive, readily available, and reliable.

However, environmental and practical drivers lend support to the adoption of PEM fuel cells by golf cart manufacturers, which offer some of the same advantages of both battery-powered and ICE-powered golf carts. These drivers include:

- Need for exhaust-free vehicles, particularly in areas with strict emission laws (note that California is home to more golf courses than any other state but Florida)
- Need for quiet equipment, since many golf courses are built near residential communities with noise ordinances
- Customer desire for fuel source that is not as vulnerable to fluctuating oil prices as gasoline
- Superior acceleration and hill climbing abilities, compared to battery-powered golf carts[479]
- Refueling speed would equal that of gas-powered engines and be significantly faster than battery recharging
- Extended operation time over battery-powered vehicles.[480]

While longer runtimes between refueling/recharging are a potential advantage, it is not clear that this will be a strong selling point for fuel cells. As long as a battery charge holds throughout the day, recharging at night is not likely viewed as an inconvenience. Other potential barriers to fuel

[479] Astris Energi Inc. 2006. Astris Energi is Looking to Form Partnership to Integrate our MODEL E7 Battery Replacement Fuel Cell Generator into Utility Vehicle Applications. Available at http://www.fuelcellmarkets.com/article_default_view.fcm?articleid=12786&subsite=912 [Accessed June 2006].

[480] Astris Energi Inc. 2006. Astris Energi is Looking to Form Partnership to Integrate our MODEL E7 Battery Replacement Fuel Cell Generator into Utility Vehicle Applications. Available at http://www.fuelcellmarkets.com/article_default_view.fcm?articleid=12786&subsite=912 [Accessed June 2006].

cell use in golf carts include the high cost and difficulties associated with storage of hydrogen, as well as the lack of existing infrastructure for hydrogen refueling.

PEM fuel cells do not appear to be ready for near-term deployment in this market, but the market size, initial interest in hydrogen fuel cells and other power alternatives (e.g. solar cells), and performance advantages suggest that this may hold promise as a mid-term market if a cost-effective hydrogen refueling solution can be developed for golf course environments and if PEM fuel cells can be competitive with battery-powered electric vehicles.

RESEARCH SUMMARY:
SPECIALTY VEHICLES - LAWNMOWERS

MARKET SEGMENT DESCRIPTION

Lawnmowers are vehicles equipped with rotating blades designed to cut grass. This analysis focuses on powered lawnmowers, which include both walk-behind and riding models. Lawnmowers can be used in residential, commercial, and institutional environments. Typical locations in which lawnmowers are used include areas serviced by professional landscapers, such as golf courses, educational facilities, parks, athletic fields, country clubs, farms, ranches, and cemeteries, as well as private yards.

Mower designs vary greatly depending on application, though there are two basic classes of power mowers: walk-behind and ride-on models. Lawnmowers designed for commercial use on golf courses, athletic fields, or other large properties are typically ride-on units with multiple blade attachments that cover a wide expanse of grass and are dragged behind or pushed in front of the vehicle. Front-engine and rear-engine riding mowers (referring to the position of the engine in relation to the driver) are available. Lawnmowers designed to be used in small yards and residential environments are typically walk-behind push mowers with a 21”-wide cutting area. Self-propelled push mowers can be either front-wheel or rear-wheel driven. Table y-1 identifies the SIC and NAICS classifications that cover manufacturing of lawnmowers.

Table y-1. SIC and NAICS Codes for Lawnmower Manufacturing.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Codes	3523 – Farm machinery and equipment 3524 – Lawn and garden tractors and home lawn and garden equipment
NAICS Codes	333111 – Farm machinery and equipment manufacturing 333112 – Lawn and garden tractor and home lawn and garden equipment manufacturing

Lawnmowers are available with several different power sources, including ICEs and batteries. ICE-powered models are fueled by gasoline, diesel, or propane. Propane is a recent addition to the lawnmower market; the clean-burning fuel is being marketed as an environmentally friendly alternative to diesel and gasoline. Some operators report that propane-powered mowers are more powerful than identical gasoline units. Dixie Chopper, which manufactures 30 to 54 HP (22.4 to 40.3 kW) propane models for commercial use, expects to sell between 500 and 1,000 units in 2006.[481]

Some manufacturers are producing both corded and cordless electric models in an effort to avoid the noise and emissions associated with fossil fuel-powered mowers. The cordless mowers, which are usually walk-behind push models suited for use in small areas, typically run on 24V of electric power (configured as one 24V or two 12V batteries). Corded electric mowers are driven by electric motors ranging in power from 6 to 12 amps. Jacobsen Golf and Turf has developed

[481] Guyette, J.E. 2006. Grounds pros claim that alternative-fuel commercial mowers have power and big potential. Landscape Management. Available at http://www.landscapemanagement.net/landscape/article/articleDetail.jsp?id=317568&pageID=1&sk=&date= [Accessed May 2006].

an electric riding mower for use on golf courses. The E-Plex™ II runs on a 3.5 HP (2.6 kW), 48V electric motor powered by six 8V batteries.[482]

In general, walk-behind mowers (both commercial and residential) are powered by smaller engines (typically < 20 HP/14.9 kW) than riding mowers. Residential walk-behind mowers with 21" mowing decks tend to have the smallest engines (< 10 HP/7.5 kW). Commercial walk-behind mowers often have wider mowing decks than residential mowers; these decks range from 21" to 60" or wider. The engines of commercial walk-behind mowers tend to be greater than 10 HP (7.5 kW) but still less than 20 HP (14.9 kW). As indicated above, electric walk-behind mowers, such as those manufactured by Sunlawn, Black and Decker, and Neuton, are typically powered by 24V, rechargeable batteries. However, a 48V, 3.5 HP (2.6 kW) electric riding mower is also on the market.

Riding mowers vary greatly in size and shape and are powered by a wide range of engines. The mowing decks on riding mowers are significantly larger than the 21" decks used in walk-behind models; large commercial riders can use multiple decks capable of covering an expansive surface. Residential riding mowers are typically powered by engines smaller than 25 HP/18.6 kW (most often < 15 HP/11.2 kW). Commercial riding mowers can be powered by smaller (< 25 HP/18.6 kW) engines, but typically they have medium-sized (25 to 50 HP/18.6 to 37.3 kW) engines. Wide-area, multi-deck mowers used on athletic fields and golf courses can have engines that exceed 50 HP (37.3 kW).

Residential mowers are available in a wide range of prices, as evidenced by a review of models available for sale online. The most basic 21" walk-behind mowers can be purchased for approximately $170, while high-end models cost over $800. Residential zero turning radius mowers range from about $2,000 to more than $5,000. Residential lawn and garden tractors range from $1,500 to over $7,000.

Commercial mowers can be significantly more expensive than residential units. A review of commercial-grade 21" walk-behind mowers available for sale online identified models ranging from $700 to nearly $1,200. A report on zero turning radius mowers indicated that small (48") commercial models start at $4,000 to $5,000. The bulk of the commercial market is sized between 52" and 61"; these models typically have 20 to 30 HP gasoline engines and sell for $7,000 to $9,000. Heavier duty, water-cooled diesel greens mowers with 72" decks typically cost between $10,000 and $12,000, though even more expensive models are available.[483]

MARKET SIZE

Current data on the size of the lawnmower manufacturing market are provided below. Table y-2 includes SIC Code 3524, which covers manufacturing of residential mowers, and SIC Code 3523, which covers manufacturing of commercial mowers. Note that the categories of "Lawn and garden tractors and equipment," "Turf and grounds equipment," and "Turf equipment, commercial" may include other types of equipment in addition to mowers. Only those eight-

[482] Jacobsen Golf & Turf. 2006. E-Plex™ II. Available at http://www.jacobsengolf.com/products/riding_greens_mowers/e-plex_ii/ [Accessed June 2006].

[483] Parish, D. 2005. Zero Turning Radius Mowers: Selection, Use, Maintenance & Safety. Louisiana State University Agricultural Center, Pub. 2911. Available at http://www.agctr.lsu.edu/NR/rdonlyres/67A1DFB8-8597-467C-AD55-5D66F71B0861/12414/pub2911ZeroTurnMowers2.pdf [Accessed June 2006].

digit SIC Code specialties relevant to residential and commercial lawnmower manufacturing are shown.

Table y-3 characterizes the expansive user market for lawnmowers (based on the number of adopters), which is comprised of golf courses and other recreational fields that might require turf or grass maintenance; amusement parks, zoos, and other tourist attractions that may include grassy areas; cemeteries; and commercial landscapers or lawn-care professionals. Note that residential users of lawnmowers, who constitute a significant segment of the market, are not included in this table. Included in Table y-3 are public golf courses (SIC Code 7992); members-only golf, country, and other recreational clubs (SIC Code 7997); small golf courses (pitch-and-putt) and driving ranges, as well as other recreational facilities (SIC Code 7999); amusement parks (SIC Code 7996); cemeteries (SIC Code 6553); athletic fields (SIC Code 7941); zoos and botanical gardens (SIC Code 8422); and lawn and garden services (SIC Code 0782). Within this table, only those eight-code SIC specialties deemed likely to require grounds or greens maintenance are shown.

Table y-2. Number of Lawnmower Manufacturers - Industries: Lawn and Garden Equipment (3524); Farm Machinery and Equipment (3523).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
3524-0100	Lawn and garden tractors and equipment	43	1,256	1,131.5
3524-0200	Lawn and garden mowers and accessories	93	2,065	242.8
3524-0201	Grass catchers, lawn mower	28	230	12.4
3524-0202	Lawnmowers, residential: hand or power	58	4,993	131.8
3523-0500	Turf and grounds equipment	53	1,216	152.8
3523-0501	Greens mowing equipment	7	121	9.9
3523-0502	Grounds mowing equipment	30	1,720	412.1
3523-0503	Turf equipment, commercial	29	405	35.9
	Total	**341**	**12,006**	**2,129**

Sales figures are in millions. Source: www.zapdata.com, accessed May 2006.

Table y-3. Potential Users of Lawnmowers - Industries: Public Golf Courses (7992); Membership Sports and Recreation Clubs (7997); Amusement and Recreation, Nec (7999); Amusement Parks (7996); Cemetery Subdividers and Developers (6553); Sports Clubs, Managers, and Promoters (7941); Botanical and Zoological Gardens (8422); Lawn and Garden Services (0782).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
7992-0000	Public golf courses	8,487	150,167	7,865.9
7997-0400	Outdoor field clubs	874	3,797	124.4
7997-0401	Baseball club, except professional and semi-professional	969	5,496	185.9
7997-0402	Football club, except professional and semi-professional	67	475	14.7
7997-0403	Polo club, membership	25	160	4.5
7997-0404	Soccer club, except professional and semi-professional	417	1,933	86.7
7997-9904	Country club, membership	3,543	143,905	10,270.1
7997-9905	Flying field, maintained by aviation clubs	44	226	8.8
7997-9906	Golf club, membership	3,080	83,928	3,935.7
7997-9907	Lawn bowling club, membership	13	194	5.6
7997-9908	Riding club, membership	114	857	28.1
7999-0200	Golf services and professionals	1,248	8,630	351.2
7999-0202	Golf driving range	1,112	7,124	339.4
7999-0203	Golf professionals	270	1,838	73.2
7999-0204	Golf, pitch-n-putt	49	386	8.2
7999-0704	Skeet shooting facility	26	159	4.9
7999-0705	Trapshooting facility, non-membership	11	54	2
7999-1100	Instruction schools, camps, and services	1,405	5,869	210
7999-1102	Baseball instruction school	290	1,742	45.9
7999-1106	Day camp	391	4,814	157.4
7999-1515	Zoological garden, commercial	156	3,664	179
7999-9909	Picnic ground operation	142	1,794	58.7
7999-9910	Recreation center	3,972	40,022	923.5
7996-0000	Amusement parks	1,186	22,069	1,690.1
7996-9901	Kiddie park	160	2,476	86.9
7996-9903	Theme park, amusement	271	85,767	10,962.2
6553-0000	Cemetery subdividers and developers	4,620	24,173	605
6553-9901	Animal cemetery operation	130	648	22.8
6553-9902	Cemeteries, real estate operation	1,559	15,762	777
6553-9903	Cemetery association	684	6,140	339.4
6553-9905	Real property subdividers and developers, cemetery lots only	312	2,842	387.1
7941-0000	Sports clubs, managers, and promoters	1,256	11,512	1,214.8
7941-0100	Professional and semi-professional sports clubs	138	1,622	225.6
7941-0101	Baseball club, professional and semi-professional	385	11,494	1,719.8
7941-0102	Basketball club	235	3,784	876.4
7941-0103	Football club	641	8,005	1,837.8
7941-0105	Soccer club	805	4,483	476.7
7941-0200	Stadium event operator services	180	4,386	434.5
7941-0202	Sports field or stadium operator, promoting sports events	391	8,696	661.5
8422-0000	Botanical and zoological gardens	157	3,864	243.6
8422-0100	Aquariums and zoological gardens	41	1,520	90.7
8422-0103	Zoological garden, noncommercial	81	6,695	559.9
8422-0200	Arboreta and botanical gardens	16	322	12.3
8422-0201	Arboretum	56	1,010	116.3
8422-0202	Botanical garden	233	4,630	436.8

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)*
0782-0000	Lawn and garden services	18,989	69,694	2,513.7
0782-0200	Lawn services	8,433	36,115	1,397.2
0782-0201	Cemetery upkeep services	152	799	27.7
0782-0203	Lawn care services	23,722	70,428	6,091
0782-0204	Mowing services, lawn	1,911	4,275	154.7
0782-0210	Turf installation services, except artificial	639	1,719	66.1
0782-9902	Highway lawn and garden maintenance services	348	2,988	165
0782-9903	Landscape contractors	27,715	182,335	8,777
	Total	**122,151**	**1,067,487**	**67,853**

Note: Not all establishments have a specialty. Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

A recent market report estimated that the U.S. demand for power lawn and garden equipment, including lawnmowers, will increase by 3.1% each year from 2005 through 2009, when the market size will reach $10.7 billion.[484] Lawnmowers are expected to remain the dominant product group within this industry, due to their widespread use in both residential and commercial applications. Analysts attribute this growth to an expansion of the 55 to 64-year-old age group, which tends to replace older lawn and garden equipment with more expensive products and to hire professional lawn care services. Product innovations and upgrades, driven by consumer demand for lighter and more powerful equipment, are also expected to encourage growth.

Residential equipment dominates the lawn and garden industry, accounting for two-thirds of total sales in 2004.[485] However, commercial sales have outpaced residential sales in recent years, in part due to extensive growth in sales of zero-degree turning radius turf mowers to both commercial and residential consumers. The commercial market is expected to continue growing, stimulated by a sustained rise in the number of landscaping professionals.

Each year, the Outdoor Power Equipment Institute (OPEI) forecasts industry trends based on an econometric model. For the 2006 model year (running from September 2005 to August 2006), OPEI predicts that sales of consumer walk-behind mowers will fall 3.0% to 6.2 million units, while consumer riding mowers are predicted to decline by 2.0% to just under 1.9 million units. OPEI also predicts that commercial turf care walk-behinds will decline slightly and that commercial riders will grow by only 1.1%. According to OPEI, "commercial products combined will close the year at a level slightly above 242,000 units."[486] Table y-4 illustrates OPEI's forecast for the 2006 model year.

[484] The Freedonia Group, Inc. 2005. Power Lawn & Garden Equipment to 2009. Report #1903. Cleveland, OH, The Freedonia Group, Inc.
[485] The Freedonia Group, Inc. 2005. Power Lawn & Garden Equipment to 2009. Report #1903. Cleveland, OH, The Freedonia Group, Inc.
[486] Outdoor Power Equipment Institute. 2006. OPEI May 2006 Forecast Press Release for Consumer and Commercial Products. Available at http://www.opei.org/newsroom/docs/56_May%202006%20Consumer%20%20Commercial%20Forecast.pdf [Accessed May 2006].

Table y-4. OPEI Predictions for Model Year 2006 – Outdoor Power Equipment Forecast.

Annual Unit Shipment Growth					
	FY2002	FY2003	FY2004	FY2005	FORECAST FY2006
Consumer Products					
Walk-Behind Powered Mowers	5.2%	3.6%	6.3%	-1.8%	-3.0%
All Riding Units	6.1%	11.1%	10.6%	-4.4%	-2.0%
Commercial Turf Care Products					
Intermediate Walkers	-9.7%	-9.2%	12.0%	-15.3%	-0.8%
Riding Mowers	1.6%	25.3%	38.9%	0.1%	1.1%

Source: Adapted from OPEI, 2006.

Also relevant to the lawnmower industry are forecasts associated with lawnmower user markets. For example, the Freedonia Group estimated that the number of golf courses in the U.S. would increase from 14,400 in 1992 to 21,500 in 2012 (See Table y-5).[487]

Table y-5. Number of Golf Courses in the United States through 2012.

	1992	**1997**	**2002**	**2007**	**2012**
Golf Courses (000's)	14.4	16.1	17.5	19.5	21.5

Source: Adapted from Freedonia Group Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number #1745.

Major lawnmower manufacturers include Electrolux North America, Inc.; The Toro Company; John Deere; MTD Products; Black and Decker; American Honda Power Equipment; Snapper Pro; and Murray Outdoor Power Equipment.

MARKET TRENDS

Evidence indicates that turf maintenance professionals are seeking alternatives to ICE-powered mowers in an attempt to address customers' concerns: namely, noise and hydraulic oil leaks. For example, the superintendent of a golf resort in Florida began using an electric greens mower after receiving complaints on a nearly daily basis from guests at the resort about the noise generated by early-morning mowing.[488] Also, the tendency of large greens mowers and tractors to leak hydraulic fluid and damage turf is a well-recognized problem within the industry.[489]

The Toro Company has developed two working prototypes powered by PEM fuel cells.[490] Toro has worked with at least three fuel cell developers (Nuvera, Hydrogenics, and Metallic Power) in evaluating the performance of fuel cell modules in mowing equipment. Nuvera supplied Toro with a hydrogen power module from its H2e (hydrogen to electricity) line of small-scale fuel cell stacks, which are capable of providing between 1 and 6 kW of electric power.[491] In 2004, Toro awarded a contract to Hydrogenics to supply a PEM fuel cell module for integration into a

[487] The Freedonia Group Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report #1745. Cleveland, OH, The Freedonia Group, Inc.
[488] Jacobsen Golf & Turf. 2006. Case Studies: Quiet Please: Jacobsen E-Plex Works Peacefully. Available at http://www.jacobsengolf.com/resources/case_studies/eplex_peacefully.html [Accessed June 2006].
[489] Bevard, D.S. 2002. After the Spill. Grounds Maintenance. Available at http://grounds-mag.com/mag/grounds_maintenance_spill/index.html [Accessed June 2006].
[490] Personal Communication between Jennifer Zewatsky (Battelle) and Jack Gust (The Toro Company), May 17, 2006.
[491] BioAge Group, LLC. 2004. Toro Evaluating Nuvera Fuel Cell. Available at http://www.greencarcongress.com/2004/11/toro_evaluating.html [Accessed June 2006].

prototype greens mower.[492] Hydrogenics' PEM fuel cell modules are capable of output ranging from 8 kW to 65 kW.[493] Metallic Power demonstrated a Toro greens mower powered by a 2 kW regenerative zinc/air fuel cell system at a South Coast Air Quality Management District meeting in October of 2001.[494] Toro's mowers are still in development and will not be commercially available for some time. At the earliest, they may be ready for commercial production by 2009 or 2010, depending on the availability and costs of hydrogen fuel, as well as the ability of engineers to protect fuel cells from the effects of outdoor storage.[495]

Mower manufacturers are not the only organizations that have investigated the use of hydrogen fuel and PEM fuel cells in mowing equipment. Hocking College in Nelsonville, Ohio, recently unveiled a project to develop a hydrogen-powered lawn tractor through its International Fuel Cell and Alternative Energy Training Center.[496] Energy Conversion Devices, Inc., a materials research and product development company, developed a prototype hydrogen-powered, walk-behind lawnmower with a 3 kW power output.[497] The Danish Technological Institute developed a lawnmower that runs on a PEM fuel cell.[498]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells, both manufacturers and users of lawnmowers were contacted. Eight manufacturers were contacted, and three responses were received. Four golf courses (identified as key users of lawnmowers) and two golf industry groups were contacted, and one response was received from an industry group representative. No user responses were received.

Manufacturer respondents included one small and one medium commercial mower manufacturer, as well as one large provider of outdoor landscaping products and equipment. All of the manufacturers offer both riding and walk-behind mowers. Two focus on commercial equipment, while the third sells both residential and commercial-grade mowers. All three manufacturers offer diesel and gasoline-fueled ICE lawnmowers. One small company is developing a propane-fueled ICE mower, and a medium-sized manufacturer is developing an electric mower.

Unscheduled downtime was identified by two manufacturers as a major problem for professional landscapers. One small manufacturer offers a loaner program to alleviate the potential impact of downtime for its professional customers.

Manufacturers commented on the O&M requirements for ICE-based equipment only. All three indicated that regular oil and filter (both oil and air) changes were necessary. One manufacturer

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[492] Fuel Cell Works. 2004. Hydrogenics Awarded Contract by the Toro Company to Provide HyPM Technology for Fuel Cell Program. Available at http://www.fuelcellsworks.com/Supppage1092.html [Accessed June 2006].
[493] Hydrogenics Corporation. 2006. HyPM® Family – Fuel Cell Power Products. Available at http://www.hydrogenics.com/power/products.asp [Accessed June 2006].
[494] Metallic Power. 2001. Metallic Power Delivers Zinc/Air Fuel Cell Prototypes for Air Quality Management District Contract. Available at http://www.ewire.com/display.cfm/Wire_ID/775 [Accessed June 2006].
[495] Personal Communication between Jennifer Zewatsky (Battelle) and Jack Gust (The Toro Company), May 2006.
[496] Ohio Fuel Cell Coalition. 2006. Events. Available at http://www.fuelcellsohio.org/events.html [Accessed June 2, 2006].
[497] Sapru, K. 2003. Keeping it Clean: Congressional Briefing on Renewably Derived Hydrogen Capitol Bldg, June 3, 2003. Available at http://www.eesi.org/briefings/2003/EnergyandClimate/6.3.03%20Renewable%20Hydrogen/RH2.Sapru.pdf [Accessed June 2006].
[498] Danish Technological Institute. 2006. Hydrogen-powered Lawnmower. Available at http://www.danishtechnology.dk/energy/16319 [Accessed June 2006].

noted that oil changes are required approximately every 50 hours, and air filter changes are required frequently in dusty environments. Another respondent noted that liquid-cooled ICEs require filling the radiator with water in the summer and anti-freeze in the winter.

Several safety concerns were associated with ICE-based lawnmowers. Two manufacturers noted the potential for burns from the vehicle's exhaust system, which gets extremely hot. One respondent indicated that running a lawnmower indoors (e.g., in a maintenance shop) can result in carbon monoxide buildup. Another noted the potential for maintenance workers to injure their hands in the machines' rotating belts and pulleys.

All three manufacturers indicated that they are happy with ICEs in their lawnmower products. However, one medium-sized manufacturer noted that battery-powered electric vehicles may represent the future of the industry, as fossil fuels become more scarce and expensive. Therefore, his company is trying to lead the industry by investigating battery-powered lawnmowers. A small manufacturer predicted that the market for alternatively fueled lawnmowers will grow, since many cities restrict the use of diesel or gasoline-powered equipment on "ozone alert" days. Such restrictions can result in a tremendous loss of income for landscapers. This has prompted the manufacturer to investigate propane ICEs.

Two of the three manufacturers were aware of PEM fuel cells as alternatives to existing power sources. Of those two, one has already begun developing a PEM fuel cell-powered prototype mower; the other does not consider fuel cells to be economically feasible in the near-term. Two of the three manufacturers evaluate new power sources based on their ability to perform as well as their compatibility with existing systems in various environments. The third manufacturer noted the importance of identifying a quiet, leak-free power source that accommodates the weight restrictions associated with turf vehicles. This manufacturer compared the performance of alternative energy sources (batteries and fuel cells) and determined PEM fuel cells to be the most attractive mobile option. Echoing their responses to an earlier question, two manufacturers identified performance equal to ICE-powered equipment as the most important factor in selecting a new power source. The third manufacturer again stressed the importance of quiet, leak-free vehicles, noting that the hydraulic oil used in ICE vehicles can leak and kill grass and that mowers must often be used in or near communities with noise ordinances. One respondent indicated that PEM fuel cells will be a viable replacement for his company's products, while another suggested that it was possible.

Several barriers to fuel cell use in lawnmowers were identified. One manufacturer cited the cost of fuel cells and lack of refueling infrastructure. Another reiterated the fact that turf maintenance products are weight-limited. He noted that even though hydrogen is light, the tanks used to store it are heavy and bulky. The issue of securing enough on-board hydrogen without adding excess weight is a problem. A large manufacturer predicted that a fuel cell-powered mower could be introduced commercially by 2009 or 2010, at the earliest; however, this would almost entirely depend on the availability and cost of hydrogen fuel, as well as the ability of fuel cell vehicles to withstand outdoor storage in extremely low temperatures. No respondents felt that their customers would have concerns with using hydrogen from a safety perspective.

One large manufacturer addressed drivers for fuel cell use. This respondent cited a need to eliminate noise and the potential for hydraulic oil leaks from ICE-powered mowers. He added that the potential for greater reliability, ease of troubleshooting, and reduced maintenance could drive the adoption of fuel cell-based products.

One small manufacturer expressed interest in working with the DOE to develop fuel cell-based products; the other two manufacturers were open to the possibility but could not respond unequivocally at this time.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Environmental and practical drivers support transition away from standard gasoline-powered ICE engines in the lawnmower market. These drivers include:

- Need for alternative fuels in regions concerned with ozone emissions (gas or diesel-powered equipment cannot be used on days when the ozone level is high)
- Need for quiet equipment, since many golf courses are built near residential communities with noise ordinances
- Need to eliminate the potential for hydraulic oil leaks from ICE-powered motors (oil kills grass)
- Need for greater reliability and reduced maintenance compared to ICE-powered machines.

Propane fuel addresses some of the emissions concerns, and electric mowers can effectively address most of these needs in small power applications; however, batteries are not yet widely employed in larger riding mower applications. These larger applications may present an opportunity for PEM fuel cell use in lawn mowers.

While PEM fuel cells could potentially meet these needs, several potential barriers to market entry would need to be addressed, including:

- Cost of hydrogen
- Lack of existing infrastructure for refueling, although for niche markets (e.g. golf courses, lawn service companies, and others that may have centralized refueling facilities) this may be less of an issue
- Bulkiness and weight of hydrogen tanks, particularly for turf vehicles which are weight limited
- Tendency of water produced by fuel cells to freeze if equipment is stored outdoors in low temperatures, which is a particular concern for commercial fleets
- Lack of confidence on the part of consumers in alternatives to ICE-powered mowers.

Considering these barriers to market entry and the expected timeframe for deployment of fuel cell technology in lawnmowers, this is not considered a likely near-term market for PEM fuel cells. However, the fact that battery-powered electric vehicles are not currently meeting the larger, commercial-scale applications, may open the door for fuel cells in the mid to longer term.

RESEARCH SUMMARY:
SPECIALTY VEHICLES – MINING

MARKET SEGMENT DESCRIPTION

Companies in this market segment use specialty vehicles to perform various functions in underground mines, such as loading and moving materials or transporting personnel. While specialty vehicles are also used for surface mining functions, the target market for this analysis is subsurface applications where emissions from ICEs pose health and safety risks. Mining segments that engage in subsurface extraction of minerals include:

- Coal Mining & Processing
- Copper Mining & Processing
- Diamond & Other Precious Stone Mining
- Precious Metals Mining & Processing (e.g., gold and silver ores)
- Industrial Metals & Minerals (e.g., iron, lead, zinc, and miscellaneous metal ores such as platinum ore).

Table z-1 identifies the SIC and NAICS classifications that represent mining segments involved in the subsurface extraction of minerals.

Table z-1. SIC and NAICS Codes for Coal and Metal Mining.

2-Digit SIC Code	12 – Coal mining
4-Digit SIC Codes	1222 – Bituminous coal underground mining
	1231 – Anthracite mining (hard coal)
	1241 – Coal mining services
NAICS Codes	21211 – Coal mining
	212112 – Bituminous coal underground mining
2-Digit SIC Code	10 – Metal mining
4-Digit SIC Codes	1011 – Iron ores
	1021 – Copper ores
	1031 – Lead and zinc ores
	1041 – Gold ores
	1044 – Silver ores
	1061 – Ferroalloy ores, except vanadium
	1081 – Metal mining services
	1094 – Uranium-radium-vanadium ores
	1099 – Miscellaneous metal ores, nec (includes platinum)
NAICS Codes	212210 – Iron ore mining
	212234 – Copper ore and nickel ore mining
	212231 – Lead ore and zinc ore mining
	212221 – Gold ore mining
	212222 – Silver ore mining
	213114 – Support activities for metal mining
	212291 – Uranium-radium-vanadium ore mining
	212299 – All other metal ore mining

Table z-2 identifies the SIC and NAICS Codes that cover manufacturing of underground mining vehicles.

Table z-2. SIC and NAICS Codes for Manufacturing of Underground Mining Vehicles.

2-Digit SIC Code	35 – Industrial and commercial machinery and computer equipment
4-Digit SIC Code	3532 – Mining machinery & equipment, except oil and gas field machinery & equipment
NAICS Code	333131 – Mining machinery and equipment manufacturing

Underground mining vehicles are used for loading and moving materials and transporting personnel. Many of the vehicles used to move materials are classified as underground load-haul-dump (LHD) vehicles. The major equipment categories that could be compatible with a fuel cell power plant are described below:

- **Shuttle cars** – A shuttle car is either a conveyer or mine car that uses rubber tires or continuous treads to transfer coal, ore, or other materials from loading machines in trackless areas of a mine to the main transportation system. Shuttle cars are estimated to require 50 to 80 HP. Underground mines typically have 2 to 3 shuttle cars.
- **Utility vehicles, personnel carriers, or mantrip** – These vehicles carry mine personnel, by rail or rubber tire, to and from the work area. They vary widely by size, structure (e.g., 3 or 4 wheels), and capacity. A case study of a moderate-sized mine had two 6-passenger carriers at 57 HP each, with an average operation of 1,500 hours per year each.[499]
- **Underground loaders** – An underground loader is a mechanical shovel or other machine that is used for loading coal, ore, mineral, or rock. A case study showed that a moderate-sized mine had three 277 HP LHD vehicles, and five 231 HP LHD vehicles, each of which operated an average of 3,500 hours per year.[500]
    - **Shaker-shovel loader** – A machine for loading coal, ore, or rock usually in headings or tunnels. It consists of a wide flat shovel that is forced into the loose material along the floor by the forward motion of the conveyor. The shaking motion of the conveyor brings the material backwards, and it is loaded into cars or a conveyor.
    - **Scraper loader** – A machine used for loading coal, rock, or ore by pulling an open-bottomed scoop back and forth between the face and the loading point and loading it into mine cars or onto a conveyor in an underground mine.
    - **Cutter loader** – A longwall machine that cuts and loads coal onto a conveyor as it travels across the face.
    - **Gathering arm loader** – A machine for loading loose rock or coal. It has a tractor-mounted chassis, carrying a chain conveyor, the front end of which is built into a wedge-shaped blade. Mounted on this blade are two arms, one on either side of the chain conveyor, which gather the material from the muck pile and feed it onto the loader conveyor. The tail or back end of the conveyor is designed to swivel and elevate hydraulically so that the coal or stone can be loaded into a car or onto another conveyor.

[499] Bickel, K., J. McDonald, J. Fruin, and D. Tiffany. 1997. Economic Comparison of Biodiesel Blends to Commercially Available Exhaust Emission Reduction Technologies for Underground Mines. Final Report to the National Biodiesel Board.
[500] Bickel, K., J. McDonald, J. Fruin, and D. Tiffany. 1997. Economic Comparison of Biodiesel Blends to Commercially Available Exhaust Emission Reduction Technologies for Underground Mines. Final Report to the National Biodiesel Board.

- **Locomotives** – An electric engine, operating either from current supplied by trolley and track or from storage batteries carried on the locomotive. The locomotive may be powered by battery, diesel, compressed air, trolley, or some combination thereof, such as battery-trolley or trolley-cable reel. Locomotives are used to move empty and loaded mine cars in and out of a mine, and to move personnel in specially designed "mantrip" cars. A leading locomotive manufacturer offers 6-ton (15 kW, 84V 42 cell battery), 10-ton (42 kW, 120V 60 cell battery), and 15-ton (90 kW with overhead line 250V DC) systems.
- **Roof bolter** – Used to install roof support bolts, primarily in underground coal mines. A model produced by DBT (LRB-15AR) has a single 40 HP (30 kW) primary drive motor, but others as big as 82 HP were identified for this analysis. A University of Minnesota case study indicates that these operate approximately 3,000 hours year.[501]
- **Forklifts** – Some mines use forklifts for surface and underground applications. The mine cited in the University of Minnesota case study above utilized one 82 HP forklift that operated 1,600 hours per year.

Power sources currently used in mining vehicles include the following:

- **Battery-powered electric vehicles** – Batteries are used primarily in underground applications where emissions from diesel-powered vehicles pose a problem. One limitation of battery power is that energy capacity is insufficient for hard rock mining.
- **Diesel-powered vehicles** – These vehicles have power density for high productivity, but emissions regulations and health and safety issues are limiting factors. Ventilation costs for underground mines are significant, representing an estimated 40% of power costs at a mine.[502] Diesel power also generates noise and heat.
- **Cable-tethered vehicles** – Tethered cables that supply electric power to vehicles (e.g., shuttle cars) from a power source outside of the mine are also frequently used in underground mining. In some cases they are remotely controlled. They are power-dense and emissions free, but the tether causes some safety concerns and can limit the operation range of the equipment.

Table z-3 presents estimated costs for underground mining utility vehicles and personnel carriers. Diesel vehicles cost more than battery-powered vehicles by as much as 45%. For instance, a 14-person diesel carrier costs $40,000 while the price of a 14-person battery-powered vehicle is $22,000. However, this does not consider the costs of operation and maintenance or accessories.

[501] Bickel, K., J. McDonald, J. Fruin, and D. Tiffany. 1997. Economic Comparison of Biodiesel Blends to Commercially Available Exhaust Emission Reduction Technologies for Underground Mines. Final Report to the National Biodiesel Board.
[502] Betournay, M.C and M. Laflamme. 2006. Current Development and Future Opportunities of the Fuel Cell Mining Initiative. Presented at the 2005 CIM Annual General Meeting, Toronto, Canada, April 25, 2006. Available at http://www.mining.ca/www/media_lib/TSM_Presentations/cimcanmet.pdf [Accessed December 2006].

Table z-3. Cost Estimates for Underground Mining Utility Vehicle/Personnel Carriers.

Model	Payload	Power Source	Price
Industrial Lil'Mac	2-person	Battery	$9,000
Lil Mac 3-4 Wheeler	2-person	Battery	$7-8,000
Mac 8	14 person	Battery	$22,000
Mac XP	3 person	Battery	$28,000
Mac 2D	4-5 person	Diesel	$35,000
Mac 3D	4-5 person	Diesel	$35,000
Mac 8D	12 person	Diesel	$38,000
Mac 10D	14 person	Diesel	$40,000

Source: Damascus Corporation, http://www.damascuscorp.com/vehicles.html. Prices provided by personal communication between Heidi Mahy (Battelle) and sales representative at Damascus on June 30, 2006.

MARKET SIZE

For this analysis, no comprehensive source of information was found that describes the market size for specific types of underground mining vehicles in the U.S. Information was available for: 1) overall mining industry size for each mineral involved in underground mining, 2) total underground mining equipment sales, and 3) the number of diesel vehicles currently used in the coal mining industry.

Mining Industry Size

Table z-4 characterizes the underground coal mining market in terms of number of businesses, number of employees, and sales volume. Of the various coal types mined in the U.S., bituminous coal dominates the underground coal mining market. Table z-5 presents the number of businesses, by state, engaged in underground coal mining. Geographically, the greatest amount of underground coal mining activity occurs in the states of Kentucky, West Virginia, Pennsylvania, and Virginia.

Table z-4. Number of Businesses in Underground Coal Mining Industry (1222).[503]

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
1222-0000	Bituminous coal-underground mining	268	17,320	15,878
1222-9901	Underground mining, semianthracite	1	100	12.8
1222-9902	Underground mining, semibituminous	6	113	165.5
1222-9903	Underground mining, subbituminous	12	1,489	233.6
	Total	**287**	**19,022**	**16,289.9**

Sales figures are in millions.

[503] Dun and Bradstreet. 2006. Zapdata industry report. Available at www.zapdata.com [Accessed May 2006].

Table z-5. Market Analysis by State: Underground Coal Mining.[504]

State	# Businesses	% Total
Total	**287**	**100**
Kentucky	79	27.5
West Virginia	58	20.2
Pennsylvania	48	16.7
Virginia	21	7.3
Ohio	12	4.2
Tennessee	12	4.2
Alabama	7	2.4
Illinois	7	2.4
Indiana	6	2.1
Utah	6	2.1
Colorado	4	1.4
Maryland	4	1.4
Nevada	4	1.4
Wyoming	3	1
Montana	2	0.7
Oklahoma	2	0.7
Arizona	1	0.3
California	1	0.3
Delaware	1	0.3
Georgia	1	0.3
Missouri	1	0.3
New Mexico	1	0.3
New York	1	0.3
North Dakota	1	0.3
South Dakota	1	0.3
Texas	1	0.3
Washington	1	0.3
Puerto Rico	1	0.3

Table z-6 presents market data for various mining segments involved in the subsurface extraction of minerals, excluding coal mining. The total number of businesses engaged in these mining segments is approximately one-half the number engaged in underground coal mining, and total sales are approximately one-third of sales generated from underground coal mining. In Table z-6, only those eight-digit SIC specialties related to mining are shown.

[504] Dun and Bradstreet. 2006. Zapdata industry report. Available at www.zapdata.com [Accessed May 2006].

Table z-6. Number of Businesses by Mining Specialty, Excluding Coal (1231, 1011, 1021, 1031, 1041, 1044, 1094, 1099).[505]

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
1231-9904	Underground mining, anthracite	6	101	62.6
1011-0103	Underground iron ore mining	3	26	2.6
1021-0103	Underground copper ore mining	5	950	428.3
1031-0100	Lead ores mining *	10	1,268	1,276.5
1031-0101	Cerussite mining*	1	2	0.3
1031-0200	Zinc ores mining*	5	351	42.7
1031-0203	Willemite mining	1	1	0.2
1041-0103	Underground gold mining	36	595	48.4
1044-0103	Underground silver mining	3	7	0.2
1094-9903	Radium ore mining, nec*	1	5	0.1
1094-9905	Uranium ore mining, nec*	39	576	1,661
1094-9906	Vanadium ore mining, nec*	1	0	N/A
1099-0101	Aluminum ore mining*	14	203	94.3
1099-0104	Beryllium ore mining*	2	1,863	196.8
1099-0200	Palladium group ores mining*	3	1,266	447.8
1099-0300	Platinum group ores mining*	2	6	0.8
1099-0400	Rare-earth ores mining*	3	23	1
1099	Other metal mining	17	290	1,725.9
	Total	**152**	**7,533**	**5,989.5**

Sales figures are in millions.
*May include both surface and underground mining.

Underground Mining Equipment Sales

Data obtained from the U.S. Census Bureau indicate that over 11,000 units of underground mining equipment were sold in 2004 (see Table z-7). The total value of underground mining equipment shipments was $466.4 million in 2004, up from $411.7 million in 2003 but down from $476.0 million in 2002.[506] Disaggregated information, according to specific applications (e.g., shuttle cars, underground loaders), was not available.

Table z-7. Manufacturers' Shipments of Mining and Mineral Processing Equipment: Underground Mining Machinery (except parts sold separately), 2004.[507]

Product Description	Units Sold	Value ($1,000)
Underground mining machinery (except parts sold separately)	11,634	396,037
Continuous mining machines, borer, ripper, auger and drum	219	192,570
Face haulage vehicles, rubber-tired, self-propelled	183	39,584
Support vehicles, rubber-tired or track-mounted	233	32,346
All other underground mining machinery	10,999	131,537

[505] Dun and Bradstreet. 2006. Zapdata industry report. Available at www.zapdata.com [Accessed May 2006].
[506] U.S. Census Bureau, Manufacturing and Construction Division. 2006. Annual Survey of Manufacturers (ASM). Available at http://www.census.gov/mcd/asm-as2.html [Accessed May 2006].
[507] US Census Bureau. 2006. MA333F - Mining Machinery and Mineral Processing Equipment. Available at http://www.census.gov/cir/www/333/ma333f.html [Accessed May 2006].

U.S. Coal Industry Diesel Vehicle Inventory

The U.S. Mining Safety and Health Administration (MSHA) maintains a current inventory of all diesel vehicles in the U.S. coal industry – for both surface and subsurface mining. Table z-8 presents the number of nationally registered diesel specialty vehicles used by coal mining companies, from the MSHA's National Diesel Inventory. While this inventory is useful, it does not include diesel vehicles used in metal/non-metal mines, and does not include battery-powered mining vehicles.

Table z-8. Number of Nationally Registered Diesel Specialty Vehicles used by Coal Mining Companies.[508]

Vehicle Type	# Registered Nationally
Personnel Carrier (Mine Tndr, Mantrip, Rabit, Bosbusy, Ribrnr)	1,421
Load-Haul-Dump (Scooptram, Front End Ld, Bobcat, LHD, Unildr)	460
Locomotive	176
Forklifts	154
Shuttle Cars (Torkar, Electrical, Ramcar)	124
Haul Truck (30 Ton Cap. or Less) (Ram-Car, Teletram, Coal-Haul)	78
Other: Diesel Generators	31
Total	**2,444**

Major manufacturers of mining vehicles include Joy Mining Machinery (roof bolters, shuttle cars), Caterpillar (underground LHD vehicles), Sandvik Mining and Construction (underground LHD vehicles), Damascus Corporation (diesel and battery utility vehicles), and Trident S.A. (mine locomotives, loaders).

MARKET TRENDS

To enter the mining industry, new power sources for mining vehicles must offer three clear benefits over competing technologies: Promote worker health and safety, improve productivity, and lower operating cost.

PEM fuel cell-powered specialty vehicles in underground mining applications offer potential benefits in each of the above areas. Conventional technologies for underground mining vehicles do not provide both acceptable worker health and safety and high productivity at the same time. Diesel engines have the horsepower to maintain higher levels of productivity in underground mining operations, but they raise health and safety concerns. Ventilation is necessary to reduce worker exposure to harmful diesel emissions when diesel engines are used. The growing use of diesel engines in the mining industry and uncertainties about the long-term health impacts of exhaust emissions have been the focus of attention of mining companies, researchers, and regulatory agencies in recent years. Equipment that improves air quality and reduces noise provides potentially important benefits to worker health and safety, but in the case of battery-powered vehicles, there can be a productivity compromise due to their lower power output. Fuel cells could potentially lower operating costs by reducing the need for ventilation, a major operating expense for mining companies, while also meeting worker health and safety and productivity requirements. PEM fuel cell-powered vehicle's quiet operation offers an advantage,

[508] Mine Safety and Health Administration. 2006. National Diesel Inventory. Available at https://lakegovprod1.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx [Accessed May 2006].

as hearing damage is one of the most common occupational health hazards in the mining industry.

The mining industry has begun to investigate the potential for fuel cells to be used in underground mining vehicles. Two fuel cell demonstration projects involving underground mining vehicles have been conducted. These demonstration projects are briefly described below.

- **Mine Loader Demonstration –** Funded through DOE's Hydrogen Program from 2001 to 2006, a joint venture between Vehicle Projects LLC and the Fuelcell Propulsion Institute aimed to develop a mine loader powered by a fuel cell and demonstrate the loader in an underground Nevada mine. The project also sought to develop metal-hydride storage and refueling capability needed for the vehicle. A hybrid fuel cell-battery power module was integrated into a Caterpillar-Elphinstone R1300 (diesel 165 HP, 123 kW) mine loader. The fuel cell module consisted of 3 PEM stacks (290V, 300A, 87 kW gross power) with an additional 65 kW provided by NiMH batteries. Peak power of the unit was 140 kW. Demonstration targets were 200 miles and operating durability of 1,000 hours. Results of the project are not yet available, but the technology is expected to be demonstrated in working gold mines in Nevada and Canada.[509]
- **Locomotive Demonstration –** Another joint venture of Vehicle Projects LLC and the Fuelcell Propulsion Institute, along with a number of partners, developed the first fuel cell locomotive for mining, with funding provided through DOE's Hydrogen Program. The locomotive, an underground mining haulage vehicle, was manufactured by RA Warren Equipment of North Bay, Ontario. The power plant and metal-hydride storage system were developed by Sandia National Laboratories of Livermore, California. The design objective was to outfit a 4-ton battery-powered locomotive with PEM fuel cells, replacing the lead-acid battery altogether.[510, 511] Specifications of the fuel cell locomotive were as follows:
    - Weight – 30% lighter than the battery version
    - Continuous power – 14 kW gross (2 PEM fuel cell stacks manufactured by Nuvera Fuel Cells with maximum output of 7 kW each)
    - Hydrogen storage – 3 kg
    - Operating time – 8 hours
    - Balance of plant – over 90% efficient
    - Refueling time – 8 times faster than for batteries.

    The team worked with Placer Dome (one of world's largest gold mining companies) to test the locomotive in an operating Ontario mine. Natural Resources Canada (NRCan) performed a cost-benefit analysis considering ventilation savings at the mine, and the results showed an overall benefit of the fuel cell over the diesel locomotive. NRCan has

[509] Barnes, D. 2006. Fuel Cell Powered Front-End Loader Mining Vehicles. FY05 Progress Report from Vehicle Projects to DOE Hydrogen Program. Available at http://www.hydrogen.energy.gov/pdfs/progress05/viii_a_6_barnes.pdf [Accessed December 2006].
[510] Sandia National Laboratory. 2006. Technology Highlight Fuel Cell Locomotive. Available at http://www.ca.sandia.gov/news/locomotive/ [Accessed May 2006].
[511] Miller, A.R. and D.L. Barnes. 2006. Fuelcell Locomotives. Available at http://www.fuelcellpropulsion.org/pdf/European%20FC%20Forum%202002%20(21%20May%2002)%20--%20preprint.pdf#search=%22fuel%20cell%20locomotive%20%22 [Accessed August 2006].

set a goal of completing a fleet changeover from diesel to fuel cell vehicles during 2012-2015.[512]

Hydrogenics, a manufacturer of hydrogen and fuel cell systems, is evaluating potential applications of its HyPM modules in the underground mining market.

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in the underground mining market, 11 companies were contacted and five responses were received. All five respondents operate underground mines. Three companies are involved in coal mining, and two engage in metal mining activities. The respondents include two small companies, two medium-sized companies, and one large company. Individuals from the Mining Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) also completed interviews.

All of the respondents utilize various types of underground mining specialty vehicles. Specialty vehicles used by the two small mining companies include underground mining loaders (2.5 cu yd, 1.5 cu yd, and 1.25 cu yd capacities), an end dump truck (7 cu yd), a single boom drill jumbo, underground ore haulage truck, an underground rock-bolting jumbo, an underground worker transport tractor, and a utility carrier. One of these companies had 83 and the other had 37 specialty vehicles. The medium and large companies utilized several LHD vehicles (four in one mine; one in a second mine; two in a third mine), utility tractor/supply haulers (three in one mine), a shuttle car for hauling coal (one in each of two mines), extraction and hauling vehicles (two in one mine), a skidsteer loader (one in each of two mines), a road grader (one in each of two mines), one boom truck, one roof bolter, and several pickup trucks (in each of two mines) used as mantrip/personnel transport vehicles. The medium and large companies have over 80 specialty vehicles at one site and over 130 at another.

The large company reported operating 24 hours a day, 7 days a week year-round at some sites, and partial days (5½ to 6 days per week) at others. One of the medium-sized companies reported operating 24 hours a day, 7 days a week year-round; the other company operates some mines 24 hours a day, 7 days a week, while other sites operate 20 hours per day, 5 days per week, with weekend maintenance crews. One of the small companies reported operating 2 shifts per day, 5 days a week; the other operates 2 shifts per day, 7 days a week year-round.

Four of the five respondents stated that specialty vehicle downtime resulted in a loss in productivity and increased operations and maintenance costs. The large coal mining company identified a loss in productivity through decreased movement of materials as the only negative impact of specialty vehicle downtime.

One medium-sized coal mining company reported that there are hundreds of downtime incidents per year involving specialty vehicles. The other medium-sized coal company did not track number of downtime incidents but estimated shuttle car availability at 65% and reported that

[512] Betournay, M.C and M. Laflamme. 2006. Current Development and Future Opportunities of the Fuel Cell Mining Initiative. Presentation at the 2005 CIM Annual General Meeting, Toronto, Canada, April 25, 2006. Available at http://www.mining.ca/www/media_lib/TSM_Presentations/cimcanmet.pdf [Accessed December 2006].

downtime incidents range from 30 minutes to 8 hours. One small metal mining company reported experiencing several hundred downtime incidents per year, and estimated that 1 to 3 occur each day. The other small metal mining company estimated that more than 500 downtime incidents occur each year. The large coal mining company defined downtime as removing a vehicle from service for corrective repair, and reported no incidents of downtime in the past year.

Respondents rated the impact of specialty vehicle downtime on their operations, ranging from not disruptive at all to highly disruptive. All but one characterized downtime greater than 1 hour as highly disruptive. One medium-sized coal company considered an incident lasting 5 minutes to 4 hours as highly disruptive, but an incident lasting over 4 hours as only moderately disruptive, perhaps because backup vehicles would be used in place of the out-of-service vehicle. Another medium-sized coal company considered only incidents of downtime greater than 8 hours as highly disruptive. The large coal company indicated that any vehicle downtime (even less than 5 minutes) was highly disruptive. The two small metal mining companies considered incidents greater than 1 hour to be highly disruptive.

Respondents indicated the type of power system used in their specialty vehicles. One large and one medium-sized coal mining company reported using diesel ICEs and battery electric drive systems. The two small metal mining companies and one medium-sized coal mining company reported using diesel ICEs (no battery-powered vehicles); one small metal mining company reported using propane ICEs as well.

Respondents reported varying operation and maintenance requirements for underground mining specialty vehicles. The large coal mining company stated that daily inspections are conducted on both ICE and battery vehicles, and batteries are replaced or recharged two to three times per week; ICE preventive maintenance is pre-scheduled but times vary by vehicle type. One medium-sized coal mining company reported that its vehicles are serviced at 250 operating hours; this takes two to four shifts for one person to complete. Pickup trucks are serviced every 1,000 miles, which requires 8 hours for one person to complete. The other medium-sized coal mining company noted that one full-time employee is dedicated to servicing and repairing battery vehicles. One of the small metal mining companies stated that maintenance is performed on ICE vehicles at about 250 hours; the other small company reported conducting daily production and preventative maintenance.

Safety concerns for battery vehicle users, as indicated by respondents, included battery or hydraulic fluid fires and risk of explosion due to improper ventilation. Safety concerns identified for ICE engines included diesel emission exposure, diesel fuel or hydraulic fluid fires, and noise.

Respondents rated the importance of various factors in choosing a specialty vehicle. Figure z-1 summarizes the responses for a number of factors. When asked which of these factors were most important, reliability was cited most often, followed by emissions and experience with the system in the past.

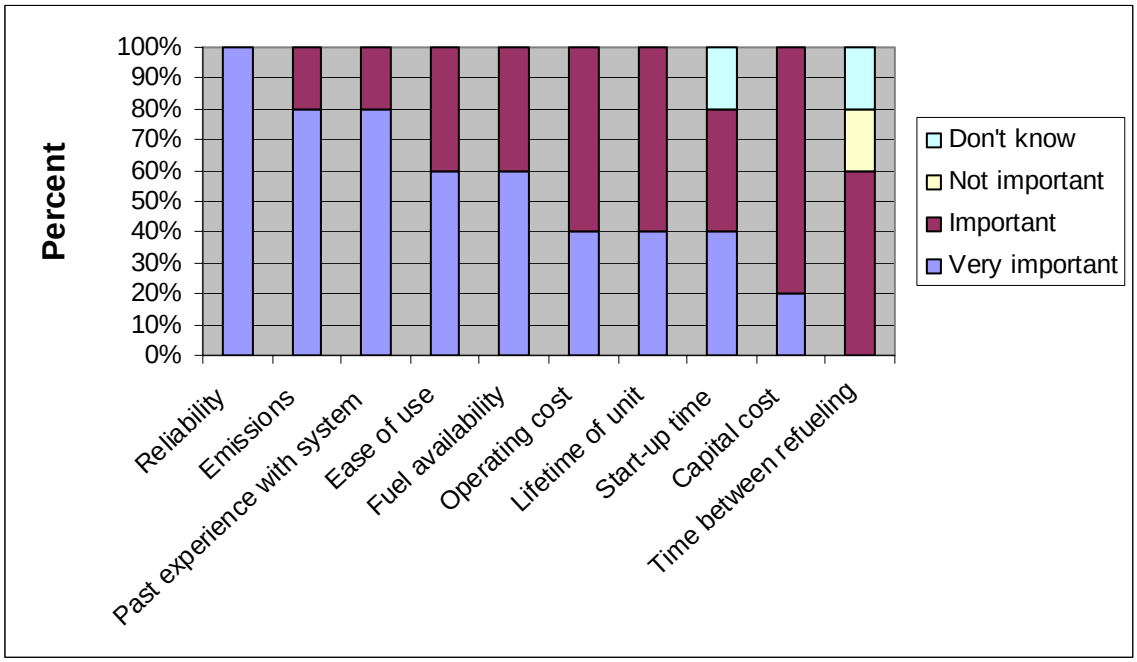

Figure z-1. Summary of Responses: Importance of Various Factors in Choosing an Underground Mining Specialty Vehicle (n=5).

When asked about the performance of battery-powered and ICE-powered specialty vehicles, four respondents rated the overall performance of these vehicles as very good or moderately good. A concern identified by two respondents was that batteries are inconvenient to recharge, and two respondents cited the hazardous emissions associated with ICEs. Other concerns mentioned include the time required to refuel, the time required to swap out batteries, and safety.

Respondents were also asked to rate the performance of their current specialty vehicles on the basis of several factors. Only three of the five respondents completed this question. Figure z-2 summarizes their responses.

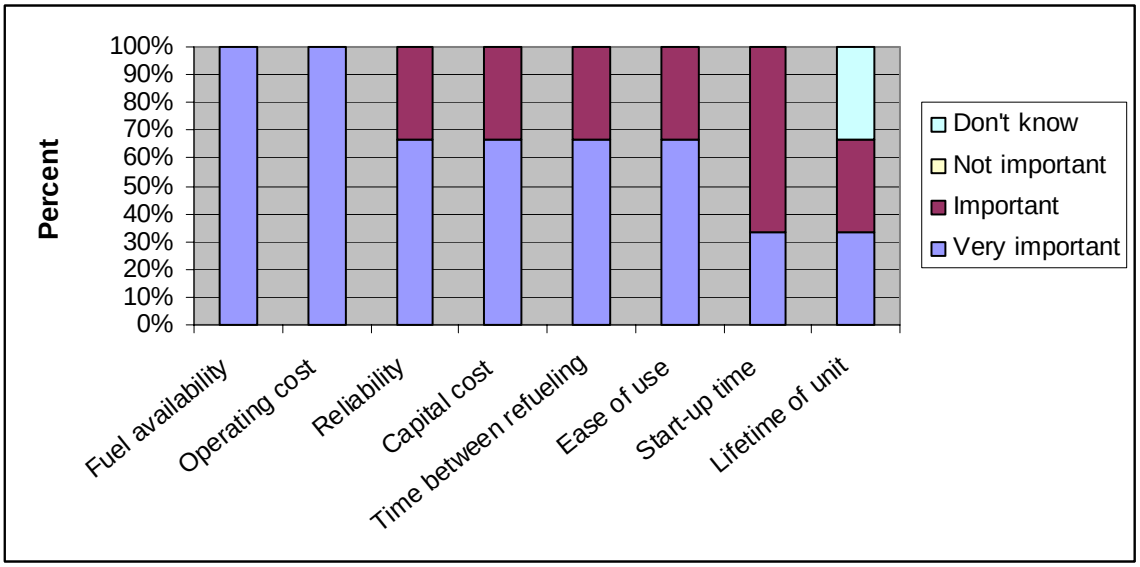

Figure z-2. Summary of Responses: Performance of Respondents' Current Underground Mining Specialty Vehicles (n=3).

Four of the five respondents anticipated a growing demand for specialty vehicles in the industry. One respondent noted that the industry is moving underground as surface pits are being depleted.

Two of the five respondents have considered alternatives to their current vehicle technologies: one has investigated biodiesel and ultra-low sulfur diesel, and the other has considered coal haulage vehicles powered by a trailing cable. Four respondents were aware of PEM fuel cells as alternatives to existing power sources, but none of those respondents thought PEM fuel cells were likely to compete with existing technologies in specialty vehicles for mining. Reasons identified were: cost, concern about the safety of introducing hydrogen in underground mines, lack of experience and familiarity with the technology, and a perceived "recharge time" and effective duty cycle per charge. Three of four companies expressed concern about using hydrogen as a fuel.

Respondents were asked about the rationale for making capital purchase decisions in their companies. In four companies, decisions about capital investments in underground mining vehicles are made using a return on investment analysis. Two companies consider payback period in making purchase decisions.

Four of the five respondents agreed to be contacted again.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

The market for PEM fuel cell-powered specialty vehicles is potentially an attractive one for certain mining vehicle applications. Approximately 11,000 units of underground mining equipment were sold in the U.S. in 2004. While many specialty vehicles, such as heavy duty LHD trucks, have larger power requirements than PEM fuel cells may be capable of supplying, certain applications provide a reasonable fit in terms of size requirements (e.g., personnel carriers and shuttle cars).

The opportunity to reduce emissions in underground mines is the key value proposition for PEM fuel cells in the mining industry. Ventilation in underground mines represents a substantial proportion (an estimated 40%) of power consumption costs. While battery-operated vehicles do not have the emission problems associated with diesel ICEs, the need to recharge and replace them can translate into lost productivity, particularly in mines that operate 24 hours a day, 7 days a week.

Additional drivers to adopt fuel cells over existing technologies include high power density, low temperature and pressure operation, component durability, and higher efficiency than diesel engines.[513] Also, respondents in this analysis cited reliability as being more important than capital cost, which suggests that the market may be willing to pay a higher price for fuel cells' reliability.

Other factors favor the adoption of PEM fuel cells in the underground mining industry:

- There is an identifiable number of potential users (approximately 450 companies) concentrated in the states of Kentucky, West Virginia, and Pennsylvania
- Growth in the industry is anticipated due to a growing emphasis on domestic coal as a fuel source and growth in underground mining activities as surface mines are depleted
- PEM fuel cell demonstration projects are paving the way for fuel cell technology in the underground mining industry.

Still, important barriers remain to PEM fuel cell use in underground mining vehicles. While PEM fuel cell mining vehicles have been tested, the mining industry in general lacks experience and familiarity with fuel cell technology, and may have concerns about the use of hydrogen, particularly in a safety-conscious industry. While there is manufacturer interest in this sector, mining vehicles are not yet commercially available and therefore will not be ready for introduction in the near term. However, the potential performance and safety advantages that PEM fuel cells offer over existing technologies, coupled with the expected growth of the domestic industry, make this a potentially attractive market in the mid-term. LHD trucks and personnel carriers may represent more promising applications, compared to locomotives, due to their wider user in mines and applicability in other industrial environments.

[513] Miller, A. 2000. Tunneling and Mining Applications of Fuel Cell Vehicles. Fuel Cells Bulletin (July): 5-9.

RESEARCH SUMMARY:
SPECIALTY VEHICLES – UNMANNED AERIAL VEHICLES (UAVs)

MARKET SEGMENT DESCRIPTION

The U.S. Department of Defense (DoD) defines an unmanned aerial vehicle (UAV) as a "powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload."[514] Payloads carried by UAVs include cameras, sensors, other types of surveillance equipment, and communications equipment. In military applications, UAVs are designed for use in missions deemed too "dull" (i.e., likely to cause excessive fatigue), "dirty" (e.g., sampling in a radioactive zone), or "dangerous" (e.g., conducting surveillance in enemy territory) for manned aircraft to perform.[515] Table aa-1 identifies the SIC and NAICS classifications that cover manufacturing of UAVs.

Table aa-1. SIC and NAICS Codes for UAV Manufacturing.

2-Digit SIC Code	37 – Transportation equipment
4-Digit SIC Code	3721 – Aircraft and parts
NAICS Code	336411 – Aircraft manufacturing

To date, the primary user of UAVs, also referred to as unmanned aerial systems (UASs), has been the U.S. government, particularly the military. DoD has budgeted $1,662,000,000 for UAS-related research and development (R&D) in the FY05-FY09 President's Budget (see Figure aa-1); the bulk of this spending will focus on broad technology initiatives (e.g., sensing and control technologies) and weaponization.[516] UAVs are also being used increasingly by U.S. governmental civilian agencies for applications ranging from border protection to disaster recovery and search and rescue operations.[517] Federal agencies that are most likely to use UAVs include the U.S. Department of Homeland Security (DHS) (disaster recovery, search and rescue, and border protection operations), the U.S. Department of Agriculture Forest Service (fire monitoring), and the U.S. Geological Survey (USGS) (remote sensing activities).

UAVs have tremendous potential to be used in commercial remote sensing applications, as well. It has been suggested that commercial spending on UAV R&D could equal that of the military within 15 years. However, the FAA has yet to develop regulations governing the safe operation of UAVs in U.S. airspace, which has delayed widespread commercial use of these vehicles and raised concerns about unregulated uses.[518]

UAVs are available in a wide range of sizes and capabilities, depending on their applications. Small UAVs are typically man-portable and can be hand-launched or bungee-launched, whereas

[514] U.S. Department of Defense. 2001, as amended through 2006. Department of Defense Dictionary of Military and Associated Terms. Joint Publication 1-02. Available at http://www.dtic.mil/doctrine/jel/new_pubs/jp1_02.pdf [Accessed June 2006].
[515] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[516] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[517] AeroVironment. 2006. AeroVironment: Beyond the Military. Available at http://www.avsuav.com/non_flash/products_beyond_the_military.php [Accessed June 2006].
[518] Jewell, J.E. 2005. White Paper: Commercial Use Of Unmanned Aerial Vehicles (UAVs): Surveying the Regulatory Landscape. Published by UAV MarketSpace. Available at http://www.rfglobalnet.com/downloads/Detail.aspx?docid=7f26ca33-51c0-40f0-a0ab-a878c18a3d53&sd=Ni8xOS8yMDA2IDI6NTA6MTcgUE0%3d [Accessed June 2006].

large UAVs are launched via remote control. UAVs range in size from extremely compact (AeroVironment's smallest product, the WASP Micro Air Vehicle, has a wingspan of 1.37 feet and weighs 0.6 lbs[519]) to extremely large (Northrop Grumman's Global Hawk has a wingspan of up to 130.9 feet and weighs approximately 15,400 lbs, minus fuel and payload[520]). Small UAVs are typically used in low-altitude (≤ 1,000 ft) applications and are powered by batteries, which limit endurance (typically ≤ 120 minutes). Generally, large UAVs such as the Global Hawk are used for long-endurance (> 24 hour) operations in high altitudes (> 30,000 feet).

Costs vary widely among available vehicles. Micro-sized UAVs may cost $5,000 or less.[521] Slightly larger, man-portable UAVs average $25,000 to $30,000 per vehicle. The high-altitude, long-endurance UAVs, manufactured by companies such as General Atomics and Northrop Grumman, range in price from $0.39 million to $26.5 million per aircraft (associated support systems not included).[522] Unmanned aircraft use a wide range of power systems; the most common appear to be ICEs (including traditional gas turbines and reciprocating engines) and batteries.

Many UAVs are manufactured with ICEs or jet engines. These vehicles run on automobile gasoline, aviation gasoline, diesel fuel, or several varieties of jet fuel. Large UAVs powered by ICEs range in weight from approximately 375 lbs to over 45,000 lbs and in power from < 30 HP (22 kW) to well over 900 HP (671 kW). Small ICE-powered UAVs are also on the market; these range in weight from 10 to 40 lbs and have payload capacities ranging from 3 to 12 lbs (horsepower not available).[523]

Smaller, lower-altitude, and shorter-duration UAVs tend to run on electric batteries. Small UAVs typically weigh less than 20 lbs and have a payload capacity of less than 3 lbs,[524] which allows them to be hand-launched or bungee-launched. Specific voltage requirements for electric UAVs were not available from the manufacturers. However, a recent report estimated upper-level power requirements for small UAVs (operating on 24V battery packs) to be approximately 300 W for initial power and 100 W for cruising power.[525] Lead acid and NiCd batteries are widely used, and some manufacturers are using Li-ion batteries, as well.[526]

A key metric used to ascertain propulsion system performance in UAVs is specific power (SP). Reciprocating engines for aircraft generally are capable of producing one horsepower/lb of engine weight (746 W/lb), and today's fuel cells are approaching this same level; however, Li-

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[519] AeroVironment. 2005. Wasp Datasheet. Available at http://avsuav.com/pdf/datasheet_wasp.pdf [Accessed June 2006].
[520] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[521] Dickerson, L. 2005. Wasp UAV Could Be Provided to U.S. Marines. Forecast International/Unmanned Vehicles Forecast. Available at http://www.forecastinternational.com/abstract.cfm?recno=114375 [Accessed June 2006].
[522] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[523] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[524] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[525] Naimer, N., B. Koretz, and R. Putt. 2002. Zinc-Air Batteries for UAVs and MAVs. Electric Fuel Corporation. Available at http://www.electric-fuel.com/defense/UVS02.pdf [Accessed June 2006].
[526] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].

ion batteries have approximately half this level of SP.[527] SP is directly related to endurance, which explains why battery-powered UAVs are not capable of remaining airborne for nearly as long as those powered by ICEs.

MARKET SIZE

Current data on the size of the UAV manufacturing market are provided below. The number of UAV manufacturers is captured within SIC Code 3721 (Aircraft), which is represented in Table aa-2. Note that this SIC Code includes all types of aircraft and that UAV manufacturers represent only a small proportion of the total.

Table aa-3 represents potential users of UAVs, including: military organizations and DHS (SIC Code 9711 – National security); government agencies involved in environmental research and remote sensing activities (SIC Code 8733 - Noncommercial research organizations); forest management and fire monitoring organizations (SIC Code 0851 - Forestry services); and search and rescue services (SIC Code 8999 - Services, Not Elsewhere Classified). Commercial entities have not been included in this analysis, since any attempt to predict which commercial markets will use UAVs once FAA regulations have been established would be purely speculative. In Tables aa-2 and aa-3, only the eight-digit SIC specialty categories deemed most relevant to UAV manufacturing and use are shown.

Table aa-2. Number of UAV Manufacturers – Industry: Aircraft (3721).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
3721-0000	Aircraft	860	101,128	54,315.5
3721-0100	Motorized aircraft	18	1,046	220
3721-0101	Airplanes, fixed or rotary wing	142	33,565	61,873.30
	Total	**1,020**	**135,739**	**116,408.80**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Table aa-3. Number of Potential UAV Users – Industries: National Security (9711); Noncommercial Research Organizations (8733); Forestry Services (0851); Services, Nec (8999).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
9711-0000	National security	1,256	110,305	N/A
9711-0400	National security, level of government	5	0	N/A
9711-0401	National security, federal government	62	1,031	N/A
9711-0402	National security, state government	19	200	0.1
9711-0403	National security, county government	13	516	N/A
9711-0404	National security, local government	6	151	N/A
9711-9901	Air Force	1,819	279,503	N/A
9711-9902	Army	3,304	250,184	N/A
9711-9904	Marine Corps	1,079	35,966	0.1
9711-9906	National Guard	2,608	90,478	2.6
9711-9907	Navy	2,182	249,060	0.1
8733-0000	Noncommercial research organizations	5,147	62,308	7,599.9
8733-9901	Physical research, noncommercial	134	2,961	325
8733-9902	Research institute	1,415	52,353	5,457.2

[527] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].

8733-9904	Scientific research agency	924	33,697	3,377.5
0851-0000	Forestry services	3,387	15,250	578.5
0851-0100	Forest management services	461	2,353	115.3
0851-0101	Forest management plans, preparation of	155	1,203	40.7
0851-0102	Reforestation services	279	4,602	239.9
0851-9901	Fire fighting services, forest	760	4,642	197.5
0851-9902	Fire prevention services, forest	212	1,337	46.8
0851-9903	Pest control services, forest	75	418	33.4
0851-9904	Timber cruising services	52	176	10.6
0851-9905	Timber estimating services	42	155	26.5
0851-9906	Timber valuation services	66	402	23.9
8999-9904	Search and rescue service	482	4,245	134.2
	Total	**25,944**	**1,203,496**	**18,210**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

The largest manufacturers of UAVs are AAI Corporation; AeroVironment, Inc.; The Boeing Company; General Atomics Aeronautical Systems, Inc.; Honeywell; L-3 BAI Aerosystems; Lockheed Martin; and Northrop Grumman Corporation.

MARKET TRENDS

Unmanned aircraft represent a relatively new and still-developing market; as such, their manufacturers may be more likely to explore alternative power sources than manufacturers of vehicles that are widely used and well-established (e.g., commercial aircraft or automobiles). UAV manufacturers are currently exploring a variety of propulsion alternatives, including scramjets, reciprocating chemical muscles, beamed power, nuclear isotopes, and fuel cells.[528]

In an effort to develop a small UAV that can conduct surveillance missions for 24-hour periods, researchers at the U.S. Naval Research Laboratory designed the Spider-Lion, a fuel cell-powered vehicle. In 2006 the vehicle completed two successful test flights, marking the first time a fuel cell-based UAV had flown for several hours. The Spider-Lion's first flight lasted for 1 hour and 43 minutes, and the second lasted for 3 hours and 19 minutes. Both flights ended when the compressed hydrogen supply was exhausted.[529]

Years earlier, a solar/fuel cell hybrid UAV was developed by AeroVironment under NASA's Environmental Research Aircraft and Sensor Technology program. The Helios Prototype ran on solar power during the day and fuel cells at night. It was designed to reach altitudes at or near 100,000 feet while completing scientific or telecommunications relay missions lasting for weeks or months without using consumable fuels. In 2003, the Helios and its experimental power system were destroyed when the plane sustained structural failures and crashed into the Pacific Ocean.[530]

[528] U.S. Department of Defense. 2005. Unmanned Aircraft Systems Roadmap – 2005-2030. Available at http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf [Accessed June 2006].
[529] Boland, R. 2006. Experimental fuel cell power system expands flight capabilities. Fuel Cell Today. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,7437,00.html [Accessed June 2006].
[530] National Aeronautics and Space Administration. 2005. Past Projects – Helios Prototype. Available at http://www.nasa.gov/centers/dryden/history/pastprojects/Erast/helios.html [Accessed June 2006].

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in UAVs, manufacturers and others familiar with these vehicles were contacted. UAV users were not contacted; it was assumed that military personnel would not be able to share tactical or potentially sensitive information. As non-military UAV markets are fragmented, no attempt was made to contact users. Four organizations were contacted, and two responses were received (one detailed and one general interview).

Respondents included a small but rapidly growing manufacturer of small UAVs and a U.S. Army contractor who has helped to develop small UAVs in the past. The manufacturer currently sells various battery-powered UAVs to the U.S. military but is developing a large, liquid hydrogen-fueled UAV and an ICE-powered UAV that runs on JP8 fuel.

Perceptions of UAV downtime and maintenance requirements differed between the two respondents. The manufacturer felt that downtime was not a significant issue, since small UAVs have been fine-tuned for optimal performance as a result of extensive combat testing. The U.S. Army contractor noted that the maintenance requirements for small UAVs are significant and that UAVs often have to return to base before completing their missions due to limited battery life. The U.S. Army contractor elaborated that regular maintenance is necessary because UAVs break apart upon landing; this impact may damage UAV components. The respondent estimated that maintenance represents 10 to 20% of the costs of a UAV. In direct contrast with this estimate, the manufacturer noted that very little maintenance is required for UAVs.

In general, both respondents seemed pleased with the performance of batteries as a power source. However, both respondents emphasized the pressure to increase flight duration without increasing the weight of the vehicle. Neither respondent perceived any safety issues with the use of existing power sources.

The manufacturer was aware of the potential for PEM fuel cells to power UAVs. This manufacturer is currently conducting feasibility studies on various alternative fuels in response to a need for increased flight duration; studies are being conducted on JP8-fueled ICEs and PEM fuel cells for small UAVs. The manufacturer indicated that fuel cells must improve upon battery performance by a factor of 2 in order to overcome logistical issues, increased costs, durability, and reliability concerns associated with existing fuel cell systems. The manufacturer reported that the most important factor when considering alternatives is performance (i.e., whether the alternative can provide extended flight duration without increasing airplane weight). The next most important factor is cost, and the third most important is logistics. The manufacturer was unsure whether fuel cells would be a viable power source for UAVs, citing hydrogen storage as a potential barrier as the container would need to withstand tremendous force upon impact. The respondent added that fuel cells may be feasible in niche applications (e.g., remote military operations) only; at this time, fuel cells do not make sense practically. The manufacturer was unsure whether customers would have concerns over the use of hydrogen as a fuel.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Recent testing of an experimental fuel cell system in a small UAV demonstrated several key advantages to using a PEM fuel cell in such vehicles. The most important advantage, from a

tactical perspective, is increased endurance. While small UAVs powered by traditional engines can fly for about 8 hours, battery-powered UAVs can remain airborne for approximately 1 hour. PEM fuel cells provide extended flight duration, compared to batteries (over 3 hours in one test flight), and increased efficiency over ICEs. Other key drivers for using fuel cells are ease of use (systems start up immediately) and the fact that fuel cell-powered UAVs are more difficult to detect than aircraft powered by small engines, since the PEM fuel cell system is nearly silent and has a low heat signature.[531] Any fuel cell system used in UAVs would have to be sensitive to the weight limitations of the vehicle.

The opportunity for PEM fuel cells in UAVs will likely be limited to small UAVs (< 10 lbs) in the foreseeable future, as existing PEM fuel cell technology is not capable of powering a large UAV or other aircraft. While the military market may be less sensitive to cost than commercial markets, the technology does not appear to be ready for broad deployment into military applications in the near term. PEM fuel cells must address concerns about the capital cost, reliability, and demonstrate significantly higher performance compared to current battery alternatives in order to attract broader interest from this market.

[531] Boland, R. 2006. Experimental fuel cell power system expands flight capabilities. Fuel Cell Today. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,7437,00.html [Accessed June 2006].

RESEARCH SUMMARY:
SPECIALTY VEHICLES – UNMANNED UNDERWATER VEHICLES (UUVs)

MARKET SEGMENT DESCRIPTION

Unmanned underwater vehicles (UUVs) are pilot-less autonomous or remotely controlled vehicles that are developed to perform tasks that would be impossible or too risky for larger watercraft.[532] The U.S. Navy is pursuing the development of UUVs for use in nine critical missions, including: (1) maritime intelligence, surveillance, and reconnaissance; (2) mine countermeasures; (3) anti-submarine warfare; (4) inspection and identification; (5) oceanography; (6) communication; (7) payload delivery; (8) information operations; and (9) time-critical strike operations. To perform these missions, the U.S. Navy is planning for the development of four general classes of UUVs: man-portable (ranging from ~25 lb to > 100 lb displacement with a diameter between 3" and 9"); light-weight (~500 lbs displacement with a diameter of 12.75"); heavy weight (< 3,000 lb displacement with a diameter of 21"); and large (~20,000 lb displacement with a diameter > 36").[533] UUVs have also been used in commercial and academic applications to conduct deepwater surveys (e.g., for oil and gas exploration), perform oceanographic research, and collect various other types of data. Table bb-1 identifies the SIC and NAICS classifications that cover manufacturing of UUVs.

Table bb-1. SIC and NAICS Codes for UUV Manufacturing.

2-Digit SIC Code	37 – Transportation equipment
4-Digit SIC Code	3731 – Ship building and repairing
NAICS Code	336611 – Ship building and repairing

As indicated above, UUVs are being developed in numerous shapes, sizes, and configurations, depending on their applications and operating environments. The vehicles can be designed to accommodate a wide variety of payloads. In 2000, the U.S. Navy estimated the costs of UUVs to be $1,000 per lb at low or prototype production rates and $100 per lb at higher production rates.[534]

The energy source selected for a UUV application is driven primarily by mission requirements for speed and endurance. Increased energy capacity is required to accommodate long-endurance, high payload power, or high-speed missions. No existing energy system is capable of meeting all mission needs and vehicle design constraints.

Representative options for UUV energy sources (based on the capabilities and characteristics of current technologies) are primary or rechargeable lithium batteries for smaller vehicles, and power plants (fuel cells or hybrid energy systems) for larger vehicles.[535] Other technologies used to power UUVs include NiCd and silver-zinc rechargeable battery systems. The main limitation

[532] Crawford, M.G. 2005. MILNET Brief: Unmanned Underwater Vehicles - UUVs. Available at http://www.milnet.com/pentagon/UUVs.html [Accessed April 2006].
[533] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].
[534] U.S. Department of the Navy. 2000. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.npt.nuwc.navy.mil/UUV/UUVMP.pdf [Accessed June 2006].
[535] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].

of current rechargeable batteries is their inability to sustain extended runtimes, which are often required for tactical UUV missions.[536] In its 2004 UUV Master Plan,[537] the U.S. Navy summarized benefits and drawbacks of typical UUV power sources, as shown in Table bb-2.

Table bb-2. UUV Energy Options versus Vehicle Size.

All Size UUVs	Large UUVs Only (21" with Difficulty)
• **$LiSOCl_2$ Primary Batteries** *Benefits:* High energy density (> 200 Wh/lb) *Drawbacks:* Expensive (capital investment, per sortie) Very difficult to replenish at sea Safety issues that may be acceptable (but desirable to eliminate) • **Li-Ion Rechargeable Battery** *Benefits:* Rechargeable Moderate range per sortie (75 Wh/lb; 100 Wh/lb stretch) Improved safety over $LiSOCl_2$ *Drawbacks:* Expensive initial capital investments	• **Hybrid Diesel – Li-ion** *Benefits:* Replenishable (Diesel / JP fuels) Low per sortie cost and probably reasonable capital investment cost Low risk for high energy density (> 400 Wh/lb w/snorkel) Improved safety over $LiSOCl_2$ *Drawbacks:* Increase system complexity (reliability?) Operational constraint (snorkel) (e.g., 80-hr dived, 4-hour surface) • **Fuel Cells** *Benefits:* Replenishable (depending on reactant storage options) High energy density (~150 Wh/lb) *Drawbacks:* High initial cost TBD Safety (H_2 and O_2 sources) Relatively immature technology

Source: Adapted from U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan.

As detailed in the 2004 UUV Master Plan, lithium-based batteries have the highest energy density among available battery technologies. Because of their relatively small size, these batteries are easily configured to fit within most UUV configurations. However, there is a tremendous cost penalty associated with using primary lithium-based batteries in large applications (> 500 lb batteries), since the batteries are discarded after use. In such cases, battery cost may exceed UUV cost. Rechargeable batteries are less costly over time; furthermore, they have a safety advantage because they can be shipped in a discharged state.[538]

For larger vehicles, fuel cells and hybrid diesel/battery power plants are more attractive due to their higher energy density and potentially lower operating costs.[539] Hybrid systems are not an optimal choice for smaller vehicles due to the need for support equipment to operate the power plant; however, they have significant advantages over battery systems in larger vehicles, as shown in Table bb-2. Also, hybrid diesel systems are widely available, low-risk, and low-cost.

[536] EurekAlert. 2000. Future power source for undersea vehicles. Available at http://www.eurekalert.org/pub_releases/2000-03/OoNR-Fpsf-0503100.php [Accessed June 2006].
[537] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].
[538] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].
[539] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].

Comparatively, fuel cell technologies are still quite costly.[540] Hybrid diesel systems are associated with one major tactical disadvantage: the need for air, which requires them to resurface and recharge.[541]

Sparse information is publicly available regarding the size of UUV power systems. However, a recent solicitation for extended-duration UUV power systems set performance targets for the propulsion system in the 5 to 10 kW range and for peak power levels in the 30 to 40 kW range.[542]

MARKET SIZE

Current data on the size of the UUV manufacturing market are provided below. Manufacturers of UUVs are captured within SIC Code 3731 (Ship Building and Repairing), which is represented in Table bb-3.

The user market for UUVs is somewhat difficult to quantify because it is so wide-ranging and not fully established. Primary user market is the DoD. In addition, a wide range of SIC categories deemed likely to utilize UUVs is captured in Table aa-3. These categories include various types of scientific consultants (SIC Code 8999 - Services, Not Elsewhere Classified); engineering services, including petroleum engineering, (SIC Code 8711); surveying services (SIC Code 8713); commercial physical and biological research establishments (SIC Code 8731 - Commercial Physical Research); noncommercial research organizations (SIC Code 8733); and environmental consultants (SIC Code 8748 - Business Consulting, Not Elsewhere Classified). Also included are government agencies that may be involved in environmental monitoring (SIC Code 9511 - Air, Water, and Solid Waste Management) and military organizations (SIC Code 9711 - National Security). It should be noted that the market for UUVs may be broader than represented here. In Tables aa-2 and aa-3, only the eight-digit SIC specialty categories deemed most relevant to UUV manufacturing and use are shown.

Table bb-3. Number of UUV Manufacturers – Industry: Shipbuilding and Repairing (3731).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
3731-9906	Submersible marine robots, manned or unmanned	11	139	9.2
	Total	**11**	**139**	**9.2**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

[540] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].
[541] Annati, M. 2005. UUVs and AUVs come of age. Military Technology. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,6217,00.html [Accessed June 2006].
[542] FedBizOpps. 2005. A – Defense Sciences Research and Technology: UUV Power Systems, SOL BAA05-19, Addendum 7. FBO Daily Issue of May 13, 2005, FBO #1264 Modification. Available at http://www.fbodaily.com/archive/2005/05-May/13-May-2005/FBO-00805485.htm [Accessed June 2006].

Table bb-3. Number of Potential UUV Users - Industries: Services, Nec (8999); Engineering Services (8711); Surveying Services (8713); Commercial Physical Research (8731); Noncommercial Research Organizations (8733); Business Consulting, Nec (8748); Air, Water, and Solid Waste Management (9511); National Security (9711).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
8999-0500	Weather related services	203	1,041	49.3
8999-0700	Earth science services	2,304	5,417	239.8
8999-0701	Geological consultant	1,387	3,846	275.5
8999-0702	Geophysical consultant	287	1,150	188.4
8999-0703	Natural resource preservation service	821	5,433	296.9
8999-0900	Scientific consulting	3,623	7,170	309.3
8999-9904	Search and rescue service	482	4,245	134.2
8711-0000	Engineering services	32,947	469,821	74,438.602
8711-0300	Petroleum, mining, and chemical engineers	114	1,256	474.7
8711-0303	Petroleum engineering	370	5,824	295.2
8711-9903	Consulting engineer	19,350	219,009	30,660.5
8711-9904	Designing: ship, boat, machine, and product	1,118	15,302	2,090.2
8711-9905	Electrical or electronic engineering	2,978	29,822	3,394.2
8711-9908	Marine engineering	387	3,749	479.7
8711-9909	Professional engineer	2,006	11,884	734.5
8713-0000	Surveying services	11,019	65,339	2,871.3
8713-9900	Surveying services, nec	197	1,247	80.6
8731-0000	Commercial physical research	5,879	107,022	10,775.3
8731-0100	Biological research	1,244	17,254	2,917
8731-0200	Commercial physical research	761	50,849	16,680.6
8731-0300	Natural resource research	286	2,889	759.7
8731-0302	Environmental research	1,129	12,162	827.7
8733-0000	Noncommercial research organizations	5,147	62,308	7,599.9
8733-0100	Noncommercial biological research organization	172	4,487	385.6
8733-0102	Biotechnical research, noncommercial	200	3,077	265.9
8733-0203	Educational research agency	540	7,625	1,232
8733-9901	Physical research, noncommercial	134	2,961	325
8733-9902	Research institute	1,415	52,353	5,457.2
8733-9904	Scientific research agency	924	33,697	3,377.5
8748-0400	Systems analysis & engineering consulting services	1,593	11,355	1,460.9
8748-9905	Environmental consultant	13,779	104,734	10,958.3
8748-9906	Fishery consultant	343	1,070	87.9
9511-0000	Air, water, and solid waste management	2,507	97,677	N/A
9511-0100	Environmental agencies	274	11,092	0.3
9511-0102	Environmental protection agency, government	357	34,690	0.1
9511-0103	Environmental quality and control agency, government	143	7,336	N/A
9511-0400	Air, water, and solid waste management, level of government	12	41	N/A
9511-0401	Air, water, and solid waste management, federal government	13	156	N/A
9511-0402	Air, water, and solid waste management, state government	38	355	N/A
9511-0403	Air, water, and solid waste management, county government	157	2,876	N/A
9511-0404	Air, water, and solid waste management, local government	420	5,594	N/A

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
9711-9902	Army	3,304	250,184	N/A
9711-9904	Marine Corps	1,079	35,966	0.1
9711-9905	Military training schools	116	2,357	0.1
9711-9906	National Guard	2,608	90,478	2.6
9711-9907	Navy	2,182	249,060	0.1
	Total	**126,349**	**2,113,260**	**180,126.7**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Major UUV manufacturers include BAE Systems, Inc., and its subsidiary, Atlas Elektronik GmbH; The Boeing Company; C&C Technologies Survey Services; Lockheed Martin; and International Submarine Engineering Ltd.

MARKET TRENDS

The market for UUVs is still very much an emerging one. Viable energy sources for UUVs must permit high voltages, have a large capacity for energy storage, and deliver stored energy safely and reliably over extended discharge periods. Energy sources must also be relatively cheap, environmentally harmless, and capable of a long shelf life.[543]

At least one commercially available UUV is powered by an aluminum oxide fuel cell.[544] Additionally, the Naval Undersea Warfare Center demonstrated a semi-fuel cell power source consisting of a hybrid system that utilizes both a hydrogen fuel cell and silver-zinc batteries. The semi-fuel cell system impressed researchers with its compactness, long shelf life, and increased energy output compared to standard silver-zinc batteries alone.[545]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells in UUVs, individuals with experience working with these vehicles were contacted. Because UUVs are most often used in military operations, it was assumed that military personnel or DoD contractors who manufacture the vehicles would not be able to share potentially sensitive information. Three individuals with experience in UUVs were contacted, and two informal interviews were conducted.

One respondent was aware of the potential for fuel cells to be used in UUVs. This user noted that much of the U.S. Navy's fuel cell work in the past had focused on diesel fuel reforming, a process that converts diesel fuel for use in a fuel cell. More recently, the U.S. Navy has become interested in alternate fuels (other than diesel). The U.S. Navy is currently engaged in a joint program with the United Kingdom to investigate a PEM fuel cell that operates on sodium borohydride via direct electrochemical reduction. The same respondent indicated that there are two UUV communities – tactical and oceanographic. Tactical units are larger and launched from a submarine; these are still in development. Most of the vehicles available today are intended for oceanographic applications, including pipeline monitoring and monitoring of undersea wires.

[543] EurekAlert. 2000. Future power source for undersea vehicles. Available at http://www.eurekalert.org/pub_releases/2000-03/OoNR-Fpsf-0503100.php [Accessed June 2006].
[544] C&C Technologies. 2005. C-Surveyor AUV Description. Available at http://www.cctechnol.com/site40.php [Accessed June 2006].
[545] EurekAlert. 2000. Future power source for undersea vehicles. Available at http://www.eurekalert.org/pub_releases/2000-03/OoNR-Fpsf-0503100.php [Accessed June 2006].

Regarding the potential for using fuel cells in UUVs, one respondent noted that UUV designers are limited by weight and volume. Fuel cells are used in some submarines, which are larger and therefore not as limited by weight and volume. Using a fuel cell in such vehicles allows them to stay underwater for weeks instead of just days. Historically, UUVs have been small for oceanographic purposes and larger for tactical purposes, but some UUV designers are beginning to consider making the vehicles even larger than tactical models. From a propulsion perspective, this would open up the possibility of using fuel cells because the engineers would not be as limited by weight and volume.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

Secondary research suggests that Li-ion batteries are sufficient for short, repetitive missions; however, certain situations are more conducive to fuel cell or hybrid use. Higher power density is required for large UUVs, prompting the use of fuel cells or hybrid propulsion systems. PEM fuel cells would permit extended run times that are not currently possible using rechargeable batteries.[546] PEM fuel cells also have the advantage of being closed-cycle, which allows them to operate continuously until all on-board fuel is consumed.[547] However, PEM fuel cells raise concerns because they represent a relatively immature technology.[548] Also, PEM fuel cells have shorter lives than hybrid systems and must eventually be refurbished. Hybrid diesel power plants have vastly superior energy capacity compared to present fuel cell technology. Hybrid diesel systems are also less costly, though fuel cell costs are expected to decrease over time.[549]

Primary research indicates that large UUVs have greater potential for using fuel cells than small, oceanographic models. As mentioned above, this is primarily due to fewer design restrictions in larger UUVs. Because fuel cells are still very much in the early test phase in UUVS, this is not considered a likely near-term market for PEM fuel cells.

[546] Annati, M. 2005. UUVs and AUVs come of age. Military Technology. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,6217,00.html [Accessed June 2006].
[547] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].
[548] Annati, M. 2005. UUVs and AUVs come of age. Military Technology. Available at http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,6217,00.html [Accessed June 2006].
[549] U.S. Department of the Navy. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf [Accessed June 2006].

RESEARCH SUMMARY:
SPECIALTY VEHICLES - WHEELCHAIRS

MARKET SEGMENT DESCRIPTION

Wheelchairs are used by people who find walking difficult due to illness, injury, or disability. Electric or powered wheelchairs are designed for use by people with limited use of their arms, since these vehicles do not require the user to roll the wheels manually. A joystick is commonly used to regulate the chair's speed and direction, though specialized control systems are available to accommodate individual user needs.[550] Table cc-1 identifies the SIC and NAICS classifications that cover manufacturing of wheelchairs.

Table cc-1. SIC and NAICS Codes for Wheelchair Manufacturing.

2-Digit SIC Code	38 – Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks
4-Digit SIC Code	3842 – Surgical appliances and supplies
NAICS Code	339113 – Surgical appliance and supplies manufacturing

Powered wheelchairs typically fall into one of two categories, based on their configuration: 1) traditional style, which is basically an adapted version of a traditional manual wheelchair, and 2) platform style, which consists of a seating system mounted on a powered base. Many specialized wheelchairs are also available for specific uses, such as raising the user to a standing position, tilting and reclining the user, or enabling the user to climb stairs. Most powered wheelchairs fall into the platform-style category.[551] The wheelchair base is usually rectangular (though it can be circular to allow for a tight turning radius) and has four to six wheels. Rear- and front-wheel drive models are the most common, though mid-wheel drive models are available, as well. Most powered wheelchairs can be used both indoors and outdoors.

Wheelchairs range in weight from approximately 75 lbs to over 200 lbs without batteries.[552] Batteries (depending on type) can add 20 to 100 lbs to the weight of the vehicle.

Power wheelchairs are driven by an electric drive system that powers the chair's wheels. Rechargeable lead acid, gel cell, or sealed wet batteries may be used in wheelchairs. Gel cell batteries are less likely to leak and require less maintenance than other battery types. Also, some airlines will only transport powered chairs that use gel cell batteries.[553] All batteries are intended to be recharged daily, using a battery charger that plugs into a standard electrical wall outlet.

The type and size of batteries used determine the range and power capabilities of a powered wheelchair. Many chairs operate on two 12V, deep-cycle batteries. Among the many size codes of deep-cycle batteries available, wheelchairs typically use Group U1, Group 22, Group 24, and

[550] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].
[551] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].
[552] Information obtained through review of wheelchair products available for online sale at 1-800-wheelchair.com. Category: Power Wheelchairs. Available at http://www.1800wheelchair.com/asp/view-category-subcats.asp?Category_id=298&src=sn [Accessed June 2006].
[553] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].

Group 27 batteries.[554,555] Group U1 batteries typically range in capacity from 34 to 40 amp-hours; Group 22 batteries range from 43 to 55 amp-hours; Group 24 batteries range from 70 to 85 amp-hours; and Group 27 batteries range from 85 to 105 amp-hours (note: all ranges are approximate).[556] Group 24 batteries provide a reasonably long range and are growing increasingly popular among wheelchair designers.[557]

Wheelchairs are somewhat unusual compared to other specialty vehicles in that their costs are not typically borne by the end-users. Wheelchair expenses are primarily funded by private medical insurance and government programs such as Medicare and Medicaid.[558] An online review of retail prices for products offered by major wheelchair manufacturers indicated that traditional powered wheelchairs typically range from $1,300 to $5,200, with an average price of approximately $2,500. Platform wheelchairs range from $1,400 to $11,000, with an average price of approximately $5,500.[559] Deluxe or specialized models can far exceed average prices.[560] Additional information about unit costs is provided in Tables cc-3 and cc-4.

MARKET SIZE

Current data on the size of the wheelchair manufacturing market are provided below. SIC Code 3842, covering manufacturing of wheelchairs, is represented by Table cc-2. Only the eight-digit SIC Code specialty relevant to wheelchairs is shown. Note that this specialty encompasses all wheelchair manufacturers, not just makers of electric models.

Table cc-2. Number of Wheelchair Manufacturers - Industry: Surgical Appliances and Supplies (3842).

SIC Code	SIC Description	Number of Businesses	Total Employees	Total Sales ($)
3842-0420	Wheelchairs	176	4,494	1,232.7
	Total	**176**	**4,494**	**1,232.7**

Sales figures are in millions. Source: www.zapdata.com, accessed June 2006.

Data specific to powered wheelchairs and specialized wheelchairs, which may include some powered models, are presented in Tables cc-3 and cc-4. Table cc-3 illustrates demand for standard powered wheelchairs from 1992 through 2012 (anticipated). Table cc-4 illustrates demand for specialized wheelchairs. As evidenced by these tables, demand for standard powered wheelchairs has been decreasing as a percentage of the wheelchair market and is expected to drop from 28.2% in 2002 to 25.9% in 2012. However, sales of standard powered wheelchairs are expected to increase from 80,000 in 2002 to 125,000 in 2012. Unit costs also are expected to increase over this same time period. Demand for specialized wheelchairs, on the other hand, is expected to increase as a percentage of total wheelchair sales from 2002 to 2012, with sales of bariatric wheelchairs (designed

[554] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].
[555] DiGiovine, C.P. and R. Cooper. 2000. Battery Power & You: How to Choose. SpinLife.com, LLC. Available at http://www.spinlife.com/spintips/spintipsdetails.cfm?artid=121&typeid=171 [Accessed June 2006].
[556] Northern Arizona Wind & Sun, Inc. 2006. The Ultimate FAQ for Deep Cycle Battery Basics and Information. Available at http://www.windsun.com/Batteries/Battery_FAQ.htm#Using%20a%20deep%20cycle%20battery%20as%20a%20starting%20battery [Accessed June 2006].
[557] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].
[558] Wikimedia Foundation, Inc. 2006. Wheelchair. Available at http://en.wikipedia.org/wiki/Wheelchair [Accessed June 7, 2006].
[559] Information obtained through review of wheelchair products available for online sale at 1-800-wheelchair.com. Category: Power Wheelchairs. Available at http://www.1800wheelchair.com/asp/view-category-subcats.asp?Category_id=298&src=sn [Accessed June 2006].
[560] ORC Macro. 2006. Fact Sheet on Powered Wheelchairs. Available at http://www.abledata.com/abledata_docs/Powered_Wheelchairs.htm [Accessed June 2006].

to meet the needs of obese patients), in particular, expected to nearly double between 2002 and 2007.[561] Specialized wheelchairs can be either manual or powered; therefore, the figures in Table cc-4 are not intended to represent the market for powered wheelchairs exclusively.

Table cc-3. Demand for Standard Powered Wheelchairs and Other Personal Mobility Devices: 1992-2012.

	1992	1997	2002	2007	2012
Wheelchair Market ($ million)	321	508	745	1050	1450
Percent (%) powered	30.5	28.9	28.2	26.2	25.9
Standard Powered Wheelchair Sales ($ million)	98	147	210	275	375
Cost ($)/Unit	2175	2450	2625	2750	3000
Standard Powered Wheelchair Sales ($000's)	45	60	80	100	125
Powered Scooters Sales ($ million)	88	143	205	300	425
Cost ($)/Unit	1175	1360	1520	1715	1890
Powered Scooters Sales (000's)	75	105	135	175	225

Source: Adapted from The Freedonia Group, Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number 1745.

Table cc-4. Demand for Specialized Wheelchairs: 1992-2012.

	1992	1997	2002	2007	2012
Wheelchair Market ($ million)	321	508	745	1050	1450
Percent (%) specialized	22.7	29.3	34.9	40.5	43.1
Specialized Wheelchair Sales ($ million)	73	149	260	425	625
Sports	30	70	115	175	250
Bariatric	7	23	60	115	175
Pediatric	12	17	25	35	50
Other Specialized	24	39	60	100	150
Cost ($)/Unit	1325	1490	1675	1890	2085
Specialized Wheelchair Sales ($000's)	55	100	155	225	300

Source: Adapted from The Freedonia Group, Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number 1745.

The user market for powered wheelchairs is expected to grow steadily through 2012. In 2002 there were 1.8 million wheelchair users; this figure is expected to reach 2.1 million and 2.4 million by 2007 and 2012, respectively.[562]

Major wheelchair manufacturers include Invacare Corp.; Medline Industries, Inc.; Graham-Field Health Products, Inc.; Electric Mobility Corp.; Sunrise Medical Inc.; Pride Mobility Products Corp.; Hoveround; and Convaid Inc.

MARKET TRENDS

Major wheelchair manufacturers do not appear to be devoting significant resources to identifying alternative power sources. Batteries are viewed as convenient and safe energy sources for these vehicles. However, a few companies were found to be conducting R&D in this area.

[561] The Freedonia Group, Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number 1745. Cleveland, OH, The Freedonia Group, Inc.
[562] The Freedonia Group, Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number 1745. Cleveland, OH, The Freedonia Group, Inc.

In 2003 a Canadian fuel cell manufacturer, Palcan Fuel Cells Company, supplied several PEM fuel cell products to Chinese organizations, including a 1.5 kW PEM fuel cell stack for use in a wheelchair.[563]

Also in 2003, Kurimoto, Ltd. of Japan developed a fuel cell wheelchair in cooperation with Asia Pacific Fuel Cell Technologies, which was demonstrated at the 15th World Hydrogen Energy Conference. The wheelchair is powered by a 250 W PEM fuel cell, is just under one meter high, and weighs about 80 kg.[564] It has a range of 38 miles and runs 3.7 mph.

Besel of Spain is working with fuel cell maker Axane (France), and electric wheelchair manufacturer Meyra (Germany) to engineer and test a wheelchair. The wheelchair has a 500 W fuel cell with two 2-liter Hydrogen cylinders at 700 bar stored under the seat. Market launch is expected to be just a couple of years away.[565]

In 2006, Suzuki Motors announced that it had produced a prototype fuel cell wheelchair – the MIO. The MIO is a motor-driven cart powered by a methanol cell that is backed up by a Li-ion battery. The wheelchair can run 25 miles or more with one recharge (4 liters) of methanol solution.[566]

MARKET SEGMENT ANALYSIS

To identify the market opportunities for direct PEM fuel cells, wheelchair manufacturers were contacted. Ten manufacturers were contacted, and three responses were received. No users were contacted, as it was not considered feasible to identify wheelchair users.

One large power wheelchair manufacturer and two medium-sized manufacturers of personal mobility devices and other types of healthcare equipment responded. One manufacturer offered power wheelchairs only, whereas the other two offered power wheelchairs as well as manual and specialized (e.g., racing) models. All manufacturers offered electric (battery-powered) wheelchairs.

Regarding downtime, all manufacturers noted that it would be devastating to anyone who depends on a wheelchair for mobility. However, two of the three manufacturers pointed out that downtime is extremely rare, since users know they must recharge their batteries daily.

O&M requirements for wheelchairs are minimal. The industry switched to sealed lead-acid or absorbed glass mat (AGM) batteries years ago, which do not require refilling. The batteries are recharged using a charger, which plugs into a standard electrical outlet. One wheelchair manufacturer that also offers personal mobility scooters noted that users sometimes forget to recharge these scooters, which are frequently left in cars for days at a time. The same manufacturer noted that wheelchair users occasionally forget to recharge their chairs every night.

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[563] The Freedonia Group, Inc. 2003. Wheelchairs & Other Personal Mobility Devices to 2007. Report Number 1745. Cleveland, OH, The Freedonia Group, Inc.
[564] Adamson, K. 2005. Fuel Cell Today Market Survey: Niche Transport (Part 1). Fuel Cell Today (August).
[565] Adamson, K. and M. Hugh. 2006. Hannover Fair, Fuel Cell and Hydrogen Group Exhibit Event Report. Fuel Cell Today (February 5, 2006).
[566] No author. 2006. Suzuki unveils fuel cell-powered wheelchair. Fuel Cell Today (September 27, 2006). Available at: http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1602,8256,00.html [Accessed October 2006].

In general, manufacturers seemed pleased with the performance of batteries in their products. No safety concerns were identified. However, one manufacturer noted that batteries add a significant amount of weight to the vehicles.

All three manufacturers were aware of PEM fuel cells as a potential substitute for batteries; one had significant experience with fuel cells based on a past position with a major automaker. Two of the three manufacturers have considered using fuel cells as a power source; however, one respondent commented that there are no commercially available fuel cell products for his company to try and that the technology is impractical in its current stage of development. The other manufacturer has been investigating the use of PEM fuel cells in an on-board charging system. This system is based on a small fuel cell that can run continuously from a hydrogen cylinder. It will be used to charge the batteries that power the vehicle (instead of using an electrical outlet). The unit being tested is approximately the size of a shoebox and is not expected to be production-ready for at least 2 years.

Manufacturers evaluate alternative power sources by considering what is safest, most reliable, and most practical for the user. The respondent who is investigating the fuel cell-based charging system suggested that some of his customers would pay for the convenience of not having to plug in their wheelchairs. Reliability, quietness, and ability to meet the power draw requirements of the vehicle were identified as key factors in selecting an alternative power source. One manufacturer indicated that fuel cells would be a viable power source for wheelchairs, but only as a supplement to batteries (i.e., in a charging system). The same respondent indicated that the technology would need to be developed enough to lower costs and improve hydrogen storage issues before it could be commercially feasible. However, many wheelchair users already have oxygen tanks attached to their chairs; therefore, they are familiar with handling compressed gas cylinders.

Several barriers to fuel cell use were identified, including high cost, maintenance requirements, and the lack of a practical hydrogen distribution system. One manufacturer pointed out that wheelchair users are often economically limited; the respondent also suggested that it would be difficult to improve upon the convenience of current recharging methods.

Perceptions of hydrogen safety issues were mixed. One manufacturer felt that customers would not have a problem. Another was unsure, and the third felt that his customers might have an issue with using hydrogen.

Similarly, interest in working with the DOE to develop fuel cell-based wheelchairs was mixed. One manufacturer was eager to be considered for such a collaboration, while the other two were reluctant to commit one way or the other. All three manufacturers agreed to be contacted again if needed.

POTENTIAL OPPORTUNITIES FOR PEM FUEL CELLS

There appears to be potential for the PEM fuel cells to power wheelchairs, and potentially as supplemental power source to battery systems. Wheelchair manufacturers are aware of PEM fuel cells and at least a few have considered them as an alternative power source. Several

prototypes are under development and are expected to be commercially ready in the next few years. Primary research did not suggest that wheelchair users are actively seeking a replacement for batteries, which have no emissions and can be conveniently recharged in the home. However, recharging is a daily burden that, as one wheelchair manufacturer noted, users sometimes forget or are unable to do before going to sleep. A hybrid fuel cell/battery system would eliminate the need for nightly recharging.

Because the competing technology is relatively clean and safe, added convenience and practicality would be the main drivers for using PEM fuel cells in wheelchairs. These include vehicle weight reduction, if heavy lead-acid batteries were entirely replaced by a fuel cell, and elimination of the need for daily recharging with combination fuel cell/battery power.

Barriers to fuel cell use in wheelchairs include:

- Cost of hydrogen fuel
- Lack of commercially available PEM fuel cell systems appropriate for use in wheelchairs, as prototype systems are still thought to be a few years away from market entry
- Lack of practical hydrogen distribution system; wheelchair users are often travel-restricted and must have fuel delivered to them.

While it is not known how users would react to hydrogen as a fuel source, it is thought that this will not be a barrier as many wheelchair users require oxygen and are familiar with the use of gas storage tanks.

Finally, the fact that wheelchairs are often paid for by Medicare instead of the user could be either a driver or barrier to entry. The government has significant buying power and a policy that creates incentives for Medicare patients to demonstrate PEM fuel cell technology could have a measurable impact on the market. Without such direction from the government, however, individual users may have little leverage in requesting more costly, experimental wheelchair systems through their Medicare programs.

In general, this market is ripening but given the maturity of the technology, it does not represent a likely near-term market. User interest in the technology should be monitored to determine what the potential for PEM fuel cell powered wheelchairs may be in the mid-term.

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Appendix E: Interim Report on the Market Opportunity Assessment of PEM Fuel Cell Applications at the Federal Aviation Administration

INTERIM REPORT
ON THE
MARKET OPPORTUNITY ASSESSMENT OF PEM FUEL CELL APPLICATIONS AT THE FEDERAL AVIATION ADMINISTRATION

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TABLE OF CONTENTS

1.0 INTRODUCTION 1
2.0 MARKET ATTRIBUTES 1
2.1 Market Segment Description 1
2.2 Applications and Opportunities 2
2.3 Market Trends 4
3.0 MARKET SEGMENT ANALYSIS 6
3.1 Specialty Vehicle Analysis 6
3.2 Backup Power Analysis 7
3.3 Economic Analysis of Backup Power Systems 9
4.0 MARKET RESEARCH SUMMARY 12
5.0 LIFECYCLE COST ANALYSIS 13
5.1 Scenario 1 - Lifecycle Cost Analysis of Backup Power Alternatives at an RTR Site 13
5.1.1 Scenario 1 Assumptions 13
5.1.2 Scenario 1 Results 15
5.2 Scenario 2 - Lifecycle Cost Analysis of Backup Power Alternatives at an RCLR Site 16
5.2.1 Scenario 2 Assumptions 16
5.2.2 Scenario 2 Results 16
5.3 Scenario 3 - Lifecycle Cost Analysis of Backup Power Alternatives at an RCAG Site 18
5.3.1 Scenario 3 Assumptions 18
5.3.2 Scenario 3 Results 20
5.4 Lifecycle Cost Analysis Summary 21
6.0 SENSITIVITY ANALYSIS 22
7.0 VALUE PROPOSITION FOR PEM FUEL CELLS 26

List of Tables

Table 1. FAA NAS Operational Facilities Requiring Backup Power..... 3
Table 2. PEM Fuel Cell Installations at the FAA. 5
Table 3. Scenario 1 - Lifecycle Cost Assumptions for NPV Analysis of a 600-Watt RTR Site 14
Table 4. Scenario 1: 600 Watts for 24 Hours, 48 Hours, 72 Hours Backup Runtime at an RTR Site – NPV of a PEM Fuel Cell and a Battery Backup System Over a 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules 15
Table 5. Scenario 2 – Lifecycle Cost Assumptions for NPV Analysis of a 3 kW RCLR Site. 17
Table 6. Scenario 2: 3 kW for 24 hours, 48 hours, 72 hours at an RCLR Site – NPV of PEM Fuel Cell and Battery Backup System Over 15-year Analysis Period with 3-Year and 5-Year Battery Replacement Schedule. 17
Table 7. Scenario 3 – Lifecycle Cost Assumptions for NPV Analysis of a 5 kW RCAG Site. 19
Table 8. Scenario 3: 5 kW for 24 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules..... 20
Table 9. Scenario 3: 5 kW for 48 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedule. 21
Table 10. Scenario 3: 5 kW for 72 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules..... 21
Table 11. Comparison of NPV of Total Cost of System for 600-Watt RTR Site, 3 kW RCLR Site, and 5 kW RCAG Site for 24 Hours, 48 Hours, and 72 Hours of Backup Runtime..... 22
Table 12. Sensitivity Analysis Cost Assumptions for 600-Watt PEM Fuel Cell Backup Power for 72 Hours: Base Assumptions +/-10%. 23
Table 13. Cost Assumptions for 3 kW PEM Fuel Cell Backup Power for 72 Hours Sensitivity Analysis: Base Assumptions +/-10%..... 24
Table 14. Cost Assumptions for 5 kW PEM Fuel Cell Backup Power for 72 Hours Sensitivity Analysis: Base Assumptions +/-10%..... 25

List of Figures

Figure 1. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 600-Watt PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime..... 23
Figure 2. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 3 kW PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime.... 24
Figure 3. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 5 kW PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime..... 25

1.0 INTRODUCTION

A complete segmentation of the federal market was performed using the benefit segmentation method. About 13 federal market segments were identified as potential adopters of direct hydrogen polymer electrolyte membrane fuel cells (hereafter referred to as PEM fuel cells) for backup power and specialty vehicle power based on their need for extended runtime, lower emissions, lower operations and maintenance (O&M) costs, and interest in cleaner alternatives to battery and internal combustion engines (ICE)-based systems. For these market segments, secondary and exploratory primary market research was conducted to identify the likely applications for PEM fuel cells, market attributes, market trends, user requirements for new technology, and economics of standard and alternative systems. Selection criteria developed with the U.S. Department of Energy (DOE) and industry were applied to this market data to identify promising near-term applications and markets. Backup power applications at the Federal Aviation Administration (FAA) are one of the seven near-term opportunities identified for PEM fuel cells. To further determine the market opportunity for PEM fuel cells at the FAA, detailed primary research was conducted to characterize the lifecycle costs of current technologies and potential alternatives. Using the modified hydrogen analysis (H2A) model lifecycle costs of PEM fuel cells against competing alternatives were determined.

This report assesses the market opportunity for PEM fuel cells at the FAA. The report is organized into the following sections: Section 2 presents an overview of the FAA market segment, applications and opportunities, and market trends, based primarily on secondary research; Section 3 analyzes input from potential users gathered through nine surveys and four interviews; Section 4 summarizes key trends from primary and secondary market research; Section 5 presents the lifecycle cost analysis of PEM fuel cells for backup power compared to batteries and generator systems; Section 6 analyzes the sensitivity of the lifecycle costs of PEM fuel cell backup power systems; and Section 7 presents the value proposition for PEM fuel cells for backup power applications at the FAA.

2.0 MARKET ATTRIBUTES

2.1 Market Segment Description

The FAA is the government agency responsible for overseeing air transportation in the United States (U.S.). An arm of the U.S. Department of Transportation (DOT), the FAA focuses on air traffic management and air transportation safety, including the enforcement of safety standards for aircraft manufacturing, operation, and maintenance in the National Airspace System (NAS). The FAA operates a network of airport towers, air traffic control centers, radio sites, and flight service stations at more than 19,000 airports. The FAA installs, operates, and maintains facilities that use visual and electronic aids to support air navigation. Critical air traffic control and air navigation systems include voice and data communication equipment, radar facilities, computer systems, and visual display equipment at flight service stations.[1] Using these facilities and systems, the agency develops air traffic rules, assigns the use of airspace, and controls air traffic.

[1] Federal Aviation Administration. 2005. What We Do. Available at http://www.faa.gov/about/mission/activities/ [Accessed September 2007].

In addition to civil aviation, the FAA also is responsible for regulation of commercial space travel, and it is developing guidelines for the emerging suborbital space tourism industry.

The FAA had an estimated budget of $2,147.5 million in fiscal year 2007 and employs approximately 48,799 people.[2] As the largest of the operating administrations in DOT, the FAA manages 85 percent of DOT buildings and facilities. A large percentage of FAA facilities have been exempted from energy reduction requirements because they are critical to the safety of air travel. The FAA has generated approximately 371 megawatt hours of renewable energy in fiscal year 2005 from a combination of hydrogen-powered fuel cell, photovoltaic (PV), and wind power systems.[3] These systems are being tested in a number of locations in the three FAA service areas, the Western, Central, and Eastern service area.

2.2 Applications and Opportunities

This analysis examines backup power and specialty vehicle applications within the FAA and includes a detailed look at opportunities for PEM fuel cells for backup power at radio communication sites. At the FAA, no portable power applications could be identified. Grid parallel and grid independent applications were not considered. Limited potential for the application of PEM fuel cell-powered forklifts was identified. Specialty vehicles, particularly forklifts, are primarily used by the FAA's logistics center in Oklahoma City, Oklahoma. The logistics center supports the NAS, and offers the ability to distribute, transport, and deliver products, equipment, and supplies.

The FAA, however, does have a critical need for reliable backup power for NAS communication equipment and facilities to ensure continuity of air traffic control operations. Communication applications requiring backup power include radio transmitter and receiver (RTR) sites, remote communications air to ground (RCAG) sites, very high frequency omnidirectional range (VOR) sites, radio communications link repeater (RCLR) sites, tactical air navigation aid (TACAN) sites, instrument landing systems (ILS) equipment, automated radar terminal systems, air route traffic control (ATC) centers, airport surveillance radar, air traffic control radar beacons, aviation weather and notice to airmen (NOTAM) systems, and air traffic control towers. Table 1 identifies the various facilities operated by the FAA that require backup power.

[2] Hoover's, Inc. 2007. Available at http://premium.hoovers.com/ [Accessed September 2007.]
[3] U.S. Department of, Energy, Energy Efficiency and Renewable Energy Federal Energy Management Program. 2006. Annual Report to Congress on Federal Government Energy Management and Conservation Programs Fiscal Year 2005. Available at http://www1.eere.energy.gov/femp/pdfs/annrep05.pdf [Accessed September 2007].

Table 1. FAA NAS Operational Facilities Requiring Backup Power.[4]

	2006	2005	2004
NAS Operational Facilities[a]			
NAS Operational Facilities, Total	40,639	40,847	41,082
Communications	14,273	14,344	14,383
Automation	3,896	3,900	3,964
Environment	6,083	6,122	6,194
Navigation	11,033	11,085	11,122
Surveillance	1,804	1,848	1,882
Weather	3,550	3,548	3,537
Air Traffic Control Facilities[b]			
Air Route Traffic Control Center	21	21	21
Airport Traffic Control Tower	517	517	517
Flight Service[c]	75	76	76
Flight Service Stations	16	16	16
Automated Flight Service Stations	60	60	60

[a] Excludes non-federal facilities and foreign facilities.
[b] Included in NAS operational facilities.
[c] Flight Service includes Flight Service Stations and Automated Flight Service Stations.

The impact of power outages can be catastrophic in this market segment, because airplanes depend on the reliability of communications systems to fly and land safely. Airlines can lose up to $3 million for every 15 minute outage at a communication facility.[5] Literature review identified several cases where the impact of power outages resulted in severe disruption of the airspace.

At the Philadelphia International Airport, two power outages due to loss of commercial power occurred in less than 2 months. On June 4, 2005, a major power outage affected the single power line to the air traffic control tower. The power line was more than 25 years old, in substandard condition, and in use well past its intended life span of 15 to 20 years. The first incident resulted in full ground stop and diverted flights; the second outage impact was minimal, as it occurred during off-peak traffic hours.[6]

The San Juan Center and Radar Approach Control facility experienced three power outages in September 2005, which severely impacted the safety of planes in the San Juan airspace. The first outage occurred when generators failed to operate during a loss of commercial power. The battery backup system engaged but only provided power to the radar. As a result, the facility had to go to what is known as "ATC Zero" for an hour, meaning it was basically shut down to all traffic and separation responsibility was shifted to adjoining facilities, including Miami Center as well as numerous international facilities in the Caribbean. Another power outage at the same facility left the facility operating first on battery power and then on one generator. To allow the controllers to work, facility managers decided to let in natural light and propped the door open.

[4] U.S. Department of Transportation. Federal Aviation Administration. 2007. Administrator's Fact Book. Available at http://www.faa.gov/about/office_org/headquarters_offices/aba/admin_factbook/media/April_2007_Fact_Book.pdf [Accessed September 2007.]
[5] Power Engineering International. 2007. Can Fuel Cells Keep Air Traffic Moving? Available at http://pepei.pennnet.com/display_article/297424/6/ARTCL/none/none/Can-Fuel-Cells-Keep-Air-Traffic-Moving?/ [Accessed September 2007.]
[6] Flight. 2005. FAA Technicians and ATC Frustrated with Persistent Power outages. Available at http://www.flightnest.com/2005/07/24faa-technicians-and-atc-frustrated-with-persistent-power-outages. [Accessed September 2007].

However, the carbon monoxide from the generator forced the door shut, and controllers had to continue working in limited light.[7]

On July 18, 2006, a power outage at Los Angeles Center, which is responsible for managing high-altitude flights, caused hundreds of flight delays. Approximately 1 hour later, a component of the electrical power distribution system failed, causing the loss of the backup power system, shutting down computers and controller displays used to track aircraft. During the recovery process, a second failure occurred as the FAA technician attempted to manually reconnect the power. These power failures caused more than 300 flight delays. Following this incident, the Los Angeles International Airport (LAX), which handled more than 650,000 operations in 2005, experienced multiple failures of the ILS, a precision landing system, between July 20 and August 20. These system failures slowed the aircraft arrival rate.[8]

As detailed above, the impacts of power outages are very severe at the FAA. Commonly used technologies that provide backup power to FAA communication equipment and facilities are batteries and generators. The FAA has considered alternatives including PEM fuel cells, wind power, and PV systems. Numerous opportunities for the application of PEM fuel cells for backup power exist at the FAA. However, in the near term, because commercially available PEM fuel cells are smaller in size and are limited to less than 5 kW, they are best suited to provide extended backup power to communications applications currently supported by batteries. Communication applications requiring battery backup power that fit fuel cell requirements include RTR, RCAG, VOR, TACAN, and ILS equipment.

2.3 Market Trends

Backup power is a requirement for most communications applications at the FAA. All sites are configuration managed, i.e., the FAA has standardized power orders that specify the requirements for backup power including types of backup power systems that can be utilized for various applications, installation requirements, and O&M schedules. The current power orders specify the use of batteries and generators for backup power. The power order requires at least 4 hours of backup runtime for its various sites and up to 72 hours at certain sites. The FAA is considering extending backup runtime to 72 hours at some remote sites, sites with unreliable grid power, and critical sites.

To extend backup runtime at these sites, FAA has considered installing PEM fuel cells in lieu of batteries. The first installations of PEM fuel cells at the FAA were through the DoD Construction Engineering Research Laboratory (CERL) PEM fuel cell demonstration program in 2003. At McChord Air Force Base, Washington, six 500-watt PEM fuel cells were connected in parallel to provide 3 kW of backup power to an RTR site.[9] At Kaolin Field in Sandersville, Georgia, a 5-kW PEM fuel cell was installed to provide backup power to an RCAG site.[10]

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[7] Flight. 2005. NATCADC Slams FAA for Power Outages. Available at http://www.flightnest.com/2005/09/17/natcadc-slams-faa-for-power-outages. [Accessed September 2007].
[8] Office of the Inspector General. 2006. FAA Equipment Outages in Southern California. Congressional Briefing. Available at http://www.oig.dot.gov/StreamFile?file=/data/pdfdocs/cc2006079.pdf. [Accessed September 2007].
[9] CERL. 2004. FAA Radio Transmit Receive Site Backup Power Demonstration, McChord Air Force Base, Washington. Final Report. Available at http://dodfuelcell.cecer.army.mil/library_items/McChord_AFB_Final_Report.pdf. Accessed Septermber 2007.
[10] CERL. 2006. Kaolin Field Sandersville, GA FAA Communications Facility PEM Demonstration Project, Initial Project Report. Available at http://dodfuelcell.cecer.army.mil/library_items/FAA_Sandersville_Initial_Report.pdf. Accessed September 2007.

The FAA has approximately 24 installations of PEM fuel cells for applications between 1 kW and 5 kW at RTR, RCAG, and RCLR sites.[11] Table 2 provides a list of FAA PEM fuel cell installations. The PEM fuel cells at these installations provide extended backup runtime from 24 hours to 72 hours and in some cases longer. The goal of the installations is to provide backup power in the event of extended outages. These installations also are being used to evaluate whether PEM fuel cells are reliable and could serve as a viable alternative to traditional battery and generator backup systems currently in use for most FAA systems.

Table 2. PEM Fuel Cell Installations at the FAA.

Location	Facility Type	Capacity
Palwaukee, IL	RTR	1 kW
Wakeman, OH	RCLR	1 kW
Milwaukee, WI	RTR	1 kW
Milwaukee, WI	RTR	1 kW
Belleville, MI	RTR	1 kW
Swinns Valley, MN	RCLR	1 kW
Fairmont, MN	RCAG	5 kW
Fargo, ND	RCAG	3 kW
Bismarck, ND	RTR	5 kW
Marion, IL	RCAG	1 kW
Kingston	RCAG	1 kW
Hilo, HI	RCAG	1 kW
Methl, NY	RCLR	1 kW
Sandersville, GA	RCAG	5 kW
Ault, CO	RCAG	1 kW
Brush, CO	RCAG	1 kW
Barro, UT	RCAG	1 kW
Shivwits, UT	RCAG	1 kW
Ogden, UT	RCAG	1 kW
Little Butte, ID	RCAG	1 kW
Marlin, WA	RCAG	1 kW
Mohler, WA	RCAG	1 kW
McChord, WA	RTR	1 kW
Geiger, WA	RCAG	2 kW

The typical configuration for FAA PEM fuel cell installations includes two small banks of lead acid batteries for primary backup power. The batteries supply a +48 volt direct current (DC) bus that supports the technical loads or communications equipment. A PEM fuel cell provides +48 volt DC power to the communications equipment bus. When the fuel cell is connected to the DC bus, the existing system will function just as it did without a fuel cell. However, during an extended grid outage, the existing backup batteries begin to deplete; causing the bus voltage to drop and triggering the PEM fuel cell to start. With the PEM fuel cell online, the 48 volts on the bus will be maintained (and the batteries will be charged) as long as the fuel cell continues to operate.

[11] Personal Communication between Jessica Sanford (Battelle) and Jessica Soper (FAA). September 2007.

While the FAA is interested in installing additional PEM fuel cells, key decision makers are yet to be convinced of system reliability and cost effectiveness compared to standard alternatives. Furthermore, the lack of a standardized order for the purchase and installation of PEM fuel cells limits the use of PEM fuel cells. Installing PEM fuel cells today at the FAA requires extensive paperwork including filing of an engineering change proposal. Large deployments require a national engineering change proposal, which has to be signed by numerous groups within the FAA. Deployments limited to one or two units require a local engineering change proposal with approvals from local and regional energy managers and engineers. To make PEM fuel cells a standard alternative to batteries, the FAA is working on developing a case for PEM fuel cells and is gathering data so a standardized order can be developed.[12]

3.0 MARKET SEGMENT ANALYSIS

To identify market opportunities for application of fuel cells in the FAA, 20 FAA employees were contacted and 14 employees provided market research input via surveys and interviews. Of the fourteen respondents, four participated in interviews, eight participated in phase 1 surveys, nd seven participated phase 2 surveys. Nine surveys were completed; four surveys were phase 1 surveys and five were phase 2 surveys. Phase 1 surveys focused on identifying potential applications for fuel cells, user requirements, interest in alternatives, and key decision making factors. Phase 2 surveys focused on understanding the economics of current systems and PEM fuel cells. One phase 1 survey was completed by the FAA logistics center on the potential for use of PEM fuel cell-powered forklifts, while the rest focused on the application of PEM fuel cells for backup power. The findings from the specialty vehicle survey will be summarized first, followed by information on the potential for PEM fuel cells as backup power, and the economic analysis findings from surveys and interviews.

3.1 Specialty Vehicle Analysis

The FAA logistics center is a medium-sized facility that is approximately 200,000 square feet in size. The branch manager of the FAA logistics center provided responses on current operations, application of forklifts, user requirements, and potential interest in alternative technology.

The respondent indicated that the facility utilizes diesel-powered and battery-powered forklifts. Types of battery-powered forklifts operated by the facility included sit-down trucks, battery swing lifts, and battery-powered standup forklifts for moving goods at the distribution center. The facility operates approximately 6 to 7 hours a day, 6 days a week. The respondent indicated that the forklift population was approximately 45 to 55 forklift trucks. The primary impact of forklift downtime was reported to be loss of productivity; however, the warehouse has spare forklifts, which limits the impact of downtime.

The respondent appeared to be very satisfied with the forklifts in use and registered no concerns on product performance. The respondent indicated that maintenance is not a concern, because it had been outsourced to a contractor. The branch manager identified reliability, capital costs, O&M costs, lifetime, annual operating costs, start-up time, time between recharging and refueling, and ease of use as very good for battery-powered forklifts. For diesel-powered

[12] Personal Communication between Kathya Mahadevan (Battelle) and Vanestra Myers (FAA), September 2007.

forklifts, the respondent was less satisfied with capital costs, O&M costs, annual operating costs, emissions, and start-up time as compared to battery-powered forklifts. The respondent was particularly satisfied with the lifetime of both diesel-powered and battery-powered trucks.

Limited growth for new forklifts was expected, particularly for stand-up forklifts. The respondent indicated that the facility has not considered any alternatives and is not familiar with PEM fuel cell-powered forklifts. The respondent was not sure if hydrogen as a fuel would be a cause for concern.

When evaluating new power systems, the respondent indicated that all factors are considered very important, including reliability, capital cost, O&M costs, emissions, start-up time, and fuel availability. When making the decision to purchase a new forklift, the respondent indicated that they primarily considered safety, capital cost, and fit with user requirements. The respondent indicated that capital purchase decisions were based on lifecycle cost analysis, and availability of funds. The procurement process was identified as fairly simple: the transportation manager determines the appropriate forklift to purchase, and the decision to purchase is then made by the division manager.

3.2 Backup Power Analysis

Eight respondents provided input to three phase 1 surveys on backup power applications, performance of current systems, user requirements, and interest in adopting alternative technologies. Two of eight respondents are responsible for making energy management decisions for two of the three FAA regions. The survey received from the Northwest region was completed by three respondents; an energy manager and two engineers. Similarly, the survey received from the Great Lakes region was completed by three respondents; an energy manager and two engineers. The third survey was completed by an environmental engineer responsible for siting and maintaining backup power systems. Four interviews were conducted with key individuals within the FAA's power group, energy program, and facilities and infrastructure team.

Respondents identified numerous potential applications for PEM fuel cells for backup power including RCLR, RCAG, VOR, TACAN, RTR sites, and ILS equipment. All the potential applications were identified as critical to FAA business operations. The capacities required for backup power of the technical loads at these sites were identified to be less than 5 kW. Current backup power systems were identified as sealed lead-acid batteries for these sites and are sized to provide 4 hours of backup power. Respondents indicated that generators were used to support remote sites and sites that required support for non-technical loads, such as facility and environmental controls needed to keep the technical loads functioning. Generators utilized are typically 15 kW or larger and operate on diesel or propane.

Some additional potential applications were identified by respondents including automated radar terminal systems, ATC centers, airport surveillance radar, air traffic control radar beacons, aviation weather, and NOTAM systems. However, respondents felt that PEM fuel cells were not yet a good fit for these applications, because of the limited capacity of the commercially

available PEM fuel cell systems and general concerns at the FAA with reliability of new technologies for highly sensitive applications.

When asked about the potential market size for PEM fuel cell applications at the FAA, one respondent indicated that there were approximately 15,000 sites across all the FAA regions with capacities less than 5 kW. For the Northwest region, one respondent indicated that there were between 200 and 300 RCAG sites, approximately 800 VOR sites, 1,700 RTR sites, and thousands of ILS equipment. For the Great Lakes region, one respondent indicated that there were approximately 220 RTR, 120 RCAG, and 107 RCLR sites.

All eight respondents appeared to be fairly dissatisfied with batteries and indicated issues with battery lifetime and safety. Respondents identified start-up time and ease of use of batteries as very good; reliability, capital cost, and lifetime were rated less favorably. One respondent was particularly concerned about the high maintenance required by these battery backup power systems to ensure reliability during a power outage and suggested that alternatives that reduce this burden would be of great benefit. Respondents appeared to be more satisfied with generators than with batteries. Factors causing user dissatisfaction were capital costs and O&M costs of generators. Respondents identified reliability, lifetime, annual operating costs, emissions, start-up time, and fuel availability of generators as very good.

While the FAA tracks outage data at the various sites, limited information was available at the time of survey on the number and length of outages. Respondents indicated that outages of any length severely impacted operations. The severity of the outage is dependent on the location of the outage. Outages could result in disruption of air traffic control and result in airplane delays, loss in productivity, and potential loss of life. Respondents anticipate an increase in the need for backup power, and alternatives considered include PEM fuel cells and solar power. When evaluating alternatives, respondents identified reliability, lifetime, start-up time, fuel availability, and good experience with a system in the past as very important. Emissions and environmental considerations were not so important when selecting a backup power system. One respondent indicated that while it was not specified by the survey, safety of the alternative also was a significant factor when evaluating power systems. The decision to purchase; however, was based on reliability, O&M, cost, and ease of use.

All eight respondents were very familiar with PEM fuel cells and believed that they would compete favorably with current technologies such as batteries and generators. None of the respondents believed that hydrogen as a fuel would be a cause for concern. Respondents indicated that hydrogen was safer than propane, which is located at several sites. Factors that would drive the adoption of PEM fuel cells include the cost of not having electricity, dissatisfaction with current backup power systems, lower cost than current backup power solutions, availability of funds, and track record of others using PEM fuel cell systems.

Respondents indicated that several factors influenced capital purchase decisions including the type of site, needs of the site, reliability of grid power, ease of use, technician satisfaction with technology, and ease of installation and maintenance. Respondents suggested that often it is unreliable commercial power that drives the capital purchase decisions for backup power.

Purchasing decisions are made at both the regional level and headquarters level. The power group at headquarters develops standardized orders for selection and installation of technologies that are used by regions to implement appropriate backup power solutions for various sites. However, requirements for backup power are generated in the field based on need. These requirements then are validated by the service areas and prioritized by the power group at headquarters for future funding. Requirements typically are generated three years in advance of the budget. Regional offices have some latitude in installing systems that work for them; for small-scale deployments a local engineering change order is filed and alternative systems can be placed. Larger-scale deployments are decided at the headquarters level and require a national engineering change proposal. Respondents indicated that financial assistance and availability of funds are considered when purchasing new systems.

3.3 Economic Analysis of Backup Power Systems

Four field engineers and three engineering technicians were surveyed to determine their perspectives on standard technologies, including batteries and generators, and PEM fuel cells as alternatives. Five phase 2 surveys were completed; one survey from the Great Lakes region was completed by three respondents. These engineers and technicians were responsible for installing and maintaining backup power systems at various sites including RTR, RCLR, RCAG sites, and ILS equipment. All seven respondents were familiar with PEM fuel cells and had experience with installing, operating, and monitoring 3 to 12 fuel-cell systems. Some installations dated back to 2002. All seven respondents confirmed that power requirements for the aforementioned sites were less than 5 kW for technical loads and were a good fit for PEM fuel cell application.

The current mode of backup is batteries when non-technical loads need to be supported and generators when technical and non-technical loads need to be supported. The required backup runtime varies by site; the minimum requirement is 4 hours for batteries and some sites need up to 72 hours. One respondent indicated that at most sites he was familiar with in his region, battery backup extended beyond the required 4 hours to at least 24 to 48 hours.

Four respondents provided input on the capital costs of current technologies. Respondents indicated that capital and installation costs of batteries ranged from approximately $5,000 to $6,000 for a 1 kW site to $18,000 for a 3 kW site for 24 hours of backup runtime. For 72 hours of backup runtime, one respondent indicated that for a 1 kW site, the capital and installation costs for batteries with DC bus could range from $75,000 up to $100,000. Respondents were very dissatisfied with battery life and indicated that lifetime of batteries was limited to 3 to 5 years after switching to valve regulated lead-acid (VRLA) batteries. Earlier, lead-acid batteries were utilized, which had longer lifetimes (up to 10 to 20 years) but had very high maintenance costs.

Four respondents indicated that maintenance on batteries can take between 2 and 3 hours per quarter. Often these sites are in remote locations, requiring technicians to travel to the site, which can take up to 6 hours. One respondent suggested that not enough battery maintenance was performed, which impacted battery life. Based on responses received, one can note that the type of maintenance performed on batteries differs between states in the three regions. Typically, batteries were checked for voltage, inner cell resistance, and inner cell connections.

Because of safety issues, two maintenance personnel are sent to the site, especially when inner cell connections are monitored. Total estimated time spent on O&M is approximately 14 to 18 hours per person per year.

Generators used are 15 kW and higher, and can be diesel or propane. Four of seven respondents indicated that capital costs of generators were very high and ranged from $50,000 for a 15 kW generator to $120,000 for a 50 kW generator. Generator maintenance varied between 4.5 and 5.25 man hours per quarter. In addition to preventive maintenance on a quarterly basis, generators require annual general maintenance, including air filter and oil change. Two respondents indicated that generator maintenance also involved examination of other systems supported by the generator such as heating systems and lighting. Only one person is dispatched to perform maintenance of a generator system. Total estimated time spent on O&M is approximately 24 to 27 hours per person per year. Respondents appeared fairly satisfied with generator lifetime and indicated they lasted for at least 15 years and in rare cases up to 30 years.

When asked about the motivation to install PEM fuel cells, respondents indicated that the successful testing of PEM fuel cells through the CERL program was one of the drivers in making the users familiar with PEM fuel cell performance and operation for FAA applications. Furthermore, unreliable grid power, dissatisfaction with batteries and generators, low maintenance requirements of PEM fuel cells, and the attractive economics of PEM fuel cells as compared to batteries and generator systems motivated further installations.

Current installations of PEM fuel cells are all less than 5 kW, and range from 600 watts to 5 kW. Installations typically are single systems and in no case had the PEM fuel cell been strung in parallel to increase power output. Fuel is supplied as compressed hydrogen gas stored in pressurized cylinders. All installations of PEM fuel cells, except for one, are outdoors. Too many issues were identified with installing PEM fuel cells inside buildings and as a result users have opted for outdoor installation of the systems. In addition to meeting local and national hydrogen codes and standards, respondents indicated that FAA orders, FAA electrical codes, and FAA grounding codes need to be followed when PEM fuel cells are installed. All respondents indicated that the process of installation had been fairly easy with the fuel cell manufacturers providing support to ensure that appropriate hydrogen installation codes and standards were met. No specific installation issues or concerns were uncovered.

PEM fuel cells are typically used for extending backup power runtime at sites to 72 hours and in some cases up to 1 week. Current sites have at least 4 hours of backup runtime provided by the battery. PEM fuel cells are added to extend backup runtime. Respondents indicated that PEM fuel cells have not replaced generators at any of the sites because of the small size of the fuel cell systems. A majority of the PEM fuel cells installed use batteries as ride-through. Two respondents indicated that they were in discussion to install some fuel cells that use ultracapacitors for ride-through. Capital costs and installation costs for a 1 kW PEM fuel cell was identified to range from $20,000 to $30,000. Respondents indicated that FAA currently performs its own installation, and indicated that contractor costs of installation ranged from $4,000 to $5,000 for a 1 kW site with no special requirements up to $10,000 to $11,000 for a site with special requirements. For a 5 kW site, contractor installation costs were cited to be approximately $18,000.

When asked about the expected lifetime of the PEM fuel cell stack, respondents were unsure. One respondent suggested that the manufacturers were estimating at least 10 years. This was a significant concern to one respondent as he was unsure if the fuel cell manufacturer would be around to support future repairs and overhauls. Respondents indicated that the PEM fuel cell system came with a 1- to 2-year warranty depending on the manufacturer, and thus far the manufacturer's warranty has been used to a limited extent. One respondent indicated that he used the warranty to install heaters in the fuel cell to prevent freezing during winter and to make software upgrades to cycle the fuel cell regularly to keep the membrane hydrated. The respondent also indicated that this problem has been addressed by the fuel cell manufacturer in newer versions of the technology. Another respondent indicated that they had to replace a PEM fuel cell stack (for approximately $300) after the warranty had expired.

Two of the seven respondents indicated that they had each decommissioned a PEM fuel cell system in their region. One respondent indicated that he decommissioned his system as it was one of the initial fuel cell models and was replacing it with a more recent model that had capabilities to perform automatic load bank testing and cycling. The other respondent indicated that his PEM fuel cell system had simply failed to come on during a routine maintenance check-up. The manufacturer has asked that the fuel cell system be shipped back to them to diagnose the problem. While the manufacturer was willing to replace the PEM fuel cell system, the region decided not to replace the PEM fuel cell at the site as reliability of commercial power had been restored.

Users appear very satisfied with PEM fuel cells to date and pointed out that PEM fuel cells have always come online during a power outage. In several cases, respondents indicated that PEM fuel cells have supported applications for several days before personnel have realized that the facility has suffered a power outage. However, no specific data were available from the respondents as to the number of times the PEM fuel cell had come online in the past 12 months.

Respondents indicated that hydrogen supply was not an issue. National contracts with Air Gas and Praxair ensure a continuous supply at all locations. Respondents indicated that the replacement of each hydrogen cylinder costs between $18 and $20 including delivery. To avoid paying for rental, the FAA owns the hydrogen cylinders; the cost of a cylinder varies from $175 to $300. A refurbished cylinder costs approximately $175 and a new cylinder can cost up to $300. Respondents reported that PEM fuel cells required very little maintenance. They require cycling, which can be scheduled automatically every 30 to 40 days for 30 to 45 minutes. Maintenance performed on the PEM fuel cell varied based on region and ranged from 1 to 2 man hours per year. Two respondents indicated that a standardized maintenance order for the PEM fuel cell did not exist, so maintenance was very minimal. One respondent indicated that a local maintenance order for PEM fuel cells for his region had been developed and only recently distributed. The order called for quarterly, semi-annual, and annual checks of the PEM fuel cell system.

All seven respondents were very satisfied with PEM fuel cells for their applications. Respondents cited various advantages of the PEM fuel cell: systems are perceived to be compact, with low maintenance requirements, and are easy to use; they can be monitored remotely; they make economic sense, are highly reliable, have no emissions, are silent, are load following, can

maintain a steady voltage, can be sized according to the load, and are safer than batteries. Disadvantages of PEM fuel cells identified included concerns about whether parts would be available for current installations 10 years hence, and current limitation to low-power sites that have a DC bus installed.

4.0 MARKET RESEARCH SUMMARY

Several key observations can be noted from user surveys, interviews, and secondary research with respect to potential applications for fuel cells at the FAA, backup power requirements, backup power usage patterns, user satisfaction with current backup power systems, and user perception of PEM fuel cells:

- Two near-term applications for PEM fuel cells were identified in the FAA market segment – PEM fuel cell-powered forklifts at the FAA logistics center and PEM fuel cell backup power systems for radio tower and communications support.
- Limited potential for application of PEM fuel cell-powered forklifts exists as the FAA operates only one single-shift distribution center with less than 60 forklifts.
- There is a critical need for backup power in the FAA market as the impact of power outages can be catastrophic. Backup power is a requirement for most FAA sites for at least 4 hours and it is anticipated that this requirement will be extended to 72 hours for certain sites.
- Applications best suited for PEM fuel cells are RCLR sites, RCAG sites, VOR sites, TACAN sites, ILS equipment, and RTR sites with backup power requirements of less than 5 kW.
- Currently, the FAA relies on batteries to provide backup power support for at least 4 hours at these sites and in some cases up to 72 hours. Batteries provide support only for the technical loads. Generators sized 15 kW and higher are used to provide extended backup runtime up to 72 hours at sites that require technical and non-technical support.
- Users are dissatisfied with batteries for backup power, particularly with battery lifetime and safety. While users appear to be more satisfied with generators than batteries, they still had significant concerns over capital costs and O&M costs of generators.
- Decisions to evaluate an alternative technology are based on reliability, maintenance, and ease of use of the technology.
- Purchasing decisions are based on type of site, needs of the site, reliability of grid power, ease of use, technician satisfaction, and ease of installation and maintenance.
- Financial subsidies are considered by this market segment when making purchasing decisions.
- Awareness of PEM fuel cells for backup power is high at the FAA. The FAA has approximately 24 PEM fuel cell installations for applications between a few hundred watts and 5 kW at RTR, RCAG, and RCLR sites. PEM fuel cells provide at least 72 hours of backup power and in some cases longer.
- There are no concerns about hydrogen as a fuel in this market segment.
- Users appear to be very satisfied with PEM fuel cells for extended backup power. No failures of PEM fuel cell systems during a power outage were reported.
- Advantages of the PEM fuel cell include the following: systems are perceived to be compact, with low maintenance requirements, and are easy to use; they can be monitored

remotely; they make economic sense, are highly reliable, have no emissions, are silent, are load following, can be sized according to the load, and are safer than batteries.

- Potential market size for application of PEM fuel cells at the FAA is 15,000 sites. A need for increased backup power runtime at these sites is anticipated.

5.0 LIFECYCLE COST ANALYSIS

Market research suggests that widespread acceptance of PEM fuel cells at the FAA is dependent on reliability and lifecycle cost of the technology compared to batteries. Current research suggests that there is potential for further adoption of PEM fuel cells based on economics and need for extended runtime, reliability, and ease of use. To provide extended backup for the technical load at the various sites, the FAA has installed longer battery strings but is concerned with the capital costs and lifetime of batteries. In a few rare cases, due to the critical need of a site for extended runtime and because users are familiar with larger generators, these systems have been installed despite the lower technical load requirements.

To determine if PEM fuel cells offer value to the various applications in this market segment, the lifecycle costs of PEM fuel cells compared to batteries and generators are examined in three different installation scenarios. This analysis examines the discounted net present value (NPV) of using PEM fuel cells compared to batteries and generators using assumptions consistent with the H2A model over a 15-year analysis period. The fuel supplied to the PEM fuel cell is compressed hydrogen gas in pressurized canisters. Due to the significant cost of tank rental, it is assumed that the FAA purchases the hydrogen tanks that it uses in all the scenarios outlined below. During replacement, the hydrogen supplier simply replaces depleted tanks with fully fueled hydrogen tanks. Because PEM fuel cell technology is relatively new, it also is assumed that users need training. Cost of training is assumed to be a one-time cost of $2,500. For all three scenarios, a discount rate of 8 percent and an inflation rate of 2.3 percent are applied. No disposal costs for the technologies are assumed. For batteries, it is assumed that the disposal costs are rolled into the initial capital cost of the system. Lifecycle costs of batteries are evaluated under 3-year and 5-year battery replacement schedules.

5.1 Scenario 1 - Lifecycle Cost Analysis of Backup Power Alternatives at an RTR Site

5.1.1 Scenario 1 Assumptions

Scenario 1 assumes that the RTR site with a 600-Watt capacity requires extended backup power beyond the traditional 4 hours currently provided by batteries. In this scenario, users are looking to support the site's technical loads only. This scenario compares the NPV over a 15-year lifecycle of PEM fuel cells to the NPV of battery strings for 24 hours, 48 hours, and 72 hours of backup runtime per year. The lifecycle cost analysis of the battery assumes both a 3-year and 5-year battery replacement schedule. Assumptions for this scenario are presented in Table 3.

Table 3. Scenario 1 - Lifecycle Cost Assumptions for NPV Analysis of a 600-Watt RTR Site.

	24 Hours Backup Runtime		48 Hours Backup Runtime		72 Hours Backup Runtime	
	Batteries	**PEM Fuel Cell**	**Batteries**	**PEM Fuel Cell**	**Batteries**	**PEM Fuel Cell**
Size (kW)	0.6	0.6	0.6	0.6	0.6	0.6
Lifetime (yrs)	3 and 5	15	3 and 5	15	3 and 5	15
Backup Runtime (hrs)	24	24	48	48	72	72
Usage (kWh/yr)	14.4	14.4	28.8	28.8	43	43
Unit Cost ($)	2,448[1]	6,740[2]	4,896[1]	6,740[2]	7,310[1]	6,740[2]
Engineering Installation Costs ($)	780[3]	7,000[4]	780[3]	7,000[4]	780[3]	7,000[4]
Non-Engineering Installation Costs ($)	3,000[5]	8,900[5]	5,000[5]	8,900[5]	7,000[5]	8,900[5]
Battery Racks ($)	*3,000*		*5,000*		*7,000*	
Hydrogen Fuel Tank Cost ($)		*1,200[6]*		*1,200[6]*		*1,200[6]*
Concrete/Moon Pad ($)		*1,200*		*1,200*		*1,200*
Outdoor Enclosure ($)		*6,500*		*6,500*		*6,500*
Battery Ride-Through ($)	NA	408[1]	NA	408[1]	NA	408[1]
Maintenance Costs ($/yr)	2,880[7]	720[8]	3,600[7]	72[7]	4,320[7]	720[8]
Annual Replacement Costs ($/yr)	NA	100[9]	NA	100[9]	NA	100[9]
Fuel Usage	Negligible	7.7 slpm	Negligible	7.7 slpm	Negligible	7.7 slpm
Fuel Cost ($)	NA	32[10]	NA	65[10]	NA	97[10]
Stack Replacement Costs at 10 years ($)	NA	900	NA	900	NA	900

[1] Battery cost is based on $0.17 watt-hour. Industry communication, September 2007.
[2] ReliOn I-1000 as listed on GSA Advantage. Accessed September 2007.
[3] Assumes engineering services installation cost of $1300/kW. Data obtained from Battelle market research surveys.
[4] Includes electrical installation costs. Industry communication. September 2007.
[5] Industry communication, September 2007.
[6] Assumes $200 per hydrogen cylinder. Six cylinders are purchased. Data obtained from Battelle market research surveys.
[7] For 24 hour runtime, assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. For 48 hour backup runtime, assumes 4 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Cost of maintenance person is assumed to be $45 per hour. Assumes cost of 2 maintenance personnel. For 72 hour backup runtime, assumes 6 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. Data obtained from Battelle market research surveys.
[8] Assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person semi-annually. Assumes cost of 1 maintenance person. Data obtained from Battelle market research surveys.
[9] Includes air filter replacement. Industry communication, September 2007.
[10] Assumes 1 cylinder provides 8 kWh of runtime. Cost per cylinder is $18. Data obtained from Battelle market research surveys.

The PEM fuel cell is sized according to the load required by the site at 600 watts. The PEM fuel cells in this installation use batteries as ride-through; these batteries are sized to provide 4 hours of runtime as the site originally had. Ride-through batteries are replaced every 3 years. At 10 years, PEM fuel cell stacks are replaced for $900. Installation costs for RTR sites vary from $4,000 to $10,000. An average of these costs is assumed for PEM fuel cell installation costs in this scenario. The PEM fuel cell system in this scenario is installed outdoors and uses an outdoor enclosure. It is assumed that the RTR site experiences frequent outages and fuel consumed is replaced annually. No residual value for the installed technologies is assumed at the end of 15 years.

5.1.2 Scenario 1 Results

In scenario 1, PEM fuel cells are competitive with batteries on an NPV of total cost basis over the 15-year analysis period with both 3-year and 5-year battery replacement cycles (Table 4). PEM fuel cells offer significant savings from an O&M perspective.

Considering the NPV of the total cost of the system, for 24 hours, 48 hours, and 72 hours of backup runtime with a 3-year battery replacement schedule, NPVs of the total costs of PEM fuel cells are 16 percent, 41 percent, and 54 percent less than the NPV of the total costs of batteries, respectively. For 24 hours, 48 hours, and 72 hours of backup runtime with a 5-year battery replacement schedule, the NPVs of the total costs of the PEM fuel cell system are 8 percent, 34 percent, and 48 percent less than the NPV of the total costs of batteries, respectively.

While the NPV of the total capital costs of the PEM fuel cell system are higher than that of batteries, the NPVs of the total O&M costs for PEM fuel cells are 70 to 79 percent less than those of batteries.

Table 4. Scenario 1: 600 Watts for 24 Hours, 48 Hours, 72 Hours Backup Runtime at an RTR Site – NPV of a PEM Fuel Cell and a Battery Backup System Over a 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules.

	24 Hours Backup Runtime			48 Hours Backup Runtime			72 Hours Backup Runtime		
	Battery (3-Year)	Battery (5-Year)	PEM Fuel Cell	Battery (3-Year)	Battery (5-Year)	PEM Fuel Cell	Battery (3-Year)	Battery (5-Year)	PEM Fuel Cell
NPV of Total Capital Costs ($)	12,458	8,495	26,362	23,191	16,721	26,362	33,802	24,142	26,362
NPV of Total O&M Costs ($)	29,432	29,432	8,707	36,791	36,791	9,044	44,149	44,149	9,371
NPV of Total Costs of the System ($)	41,883	37,920	35,062	59,967	53,497	35,392	77,929	68,269	35,712

The NPV of total capital costs for PEM fuel cells are more expensive than battery alternatives for 24 hours and 48 hours of backup runtime with 3-year and 5-year battery replacement schedules (Table 4). For 24 hours of backup runtime, the NPV of the total capital costs of the battery are 53 percent less than the NPV of the total capital cost of the PEM fuel cell with a 3-year replacement schedule. With a 5-year replacement schedule for 24 hours of backup runtime, the NPV of the total capital costs of the battery are approximately 68 percent less than the NPV of the total capital cost of the PEM fuel cell.

For 48 hours of backup runtime, the NPV of the total capital costs of the PEM fuel cell are 14 percent more than the NPV of the total capital cost of the batteries with a 3-year replacement schedule. For 48 hours of backup runtime, the NPV of the total capital costs of the PEM fuel cell are 58 percent more than the NPV of the total capital cost of the batteries with a 5-year replacement schedule.

For 72 hours of backup runtime, the NPV of the total capital costs of the PEM fuel cell are 22 percent less than the NPV of the total capital cost of the batteries with a 3-year replacement

schedule. For 72 hours of backup runtime, the NPV of the total capital costs of the PEM fuel cell are 9 percent more than the NPV of the total capital cost of the batteries with a 5-year replacement schedule.

5.2 Scenario 2 - Lifecycle Cost Analysis of Backup Power Alternatives at an RCLR Site

5.2.1 Scenario 2 Assumptions

Scenario 2 assumes that an RCLR site has a 3 kW capacity with batteries providing 4 hours of backup runtime and users are looking to extend backup runtime. Assumptions used for this scenario are presented in Table 5. In this scenario, users are looking to support only the technical loads and not the non-technical loads. This scenario compares the lifecycle costs of a battery string and PEM fuel cells for 24 hours, 48 hours, and 72 hours of backup runtime.

The lifecycle cost analysis of the battery string assumes both a 3-year and 5-year battery replacement schedule. The PEM fuel cell is sized according to the load required by the site at 3 kW. The PEM fuel cells in this installation use batteries as ride-through; these batteries are sized to provide 4 hours of runtime until the first battery replacement, after which these batteries are sized to provide 1 hour of runtime. It is assumed that users become comfortable with the reliability of the PEM fuel cell solution and as a result reduce the redundancy within the system. Batteries that provide ride-through for the fuel cell are replaced every 3 years. The RCLR site is assumed to have some special outdoor installation requirements, which are reflected in the higher engineering installation costs. At 10 years, PEM fuel cell stacks are replaced for $4,500. It is assumed that the RCLR site experiences annual outages and fuel consumed is replaced annually. No residual value for the installed technologies is assumed at the end of 15 years.

5.2.2 Scenario 2 Results

For a 3 kW RCLR site, the cost of a PEM fuel cell is very competitive with batteries with a 3-year and 5-year battery replacement schedule for 24 hours, 48 hours, and 72 hours of backup runtime (Table 6).

For 24 hours, 48 hours, and 72 hours of backup runtime with a 3-year battery replacement schedule, the NPVs of the total costs of the PEM fuel cell system are 36 percent, 59 percent, and 69 percent less than the NPVs of the total costs of batteries, respectively. For 24 hours, 48 hours, and 72 hours of backup runtime with a 5-year battery replacement schedule, the NPVs of the total costs of the PEM fuel cell system are 20 percent, 45 percent, and 58 percent less than the NPVs of the total costs of batteries, respectively.

The NPV of the total O&M costs for PEM fuel cells are 68 to 70 percent less than the NPVs of total O&M costs of batteries.

Table 5. Scenario 2 – Lifecycle Cost Assumptions for NPV Analysis of a 3 kW RCLR Site.

	24 Hours Backup Runtime		48 Hours Backup Runtime		72 Hours Backup Runtime	
	Batteries	**PEM Fuel Cell**	**Batteries**	**PEM Fuel Cell**	**Batteries**	**PEM Fuel Cell**
Size (kW)	3	3	3	3	3	3
Lifetime (yrs)	3 and 5	15	3 and 5	15	3 and 5	15
Backup Runtime (hrs)	24	24	48	48	72	72
Usage (kWh/yr)	72	72	144	144	216	216
Unit Cost ($)	12,240[1]	15,000[2]	24,480[1]	15,000[2]	36,720[1]	15,000[2]
Engineering Installation Costs ($)	3,900[3]	10,000[2]	3,900[3]	10,000[2]	3,900[3]	10,000[2]
Non-Engineering Installation Costs ($)	3,000[2]	9,500	5,000[2]	11,300	7,000[2]	13,100
Battery Racks ($)	*3,000*		*5,000*		*7,000*	
Hydrogen Fuel Tank Cost ($)		*1,800*[4]		*3,600*[4]		*5,400*[4]
Concrete/Moon Pad ($)		*1,200*[2]		*1,200*[2]		*1,200*[2]
Outdoor Enclosure ($)		*6,500*[2]		*6,500*[2]		*6,500*[2]
Battery Ride-Through ($)	NA	2,040-510[1]	NA	2,040-510[1]	NA	2,040-510[1]
Maintenance Costs ($/yr)	2,880[5]	720[6]	3,600[5]	720[6]	4,320[5]	720[6]
Annual Replacement Costs ($/yr)		100[7]		100[7]		100[7]
Fuel Usage	Negligible	7.7 slpm	Negligible	7.7 slpm	Negligible	7.7 slpm
Fuel Cost ($)	NA	97[8]	NA	324[8]	NA	48[7]
Stack Replacement Costs at 10 Years ($)	NA	4,500	NA	4,500	NA	4,500

[1] Battery cost is based on $0.17 watt-hour. Industry communication. September 2007.
[2] Industry communication, September 2007.
[3] Assumes engineering services installation cost of $1300/kW. Data obtained from Battelle market research surveys.
[4] Assumes $200 per hydrogen cylinder. Assumes 9 cylinders for 24 hours of backup runtime. Assumes 18 cylinders for 48 hours of backup runtime. Assumes 27 cylinders for 72 hours of backup runtime. Data obtained from Battelle market research surveys.
[5] For 24 hour runtime, assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. For 48 hour backup runtime, assumes 4 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Cost of maintenance person is assumed to be $45 per hour. Assumes cost of 2 maintenance personnel. For 72 hour backup runtime, assumes 6 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. Data obtained from Battelle market research surveys.
[6] Assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person semi-annually. Assumes cost of 1 maintenance person. Cost of maintenance person is assumed to be $45 per hour. Data obtained from Battelle market research surveys.
[7] Includes air filter changes. Industry communication, September 2007.
[8] Assumes 1 cylinder provides 8 kWh of runtime. Cost per cylinder is $18. Data obtained from Battelle market research surveys.

Table 6. Scenario 2: 3 kW for 24 hours, 48 hours, 72 hours at an RCLR Site – NPV of PEM Fuel Cell and Battery Backup System Over 15-year Analysis Period with 3-Year and 5-Year Battery Replacement Schedule.

	24 Hours Backup Runtime			48 Hours Backup Runtime			72 Hours Backup Runtime		
	Battery (3-Year)	**Battery (5-Year)**	**PEM Fuel Cell**	**Battery (3-Year)**	**Battery (5-Year)**	**PEM Fuel Cell**	**Battery (3-Year)**	**Battery (5-Year)**	**PEM Fuel Cell**
NPV of Total Capital Costs ($)	50,662	34,487	41,845	96,576	64,227	43,589	142,490	93,966	45,333
NPV of Total O&M Costs ($)	29,432	29,432	9,371	36,791	36,791	11,691	44,149	44,149	13,347
NPV of Total Costs of the System ($)	80,058	63,884	51,180	133,294	100,945	55,208	186,530	138,006	58,572

When the NPV of total capital costs of PEM fuel cells are compared to batteries, the PEM fuel cell is competitive in all cases except with batteries providing 24 hours of backup runtime on a 5-year battery replacement schedule. In this case, the NPV of the total capital costs of the PEM fuel cell are 21 percent more than the NPV of the total capital cost of batteries.

5.3 Scenario 3 - Lifecycle Cost Analysis of Backup Power Alternatives at an RCAG Site

5.3.1 Scenario 3 Assumptions

Scenario 3 assumes that an RCAG site has a 5-kW capacity with batteries providing 4 hours of backup runtime and users are looking to extend backup runtime. Users here are looking to support only the technical loads and not the non-technical loads. As referenced earlier, in certain rare cases, a large diesel generator may be installed to support extended runtime at remote sites. This scenario compares the lifecycle costs of a battery string, an oversized diesel generator per capacity required by the site, and PEM fuel cells for 24 hours, 48 hours, and 72 hours of backup runtime. Assumptions used for this scenario are presented in Table 7.

The lifecycle cost analysis of the battery string assumes both a 3-year and 5-year battery replacement schedule. The diesel generator used in this scenario is sized at 20 kW and is a commercial generator typically used by the FAA for supporting non-technical loads including environmental loads and facility loads; in rare cases, it is used to support technical loads as backup to batteries. The PEM fuel cell is sized according to the load required by the site at 5 kW. The PEM fuel cells and generators in this installation use batteries as ride-through; these batteries are sized to provide 4 hours of runtime until the first replacement, after which these batteries are sized to provide 1 hour of runtime. It is assumed that users become comfortable with the reliability of the generator and the PEM fuel cell solution, resulting in the reduction in the redundancy with their system. Batteries that provide ride-through for the PEM fuel cell and generator are replaced every 3 years. In this scenario, it is assumed that the fuel is replaced annually, as the site experiences frequent outages. An engine overhaul is performed at 10 years for the diesel generator for $10,000. At 10 years, the PEM fuel cell also requires stack replacement ($7,500). No residual value for the installed technologies is assumed at the end of 15 years.

Table 7. Scenario 3 – Lifecycle Cost Assumptions for NPV Analysis of a 5 kW RCAG Site.

	24 Hours Backup Runtime			48 Hours Backup Runtime			72 Hours Backup Runtime		
	Batteries	**Generator[1]**	**PEM Fuel Cell**	**Batteries**	**Generator[1]**	**PEM Fuel Cell**	**Batteries**	**Generator[1]**	**PEM Fuel Cell**
Size (kW)	5	20	5	5	20	5	5	20	5
Lifetime (yrs)	3 and 5	15	15	3 and 5	15	15	3 and 5	15	15
Backup Runtime (hrs)	24	24	24	48	24	48	72	24	72
Usage (kWh/yr)	120	120	120	240	240	240	360	360	360
Unit Cost ($)	20,400[2]	20,000[1]	15,940[3]	40,800[2]	20,000[1]	15,940[3]	61,200[2]	20,000[1]	15,940[3]
Engineering Installation Costs ($)	6,500[4]	16,000[5]	15,000[6]	6,500[4]	16,000[5]	15,000[6]	6,500[4]	16,000[5]	15,000[6]
Non-Engineering Installation Costs ($)	7,000[6]	7,650[6]	8,200[6]	8,500[6]	7,650[6]	11,200[6]	10,000[6]	7,650[6]	14,200[6]
Battery Racks ($)	*7,000*			*8,500*			*10,000*		
Fuel Tank Cost ($)		*2,250*	*3,000[7]*		*2,250*	*6,000[7]*		*2,250*	*9,000[7]*
Transfer Switch ($)		*2000*			*2000*				
Fuel Tank Pad ($)		*2000*			*2000*			*2000*	
Concrete Pad ($)		*1,400*			*1,400*			*1,400*	
Moon Pad ($)			*1,200*			*1,200*			*1,200*
Outdoor Enclosure ($)			*4,000*			*4,000*			*4,000*
Battery Ride-Through ($)	NA	3,400-425[2]	3,400-425[2]	NA	3,400-425[2]	3,400-425[2]	NA	3,400-425[2]	3,400-425[2]
Maintenance Costs ($/yr)	2,880[8]	1,800[9]	360[10]	3,600[8]	1,800[9]	360[10]	4,320[8]	1,800[9]	360[10]
Annual Replacement Costs ($/yr)		700[11]	250[12]		700[11]	250[12]		700[11]	250[12]
Fuel Usage	Negligible	1.2 gal/hr	7.7 slpm	Negligible	1.2 gal/hr	7.7 slpm	Negligible	1.2 gal/hr	7.7 slpm
Fuel Cost ($)		86[13]	270[14]		173[13]	540[14]		259[13]	810[14]
Replacement Costs at 10 Years ($)	NA	10,000[6]	7,500[6]	NA	10,000[6]	7,500[6]	NA	10,000[6]	7,500[6]

[1] Assumes a 20 kW diesel generator. Data obtained from Battelle market research surveys.
[2] Battery cost is based on $0.17 watt-hour. Industry communication. September 2007.
[3] Cost based on Plug Power Gencore 5B48 System available through GSA Advantage. Accessed September 2007.
[4] Assumes engineering services installation cost of $1300/kW. Data obtained from Battelle market research surveys.
[5] Assumes engineering services installation cost of $800/kW. Data obtained from Battelle market research surveys.
[6] Industry communication. September 2007.
[7] Assumes $200 per hydrogen cylinder. Assumes 15 cylinders for 24 hours of backup runtime. Assumes 30 cylinders for 48 hours of backup runtime. Assumes 45 cylinders for 72 hours of backup runtime. Data obtained from Battelle market research surveys.
[8] For 24 hour runtime, assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. For 48 hour backup runtime, assumes 4 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Cost of maintenance person is assumed to be $45 per hour. Assumes cost of 2 maintenance personnel. For 72 hour backup runtime, assumes 6 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 2 maintenance personnel. Data obtained from Battelle market research surveys.
[9] Assumes 4 hours of maintenance, plus 6 hours of travel time to remote location per person per quarter. Assumes cost of 1 maintenance person. Data obtained from Battelle market research surveys.
[10] Assumes 2 hours of maintenance, plus 6 hours of travel time to remote location per person annually. Cost of maintenance person is assumed to be $45 per hour. Assumes cost of 1 maintenance person. Industry communication, September 2007.
[11] Includes oil changes, filter changes, spark plug changes. Industry communication, September 2007.
[12] Includes air filter changes, coolant change. Industry communication, September 2007.
[13] Cost of diesel is assumed at $3 per gallon.
[14] Assumes 1 cylinder provides 8 kWh of runtime. Cost per cylinder is $18. Data obtained from Battelle market research surveys.

5.3.2 Scenario 3 Results

For the 5 kW RCAG site, the PEM fuel cell is very competitive with both the battery (with 3-year and 5-year battery replacement schedules) and generator systems from a capital cost, O&M costs, and total cost perspective for 24 hours, 48 hours, and 72 hours of backup runtime (Table 8, Table 9, and Table 10).

24 hours of Backup Runtime

Considering total lifecycle costs, the NPV of the total costs of the PEM fuel cell are approximately 50 percent less than the NPV of the total costs of the battery system with 3-year battery replacement, 34 percent less than the NPV of the total costs of the battery system with 5-year battery replacement, and 26 percent less than the NPV of the total costs of the diesel generator (Table 8).

The NPV of the total O&M cost of the PEM fuel cell system is 69 percent less than the NPVs of total O&M costs of the battery system with 3-year and 5-year battery replacement and 66 percent less than the NPV of the total O&M cost of the diesel generator.

The NPV of the total capital costs of the PEM fuel cell system are 43 percent less than the NPV of the total capital costs of the battery system with 3-year battery replacement, 17 percent less than the NPV of the total capital costs the battery system with 5-year battery replacement, and 6 percent less than the NPV of the total capital costs of the diesel generator.

Table 8. Scenario 3: 5 kW for 24 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules.

	24 Hours Backup Runtime			
	Battery (3-Year)	**Battery (5-Year)**	**Generator (20 kW)**	**PEM Fuel Cell**
NPV of Total Capital Costs ($)	86,375	59,417	52,341	49,220
NPV of Total O&M Costs ($)	29,432	29,432	26,428	8,993
NPV of Total Costs of the System ($)	115,771	88,813	78,733	58,178

48 hours of Backup Runtime

The NPV of the total costs of the PEM fuel cell are 68 percent less than the NPV of the total costs of the battery system with 3-year battery replacement, 55 percent less than the NPV of the total costs of the battery system with 5-year battery replacement, and 12 percent less than the NPV of the total costs of the diesel generator (Table 9).

The NPV of the total O&M costs of the PEM fuel cell system are 68 percent less than the NPV of the total O&M costs of the battery system with 3-year and 5-year battery replacement and 57 percent less than the NPV of the total O&M costs of the diesel generator.

The NPV of the total capital costs of the PEM fuel cell system are 68 percent less than the NPV of the total capital costs of the battery system with 3-year battery replacement, 51 percent less

than the NPV of the total capital costs of the battery system with 5-year battery replacement, and 0.4 percent less than the NPV of the total capital costs of the diesel generator.

Table 9. Scenario 3: 5 kW for 48 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedule.

	48 Hours Backup Runtime			
	Battery (3-Year)	**Battery (5-Year)**	**Generator (20 kW)**	**PEM Fuel Cell**
NPV of Total Capital Costs ($)	160,637	106,722	52,341	52,128
NPV of Total O&M Costs ($)	36,791	36,791	27,317	11,753
NPV of Total Costs of the System ($)	197,356	143,440	79,538	63,844

72 hours of Backup Runtime

The NPV of the total costs of the PEM fuel cell are 75 percent less than the NPV of the total costs of the battery system with 3-year battery replacement, 65 percent less than the NPV of the total costs of the battery system with 5-year battery replacement, and 13 percent less than the NPV of the total costs of the diesel generator (Table 10).

The NPV of the total O&M costs of the PEM fuel cell system are 67 percent less than the NPV of the total O&M costs of the battery system with 3-year and 5-year battery replacement and 49 percent less than the NPV of the total O&M costs of the diesel generator.

Table 10. Scenario 3: 5 kW for 72 Hours – NPV of PEM Fuel Cell, Diesel Generator, and Battery Backup System Over 15-Year Analysis Period with 3-Year and 5-Year Battery Replacement Schedules.

	72 Hours Backup Runtime			
	Battery (3-Year)	**Battery (5-Year)**	**Generator (20 kW)**	**PEM Fuel Cell**
NPV of Total Capital Costs ($)	235,869	154,995	52,341	55,035
NPV of Total O&M Costs ($)	44,149	44,149	28,196	14,512
NPV of Total Costs of the System ($)	279,909	199,035	80,356	69,510

The NPV of the total capital costs of the PEM fuel cell system are 77 percent less than the NPV of the total capital costs of the battery system with 3-year battery replacement, 64 percent less than the NPV of the total capital costs of the battery system with 5-year battery replacement, and 5 percent more than the NPV of the total capital costs of the diesel generator.

5.4 Lifecycle Cost Analysis Summary

The lifecycle cost analyses presented above for an expected operating period of 15 years in each scenario, show that PEM fuel cells can compete effectively on a total cost basis with batteries in all three scenarios for 24 hours, 48 hours, and 72 hours of backup runtime (Table 11) for varying capacities less than 5 kW. The lifecycle cost analyses also shows that PEM fuel cells can

compete effectively with generators for varying levels of backup runtime. On an NPV of total lifecycle costs, PEM fuel cells are competitive with batteries under a 3-year and 5-year battery replacement schedule. In all three scenarios, PEM fuel cells have significantly lower O&M costs than batteries. In scenario 1, for a site with 600-watt capacity, the NPV of the total capital costs of batteries with 3-year and 5-year replacement for 24 hours and 48 hours of backup runtime and for 5-year replacement for 72 hours of backup runtime are lower than the NPV of the total capital costs of PEM fuel cell systems. Similarly, in scenario 2, the NPV of the total capital costs of batteries 5-year replacement for 3 kW capacity for 24 hours of backup runtime are lower that the NPV of the total capital costs of PEM fuel cells. In all other cases, the NPV of the total capital costs of PEM fuel cells are less than that of competing alternatives.

Table 11. Comparison of NPV of Total Cost of System for 600-Watt RTR Site, 3 kW RCLR Site, and 5 kW RCAG Site for 24 Hours, 48 Hours, and 72 Hours of Backup Runtime.

	600-Watt RTR Site			3 kW RCLR Site			5 kW RCAG Site			
	Battery (3-Year)	**Battery (5-Year)**	**PEM Fuel Cell**	**Battery (3-Year)**	**Battery (5-Year)**	**PEM Fuel Cell**	**Battery (3-Year)**	**Battery (5-Year)**	**Generator**	**PEM Fuel Cell**
24 Hours Backup Runtime ($)	41,883	37,920	35,062	80,058	63,884	51,180	115,771	88,813	78,733	58,178
48 Hours Backup Runtime ($)	59,967	53,497	35,392	133,294	100,945	55,208	197,356	143,440	79,538	63,844
72 Hours Backup Runtime ($)	77,929	68,269	35,712	186,530	138,006	58,572	279,909	199,035	80,356	69,510

6.0 SENSITIVITY ANALYSIS

Single-factor sensitivity analysis was performed to show the variability in average annual system cost of PEM fuel cells as individual factors are varied while all other factors are held constant. The base values for each factor are the same as the values for 72 hours backup runtime in scenarios 1, 2, and 3. Here, each factor was allowed to vary by +/-10 percent of the base assumption (Tables 12, 13, and 14). In the sensitivity analysis, the average annual cash outlay for use of a PEM fuel cell was calculated using Equation 1.

$$\overline{C} = \frac{\text{(Fuel Cell Cost + Installation Cost)}}{\text{Fuel Cell Life}} + \frac{\text{Battery Cost}}{\text{Battery Life}} + \frac{\text{Fuel Cell Stack Cost}}{\text{Stack Life}} + \text{Annual Hydrogen Cost} + \text{Annual O \& M Cost}$$

The results of the sensitivity analysis are presented in tornado diagrams (Figures 1, 2, and 3). The factor that shows the greatest cost leverage is graphed at the top of the tornado diagram, with other factors arrayed below it in descending order of cost leverage, creating the “tornado” shape. Two numbers are shown at each end of the horizontal bar graph for each factor. The upper number is the average cost per year if this factor is varied by 10 percent from base assumptions, holding all other factors at base assumptions. In brackets under the average cost figure is the value of the factor when varied by 10 percent. For example, in Figure 1, if the fuel cell life is assumed in the base case to be 15 years, then increasing the life by 10 percent, to 16.5 years, results in a $125 annual average cost savings.

Scenario 1 Sensitivity Analysis - 600 Watts for 72 Hours of Backup Runtime

The assumptions for sensitivity analysis of 600-Watt PEM fuel cell system for 72 hours of backup runtime are presented in Table 12.

Table 12. Sensitivity Analysis Cost Assumptions for 600-Watt PEM Fuel Cell Backup Power for 72 Hours: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
O&M Cost, $	648	720	792
Ride-Through Batteries (capital cost), $	367	408	449
Ride-Through Battery Life, years	2.7	3	3.3
Fuel (hydrogen), $/year	87	97	107
Fuel Cell Stack Cost ($)	810	900	990
Fuel Cell Stack Life, years	9	10	11
Fuel Cell Cost, $	6,066	6740	7,414
Installation Cost, $	14,310	15,900	17490
Fuel Cell Life, years	13.5	15	16.5

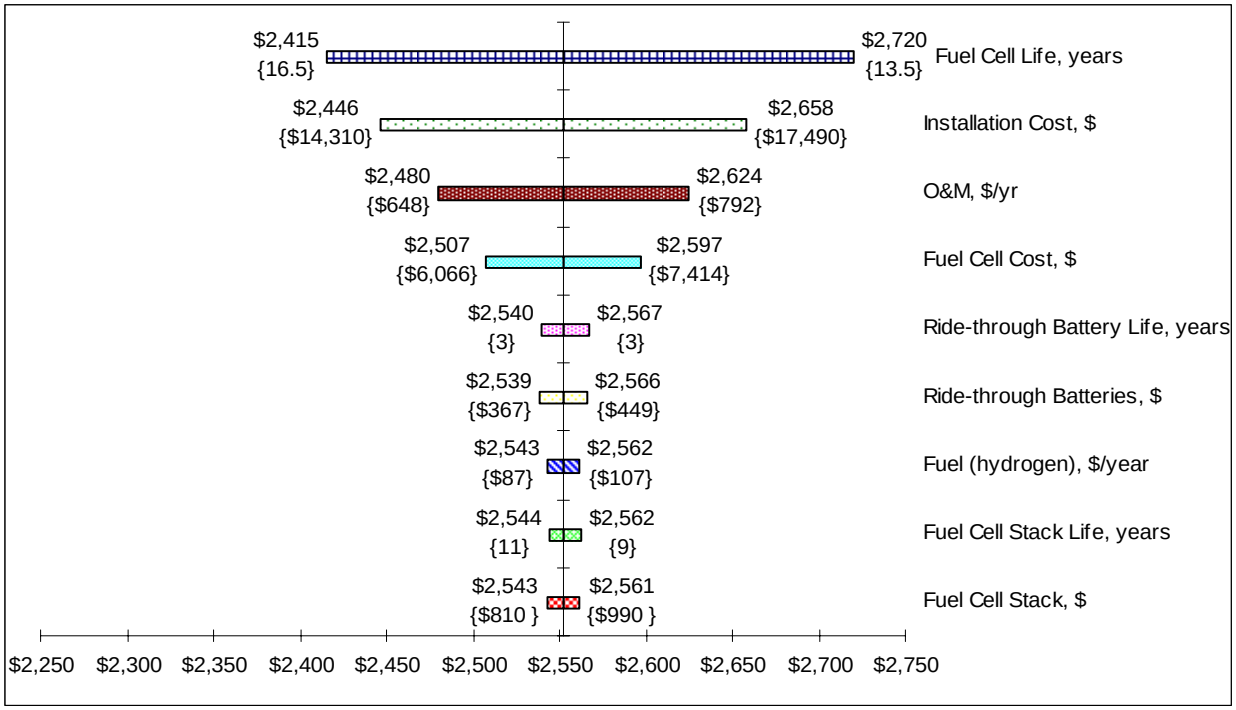

Figure 1. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 600-Watt PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime.

The results of the sensitivity analysis are shown in Figure 1. For a 600-Watt PEM fuel cell used in backup power applications for 72 hours of runtime, improving the fuel cell life has the largest impact on the average annual cost. Installation cost is the second largest cost driver of the cost of owning and operating a PEM fuel cell. O&M costs and fuel cell cost are the third and fourth largest cost drivers.

Scenario 2 Sensitivity Analysis – 3 kW for 72 Hours of Backup Runtime

The assumptions for sensitivity analysis of 3 kW PEM fuel cell system for 72 hours of backup runtime are presented in Table 13.

Table 13. Cost Assumptions for 3 kW PEM Fuel Cell Backup Power for 72 Hours Sensitivity Analysis: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
O&M Cost, $	648	720	792
Ride-Through Batteries, (capital cost) $	734	816	898
Ride-Through Battery Life, years	2.7	3	3.3
Fuel (hydrogen), $/year	437	486	535
Fuel Cell Stack Cost ($)	4,050	4,500	4,950
Fuel Cell Stack Life, years	9	10	11
Fuel Cell Cost, $	13,500	15,000	16,500
Installation Cost, $	20,790	23,100	25,410
Fuel Cell Life, years	13.5	15	16.5

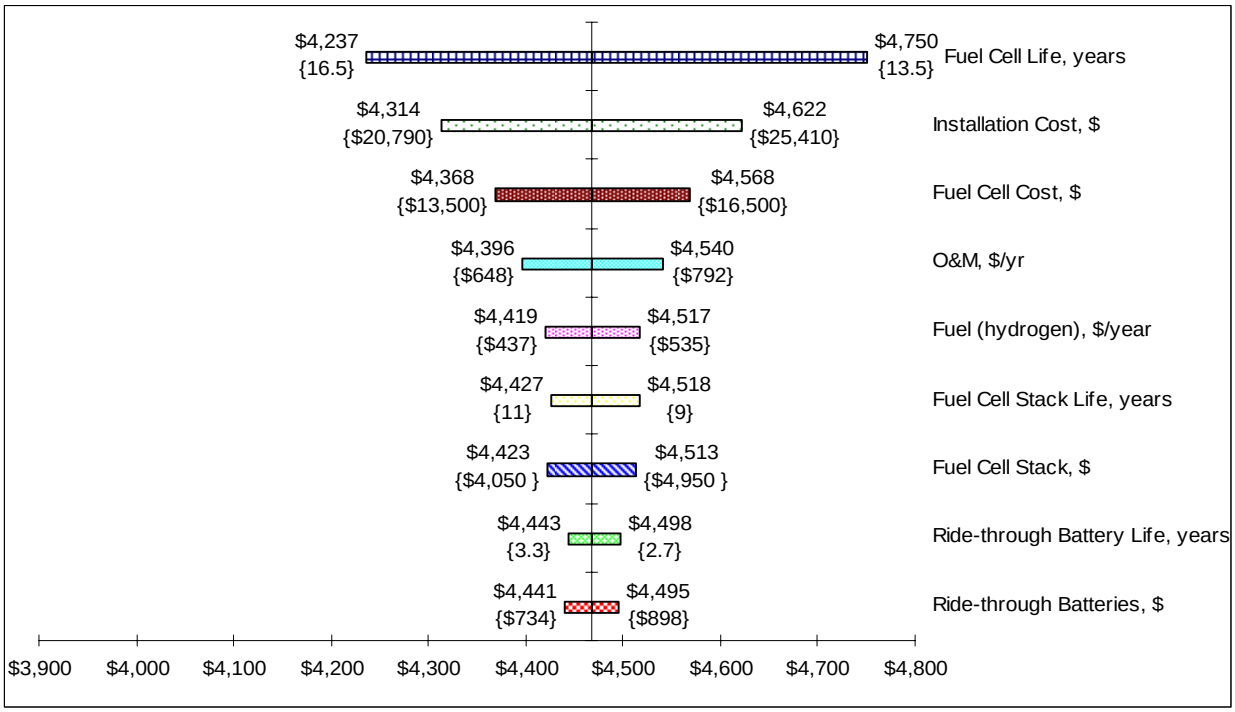

Figure 2. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 3 kW PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime.

The results of the sensitivity analysis are shown in Figure 2. For a 3 kW PEM fuel cell used in backup power applications for 72 hours of runtime, improving the fuel cell life has the largest impact on the average annual cost. Installation cost is the second largest cost driver of the cost of owning and operating a PEM fuel cell. Fuel cell cost and O&M costs are the third and fourth largest cost drivers.

Scenario 3 Sensitivity Analysis – 5 kW for 72 Hours of Backup Runtime

The assumptions for sensitivity analysis of 5 kW PEM fuel cell system for 72 hours of backup runtime are presented in Table 14.

Table 14. Cost Assumptions for 5 kW PEM Fuel Cell Backup Power for 72 Hours Sensitivity Analysis: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
O&M Cost, $	324	360	396
Ride-Through Batteries, $	918	1,020	1,122
Ride-Through Battery Life, years	2.7	3.0	3.3
Fuel (hydrogen), $/year	729	810	891
Fuel Cell Stack Cost ($)	6,750	7,500	8,250
Fuel Cell Stack Life, years	9	10	11
Fuel Cell Cost, $	14,346	15,940	17,534
Installation Cost, $	9,180	10,200	11,220
Fuel Cell Life, years	13.5	15	16.5

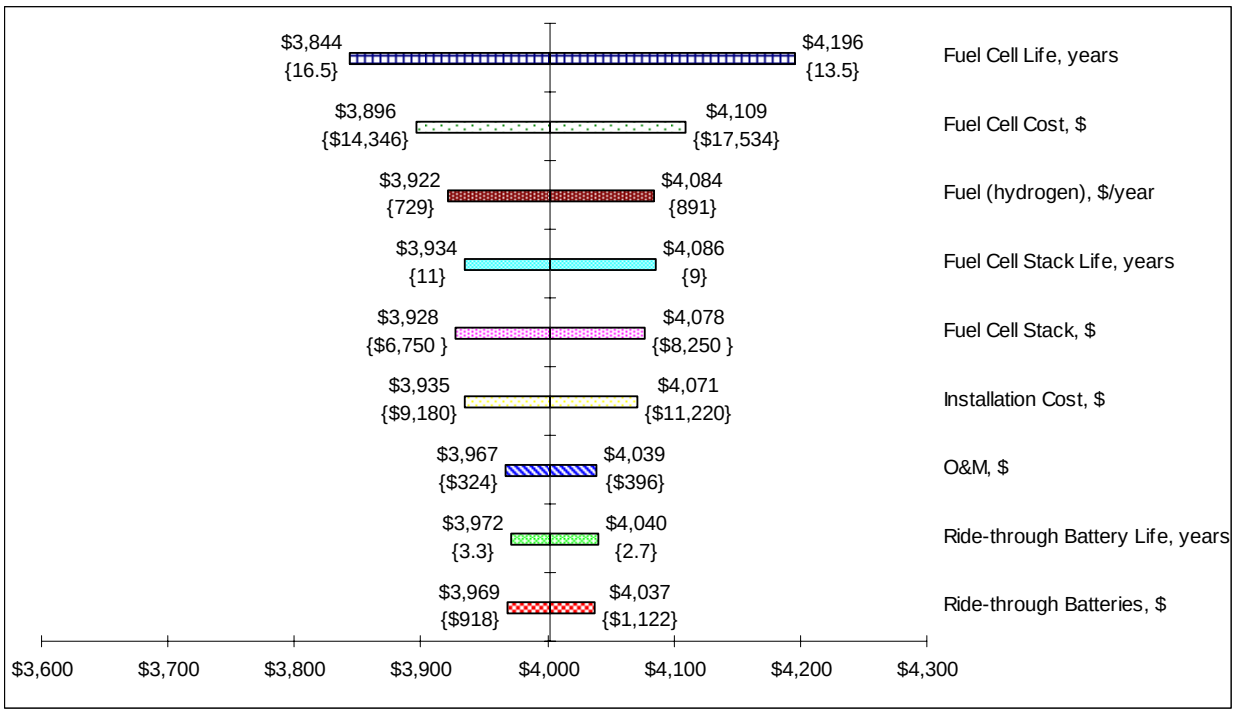

Figure 3. Sensitivity Analysis of Average Annual Cost of Owning and Operating a 5 kW PEM Fuel Cell Backup Power System for 72 Hours of Backup Runtime.

The results of the sensitivity analysis are shown in Figure 3. For a 5 kW PEM fuel cell used in backup power applications for 72 hours of runtime, improving the fuel cell life has the largest impact on the average annual cost. Fuel cell cost is the second largest cost driver of the cost of owning and operating a PEM fuel cell. Hydrogen fuel costs and installation costs are the third and fourth largest cost drivers.

7.0 VALUE PROPOSITION FOR PEM FUEL CELLS

The FAA appears to be a very promising early market for PEM fuel cells for backup power applications. The primary driver for adoption of alternative power sources by the FAA is increased reliability. The FAA's primary goal is to ensure the safety of the air traffic system. Interruptions in power cannot be tolerated and reliable backup power is a necessity. Power interruptions can lead to delays and frustrations in the tightly orchestrated commercial flight system, which can have major, negative monetary impacts. O&M costs also were mentioned by key decision makers as an influential driver in the selection of alternative energy sources for FAA systems. Given the large number of radar and communications sites and the highly structured maintenance schedule established to ensure the proper functioning of primary and backup systems, routine maintenance results in a large burden on FAA personnel.

To ensure power reliability, the FAA has recommended backup power through batteries and generators. However, general dissatisfaction with these technologies, including the extensive O&M needs, has caused engineers responsible for site maintenance to evaluate PEM fuel cells as alternatives for backup power. Various user requirements for system size, backup runtime, reliability, lower O&M costs, and ease of use fit well with commercially available PEM fuel cell systems.

PEM fuel cells offer lifecycle cost advantages over batteries for applications requiring less than 5 kW capacities for 24 hours, 48 hours, and 72 hours of backup runtime. PEM fuel cells are competitive on a total cost basis as well as offering significant savings in O&M costs as compared to batteries. In addition to significant cost savings, PEM fuel cells offer many other advantages over batteries for FAA applications. Compared to batteries, PEM fuel cells offer extended backup power, continuous runtime, stable voltage, and lower maintenance requirements. They can be monitored remotely, have longer lifetimes, and are more durable in harsh environments.

The FAA market segment offers a sizeable niche for PEM fuel cell applications in the near term. Approximately 15,000 towers exist where PEM fuel cells can potentially be used to provide backup power support. To support wide-spread adoption, a standardized order for the application of PEM fuel cells needs to be developed. To accomplish this, a formal assessment of the reliability of installed PEM fuel cells needs to be performed and a business case that supports the economics of PEM fuel cells against competing alternatives needs to be developed. While anecdotal evidence exists from the 24 installations showing that PEM fuel cells are highly reliable with no failures during outages, gathering statistically valid reliability data will go a long way in formalizing the adoption of PEM fuel cells as standard backup power technology for FAA applications. In addition to reliability and economic data, the availability of funds is a concern for the FAA. Currently, funding decisions are based on priority of a site; for widespread application, alternative sources of funding will be necessary.

Appendix F: Interim Report on the Market Opportunity Assessment of PEM Fuel Cell Applications at the Defense Logistics Agency

INTERIM REPORT
ON THE
MARKET OPPORTUNITY ASSESSMENT OF PEM FUEL CELL APPLICATIONS AT THE DEFENSE LOGISTICS AGENCY

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TABLE OF CONTENTS

1.0 INTRODUCTION 1
2.0 MARKET ATTRIBUTES 1
2.1 Market Segment Description 1
2.2 Applications and Opportunities 2
2.3 Market Trends 4
3.0 MARKET SEGMENT ANALYSIS 7
3.1 Specialty Vehicle Analysis – Operational Considerations 7
3.2 Specialty Vehicle Analysis – Economic Considerations 9
4.0 MARKET RESEARCH SUMMARY 11
5.0 LIFECYCLE COST ANALYSIS 12
5.1 Scenario 1 – Comparison of Battery-Powered Forklift to PEM Fuel Cell-Powered Forklift for Single-Shift Operations 13
5.1.1 Scenario 1 Assumptions 13
5.1.2 Scenario 1 Results 15
5.2 Scenario 2 – Comparison of Battery-Powered Forklifts to PEM Fuel Cell-Powered Forklifts for Double-Shift Operations 17
5.2.1 Scenario 2 Assumptions 17
5.2.2 Scenario 2 Results 19
5.3 Scenario 3 – Comparison of Propane-Powered Forklift to PEM Fuel Cell-Powered Forklift for Single-Shift Operations 22
5.3.1 Scenario 3 Assumptions 22
5.3.2 Scenario 3 Results 23
5.4 Scenario 4 – Comparison of Propane-Powered Forklift to PEM Fuel Cell-Powered Forklift for Double-Shift Operations 24
5.4.1 Scenario 4 Assumptions 24
5.4.2 Scenario 4 Results 25
5.5 Lifecycle Cost Analysis Summary 26
6.0 SENSITIVITY ANALYSIS 27
7.0 VALUE PROPOSITION ANALYSIS 31

List of Tables

Table 1. Forklift Classifications. 6
Table 2. Scenario 1 - Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts for Single-Shift Operations. 14
Table 3. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 1 Forklifts for Single-Shift Operations..... 15
Table 4. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 2 Forklifts for Single-Shift Operations..... 16
Table 5. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 3 Forklifts for Single-Shift Operations..... 16
Table 6. Scenario 2 – Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts for Double-Shift Operations..... 18
Table 7. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 1 Forklifts for Double-Shift Operations. 19
Table 8. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 2 Forklifts for Double-Shift Operations. 20
Table 9. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 3 Pallet Jacks for Double-Shift Operations..... 22
Table 10. Scenario 3 - Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Propane-Powered Forklifts for Single-Shift Operations..... 23
Table 11. Scenario 3 - NPV Analysis of Propane-Powered and PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklifts for Single-Shift Operations..... 24
Table 12. Scenario 4 – Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Propane-Powered Forklifts for Double-Shift Operations. 24
Table 13. Scenario 4 - NPV Analysis of a Propane-Powered and a PEM Fuel Cell Powered Sit-Down Counterbalanced Forklift for Double-Shift Operations. ... 25
Table 14. NPV of Total Costs ($) of a Battery-Powered Forklift Compared to a PEM Fuel Cell-Powered Forklift for Single-Shift Operations. 26
Table 15. NPV of Total Costs of a Propane-Powered Sit-Down Counterbalanced Forklift Compared to a PEM Fuel Cell-Powered Forklift for Single-Shift Operations. 26
Table 16. NPV of Total Costs ($) of a Battery-Powered Forklift Compared to a PEM Fuel Cell-Powered Forklift for Double-Shift Operations..... 26
Table 17. NPV of Total Costs of a Propane-Powered Sit-Down Counterbalanced Forklift Compared to a PEM Fuel Cell-Powered Forklift for Double-Shift Operations..... 27
Table 18. Sensitivity Analysis Cost Assumptions for Class 1 PEM Fuel Cell-Powered Forklift for Double-Shift Operations: Base Assumptions +/-10%. 28
Table 19. Sensitivity Analysis Cost Assumptions for Class 2 PEM Fuel Cell-Powered Forklift for Double-Shift Operations: Base Assumptions +/-10%. 29
Table 20. Sensitivity Analysis Cost Assumptions for Class 3 PEM Fuel Cell-Powered Pallet Jack for Double-Shift Operations: Base Assumptions +/-10%. 30

List of Figures

Figure 1. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 1 PEM Fuel Cell-Powered Forklift for Double-Shift Operations. 28
Figure 2. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 2 PEM Fuel Cell-Powered Forklift for Double-Shift Operations. 29
Figure 3. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 3 PEM Fuel Cell-Powered Pallet Jack for Double-Shift Operations. 30

1.0 INTRODUCTION

A complete segmentation of the federal market was performed using the benefit segmentation method. About 13 federal market segments were identified as potential adopters of direct hydrogen polymer electrolyte membrane fuel cells (hereafter referred to as PEM fuel cells) for backup power and specialty vehicle power based on their need for extended runtime, lower emissions, lower operations and maintenance (O&M) costs, and interest in alternatives to battery and internal combustion engine (ICE)-based systems. For these market segments, secondary and exploratory primary market research was conducted to identify the likely applications for PEM fuel cells, market attributes, market trends, user requirements for new technology, and economics of incumbent and PEM fuel cell systems. Selection criteria developed in collaboration with the U.S. Department of Energy (DOE) and industry were applied to these market data to identify promising near-term applications and markets. Forklift applications at the Defense Logistics Agency (DLA) were one of the seven near-term opportunities identified for PEM fuel cells. To further determine the market opportunity for PEM fuel cells at the DLA, detailed primary research was conducted to characterize the lifecycle costs of current technologies and potential alternatives. The modified hydrogen analysis (H2A) model was used to compare the lifecycle costs of PEM fuel cell-powered forklifts and the costs of battery- and propane-powered forklifts.

This report assesses the market opportunity for PEM fuel cells at the DLA. The report is organized into the following sections: Section 2 presents an overview of the DLA market segment, applications and opportunities, and market trends, based primarily on secondary research; Section 3 analyzes input from potential users gathered through six surveys and eight interviews; Section 4 summarizes key conclusions from primary and secondary market research; Section 5 presents the lifecycle cost analysis of PEM fuel cell-powered forklifts compared to battery- and propane-powered forklifts; Section 6 analyzes the sensitivity of the lifecycle costs of PEM fuel cell-powered forklifts to various factors; and Section 7 presents the value proposition for PEM fuel cells for specialty vehicle applications at the DLA.

2.0 MARKET ATTRIBUTES

2.1 Market Segment Description

The DLA is the largest combat support organization within the U.S. Department of Defense (DoD). Headquartered at Fort Belvoir in Virginia, the DLA supplies nearly all of the consumable items used by U.S. military services, including but not limited to food, clothing, medical supplies, weapons, and fuel. The DLA processes over 50,000 requisitions each day in its management of approximately 5.2 million items. In fiscal year 2006, the DLA was responsible for $35.5 billion in sales and services.[1]

The DLA's 21,000 employees are scattered among the agency's various field activities and offices, located both in the U.S. and abroad.[2] The Defense Distribution Center (DDC) is the DLA's lead center for distributing supplies, and it operates 26 distribution depots around the

[1] Defense Logistics Agency. 2007. Facts and figures about the Defense Logistics Agency. Available at http://www.dla.mil/facts.aspx [Last updated May 2007; Accessed September 27, 2007].
[2] Defense Logistics Agency. 2007. Facts and figures about the Defense Logistics Agency. Available at http://www.dla.mil/facts.aspx [Last updated May 2007; Accessed September 27, 2007].

world. These depots occupy over 325 million square feet of storage space.[3] In addition to the DDC, the DLA operates various distribution operations focused on providing supply chain solutions for aviation, land, and maritime operations.

2.2 Applications and Opportunities

This analysis examines specialty vehicle applications for PEM fuel cells within the DLA. No portable or backup power applications were identified within this agency. Grid parallel and grid independent applications were not considered. However, the DLA's use of forklifts to fulfill its logistical responsibilities represents a significant opportunity for the application of PEM fuel cells.

Current forklifts, or lift trucks, are powered by electric motors with electricity supplied by batteries or ICEs that use fossil fuels. In general, electric forklifts are typically used in indoor materials handling applications that do not require substantial lift capacities, whereas the more rugged and higher-powered ICE forklifts are often used in outdoor applications and for heavy lifting. In some instances, electric forklifts are selected primarily for worker safety in cases where ICE-powered forklifts are impractical, such as confined spaces or narrow aisles.[4] Electric forklifts are available with lift capacities up to approximately 15,000 lbs, while ICE-powered forklifts are capable of lifting 35,000 lbs or more.[5] Forklift motors range in size from 50 HP (approximately 37 kW) to over 175 HP (approximately 130 kW).

The cost of purchasing and maintaining electric and ICE-powered forklifts varies widely based on class and capacity. New, electric forklifts can cost 20% to 40% more than ICE-powered trucks of a comparable size. A 5,000 lb walk-behind electric forklift retails for $18,000 to $25,000, on average, plus $2,000 to $5,000 for one battery and charger.[6] Quotes received from Crown Equipment indicate that electric forklifts can range from approximately $8,000 for a 6,000 to 8,000 lb rider pallet truck to $75,000 for a 3,000 lb narrow-aisle stock picker.[7] Comparatively, a 5,000 lb ICE-powered forklift can range from $16,000 to $28,000. A 10,000 lb diesel ICE forklift typically ranges in price from $28,000 to $45,000.[8] Operating costs for conventional forklifts can range from $1 per hour for small electric forklifts to over $20 per hour for large diesel lift trucks.[9]

Employees at the depots and other sites operated by the DLA rely on material handling equipment, primarily forklifts, to stack, retrieve, and otherwise move items throughout the

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[3] FedBizOpps. 2007. N00164-07-R-6685 - Broad Agency Announcement (BAA): Research and Development for Hydrogen-Fueled Material Handling Equipment and Hydrogen Vehicle Fueling Station Pilot Projects. FedBizOpps/Commerce Business Daily (01/26/2007). Available at http://fedbizopps.cos.com/cgi-bin/cbdret?DOWNLOAD_CMD=DownLoadInd&START=35432&END=39085&FILE=/20070126&NAVCNT=11&MAXSCORE=910 [Accessed August 31, 2007].

[4] Antelope Valley Air Quality Management District. 2006. Chapter VII. Forklifts. Available at http://www.avaqmd.ca.gov/carlm/g_forklift.pdf [Accessed March 28, 2006].

[5] Buyerzone.com. 2007. Forklift fuel choices. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide3.html#section2 [Accessed September 28, 2007].

[6] Buyerzone.com. 2007. New and used forklift pricing. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide7.html [Accessed September 28, 2007].

[7] Personal communication between Kathya Mahadevan (Battelle) and Rich Bair (OKI Systems). April 2006.

[8] Buyerzone.com. 2007. New and used forklift pricing. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide7.html [Accessed September 28, 2007].

[9] EPRI. 2001. Increasing Profits with Electric Industrial Vehicles: A Case Study on the Alabama Power Company Electric Forklift Incentive Program. Report 1006013. Available at http://www.epri.com [Accessed September 27, 2007].

facilities. According to DLA records, in 2007 the agency was responsible for 5,340 pieces of material handling equipment, over 4,000 of which are forklifts.[10,11] Approximately half of the DLA's forklifts are electric, while the rest are powered by ICE.

The DDC's distribution depots are variously sized, and their responsibilities range widely in magnitude. Continuous (24-hour, 7-day) forklift operations are rare; most depot warehouses operate forklifts for only one or two 8-hour shifts per day.[12,13] For example, the Army's goal for its five main DDC depots in 2005 was to operate them at 85% capacity using a 40-hour work week (one shift per day, five days per week), leaving the remaining 15% available to accommodate "surges" or sudden, short-term increases in demand for supplies.[14] In general, forklift usage patterns depend on the size and characteristics of the warehouse in which they are used (i.e., the types of items stocked there), as well as the location and needs of the depot's customers.

Significant expansion in this market via the establishment of new distribution centers or large-scale additions to forklift fleets is not expected. However, the existing depots must continually replace aging vehicles. In a study conducted by the Electric Power Research Institute (EPRI), one battery manufacturer estimated median forklift service life to be 11 years and 7.5 years for electric and ICE-powered versions used in continuous operations, respectively.[15] Alternate estimates of forklift lifetimes vary widely based on use patterns and adherence to maintenance schedules, among other factors.

The impacts of forklift downtime on material handling operations vary by location. The most serious impacts include productivity loss, disrupted distribution schedules, and increased O&M costs. In order to avoid these problems, many facilities maintain backup forklifts to replace vehicles that fail or are taken out of service for maintenance or repair. At facilities with no backup vehicles, downtime could dramatically impact productivity.

Because the DLA is tasked with providing goods to military personnel all over the world in a timely fashion, equipment functionality is of primary importance to the agency. Therefore, the key requirements for forklifts used at the DLA are reliability, ease of use and maintenance, and fuel availability.

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[10] Personal communication between Kathya Mahadevan (Battelle) and representatives of the Defense Logistics Agency, July 2007.
[11] FedBizOpps. 2007. N00164-07-R-6685 - Broad Agency Announcement (BAA): Research and Development for Hydrogen-Fueled Material Handling Equipment and Hydrogen Vehicle Fueling Station Pilot Projects. FedBizOpps/Commerce Business Daily (01/26/2007). Available at http://fedbizopps.cos.com/cgi-bin/cbdret?DOWNLOAD_CMD=DownLoadInd&START=35432&END=39085&FILE=/20070126&NAVCNT=11&MAXSCORE=910 [Accessed August 31, 2007].
[12] Personal communication between Kathya Mahadevan (Battelle) and representatives of the Defense Logistics Agency, August 2007.
[13] Personal communication between Kathya Mahadevan (Battelle) and representative of LMI Government Consulting, September 2007.
[14] Department of the Army. 2005. Department of Defense Report to the Defense Base Closure and Realignment Commission: Department of the Army Analysis and Recommendations BRAC 2005, Volume III. Available at http://www.defenselink.mil/brac/pdf/VolIII_Army-o.pdf [Accessed September 28, 2007].
[15] EPRI. 2001. Increasing Profits with Electric Industrial Vehicles: A Case Study on the Alabama Power Company Electric Forklift Incentive Program. Report 1006013. Available at http://www.epri.com [Accessed September 27, 2007].

2.3 Market Trends

As indicated above, forklifts can be powered by electric motors with batteries or ICEs. ICE-powered trucks run on a variety of fuels including gasoline, diesel, liquefied petroleum gas (LPG or propane), and compressed or liquefied natural gas. Electric forklifts, which typically run on lead-acid batteries, are more expensive to purchase than comparable ICE-powered vehicles.[16] However, electric forklifts have lower lifecycle costs compared to ICE models due to lower maintenance costs, lower fuel costs, and a longer useful life.[17] The main benefit of using an ICE is the ease of refueling it. The average refueling time varies between 5 and 15 minutes.[18]

The batteries used in electric forklifts usually are capable of running for one 8-hour shift after each charge, which translates into 5 to 6 hours of constant usage. In addition to lower lifecycle cost, the primary advantages of electric forklifts are that they produce zero emissions and can be used indoors. However, a major disadvantage of the battery-powered forklift is the downtime and labor associated with battery change-out, which impact productivity and increase operational costs. In a typical operation, battery change-out takes 20 to 45 minutes. Charging the battery takes 8 hours, and an additional 8 hours of cooling time is needed before the battery can be used. Due to this time burden, multiple shift operations must generally keep extra batteries charged and available. Battery chargers are usually located in a dry, ventilated, and temperature-controlled location, because batteries release a potentially explosive combination of oxygen and hydrogen during charging.[19] Furthermore, because overcharging of the battery can often result in acid spills, it is necessary to locate battery charging operations away from other operations so that spills can be easily addressed. In locations where space is at a premium, battery charging stations can be costly.

Forklift manufacturers are heavily impacted by recent regulatory activity at the federal and state levels. In 2004, the U.S. Environmental Protection Agency (EPA) adopted nitrogen oxide (NO_x) and particulate matter (PM) emission standards for non-road diesel engines used in construction, agricultural, industrial, and airport equipment, including forklifts.[20] The standards, which require engine manufacturers to incorporate advanced emission-control technologies into their products, will be phased in from 2008 through 2015 and vary based on engine size. Engines smaller than 25 HP (19 kW) will have to comply with the standards beginning in 2008, while engines greater than 750 HP (559 kW) will not be required to meet the standards until 2011. EPA's non-road diesel rule also mandates reductions in sulfur levels in non-road diesel fuel from 3,000 ppm to 15 ppm when fully implemented. The sulfur reduction elements of the rule are designed to be phased in for most non-road diesel fuel from 2007 through 2010.[21] The California Air Resources Board (CARB) also has proposed to adopt more stringent emissions standards and test procedures for large spark-ignition engines (> 19 kW), including forklifts,

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[16] Buyerzone.com. 2007. New and used forklift pricing. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide7.html [Accessed September 27, 2007].
[17] EPRI. 2001. Increasing Profits with Electric Industrial Vehicles: A Case Study on the Alabama Power Company Electric Forklift Incentive Program. Report 1006013. Available at http://www.epri.com [Accessed September 27, 2007].
[18] Buyerzone.com. 2007. Forklift fuel choices. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide3.html#section2 [Accessed September 28, 2007].
[19] Buyerzone.com. 2007. Forklift fuel choices. Available at http://www.buyerzone.com/industrial/forklifts/buyers_guide3.html#section2 [Accessed September 28, 2007].
[20] U.S. Environmental Protection Agency. 2004. Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule. Federal Register 69 (124): 38958-39273.
[21] U.S. Environmental Protection Agency. 2004. Clean Air Nonroad Diesel Rule. EPA420-F-04-032. Available at http://www.epa.gov/nonroad-diesel/2004fr/420f04032.htm#description [Accessed September 28, 2007].

sweepers/scrubbers, industrial tow tractors, and ground support equipment.[22] CARB proposes the adoption of EPA's 2007 model-year emission standard and a more stringent 2010 model-year emissions standard. CARB has also proposed stricter emission standards for fleets in use that would require them to reduce their emissions by retrofitting or replacing engines or equipment with cleaner models by 2009. Three of the DDC's distribution depots, including one of the largest in the nation, are located in California. However, both the federal government and State of California allow government agencies responsible for national defense to request a "national security exemption" from pollution control requirements for equipment and vehicles.[23,24]

Although military users are not necessarily required to comply with non-road vehicle emission regulations, the DoD appears committed to doing so whenever possible. In 2006, the Department of the Navy updated a list of tactical vehicles and equipment maintained by the DoD in California that are exempt from emissions requirements. This list included a number of ICE-powered forklifts, but in an attached letter to CARB, a Navy representative affirmed DoD's commitment to procuring equipment that complies with the new standards whenever feasible and specifically noted the Department's pursuit of "advanced vehicles powered by hydrogen fuel cells."[25]

PEM fuel cell-powered electric forklifts have emerged as promising alternatives to battery- and ICE-powered forklifts. PEM fuel cell forklifts require minimal time for refueling and significantly less maintenance than battery-powered forklifts. In addition, the fuel cell system ensures constant power delivery and performance, eliminating the reduction in voltage output that occurs as batteries discharge. These and other features make fuel cell-powered forklifts a potentially better value than batteries to power electric vehicles in multi-shift operations. Fuel cell-powered forklifts also have advantages over ICE-powered forklifts, including zero emissions, quiet operation, and longer runtimes between refueling. A study exploring the economics of converting an entire warehouse from batteries to fuel cells indicates that sites with high labor rates and multiple shifts are good initial targets of the technology.[26]

The PEM fuel cell power packs currently sold as battery replacements in electric forklifts require higher capital investment than the conventional technology. A PEM fuel cell replacement for batteries in Class 1 electric forklifts (see Table 1 for forklift class descriptions) retails for $30,000 to $40,000, compared to $4,000 to $7,000 for the battery system. A PEM fuel cell replacement for batteries in a Class 2 fuel cell forklift retails for $27,000 to $34,000 compared to $4,000 to $6,000. A PEM fuel cell replacement for batteries in a Class 3 fuel cell forklift ranges from $15,000 to $20,000 compared to $1,800 to $3,000.

The expected lifespan of a PEM fuel cell is between 10,000 and 20,000 operating hours, with maintenance performed every 1,000 hours of operation at a cost of approximately $200 to

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[22] California Air Resources Board. 2006. Staff Report: New Emissions Standards, Fleet Requirements, and Test Procedures for Forklifts, and Other Industrial Equipment. Available at http://www.arb.ca.gov/regact/lore2006/isor.pdf [Accessed September 27, 2007].
[23] U.S. Environmental Protection Agency. 1996. Title 40 Code of Federal Regulations. 40 CFR § 90.903 Exclusions, application of section 216 (10) and (11) of the Act.
[24] California Air Resources Board. 1996. Title 13 Code of California Regulations. 13 CCR § 2420 Applicability.
[25] Trevino, R. 2006. Letter from Rene Trevino, Office of the Commander, Navy Region Southwest, to California Air Resources Board. Available online at http://www.arb.ca.gov/regact/2007/ordiesl07/tsdappf.pdf [Accessed September 28, 2007].
[26] Medwin, S. 2005. Application of fuel cells to fork lift trucks. Industrial Utility Vehicle & Mobile Equipment 7(5). Available at http://www.cellexpower.com/Downloads/pdf/Raymond%20Bulletin.pdf [Accessed September 27, 2007].

$400.[27] The cost of replacing a PEM fuel cell stack is estimated to be approximately $1,500 per kW.[28]

Table 1. Forklift Classifications.

Class	Power Source	Tires	Type	Typical Lift Capacity Range
1	Electric	Cushion or pneumatic	Sit-down or stand-up rider	3,000 to 6,000 lbs
2	Electric	Solid	Narrow-aisle or order pickers	3,000 to 5,000 lbs
3	Electric	Solid	Walk-behind or stand-up rider	4,000 to 8,000 lbs
4	ICE	Cushion	Sit-down rider (suited for indoor use)	3,000 to 15,000 lbs
5	ICE	Pneumatic	Sit-down rider (suited for outdoor use)	3,000 to 17,000 lbs

The DLA supports development and commercialization initiatives related to the use of hydrogen fuels in forklifts. The agency has expressed interest in being an early adopter and principal demonstrator of fuel cell forklifts and creating momentum in the fuel cell market.[29] In support of these goals, the DLA has embarked on a pilot program to demonstrate hydrogen fuel cell-powered forklifts at several DDC depots. Congressional earmarks are being used to fund this program.

Thus far, the DLA has issued a contract for only one of the planned forklift demonstrations. In 2007 Air Products & Chemicals, Inc., in collaboration with General Hydrogen, was awarded a $5.6 million contract to supply the Defense Depot Susquehanna, PA (DDSP) in New Cumberland, Pennsylvania, with at least 20 hydrogen-powered forklifts. Work under this contract is expected to be complete in 2010.[30,31] The direct hydrogen fuel cell systems being demonstrated at the DDSP – battery retrofits capable of providing 4 to 12 kW of electricity – cost between $38,000 and $40,000. However, these expenses include unforeseen re-engineering costs associated with the modification of forklifts to fit DLA size requirements (i.e., DLA uses particularly narrow forklifts). The typical price of an electric forklift used by the DLA is $30,000. The DLA plans to demonstrate 20 additional fuel cell-powered forklifts at this site through a separate, as-yet-unconfirmed contract with East Penn Manufacturing Company and Nuvera.[32] A key aspect of this demonstration is the establishment of viable onsite storage and dispensing systems for the hydrogen used in the fuel cells.[33]

[27] Personal communication between Kathya Mahadevan (Battelle) and representatives of several fuel cell manufacturers, September 2007.
[28] Personal communication between Kathya Mahadevan (Battelle) and industry representatives. September 2006.
[29] Christensen, J. 2007. Hydrogen & Fuel Cell Activity. Presented at U.S. Fuel Cell Council – Matching Federal Government Needs, Washington, DC, April 26.
[30] FuelCellWorks. 2007. Air Products awarded $5.6 million U.S. Navy R&D contract for hydrogen fork lifts. Available at http://www.fuelcellsworks.com/Supppage7690.html [Accessed September 28, 2007].
[31] FedBizOpps. 2007. N00164-07-R-6685 - Broad Agency Announcement (BAA): Research and Development for Hydrogen-Fueled Material Handling Equipment and Hydrogen Vehicle Fueling Station Pilot Projects. FedBizOpps/Commerce Business Daily (01/26/2007). Available at http://fedbizopps.cos.com/cgi-bin/cbdret?DOWNLOAD_CMD=DownLoadInd&START=35432&END=39085&FILE=/20070126&NAVCNT=11&MAXSCORE=910 [Accessed August 31, 2007].
[32] Personal communication between Kathya Mahadevan (Battelle) and representative of LMI Government Consulting, September 2007.
[33] Christensen, J. 2007. Hydrogen & Fuel Cell Activity. Presented at U.S. Fuel Cell Council – Matching Federal Government Needs, Washington, DC, April 26.

Additional forklift demonstrations are being planned for three other DoD facilities. A recent DLA solicitation aims to retrofit or replace the existing fleet of 19 electric forklifts at Fort Lewis, Washington, the only major Army installation on the West Coast. Up to $4 million in funding is available for this effort.[34] Subsequent demonstrations are planned for the Defense Depot Norfolk, VA (DDNV) and the Defense Depot San Joaquin, CA (DDJC) in Tracy, California. At DDNV the DLA will work with Concurrent Technologies Corporation (CTC) and Hydrogenics to replace forklift batteries with fuel cells, using reformed natural gas as the fuel. A mobile refueler will be used at DDNV to refuel forklifts scattered throughout the base. At DDJC the DLA expects to replace 20 propane forklifts with Hydrogenics fuel cell-powered Hyster vehicles. Hydrogen at the DDJC will be generated using electrolysis, at a cost of $1.4 to $1.5 million for the electrolysis unit. The fuel cell forklifts to be used at DDJC are expected to cost approximately $80,000 each.[35]

3.0 MARKET SEGMENT ANALYSIS

A convenience sample of individuals and groups associated with the procurement, management, or use of forklifts at DoD distribution facilities was contacted for this exploratory research and analysis, resulting in two DLA-specific interviews and six completed surveys. The job descriptions of those surveyed and interviewed included: installation manager, environmental specialist, equipment specialist, transportation manager, and facilities service personnel. Seven of the eight interviewees/survey respondents worked at distribution depots, five of which were managed by DLA and two by other branches of the DoD. In addition to the two interviews that focused on DLA applications, six other individuals (i.e., industry experts and R&D professionals who were not being interviewed specifically about the DLA or forklifts) commented on the likelihood of fuel cell integration into forklifts when asked about the general prospects for fuel cell use within the DoD during the course of their interviews. Key insights gleaned from these contributions are summarized below.

3.1 Specialty Vehicle Analysis – Operational Considerations

Most of the distribution center representatives that provided input operate electric, propane, and diesel forklifts; just one facility reported using gasoline-powered forklifts. Fleet sizes ranged from 30 to 466 forklifts; across all survey respondents, the average fleet size was 200. Several respondents noted that the DLA fleet size is unlikely to increase; however, a portion of the forklift fleet needs to be replaced annually. At one distribution center, 20 to 30 forklifts are replaced each year.

Only one respondent (a major distribution center) runs three 8-hour shifts per day at one warehouse, and another reported the ability to run forklifts six days per week; the remainder use forklifts from 8 hours to 16 hours per day, 5 days per week. Four respondents reported using forklifts for less than 10 hours each day.

[34] Crane NAVSEA Warfare Centers Acquisition Division. 2007. N00164-07-R-6982 - Broad Agency Announcement (BAA) Research and Development for Hydrogen-Fueled Material Handling Equipment and Hydrogen Vehicle Fueling Station Pilot Projects. Available online at http://www.crane.navy.mil/acquisition/07r6982/07r6982.htm [Accessed August 31, 2007].
[35] Personal communication between Kathya Mahadevan (Battelle) and representative of LMI Government Consulting, September 2007.

Minimal safety concerns were noted for battery and ICE-powered forklifts. Four out of six survey respondents had no safety concerns. One respondent noted the possibility of acid spills with respect to batteries, and another expressed concern over carbon monoxide concentrations in the warehouse when diesel forklifts are used in winter.

Respondents generally reported following the manufacturers' recommended maintenance schedules. Daily inspections of both electric and ICE-powered vehicles were common, with preventive maintenance performed quarterly and semi-annually.

No one type of forklift (battery, propane, or diesel) was judged to perform significantly better than any other by the respondents. With regard to specific performance characteristics, batteries tended to outrank diesel and propane models in the emissions and start-up time categories, but battery systems did not fare as well in operating and capital costs or ease of use. Diesel forklifts ranked lower than other models in emissions and start-up time in multiple surveys. When asked which performance characteristics are most important in selecting a specialty vehicle, reliability (5 out of 6), capital and/or O&M costs (5 out of 6), and ease of use (3 out of 6) were cited most often by the six survey respondents. Other considerations cited as most important by at least one respondent included lifetime, emissions, durability, and availability of parts.

Forklift downtime was considered disruptive to varying degrees. In two cases, downtime was viewed as having minimal impact due to the availability of backup forklifts. No one considered brief (less than ½ hour) service interruptions to be highly disruptive, though disruptions greater than ½ hour in length were considered moderately to highly disruptive by multiple respondents. Two respondents considered disruptions of any length to be moderately disruptive. The major impact associated with downtime was a loss of productivity, cited by 4 of the 6 survey respondents.

Five of the six survey respondents indicated that they were unfamiliar with the use of PEM fuel cells in forklifts. Four of six had no concerns with using hydrogen as a fuel; one cited fuel availability as a concern, and the sixth noted that the use of hydrogen would have to comply with all safety restrictions at the installation. Five of the six respondents had not considered alternatives to existing equipment, while one had considered replacing ICE forklifts with electric ones.

Survey respondents indicated that distribution depots are not responsible for making procurement decisions about their equipment – such decisions are passed down from organization headquarters. Capital costs and lifecycle costs of alternative technologies are considered when making capital purchase decisions. For example, DLA headquarters maintains an equipment management system that automatically generates a list of equipment requiring replacement each year based on utilization rates, maintenance costs, and age. This list is shared with the transportation managers of the individual distribution depots, and replacement needs are further prioritized. Then, based on budgetary considerations and other priorities, personnel at headquarters determine how funding for new equipment will be allocated. According to one estimate, 25% of yearly requirements are funded.[36]

[36] Personal communication between Kathya Mahadevan (Battelle) and representative of the Defense Logistics Agency, August 2007.

In addition to the surveys, information was gleaned from eight interviews with industry experts and individuals or groups involved in R&D regarding the potential for PEM fuel cell use in forklifts within the DoD. Three interviewees suggested that forklifts are a highly promising near-term market due to the non-tactical nature of DLA, the availability of existing fuel cell products for this application, and the funding available to DLA for fuel cell pilot projects. Several interviewees stressed that fuel cell forklifts need to perform as well as, or better than, existing forklift technologies in order to be viable within the DLA. Two interviewees noted that using fuel cells in forklifts makes the most sense economically when operations are continuous (i.e., 24/7) and/or when the labor rates of individuals responsible for battery charging and replacement are high, since these activities can be time-consuming. One interviewee indicated that the business case for using fuel cells at the DLA has yet to be developed. This analysis will likely take at least 2 to 3 years, as demonstrations are scheduled to begin in June 2008. The use of fuel cell forklifts needs to be justifiable to the end user because the DLA competes with commercial warehousing operations. The individual suggested that Congressional earmarks and available sources of funding should be helpful in building the infrastructure needed to support hydrogen use within the DLA.

3.2 Specialty Vehicle Analysis – Economic Considerations

Three DLA facility representatives – a subset of the original six survey respondents – completed an in-depth survey designed to assess their perspectives on the economics of current systems and specific O&M requirements. These individuals were responsible for managing environmental issues, transportation, and general installation operations at their facilities, all of which are DDC distribution depots. Two of the facilities were small (<500 employees), while the third employed between 500 and 3,000 people.

A wide variety of forklift vehicles are used at the respondents' facilities. All respondents reported having electric and propane-powered forklifts, two out of three reported having diesel units, and one facility had a small number (10 combined) of natural gas and gasoline forklifts. All facilities reported using Yale electric and/or propane forklifts, while two purchased Hyster models of all types. Other brands used by at least one of the three respondents included Raymond, Clark, Crown, Caterpillar, Wiggins, Nissan, Toyota, Drexel, Big Joe, and Powerlift. None of the respondents were able to report the power output (in kW or HP) of their forklift engines.

The typical usage patterns of individual electric forklifts at the respondents' facilities ranged from <1 hour to over 16 hours per day. Among the two respondents who used diesel forklifts, one reported using them for <2 hours per day, while the other reported their use on an "as needed" basis. Gasoline and natural gas forklifts were each reportedly used for <3 hours per day. Propane forklifts were estimated to be used from <1 hour to over 16 hours per day. All facilities reported having more forklifts than needed.

The number of forklifts used by the respondents varied, as follows: the largest facility reported having 293 propane, 168 electric, 21 diesel, 8 gasoline, and 2 natural gas forklifts (for a total of 492 units); the other two facilities reported having approximately 214 forklifts between them

(one specified 81 propane and 33 electric units, while the other did not break out its 100 units by equipment type).

Two respondents reported the capital costs of their forklift equipment. The one facility that reported the unit costs of its diesel forklifts spent $10,800 (4,000 lb capacity) to $95,000 (23,000 lb capacity) for these vehicles; the same facility spent $13,900 to $20,200 for gasoline forklifts (4,000 lb to 6,000 lb capacities) and $21,400 to $33,500 for natural gas-powered units (6,000 lb to 10,000 lb capacities). Like diesel units, the cost of propane forklifts ranged widely, from $12,000 (4,000 lb capacity) to $88,000 (for 4,000 to 6,000 lb capacity, side-loading forklifts), though forklifts without the side-loading functionality cost up to $52,000 (15,000 lb capacity). One site reported the cost of all its electric material handling equipment, including wire-guided cranes that ranged from $85,000 to $153,000; however, the electric forklifts used at the two sites that reported cost information ranged in price from $1,800 (for motorized pallet jacks with 4,000 lb capacities) to $64,000 (for a 4,000 lb rider vehicle).

All three respondents provided information on the estimated lifespan of their forklifts. These estimates ranged from 8 years to 20 years for ICE-powered units and from 15 to 17 years for electric units. Responses were inconsistent as to whether electric or ICE forklifts had a longer lifespan – one site representative reported that ICE-powered units last 3 to 5 years longer than electric units; another reported that electric forklifts outlast ICE forklifts by 5 to 7 years, and the third indicated that both types last 15 years on average.

The respondents answered various questions about electric forklift maintenance and operational considerations. One respondent indicated that batteries are changed out twice during an 8-hour shift, while the other two respondents noted that batteries are not changed out during a shift. Instead, forklifts are taken to a charger station at the end of the shift for charging. At one facility, backup forklifts are available to replace vehicles that need to be charged. One respondent indicated that the process of changing out a battery takes 20 minutes. Two respondents addressed the potential for change-outs to affect productivity – both noted that extra vehicles are maintained onsite so that productivity is not impacted. All three respondents noted that if change-outs are required, maintenance personnel perform the work. The labor rates for maintenance personnel were reported to range from $16.00 to $40.00 per hour.

Daily battery maintenance was estimated by the three respondents to take 5 to 20 minutes. Quarterly battery maintenance was estimated to take 2 to 4 hours at one site and 4 to 10 hours at another; the third site reported performing semi-annual maintenance (40-minute duration) only. Battery life was estimated by two respondents to range from 3 years to 7 years. Reported battery disposal costs varied among the three respondents: one was unsure about such costs but noted that all batteries are treated as hazardous waste; another noted that disposal of lead-acid batteries is free, while Ni-Cd battery disposal is associated with a weight-based fee; the third indicated that forklift batteries cost $0.29/lb for disposal but that automotive batteries are recycled for free. Finally, all three respondents acknowledged that space at their facilities had to be dedicated to battery change-outs, though two were unsure of the exact size of the area. At the largest of the surveyed facilities, battery change-out areas occupy 2,670 square feet at one warehouse and 1,400 square feet at another.

The respondents addressed similar maintenance and operational questions regarding ICE-powered forklifts. The amount of time required to fuel ICE forklifts ranged from 3 to 5 minutes at one facility to 10 minutes at the other two. Two facilities reported refueling all ICE-powered forklifts once per shift, while the third noted that propane forklifts are filled daily but diesel forklifts are fueled approximately once every three days. Maintenance personnel were responsible for refueling activities at two of the surveyed sites; the forklift operator was responsible at the third.

Two of the three respondents reported maintaining fuel dispensing stations onsite, while the third (which only used propane ICEs) noted that propane tanks are brought into the facility for use in forklifts. Fuel costs were not specified by any respondents. Daily ICE forklift maintenance was estimated to take from 5 to 10 minutes per unit. Quarterly maintenance was estimated to take from 4 to 10 hours per vehicle. Quarterly battery maintenance was estimated to take 2 to 4 hours at one site and 4 to 10 hours at another. Specific engine maintenance costs (other than labor) were reported by only one respondent: $44,597 per month for the entire fleet (or $91 per unit). Two of the three respondents reported that extra ICE vehicles are maintained to ensure continued operation in case of downtime; however, neither respondent indicated how many backup vehicles are maintained.

Estimates varied among the respondents as to the impacts of forklift downtime: one site reported minimal instances of downtime and associated impacts; another reported approximately 25 incidents in the prior year, with impacts varying based on the cause of the downtime; the third reported 2,773 incidents of downtime in the past year at an average duration of 4 hours per incident.

The labor rate of forklift operators was reported to range from $17 to $60 per hour. All three respondents noted that personnel must be trained to use specialty vehicles, and two provided specific cost estimates for this training. One respondent estimated training to cost $368/person, and the other noted that OSHA certification costs $75/person the first year and $30 to $35 for refresher courses every three years thereafter.

4.0 MARKET RESEARCH SUMMARY

A number of important observations emerged from user surveys, interviews, and secondary research regarding potential applications for PEM fuel cells at the DLA, specialty vehicle requirements and usage patterns, user satisfaction with current specialty vehicle power systems, and user perceptions of PEM fuel cells. Key findings include:

- One near-term application for PEM fuel cells was identified in the DLA market segment – PEM fuel cell-powered forklifts used at 26 distribution depots operated by DDC and other distribution centers. The depots supply food, clothing, weapons, and other resources to military personnel worldwide. Most depots operate forklifts daily for one or two 8-hour shifts, five days per week, although they are required to maintain the capacity to support short-term surges in supply needs that would dictate extended work schedules.
- The DLA has over 4,000 forklifts in its inventory. Batteries and ICEs fueled by propane or diesel fuel are most commonly used to power the forklifts. Battery-powered forklifts tend to have higher capital costs but lower lifecycle costs than ICE-powered units, while

ICE forklifts are easier to refuel. Concerns exist over the toxic emissions produced by diesel ICEs.

- The impact of downtime on DLA fleets varies depending on whether backup vehicles are available at the depot. Some distribution centers maintain fleets of backup vehicles, since it is critical to the lives and well-being of military personnel to keep supplies moving.
- There is little potential for significant growth in the DLA market, although aging forklifts are replaced.
- Users at distribution depots are not responsible for making capital purchase decisions; this responsibility falls to DLA Headquarters. The DLA makes such decisions based on depot needs, the age of existing equipment, and budgetary considerations.
- Reliability, capital and O&M costs, and ease of use are considered the most critical factors in selecting a forklift.
- Awareness of PEM fuel cells for use in forklifts is high at DLA Headquarters but generally low among the users who work at distribution depots. DLA has expressed interest in being an early adopter of fuel cell technologies and is using Congressional earmarks to fund a fuel cell forklift pilot program at several depots.
- Most surveyed users had no concerns about using hydrogen as a fuel, although fuel availability and compliance with installation requirements were cited as concerns by a few individuals.
- Advantages of fuel cell forklifts compared to electric forklifts include reduced refueling time, significantly less maintenance, and more consistent power delivery and performance. Compared to ICE forklifts, fuel cell units have zero emissions, quiet operation, and longer runtimes between refueling.

5.0 LIFECYCLE COST ANALYSIS

Users appear reasonably satisfied with current technologies but have concerns with O&M of battery and ICE-powered forklifts. While users are not actively looking for alternatives, there is interest among the decision-makers to test and adopt alternatives that offer improved performance and lower O&M costs. To determine if PEM fuel cells offer a cost advantage to this market segment, the lifecycle costs of PEM fuel cell-powered forklifts were compared to battery-powered forklifts and propane-powered forklifts in four different scenarios over a 15-year period. In Scenario 1, the discounted net present value (NPV) of battery-powered forklifts against PEM fuel cell-powered forklifts are examined for Class 1, Class 2, and Class 3 battery-powered forklifts operating in single-shift operations. Scenario 2 is the same, except that double-shift operations are assumed. In Scenario 3 and Scenario 4, the discounted NPV of a propane-powered sit-down counterbalanced forklift is compared to a sit-down counterbalanced PEM fuel cell-powered forklift for single-shift and double-shift operations, respectively. For all four scenarios, a discount rate of 8% and an inflation rate of 2.3% are applied. No disposal costs for the technologies are assumed.

5.1 Scenario 1 – Comparison of Battery-Powered Forklift to PEM Fuel Cell-Powered Forklift for Single-Shift Operations

5.1.1 Scenario 1 Assumptions

Scenario 1 compares the cost of using batteries versus PEM fuel cells to power a Class 1, Class 2, and Class 3 forklift in a standard one-shift operation. This scenario assumes that the warehouse operates only 8 hours per day and 5 days a week for a total of 2,080 hours per year. Batteries are not changed out at the end of a shift; instead, they are charged on the truck at the end of a shift. No extra batteries per truck are maintained. In this scenario, in case of unanticipated downtime, it is assumed that the user will switch to another forklift that is charged and ready. Assumptions for scenario 1 are shown in Table 2. The costs of operating a battery-powered forklift assuming a 3-year and 5-year battery lifetimes are examined. The cost of batteries varies by forklift class; the cost of a battery for a sit-down counterbalanced truck is $6,000, for a narrow-aisle forklift is $4,500, and for a pallet truck is $1,800. Similarly, the size of the PEM fuel cell stack varies in the three classes of trucks: the sit-down counterbalanced truck uses an 8 kW stack; the narrow-aisle forklift uses a 5 kW stack, and the pallet truck uses a 3 kW stack. The lifetime of the PEM fuel cell is assumed to be 10,000 hours. In this scenario, the stack is changed out every 5 years. It is assumed that the cost of stack change-outs is $1,500 per kW. The hydrogen in this scenario is assumed to be supplied as liquid hydrogen and compressed and stored onsite. The current capacity of hydrogen at the site is approximately 30 kg and the cost is approximately $17.50 per kg. No residual value for the technologies is assumed.

Table 2. Scenario 1 - Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts for Single-Shift Operations.

	Battery-Powered Sit-Down Counterbalanced Forklift (Class 1)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1)	Battery-Powered Narrow-Aisle Forklift (Class 2)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2)	Battery-Powered Pallet Jack (Class 3)	PEM Fuel Cell-Powered Pallet Jack (Class 3)
Number of Shifts per Day	1	1	1	1	1	1
Hours of Operation per Day	8	8	8	8	8	8
Number of Shifts per Week	5	5	5	5	5	5
Number of Days of Operation per Year	260	260	260	260	260	260
Hours of Operation (hrs/yr)	2,080	2,080	2,080	2,080	2,080	2,080
Forklift Cost ($)	38,500[1]	38,500[1]	21,500[2]	21,500[2]	$11,000[3]	11,000[3]
Size of PEM Fuel Cell (kW)	-	8	-	5	-	3
Battery/PEM Fuel Cell Cost ($)	6,000[4]	35,000[4]	4,500[4]	30,500[4]	1,800[4]	15,000[4]
Battery/PEM Fuel Cell Lifetime	3 and 5 years	5 years	3 and 5 years	5 years	3 and 5 years	5 years
Forklift Lifetime	15	15	15	15	15	15
Cost of Accessories ($) Battery Charger/ Cranes/Hoists/Washers	2,460	-	2,160	-	1,960	-
Routine Maintenance Costs ($/yr)	1,539[5]	240[6]	1,539[5]	240[6]	1,539[5]	240[6]
Recharging/Fuel Costs ($/yr)	1,316[7]	7,483[8]	1,316[7]	7,483[8]	1,316[7]	3,640[9]
Time for Recharging/Refueling (min)	NA	3 minutes[4]	NA	3 minutes[4]	NA	1 minute[4]
Cost for Recharging/ Refueling ($)	None	130[10]	None	130[10]	None	87[11]
Replacement Costs ($)	6,000	12,000[12]	4,500	7,500[12]	1,800	4,500[12]

[1] Prices of electric sit-down counterbalanced forklift vary by lift capacity. For forklifts with lift capacities between 3,000 lbs to 12,000 lbs prices can vary from $17,000 to $60,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[2] Prices of narrow-aisle reach truck vary by lift capacity. For forklifts with lift capacities between 3,000 – 4,500 lbs price varies from $18,000 to 25,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[3] Prices of pallet trucks vary by lift capacity. For pallet trucks with lift capacities between 3,000 – 8,000 lbs price varies from $7,000 to 15,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[4] Industry communication. September 2006.
[5] Routine maintenance for the battery powered forklift 10 minutes per shift which is about 43.3 hours per year per truck. Maintenance includes checking battery terminals and water. On a quarterly basis, 2 hours are spent on battery maintenance. Total time spent on maintenance is about 51.3 hours per year. The average cost for battery maintenance person is dependent on wage grade and can range from $20 to $40. For the purposes of this analysis the cost of a maintenance person was considered to be $30. Data obtained from Battelle market research surveys. September 2007.
[6] Routine maintenance on the PEM fuel cell is conducted during the quarterly schedule specified by the OEM for the electric forklift. Maintenance is about 2 hours every quarter. Cost of maintenance person is assumed to be $30. Industry communication. September 2007.
[7] Cost is for charging the battery is assumed to be $5.06 per shift. Industry communication. September 2007.
[8] Assumes a tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Assumes that 425.5 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $17.50 per kg. Industry communication, September 2006 and September 2007.
[9] Assume a tank size of 0.8 kg. Runtime from a single tank is approximately 8 hours. Assumes that 208 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $17.50 per kg. Industry communication, September 2006 and September 2007.
[10] Fuel cell takes 3 minute to refuel. The fuel cell is refueled once every 3 days. The forklift is refueled by the forklift operator and forklift operator cost is assumed to be $20 per hour. Industry communication, September 2006 and September 2007.
[11] Fuel cell takes 1 minute to refuel. The fuel cell is refueled once every shift. The forklift is refueled by the forklift operator and forklift operator cost is assumed to be $20 per hour. The forklift is refueled by the operator and operator cost is assumed to be $20 per hour. Industry communication, September 2006 and September 2007.
[12] Cost of stack is assumed to be $1,500 per kW. Industry communication. September 2006.

5.1.2 Scenario 1 Results

Class 1 Results

For a Class 1 forklift in scenario 1, battery-powered sit-down counterbalanced forklifts are significantly more competitive than PEM fuel cell-powered forklifts from a capital cost and total cost perspective for single-shift operations (Table 3).

From a total cost perspective, the NPV of the total costs of a PEM fuel cell forklift is approximately 85% higher than the NPV of the total costs of a battery-powered forklift with a 3-year battery replacement schedule. With a 5-year battery replacement schedule, the NPV of the total costs of a PEM fuel cell-powered forklift is approximately 103% more than the battery-powered alternative.

Table 3. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell-Powered Class 1 Forklifts for Single-Shift Operations.

	Battery-Powered Sit-Down Counterbalanced Forklift (Class 1) (3-Year Battery Lifetime)	**Battery-Powered Sit-Down Counterbalanced Forklift (Class 1) (5-Year Battery Lifetime)**	**PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1)**
NPV of Total Capital Costs ($)	61,247	53,319	86,850
NPV of Total O&M Costs ($)	29,177	29,177	80,254
NPV of Total Costs of the System ($)	90,424	82,496	167,105

In this scenario, for single-shift operations, the NPV of total O&M costs for a battery-powered sit-down counterbalanced forklift is approximately 64% less than the NPV of total O&M costs of the PEM-fuel cell powered forklift. This is driven by the higher annual costs of hydrogen fuel as compared to battery recharging costs.

The NPV of the capital cost of the PEM fuel cell-powered forklift is approximately 42% greater than the NPV of the total capital cost of the battery-powered forklift under a 3-year battery replacement schedule. With a 5-year battery replacement schedule, the NPV of total capital costs of the PEM fuel cell-powered forklift is 63% greater than the battery-powered sit-down counterbalanced truck.

Class 2 Results

In single-shift operations, the Class 2 battery-powered narrow-aisle forklift is more competitive than the PEM fuel cell-powered electric forklift on a lifecycle cost basis (Table 4).

The NPV of the total cost of the battery-powered narrow-aisle forklift is 51% and 56% less than the NPV of the PEM fuel cell-powered narrow-aisle forklift with a 3-year and 5-year battery replacement cycle, respectively.

Table 4. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 2 Forklifts for Single-Shift Operations.

	Battery-Powered Narrow-Aisle Forklift (Class 2) (3-Year Battery Lifetime)	Battery-Powered Narrow-Aisle Forklift (Class 2) (5-Year Battery Lifetime)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2)
NPV of Total Capital Costs ($)	39,094	33,148	60,156
NPV of Total O&M Costs ($)	29,177	29,177	80,254
NPV of Total Costs of the System ($)	68,271	62,325	140,410

In this scenario, for single-shift operations, the NPV of total O&M costs for a battery-powered sit-down counterbalanced forklift is approximately 64% less than the NPV of total O&M costs of the PEM-fuel cell powered forklift. This is driven by the higher annual costs of hydrogen fuel as compared to battery recharging costs.

The NPV of the total capital costs of the PEM fuel cell-powered forklift is 54% greater than the NPV of the total capital costs of the battery-powered alternative with a 3-year battery replacement schedule (Table 4). The NPV of the total capital costs of the PEM fuel cell-powered forklift is 81% greater than the NPV of the total capital costs of the battery-powered forklift with a 5-year battery replacement schedule. The higher capital costs of the PEM fuel cell over its lifetime are driven by the higher costs of the PEM fuel cell battery replacement system and the PEM fuel cell stack as compared to batteries.

Class 3 Results

In single-shift operations, the Class 3 battery-powered pallet jack is more competitive than the PEM fuel cell-powered pallet jack on a lifecycle cost basis (Table 5).

On a total cost basis, the NPV of a PEM fuel cell-powered pallet jack is 49% and 56% greater than the NPV of a battery-powered pallet jack, based on a 3-year and a 5-year battery replacement schedule, respectively.

Table 5. Scenario 1 - NPV Analysis of Battery-Powered and PEM Fuel Cell-Powered Class 3 Forklifts for Single-Shift Operations.

	Battery-Powered Pallet Jack (Class 3) (3-Year Battery Lifetime)	Battery-Powered Pallet Jack (Class 3) (5-Year Battery Lifetime)	PEM Fuel Cell-Powered Pallet Jack (Class 3)
NPV of Total Capital Costs ($)	19,025	16,647	31,055
NPV of Total O&M Costs ($)	29,177	29,177	40,541
NPV of Total Costs of the System ($)	48,202	45,824	71,596

In this scenario, for single-shift operations, the NPV of total O&M costs for a PEM fuel cell-powered pallet jack is approximately 39% greater than the NPV of the total O&M costs of the battery-powered pallet jacks. This is primarily due to the cost of using hydrogen as a fuel as compared to battery recharging.

The NPV of the total capital costs of the PEM fuel cell-powered forklift is 63% and 87% greater than the NPV of the total capital costs of the battery-powered alternative with a 3-year and 5-year battery replacement schedule, respectively.

5.2 Scenario 2 – Comparison of Battery-Powered Forklifts to PEM Fuel Cell-Powered Forklifts for Double-Shift Operations

5.2.1 Scenario 2 Assumptions

Scenario 2 compares the cost of using batteries versus PEM fuel cells to power Class 1, Class 2, and Class 3 forklifts in a standard double-shift operation. This scenario assumes that the warehouse operates 16 hours per day and 5 days a week for a total of 4,160 hours per year. Batteries are changed out at the end of each shift; two batteries are maintained per truck. Battery change-outs take approximately 30 minutes and are performed by maintenance personnel and not the forklift operator. Assumptions for scenario 2 are shown in Table 6. The costs of operating battery-powered forklifts with 3-year and 5-year battery lifetimes are examined. The cost of batteries varies by forklift class; the cost of a battery for a sit-down counterbalanced truck is $6,000, for a narrow-aisle forklift is $4,500, and for a pallet jack is $1,800. Similarly, the size of the PEM fuel cell stack varies among the three classes of trucks; the sit-down counterbalanced truck uses an 8 kW stack; the narrow-aisle forklift uses a 5 kW stack, and the pallet truck uses a 3 kW stack. The lifetime of the PEM fuel cell is assumed to be 10,000 hours. In this scenario, the NPV of PEM fuel cell-powered forklifts is examined for stack change-outs at 2 years and 5 years. It is assumed that the cost of stack change-outs is $1,500 per kW. The hydrogen in this scenario is assumed to be supplied through steam methane reforming onsite, and its cost is assumed to be $12.50 per kg. NPV of the PEM fuel cell-powered forklifts are analyzed with 5-year and 2-year stack replacement schedules representing current life of the stack.[37] No residual value for the technologies is assumed for the battery-powered forklifts or the PEM fuel cell-powered forklifts with a 5-year stack replacement schedule. Residual value for the PEM fuel cell stack is assumed with the 2-year stack replacement schedule.

[37] Personal communication between Kathya Mahadevan (Battelle) and industry representatives. September 2007.

Table 6. Scenario 2 – Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Battery-Powered Forklifts for Double-Shift Operations.

	Battery-Powered Sit-Down Counterbalanced Forklift (Class 1)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1)	Battery-Powered Narrow-Aisle Forklift (Class 2)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2)	Battery-Powered Pallet Jack (Class 3)	PEM Fuel Cell-Powered Pallet Jack (Class 3)
Number of Shifts per Day	2	2	2	2	2	2
Hours of Operation per Day	16	16	16	16	16	16
Number of Shifts per Week	10	10	10	10	10	10
Number of Days of Operation per Year	260	260	260	260	260	260
Hours of Operation (hrs/yr)	4,160	4,160	4,160	4,160	4,160	4,160
Forklift Cost ($)	38,500[1]	38,500[1]	21,500[2]	21,500[2]	$11,000[3]	11,000[3]
Size of PEM Fuel Cell (kW)	-	8	-	5	-	3
Battery/PEM Fuel Cell Cost ($)	6,000[4]	35,000[4]	4,500[4]	30,500[4]	1,800[4]	15,000[4]
Battery/PEM Fuel Cell Lifetime (yrs)	3 and 5	2 and 5	3 and 5 years	2 and 5	3 and 5 years	2 and 5
Forklift Lifetime	15	15	15	15	15	15
Cost of Accessories ($) – Battery Charger/ Cranes/Hoists/Washers	2,460[4]	-	2,160[4]	-	1,960[4]	
Routine Maintenance Costs ($/yr)	2,901[5]	240[6]	2,901[5]	240[6]	2,901[5]	240[6]
Recharging/Fuel Costs ($/yr)	2,631[7]	10,688[8]	2,631[7]	10,688[8]	2,631[7]	5,200[9]
Time for Recharging/Refueling (min)	NA	3 minutes[4]	NA	3 minutes[4]	NA	1 minute[4]
Cost for Recharging/ Refueling ($)	7,800[10]	260[11]	7,800	260[10]	7,800	173[12]
Replacement Costs ($)	6,000	12,000[13]	4,500	7,500[13]	1,800	4,500[13]
Residual Value ($)	-	6,000		3,750	-	2,250

[1] Prices of electric sit-down counterbalanced forklift vary by lift capacity. For forklifts with lift capacities between 3,000 lbs to 12,000 lbs prices can vary from $17,000 to $60,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[2] Prices of narrow-aisle reach truck vary by lift capacity. For forklifts with lift capacities between 3,000 – 4,500 lbs price varies from $18,000 to 25,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[3] Prices of pallet trucks vary by lift capacity. For pallet trucks with lift capacities between 3,000 – 8,000 lbs price varies from $7,000 to 15,000. Average of this range of prices is assumed, price obtained from GSA Advantage.
[4] Industry communication. September 2006.
[5] Routine maintenance for the battery powered forklift 10 minutes per shift which is about 86.7 hours per year per truck. Maintenance includes checking battery terminals and water. On a quarterly basis, 2 hours are spent on battery maintenance. Total time spent on maintenance is about 96.7 hours per year. The average cost for battery maintenance person is dependent on wage grade and can range from $20 to $40. For the purposes of this analysis the cost of a maintenance person was considered to be $30. Data obtained from Battelle market research surveys. September 2007.
[6] Routine maintenance on the PEM fuel cell is conducted during the quarterly schedule specified by the OEM for the electric forklift. Maintenance is about 2 hours every quarter. Cost of maintenance person is assumed to be $30. Industry communication. September 2007.
[7] Cost is for charging the battery is assumed to be $5.06 per shift. Industry communication. September 2007.
[8] Assumes a tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Assumes that 855 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $12.50 per kg. Industry communication, September 2006 and September 2007.
[9] Assume a tank size of 0.8 kg. Runtime from a single tank is approximately 8 hours. Assumes that 416 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $12.50 per kg. Industry communication, September 2006 and September 2007.
[10] Batteries are replaced after every shift. Time taken to replace batteries is 30 minutes. The batteries are changed out by maintenance personnel and the maintenance personnel cost is assumed to be $30 per hour. Industry communication. September 2007.
[11] Fuel cell takes 3 minute to refuel. The fuel cell is refueled everyday. The forklift is refueled by the forklift operator and forklift operator cost is assumed to be $20 per hour. Industry communication, September 2006 and September 2007.
[12] Fuel cell takes 1 minute to refuel. The fuel cell is refueled once every shift. The forklift is refueled by the forklift operator and forklift operator cost is assumed to be $20 per hour. Industry communication, September 2006 and September 2007.
[13] Cost of stack is assumed to be $1,500 per kW. Industry communication. September 2007.

5.2.2 Scenario 2 Results

Class 1 Forklifts

In Scenario 2, in double-shift operations, the Class 1 PEM fuel cell-powered forklift with a 5-year stack replacement schedule is competitive on a total lifecycle cost basis with a battery-powered Class 1 forklift under a 3-year and 5-year battery replacement schedule (Table 7). With a 3-year stack replacement schedule, the PEM fuel cell-powered forklift is more economical on a lifecycle cost basis than the battery-powered sit-down counterbalanced forklift with a 3-year battery replacement schedule. While PEM fuel cells require more investment from a capital cost perspective, they have lower total O&M costs.

Table 7. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell-Powered Class 1 Forklifts for Double-Shift Operations.

	Battery-Powered Sit-Down Counterbalanced Forklift (Class 1) (3-Year Battery Lifetime)	Battery-Powered Sit-Down Counterbalanced Forklift (Class 1) (5-Year Battery Lifetime)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1) (5-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1) (3-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1) (2-Year Stack Replacement)
NPV of Total Capital Costs ($)	82,804	66,947	86,850	102,708	122,621
NPV of Total O&M Costs ($)	136,248	136,248	114,337	114,337	114,337
NPV of Total Costs of the System ($)	219,052	203,194	201,187	217,045	236,958

5-Year Stack Replacement

The NPV of total costs of the PEM fuel cell-powered sit-down counterbalanced forklift is approximately 8% and 1% less than the battery-powered sit-down counterbalanced forklift with 3-year and 5-year battery replacement schedules, respectively.

The NVP of the O&M costs for the PEM fuel cell-powered forklift is 16% less than the NPV of O&M costs for the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered forklift is 5% and 23% less than the PEM fuel cell-powered forklift with 3-year and 5-year battery replacement schedule, respectively.

3-Year Stack Replacement

The NPV of total costs of the PEM fuel cell-powered sit-down counterbalanced forklift is approximately 1% less than the battery-powered sit-down counterbalanced forklift with a 3-year battery replacement schedule. Under a 5-year battery replacement schedule, the NPV of the total costs of the battery-powered sit-down counterbalanced forklift is 6% less than the PEM fuel cell-powered alternative.

On an O&M basis, the NPV of the PEM fuel cell-powered forklift is 16% less than the NPV of the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered forklift is 19% and 35% less than the PEM fuel cell-powered forklift with a 3-year and 5-year battery replacement schedule, respectively.

2-Year Stack Replacement
The NPV of total costs of the PEM fuel cell-powered sit-down counterbalanced forklift is approximately 8% and 17% greater than the battery-powered sit-down counterbalanced forklift with 3-year and 5-year battery replacement schedules, respectively.

On an O&M basis, the NPV of the PEM fuel cell-powered forklift is 16% less than the NPV of the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered powered forklift with 3-year and 5-year battery replacement schedules is 32% and 45% less, respectively, than the PEM fuel cell-powered forklift.

Class 2 Forklifts

In scenario 2, in double-shift operations, the Class 2 PEM fuel cell-powered narrow-aisle forklift with a 5-year stack replacement schedule is more cost effective on a total lifecycle cost basis than the battery-powered alternative with a 3-year and 5-year battery replacement schedule (Table 8). With a 3-year stack replacement schedule, the PEM fuel cell-powered forklift is more economical on a lifecycle cost basis as compared to the battery-powered forklift with a 3-year battery replacement schedule. While PEM fuel cells require more investment from a capital cost perspective, they have lower total O&M costs.

Table 8. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell-Powered Class 2 Forklifts for Double-Shift Operations.

	Battery-Powered Narrow-Aisle Forklift (Class 2) (3-Year Battery Lifetime)	Battery-Powered Narrow-Aisle Forklift (Class 2) (5-Year Battery Lifetime)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2) (5-Year Stack Replacement)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2) (3-Year Stack Replacement)	PEM Fuel Cell-Powered Narrow-Aisle Forklift (Class 2) (2-Year Stack Replacement)
NPV of Total Capital Costs ($)	55,262	43,369	60,156	70,067	82,513
NPV of Total O&M Costs ($)	136,248	136,248	114,337	114,337	114,337
NPV of Total Costs of the System ($)	191,510	179,616	174,493	184,404	196,849

5-Year Stack Replacement
The NPV of total costs of the PEM fuel cell-powered narrow-aisle forklift is approximately 9% and 3% less than the battery-powered narrow-aisle forklift with 3-year and 5-year battery replacement schedules, respectively.

On an O&M basis, the NPV of the PEM fuel cell-powered forklift is 16% less than the NPV of the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered forklift with 3-year and 5-year battery replacement schedule is 8% and 28% less, respectively, than the PEM fuel cell-powered forklift.

3-Year Stack Replacement
The NPV of total costs of the PEM fuel cell-powered narrow-aisle forklift is approximately 4% less than the battery-powered narrow-aisle forklift with a 3-year battery replacement schedule. Under a 5-year battery replacement schedule, the battery-powered narrow-aisle forklift is 3% less than the PEM fuel cell-powered alternative.

On an O&M basis, the NPV of the PEM fuel cell-powered forklift is 16% less than the NPV of the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered forklift with 3-year and 5-year battery replacement schedule is 21% and 38% less, respectively, than the PEM fuel cell-powered forklift.

2-Year Stack Replacement
The NPV of total costs of the PEM fuel cell-powered narrow-aisle forklift is approximately 3% and 10% greater than the battery-powered narrow-aisle forklift with 3-year and 5-year battery replacement schedules, respectively.

On an O&M basis, the NPV of the PEM fuel cell-powered forklift is 16% less than the NPV of the battery-powered forklift with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered forklift with 3-year and 5-year battery replacement schedules is 33% and 47% less, respectively, than the PEM fuel cell-powered forklift.

Class 3 Forklifts
In Scenario 2, in double-shift operations, the Class 3 PEM fuel cell-powered pallet jack with a 5-year, 3-year, or 2-year stack replacement schedule is more cost effective on a total lifecycle NPV cost basis than the battery-powered alternative with a 3-year or 5-year battery replacement schedule (Table 9). While PEM fuel cells have higher capital costs, they have significantly lower total O&M costs in this scenario.

5-Year Stack Replacement
The NPV of total costs of the Class 3 PEM fuel cell-powered pallet jack is approximately 45% and 44% less than the battery-powered pallet jack with 3-year battery and 5-year battery replacement schedules, respectively.

The NPV of the O&M costs for the PEM fuel cell-powered pallet jack is 58% less than the NPV of the battery-powered pallet jack with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered pallet jack with 3-year and 5-year battery replacement schedule is 18% and 33% less, respectively, less than the PEM fuel cell-powered pallet jack.

Table 9. Scenario 2 - NPV Analysis of Battery-Powered and PEM Fuel Cell Powered Class 3 Pallet Jacks for Double-Shift Operations.

	Battery-Powered Pallet Jack (Class 3) (3-Year Battery Lifetime)	Battery-Powered Pallet Jack (Class 3) (5-Year Battery Lifetime)	PEM Fuel Cell-Powered Pallet Jack (Class 3) (5-Year Stack Replacement)	PEM Fuel Cell-Powered Pallet Jack (Class 3) (3Year Stack Replacement)	PEM Fuel Cell-Powered Pallet Jack (Class 3) (2-Year Stack Replacement)
NPV of Total Capital Costs ($)	25,492	20,735	31,055	37,001	44,469
NPV of Total O&M Costs ($)	136,248	136,248	57,363	57,363	57,363
NPV of Total Costs of the System ($)	161,740	156,983	88,417	94,364	101,831

3-Year Stack Replacement

The NPV of total costs of the Class 3 PEM fuel cell-powered pallet jack is approximately 42% and 40% less than the battery-powered pallet jack with 3-year battery and 5-year battery replacement schedules, respectively.

The NPV of the O&M costs for the PEM fuel cell-powered pallet jack is 58% less than the NPV of the battery-powered pallet jack with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered pallet jack with 3-year and 5-year battery replacement schedules is 31% and 44% less, respectively, than the PEM fuel cell-powered pallet jack.

2-Year Stack Replacement

The NPV of total costs of the PEM fuel cell-powered pallet jack is approximately 37% and 35% less than the battery-powered pallet jack with 3-year and 5-year battery replacement schedules, respectively.

The NPV of the O&M costs for the PEM fuel cell-powered pallet jack is 58% less than the NPV of the battery-powered pallet jack with 3-year and 5-year battery replacement schedules.

The NPV of the total capital costs of the battery-powered pallet jack with 3-year and 5-year battery replacement schedules is 43% and 53% less, respectively, than the PEM fuel cell-powered pallet jack.

5.3 Scenario 3 – Comparison of Propane-Powered Forklift to PEM Fuel Cell-Powered Forklift for Single-Shift Operations

5.3.1 Scenario 3 Assumptions

Scenario 3 compares the lifecycle costs of a 4,000 lb, propane-powered, sit-down counterbalanced forklift to the lifecycle costs of a 4,000 lb, sit-down, counterbalanced PEM fuel cell-powered forklift (Table 10). This scenario assumes that the warehouse operates the forklifts for only 8 hours per day and 5 days per week for a total of 2,080 hours per year. It is assumed

that approximately 15 minutes are spent on daily maintenance and 4 hours each quarter on complete maintenance of the propane-powered forklift. The cost of propane is assumed to be $1.87 per gallon. For the PEM fuel cell-powered forklift, the size of the PEM fuel cell stack is assumed to be 8 kW and its expected lifetime is 5 years. Runtime on a single tank is assumed to be 18 hours. The lifetime of the PEM fuel cell is assumed to be 10,000 hours. In this scenario, the stack is changed out every 5 years. It is assumed that the cost of stack change-outs is $1,500 per kW. The hydrogen in this scenario is assumed to be supplied as liquid hydrogen and compressed and stored onsite. The hydrogen cost is approximately $17.50 per kg. No residual value for the technologies is assumed.

Table 10. Scenario 3 - Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Propane-Powered Forklifts for Single-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift (Class 4)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1)
Number of Shifts per Day	1	1
Hours of Operation per Day	8	8
Number of Shifts per Week	5	5
Number of Days of Operation per Year	260	260
Hours of Operation (hrs/yr)	2,080	2,080
Forklift Cost ($)	18,000[1]	21,500[2]
Size of PEM Fuel Cell (kW)	-	8
PEM Fuel Cell Cost ($)	-	35,000[3]
PEM Fuel Cell Lifetime (yrs)	-	5
Forklift Lifetime	15	15
Routine Maintenance Costs ($/yr)	2,430[4]	240[5]
Fuel Costs ($/yr)	9,724[6]	7,483[7]
Time for Refueling (min)	10 minutes[4]	3 minutes[4]
Cost for Refueling ($)	867[8]	195[9]
Stack Replacement Costs ($)	-	12,000[10]

[1] Assumes cost of a 4,000 lb propane forklift. Price obtained from GSA Advantage.
[2] Assumes cost of a 4,000 lb sit-down electric forklift from Crown Equipment. Price obtained from GSA Advantage.
[3] Industry Communication. September 2007.
[4] Routine maintenance for the propane-powered forklift 15 minutes per day which is about 65 hours per year per truck. On a quarterly basis, 4 hours are spent on ICE maintenance. Total time spent on maintenance is about 81 hours per year. The average cost for maintenance person is dependent on wage grade and can range from $20 to $40. For the purposes of this analysis the cost of a maintenance person was considered to be $30. Data obtained from Battelle market research surveys. September 2007.
[5] Routine maintenance on the PEM fuel cell is conducted during the quarterly schedule specified by the OEM for the electric forklift. Maintenance is about 2 hours every quarter. Cost of maintenance person is assumed to be $30. Industry communication. September 2007.
[6] Assumes that a 20 gallon propane tank lasts about 8 hours and is replaced each day. The cost of propane is assumed to be $1.87 per gallon.
[7] Assumes a tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Assumes that 425.5 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $17.50 per kg. Industry communication, September 2006 and September 2007.
[8] Assumes that propane truck takes 10 minutes to refill and is refilled by the forklift operator at the end of each shift. Cost of forklift operator is assumed to be $20. Data obtained from Battelle market research surveys.
[9] Fuel cell takes 3 minute to refuel. The fuel cell is refueled once every 3 days. The forklift is refueled by maintenance personnel and maintenance personnel cost is assumed to be $30 per hour. Industry communication, September 2006 and September 2007.
[10] PEM fuel cell stack is 8 kW. Cost of stack is assumed to be $1,500 per kW. Industry communication. September 2006.

5.3.2 Scenario 3 Results

In scenario 3, in single-shift operations the NPV of total costs of the PEM fuel cell-powered forklift is equal to the NPV of the total costs of propane-powered sit-down counterbalanced forklifts (Table 11). The NPV of the O&M costs for the propane-powered sit-down counterbalanced forklift is 64% greater than the PEM fuel cell-powered alternative. The NPV of total capital costs of the propane-powered forklift is 75% less than the NPV of the total capital costs of the PEM fuel cell-powered alternative.

Table 11. Scenario 3 - NPV Analysis of Propane-Powered and PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklifts for Single-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift
NPV of Total Capital Costs ($)	17,442	70,377
NPV of Total O&M Costs ($)	133,069	80,919
NPV of Total Costs of the System ($)	150,511	151,296

5.4 Scenario 4 – Comparison of Propane-Powered Forklift to PEM Fuel Cell-Powered Forklift for Double-Shift Operations

5.4.1 Scenario 4 Assumptions

Scenario 4 compares the lifecycle costs of a 4,000 lb, propane-powered, sit-down counterbalanced forklift to the lifecycle costs of a 4,000 lb, sit-down, counterbalanced PEM fuel cell-powered forklift for double-shift operations (Table 12).

Table 12. Scenario 4 – Cost Assumptions for NPV Analysis of PEM Fuel Cell- and Propane-Powered Forklifts for Double-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift (Class 4)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (Class 1)
Number of Shifts per Day	2	2
Hours of Operation per Day	16	16
Number of Shifts per Week	10	10
Number of Days of Operation per Year	260	260
Hours of Operation (hrs/yr)	4,160	4,160
Forklift Cost ($)	18,000[1]	21,500[2]
PEM Fuel Cell Cost	-	35,000[3]
PEM Fuel Cell Lifetime	-	5 years
Forklift Lifetime	15	15
Routine Maintenance Costs ($/yr)	2,430[4]	240[5]
Fuel Costs ($/yr)	19,448[6]	10,688[7]
Time for Recharging/Refueling (min)	20 minutes[4]	3 minutes[4]
Cost for Recharging/ Refueling ($)	1,733[8]	260[9]
Replacement Costs ($)	-	12,000[10]
Residual Value	-	6,000

[1] Assumes cost of a 4,000 lb propane forklift. Price obtained from GSA Advantage.
[2] Assumes cost of a 4,000 lb sit-down electric forklift from Crown Equipment. Price obtained from GSA Advantage.
[3] Industry Communication. September 2007.
[4] Routine maintenance for the propane-powered forklift 15 minutes per day which is about 65 hours per year per truck. On a quarterly basis, 4 hours are spent on ICE maintenance. Total time spent on maintenance is about 81 hours per year. The average cost for maintenance person is dependent on wage grade and can range from $20 to $40. For the purposes of this analysis the cost of a maintenance person was considered to be $30. Data obtained from Battelle market research surveys. September 2007.
[5] Routine maintenance on the PEM fuel cell is conducted during the quarterly schedule specified by the OEM for the electric forklift. Maintenance is about 2 hours every quarter. Cost of maintenance person is assumed to be $30. Industry communication. September 2007.
[6] Assumes that a 20 gallon propane tank lasts about 8 hours and is replaced twice each day. The cost of propane is assumed to be $1.87 per gallon.
[7] Assumes a tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Assumes that 855 kg of hydrogen is used per year. Cost of hydrogen is assumed to be $12.50 per kg. Industry communication, September 2006 and September 2007.
[8] Assumes that propane truck takes 10 minutes to refill and is refilled by the forklift operator at the end of each shift. Cost of forklift operator is assumed to be $20. Data obtained from Battelle market research surveys.
[9] Fuel cell takes 3 minute to refuel. The fuel cell is refueled once everyday. The forklift is refueled by maintenance personnel and maintenance personnel cost is assumed to be $30 per hour. Industry communication, September 2006 and September 2007.
[10] PEM fuel cell stack is 8 kW. Cost of stack is assumed to be $1,500 per kW. Industry communication. September 2006.

This scenario assumes that the warehouse operates the forklifts for 16 hours per day and 5 days per week for a total of 4,160 hours per year. It is assumed that approximately 15 minutes are spent on daily maintenance and 4 hours each quarter on complete maintenance of the propane-powered forklift. The cost of propane is assumed to be $1.87 per gallon. For the PEM fuel cell-powered forklift, the size of the PEM fuel cell stack is assumed to be 8 kW. The lifetime of the PEM fuel cell stack is assumed to be 10,000 hours. Lifecycle costs for the PEM fuel cell-powered forklift for 2-year and 5-year stack lifetimes are examined. It is assumed that the cost of stack change-outs is $1,500 per kW. Runtime on a single tank is assumed to be 18 hours. The hydrogen in this scenario is assumed to be supplied through onsite steam reformation. The hydrogen cost is assumed to be $12.50 per kg. No residual value for the technologies is assumed for the propane-powered forklift or the PEM fuel cell-powered forklift with a 5-year stack replacement schedule. Residual value is assumed for the PEM fuel cell-powered forklift with a 2-year stack replacement schedule.

5.4.2 Scenario 4 Results

The PEM fuel cell-powered sit-down counterbalanced forklift in Scenario 4 with 5-year, 3-year, and 2-year stack replacement schedules is very competitive with the propane-powered sit-down counterbalanced forklift based on the NPV of the total lifecycle cost (Table 13). While PEM fuel cells have higher capital costs than propane-powered forklifts, they offer significant savings in O&M costs.

Table 13. Scenario 4 - NPV Analysis of a Propane-Powered and a PEM Fuel Cell Powered Sit-Down Counterbalanced Forklift for Double-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (5-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (3-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (2-Year Stack Replacement)
NPV of Total Capital Costs ($)	17,442	70,377	83,634	106,148
NPV of Total O&M Costs ($)	241,295	114,337	114,337	114,337
NPV of Total Costs of the System ($)	258,737	184,714	197,971	220,484

The NPV of the total costs of the propane-powered sit-down counterbalanced forklift is 40%, 31%, and 17% greater than the PEM fuel cell-powered sit-down counterbalanced forklift with 5-year, 3-year, and 2-year stack replacement schedules.

The NPV of the O&M costs for the PEM fuel cell-powered sit-down counterbalanced forklift requires 53% less investment in O&M than the propane-powered alternative.

The propane-powered sit-down counterbalanced forklift requires approximately 75%, 79%, and 84% less capital investment than the PEM fuel cell-powered sit-down counterbalanced forklift over the 15-year lifetime with 5-year, 3-year, and 2-year stack replacement schedules, respectively.

5.5 Lifecycle Cost Analysis Summary

The lifecycle cost analyses presented above indicate that PEM fuel cell-powered forklifts can compete effectively on a total cost basis with both batteries and propane-powered ICEs under certain conditions. Fuel cells do not appear to be competitive with batteries in single-shift situations for any forklift class on a NPV of total lifecycle cost basis (Table 14). Forklifts operated on PEM fuel cells have equivalent lifecycle costs to propane engines in single-shift scenarios. The high capital costs of PEM fuel cell-powered forklifts compared to propane units are offset by significant O&M savings in the use of PEM fuel cells (Table 15). The NPV of the total capital costs associated with PEM fuel cell-powered forklifts are much higher than those associated with battery- or propane-powered equipment in either single shift or double shift operations.

Table 14. NPV of Total Costs ($) of a Battery-Powered Forklift Compared to a PEM Fuel Cell-Powered Forklift for Single-Shift Operations.

	Battery-Powered Forklift (3-Year)	Battery-Powered Forklift (5-Year)	PEM Fuel Cell-Powered Forklift
Class 1	90,424	82,496	167,105
Class 2	68,271	62,325	140,410
Class 3	48,202	45,824	71,596

Table 15. NPV of Total Costs of a Propane-Powered Sit-Down Counterbalanced Forklift Compared to a PEM Fuel Cell-Powered Forklift for Single-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift
NPV of Total System Costs ($)	150,511	151,296

In double-shift operations, PEM fuel cells are competitive on the basis of the NPV of lifecycle costs with batteries replaced every 3 or 5 years in Class 1, 2, and 3 forklifts when the PEM fuel cell stack is replaced every 5 years (Table 16). When the fuel cell stack is replaced every 3 years or 2 years, PEM fuel cells are not cost-competitive with batteries on a 3-year or 5-year battery replacement schedule in Class 1 and 2 forklifts. PEM fuel cells are cost-competitive batteries for Class 3 forklifts with 3-year and 5-year battery replacement schedules.

Table 16. NPV of Total Costs ($) of a Battery-Powered Forklift Compared to a PEM Fuel Cell-Powered Forklift for Double-Shift Operations.

	Electric Forklift (3-Year)	Electric Forklift (5-Year)	PEM Fuel Cell-Powered Forklift (5-Year Stack Replacement)	PEM Fuel Cell-Powered Forklift (3-Year Stack Replacement)	PEM Fuel Cell-Powered Forklift (2-Year Stack Replacement)
Class 1	219,052	203,194	201,187	217,045	236,958
Class 2	191,510	179,616	174,493	184,404	196,849
Class 3	161,740	156,983	88,417	94,364	101,831

Lifecycle costs of PEM fuel cells are highly competitive with the lifecycle costs of propane-powered forklifts in double-shift operations under 2-year, 3-year, and 5-year stack replacement schedules (Table 17). While the NPV of the total capital costs of a PEM fuel cell-powered forklift is significantly higher than that of a propane-fueled forklift, the O&M costs of the fuel cells are much lower in all double-shift scenarios.

Table 17. NPV of Total Costs ($) of a Propane-Powered Sit-Down Counterbalanced Forklift Compared to a PEM Fuel Cell-Powered Forklift for Double-Shift Operations.

	Propane-Powered Sit-Down Counterbalanced Forklift	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (5-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (3-Year Stack Replacement)	PEM Fuel Cell-Powered Sit-Down Counterbalanced Forklift (2-Year Stack Replacement)
NPV of Total System Costs ($)	258,737	184,714	197,971	220,484

6.0 SENSITIVITY ANALYSIS

Single-factor sensitivity analysis was performed to show the variability in the average annual system cost of PEM fuel cells as individual factors are varied while all other factors are held constant. The base values for each factor are the values assumed for double-shift operations in Scenario 2. Here, each factor was allowed to vary by +/-10% of the base assumption (Tables 18, 19, and 20). In the sensitivity analysis, the average annual cash outlay ($\overline{C}$) for use of a PEM fuel cell was calculated using Equation 1.

Equation 1

$$\overline{C} = \frac{\text{Fuel Cell Cost}}{\text{Fuel Cell Life}} + \frac{\text{Fuel Cell Stack Cost}}{\text{Stack Life}} + (\text{Hydrogen Cost/kg} \times \text{Annual Hydrogen Used}) + \text{Annual O \& M Cost}$$

The results of the sensitivity analysis are presented in tornado diagrams (Figures 1, 2, and 3). The factor that shows the greatest cost leverage is graphed at the top of the tornado diagram, with other factors arrayed below it in descending order of cost leverage, creating the “tornado” shape. Two numbers are shown at each end of the horizontal bar graph for each factor. The upper number is the average cash outlay per year if this factor is varied by 10% from base assumptions, holding all other factors at base assumptions. In brackets under the average cash outlay per year figure is the value of the factor when varied by +/-10%.

Class 1 PEM Fuel Cell-Powered Forklift in Double-Shift Operations

The assumptions for the sensitivity analysis of the average annual cost of owning and operating a PEM fuel cell-powered Class 1 forklift are shown in Table 18.

Table 18. Sensitivity Analysis Cost Assumptions for Class 1 PEM Fuel Cell-Powered Forklift for Double-Shift Operations: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
Fuel Cell Life, years	13.5	15.0	16.5
Fuel Cell Cost, $	31,500	35,000	38,500
Fuel Cell Stack Life, years	1.8	2.0	2.2
Fuel Cell Stack, $	10,800	12,000	13,200
Hydrogen, $/kg	11.3	12.5	13.8
Annual O&M (Including Refueling Time), $	450	500	550

The results of the sensitivity analysis are shown in Figure 1. For a Class 1 PEM fuel cell-powered sit-down counterbalanced forklift used in double-shift operations, improving (reducing) the cost of hydrogen, followed by fuel cell stack life and fuel cell stack cost, will have the greatest impact on the cost of owning and operating a PEM fuel cell.

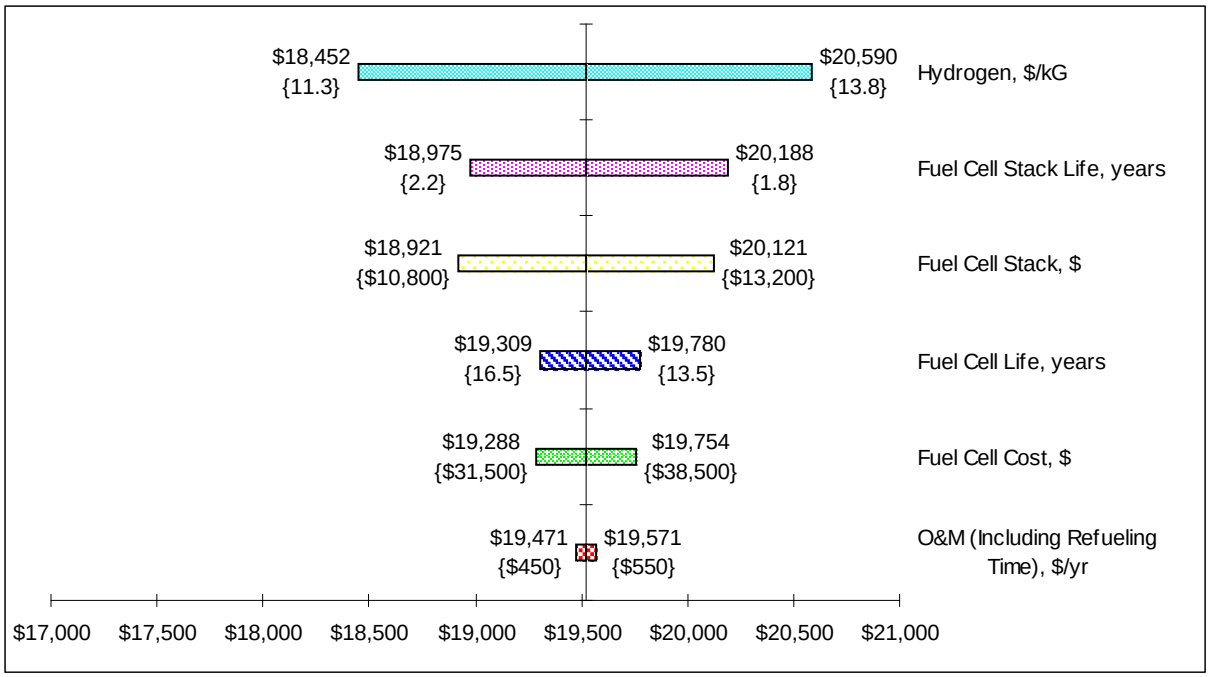


Figure 1. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 1 PEM Fuel Cell-Powered Forklift for Double-Shift Operations.

Class 2 PEM Fuel Cell-Powered Forklift in Double-Shift Operations

The assumptions for the sensitivity analysis of the average annual cost of owning and operating a PEM fuel cell-powered Class 2 forklift are shown in Table 19.

Table 19. Sensitivity Analysis Cost Assumptions for Class 2 PEM Fuel Cell-Powered Forklift for Double-Shift Operations: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
Fuel Cell Life, years	13.5	15.0	16.5
Fuel Cell Cost, $	27,450	30,500	33,550
Fuel Cell Stack Life, years	1.8	2.0	2.2
Fuel Cell Stack, $	6,750	7,500	8,250
Hydrogen, $/kg	11.3	12.5	13.8
O&M (Including Refueling Time), $	450	500	550

The results of the sensitivity analysis are shown in Figure 2. For a Class 2 PEM fuel cell-powered narrow-aisle forklift used in double-shift operations, improving the cost of hydrogen, followed by fuel cell stack life and fuel cell stack cost, will have the greatest impact on the cost of owning and operating a PEM fuel cell.

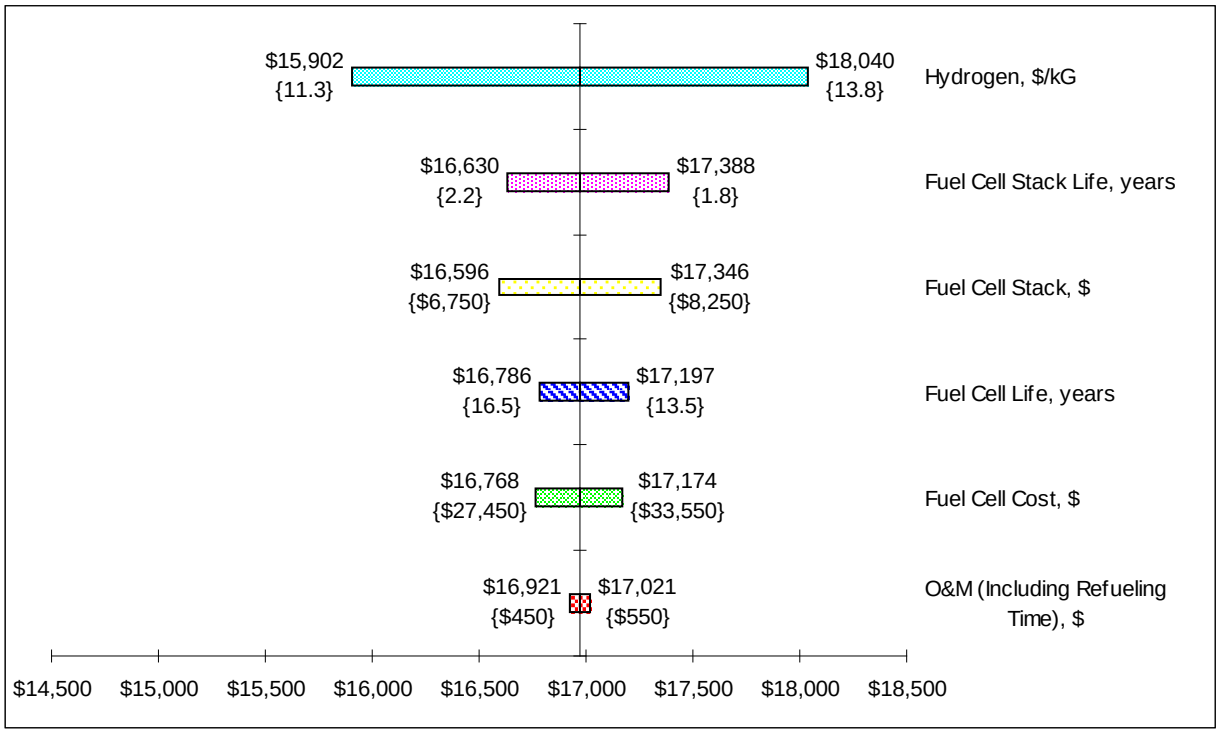


Figure 2. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 2 PEM Fuel Cell-Powered Forklift for Double-Shift Operations.

Class 3 PEM Fuel Cell-Powered Forklift in Double-Shift Operations

The assumptions for the sensitivity analysis of the average annual cost of owning and operating a PEM fuel cell-powered Class 3 pallet jack are shown in Table 20.

Table 20. Sensitivity Analysis Cost Assumptions for Class 3 PEM Fuel Cell-Powered Pallet Jack for Double-Shift Operations: Base Assumptions +/-10%.

	-10% of Base Value	Base Value	+10% of Base Value
Fuel Cell Life, years	13.50	15	16.50
Fuel Cell Cost, $	9,900	11,000	12,100
Fuel Cell Stack Life, years	1.8	2.0	2.2
Fuel Cell Stack, $	4,050	4,500	4,950
Hydrogen, $/kg	11.3	12.5	13.8
O&M (Including Refueling Time), $	450	500	550

The results of the sensitivity analysis are shown in Figure 3. For a Class 3 PEM fuel cell-powered pallet jack used in double-shift operations, improving the cost of hydrogen, followed by fuel cell stack life and fuel cell stack cost, will have the greatest impact on the cost of owning and operating a PEM fuel cell.

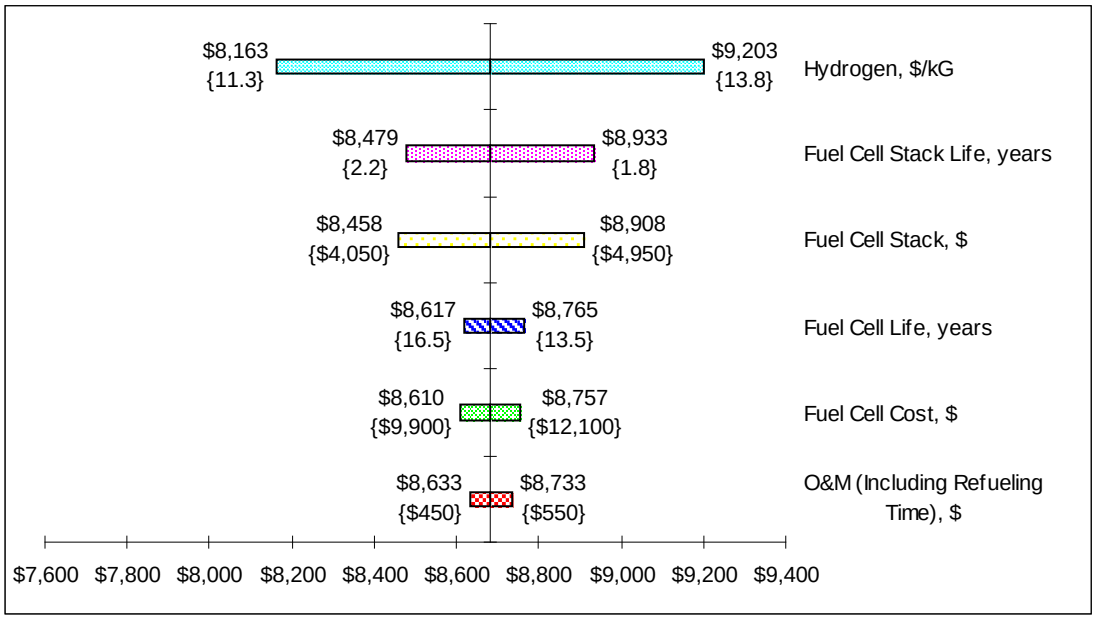


Figure 3. Sensitivity Analysis of Average Annual Cost of Owning and Operating a Class 3 PEM Fuel Cell-Powered Pallet Jack for Double-Shift Operations.

7.0 VALUE PROPOSITION ANALYSIS

An interest within DoD, and DLA in particular, in being an early adopter of new energy technologies is currently the most important driver for fuel cell adoption in this market. Also, the fact that forklifts are not subject to the same engineering and testing requirements as equipment used by warfighters increases the near-term potential for fuel cells to be adopted by the military.

While users appear to be fairly satisfied with existing technologies, they have some concerns, including the O&M requirements associated with battery-powered forklifts and the emissions and reliability of aging ICE-powered forklifts. PEM fuel cell-powered forklifts can offer unique value to these users including lower O&M costs, rapid refueling (eliminating the time and cost of recharging batteries), no emissions, and higher power availability than battery-powered forklifts.

Presently, PEM fuel cell-powered forklifts can compete effectively on a lifecycle cost basis with both battery- and propane-powered forklifts in double-shift operations. In single shift operations, PEM fuel cell-powered forklifts are competitive with the propane-powered alternatives. PEM fuel cells are very competitive with alternatives from an O&M perspective; however, from a total capital cost perspective, PEM fuel cells require more investment than both battery- and propane-powered forklifts. The lifecycle costs of PEM fuel cell-powered forklifts are sensitive to hydrogen costs, fuel cell stack costs, and fuel cell life. The value of PEM fuel cell-powered forklifts compared to alternatives is improved by declining battery life, higher labor rates, and increasing hours of operation.

The DLA is a fairly small market for PEM fuel cell-powered forklifts but is an important niche. The installed base is approximately 4,000 units, with approximately 400 forklifts (about half electric) replaced per year. To further penetrate this market, funding must be available that is mandated, or can be used, for the purchase of fuel cells. Increased awareness and a positive perception toward the value proposition in this market needs to be established in forklift purchase influencers and decision makers. It is anticipated that the pilot demonstrations will help establish the awareness and positive perception of PEM fuel cells as a viable alternative to batteries for electric forklifts. Attractive reliability and performance data from these demonstrations are expected to spur adoption of PEM fuel cell-powered forklifts in and beyond the DLA market. As indicated above, high capital costs prevent PEM fuel cells from being competitive with incumbent technologies in single-shift operations at this time. Although the DLA's depots generally fit the single-shift profile, the agency's interest in adopting hydrogen technologies and demonstrating fuel cells at several of its facilities are positive signs that capital costs will not be the sole driver of future procurement decisions.

In summary, for two-shift operations, fuel cell-powered electric forklifts offer lower overall costs than any competing technology. Fuel cells provide constant power – no sluggish forklift operation at the end of the shift like with batteries. Yet fuel cells offer all of the benefits of electric power – quiet operation with no health-damaging air pollution. Quick-refueling fuel cells eliminate the wasted time and lost productivity associated with changing and recharging batteries. Further, selecting fuel cells supports agency goals under Executive Order 13423 to

adopt environmentally, economically, and fiscally sound technologies to improve energy efficiency, reduce greenhouse gas emissions, and, potentially, use fuel from renewable sources.

Appendix G: Analysis and Opportunity for Fuel Cell Application at Data Centers and Wastewater Treatment Plants

Battelle
The Business of Innovation

Analysis and Opportunity for Fuel Cell Application at Data Centers and Wastewater Treatment Plants

K. Mahadevan, K. Judd, B. Boczek, A. Leibrand, and A. Sommer

October 29, 2008

2008 Fuel Cell Seminar

Phoenix, Arizona

Presentation Outline

- **Data Center Market**
  - Market Description and Trends
  - Market Analysis
  - Verizon Fuel Cell Case Study
  - Value Proposition and Market Opportunity for Fuel Cells
- **Wastewater Treatment Plant Market**
  - Market Description and Trends
  - Market Analysis
  - City of Tulare Case Study
  - Value Proposition and Market Opportunity for Fuel Cells

DATA CENTERS

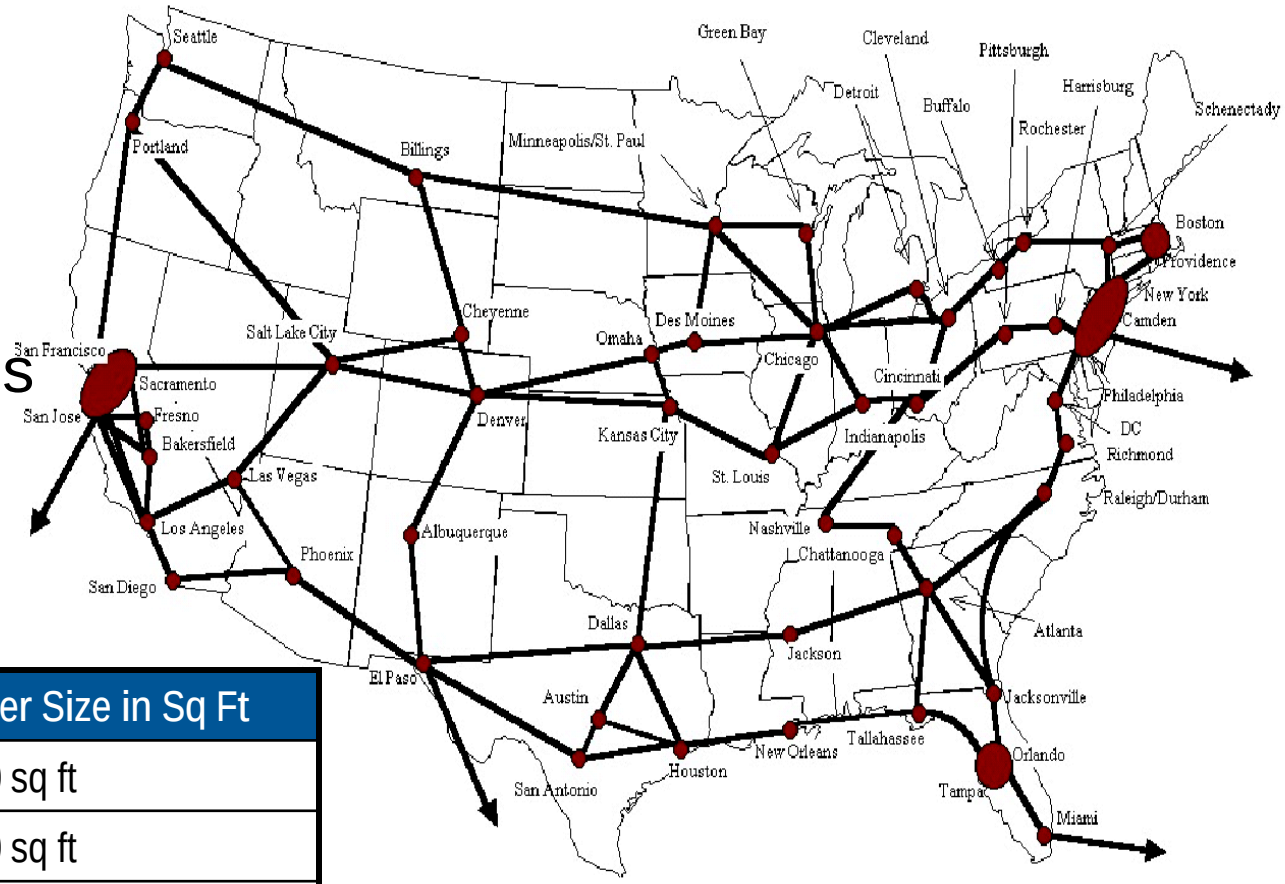
The Data Center Market

- A data center houses **sensitive** electronic equipment including servers, computers, and storage devices for the purpose of storing, managing, processing, and communicating digital data for **business continuity**
- **Electricity reliability** is a critical requirement for data center operation
- Data centers are **energy intensive;** in 2006, energy use was around 60 billion kWh/year and is expected to **nearly double by 2011** to 100 billion kWh/year

Industry	Average Cost of Power Outage, $/hr
Brokerage Operations	6,480,000
Credit Card Operations	2,580,000
Airline Reservations	90,000
Telephone Ticket Sales	72,000
Cellular Communications	41,000

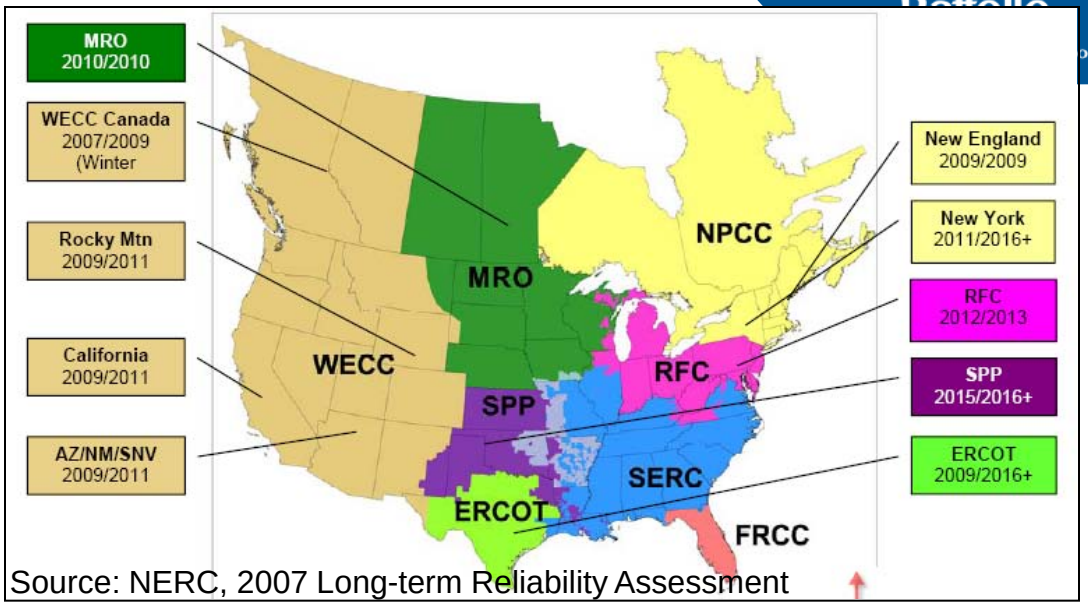
Data Center Market Segments

- Corporate data centers
- Co-location data centers
- Managed services



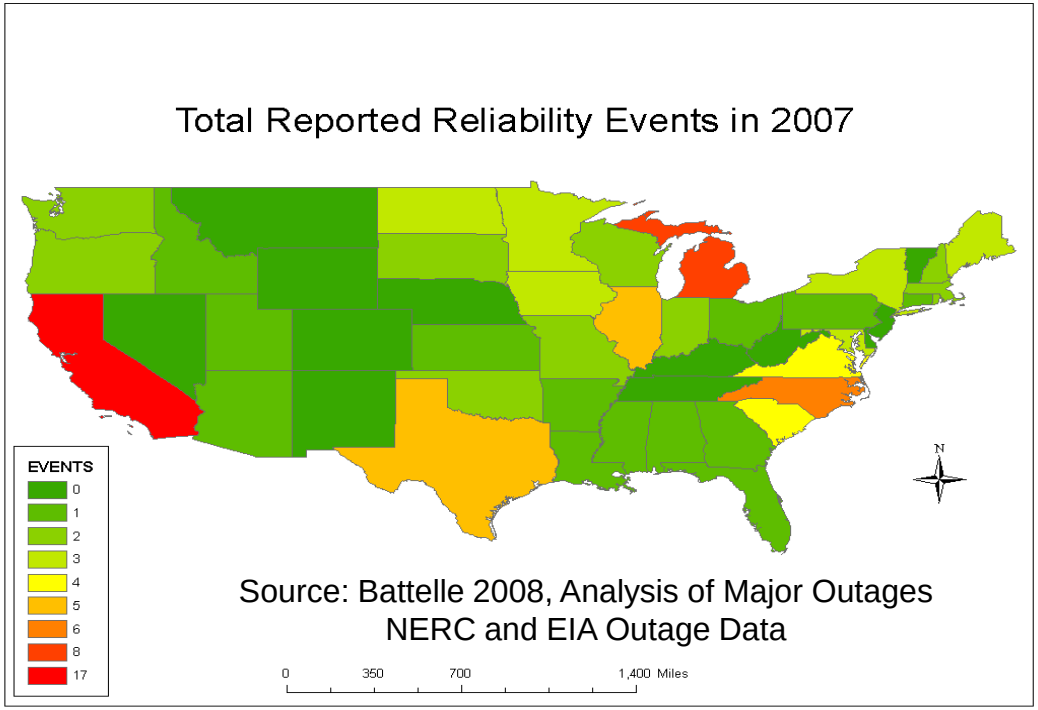
Server/Data Center Type	Server Size in Sq Ft
Server closets	<200 sq ft
Server rooms	<500 sq ft
Localized data centers	<1000 sq ft
Mid-tier data centers	<5000 sq ft
Enterprise-class	5000+ sq ft

Grid Reliability



Source: NERC, 2007 Long-term Reliability Assessment

Source: DOE 2006, National Electric Congestion Study



Source: Battelle 2008, Analysis of Major Outages NERC and EIA Outage Data

Data Center Market Analysis

- Data centers in grid congested areas are concerned about **power shortages, electricity costs, power consumption, and cooling**
- Data center operations projected to expand; grid still considered as **primary power source** despite concerns
- Distributed generation is considered; however, **perceptions** that CHP **adds complexity** and **cost** exist
- Significant interest in **energy efficiency** practices and devices – **low hanging fruit**
- Drivers for considering fuel cells for CHP: increased **energy efficiency**, reducing **environmental impact** of energy production, and opportunity to **reduce electricity costs** during peak demand periods
- Data center operators are **risk averse** as business continuity is critical; **Proven track record** of technology application and performance is considered
- Capital purchase decision making is based on **return on investment**, **capital cost** also is a consideration
- **Government incentives** are considered in purchasing
- Decision making is **split** between facilities managers and IT managers

Fuel Cell Emissions vs. Competing Alternatives

Technology	Natural Gas Input (MMBtu)	Net Electrical Energy Output (MW_{net}-hr)	Net Thermal Output (MMBtu) [ton-hr]	Pollutant Emissions Savings (lb/MW_{net}-hr)*			Total System Efficiency (Fuel Cell and Absorption Chiller**)
				NO_x	CO_2	SO_2	
PAFC	3.6	0.4	0.48	2.2	295.4	5.7	50.83%
Microturbine	0.731	0.06	0.12	1.4	-58.7	5.8	43.40%
Reciprocating Engine	2.66	0.19	0.78	-56.3	4.1	6.3	53.00%

*Pollutant emissions considered against the gird; Electricity grid is assumed to be 44.7% efficient as determined from eGrid database

**Assumes use of only high grade heat using absorption chiller

Fuel Cell Value Proposition and Market Opportunity for Data Centers

- Fuel cells offer the end user:
  - Increased **energy efficiency**
  - **Emissions savings** through better fuel utilization and increased efficiency
  - Better power quality, reliability, and **decreased risk** from outages
  - **Stability** to the grid through distributed generation
  - **DC power output** reducing efficiency losses
- Fuel cells offer value in regions where **grid reliability** is a concern and where **cost of electricity** is high; for e.g., California, Washington D.C., Connecticut, metropolitan areas like Minneapolis St. Paul
- Fuel cells are best fit to support **baseload power** needs; with **hybridization** can support peaking needs
- **Corporate data centers** have power requirements and associated office buildings that make them a more suitable candidate for fuel cell application

WASTEWATER TREATMENT PLANTS

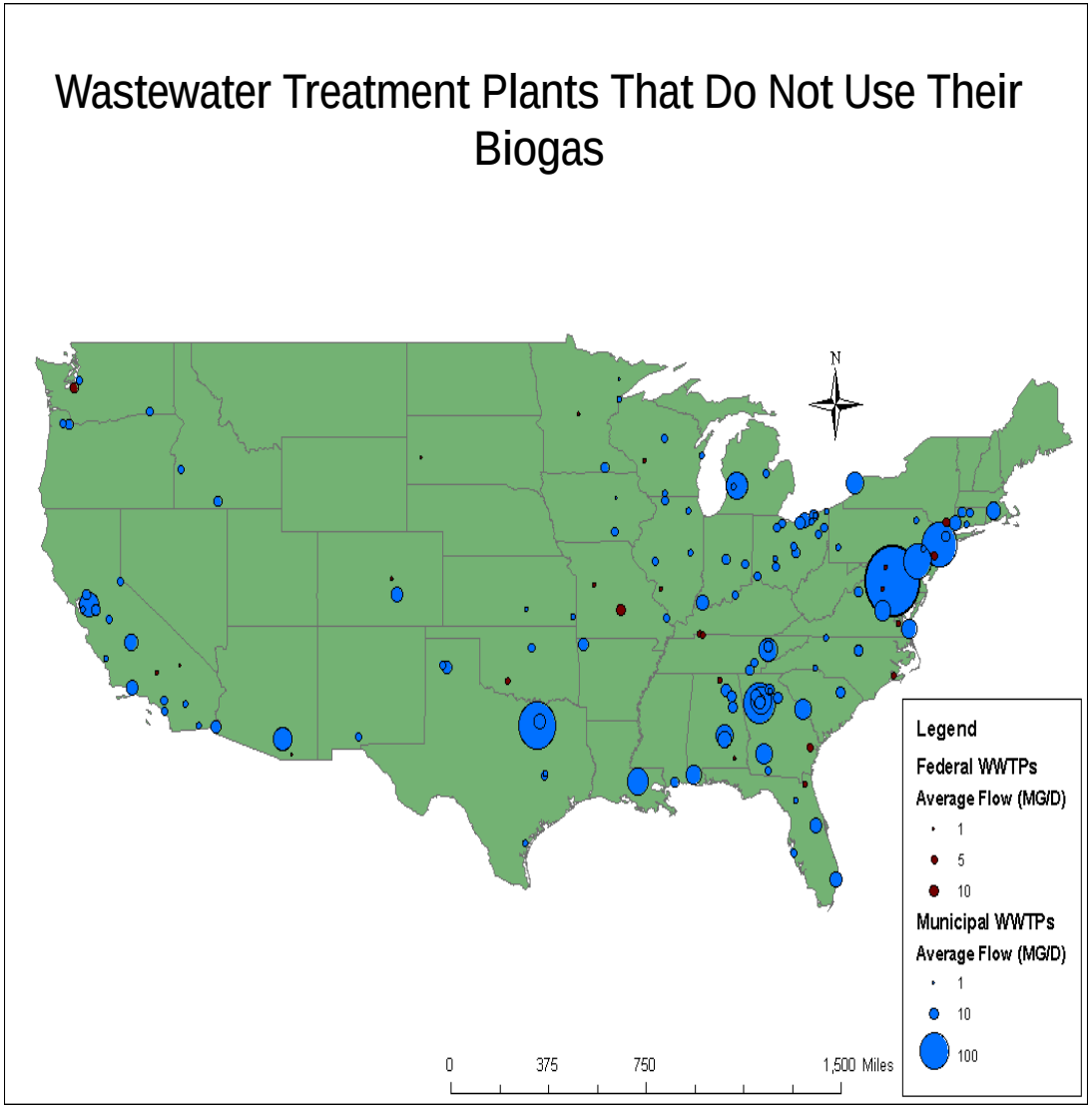
Anaerobic Digestion and Biogas

- Anaerobic digestion is a process used to stabilize wastewater sludge before final disposal
- The process uses microorganisms in the absence of oxygen to convert organic materials to biogas consisting of methane, carbon dioxide, some trace gases, and water

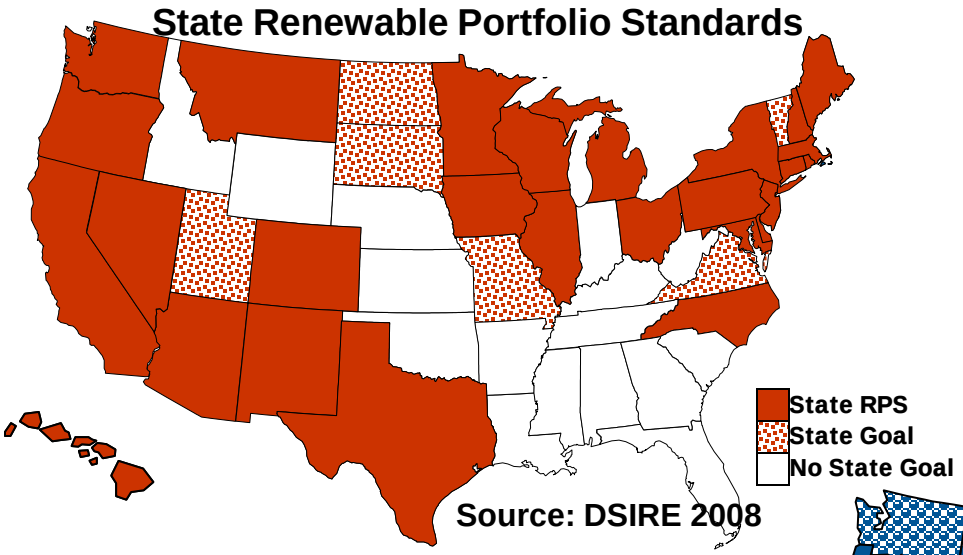
Matter	Percent (%)
Methane, CH_4	50-75
Carbon dioxide, CO_2	25-50
Nitrogen, N_2	0-10
Hydrogen, H_2	0-1
Hydrogen sulfide, H_2S	0-3
Oxygen, O_2	0-2

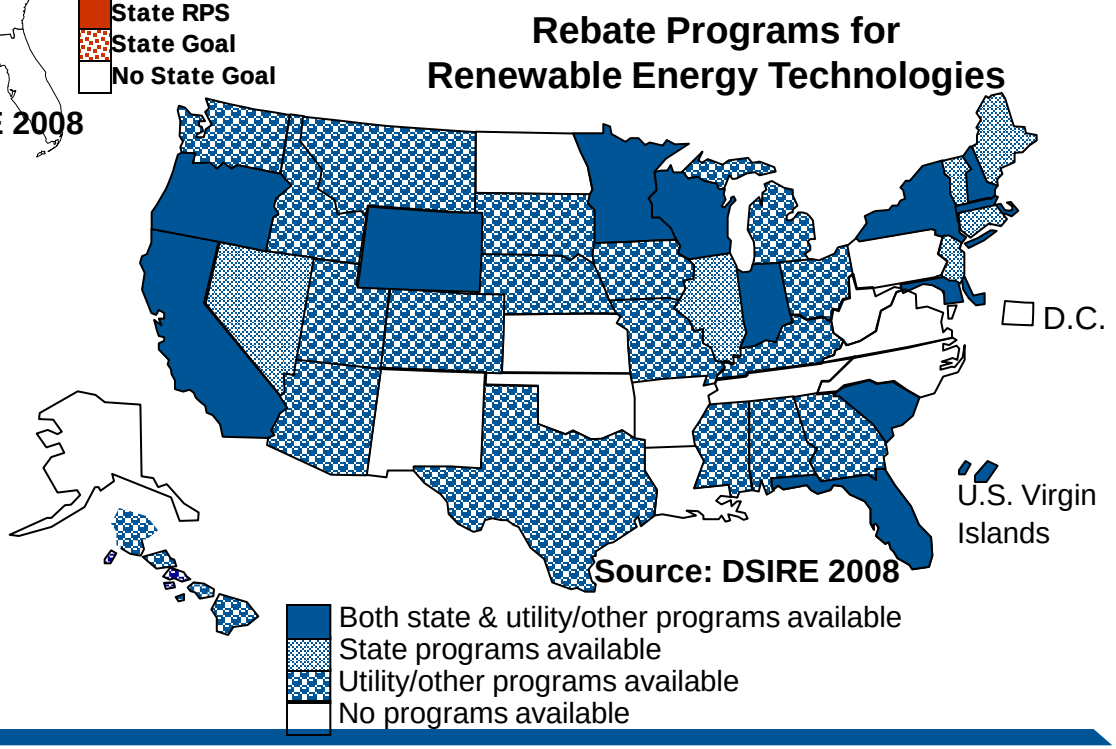
Wastewater Treatment Plant Market

- Approximately 16,847 WWTPs in the United States
  - 615 facilities with flow >3 mgd use anaerobic digestion
  - 215 (35%) facilities do not use their biogas, primarily flare their biogas
- Approximately 45 federal WWTPs with flow >1 mgd
  - 12 facilities have flows > 3 mgd and do not use their biogas
- California has the highest number of municipal facilities using anaerobic digestion (102 confirmed facilities, 77 use their biogas)



Wastewater Treatment Plant Market Trends





Wastewater Treatment Plant Analysis

- WWTP operators are looking for opportunities to utilize biogas as it is a **renewable source**
- Majority use biogas through boilers for **reheating digesters (48%)**; interest in distributed generation is increasing in areas where cost of electricity and fuel is high
- Factors considered when evaluating an alternative energy technology: **reliability, O&M costs, capital costs, and ease of use**
- Decision drivers to purchase fuel cells for on-site power: **availability of biogas**, desire to reduce electricity costs, availability of government incentives, environmental concerns, and track record of the technology
- Factors that most influence purchase decisions: **capital costs**, O&M costs, and reliability of technology alternative
- Purchasing decisions are made based on analysis of the combination of initial capital costs, return on investment, and payback period **AND availability of government incentives**

Fuel Cell Installation Case Study: City of Tulare

Facility size	11.5 million gallons per day (mgd)
Quantity of biogas generated	~ 600,000 cubic feet per day
Fuel cell startup date	September 2007
Technology	Three DFC300MA MCFC rated @ 300 kW; Applied Filter Technology GPS
Fuel cell electrical efficiency	47%
Combined heat and power efficiency	74%
Total number of hours logged	23,300 hours from September 2007 through July 2008
Costs	Total cost of fuel cell power plant: $7 million Funding: about $4.05 million from Southern California Edison as part of California's Self-Generation Incentive Program Total cost to City of Tulare: ~ $2.95 million, with an estimated payback of about 4.5 years
Avoided costs	An estimated one-time cost of $600,000 was avoided in Emission Reduction Credits (ERCs) that would have been required for combustion technologies An average $2,500/day is saved in electricity costs

Technology Analysis for 30 MGD WWTP in California

Technology Type	Phosphoric Acid Fuel Cell	Molten Carbonate Fuel Cell	Microturbine	Reciprocating Engine
Population Served (persons)	300,000			
Biogas Available (scf/year)	109,500,000			
Technology Electrical Capacity (kW/unit)	877.1	1,044.4	568.1	469.5
Total Energy Produced (kW-hr/yr)	7,683,324.13	9,149,001.72	4,976,935.84	4,113,083.84
Overall Grid Energy Savings (MW-hr/yr)	7,683.32	9,149.00	4,976.94	4,113.08
Overall Natural Gas Savings (MMBtu/yr)	25,646.65	12,253.40	20,446.08	23,081.99
NO_x Emission Savings (ton/yr)	422.3	422.3	420.1	396.8
CO Emission Savings (ton.yr)	14.2	12.9	-4.5	-105.2
CO_2 Emission Savings (ton/yr)	4,593.0	2,240.9	1,499.5	4,658.0
SO_2 Emission Savings (ton/yr)	572.6	572.7	572.4	572.4
CH_4 Emission Savings (ton/yr)	24.8	20.5	21.6	-203.8
Overall Emission Savings (ton CO_2 equivalents/yr)	5,113.1	2,672.1	1,952.8	378.2

Economic Analysis for Technology Alternatives at 30 MGD WWTP in California

Technology	PAFC	MCFC	Microturbine	Reciprocating Engine
Power Output (kW)	877.1	1,044.4	568.1	469.5
Capital Costs PV ($)	0	0	2,136,800	1,347,400
O&M Costs PV ($)	3,615,200	6,619,400	1,707,600	1,569,000
Total Cost of System PV ($)	3,615,200	6,619,400	3,844,400	2,916,400
Capital Cost PV w/o Incentives ($)	2,317,300	4,058,400	2,181,000	1,347,400
Natural Gas Savings NPV ($)	4,200	2,000	3,400	3,800
Electricity Savings NPV ($)	10,642,200	12,672,300	6,893,500	5,697,000
Emission Savings NPV ($)	178,400	93,300	68,100	13,200
Scenario Benefits NPV ($)	10,824,800	12,767,500	6,965,000	5,714,000
Scenario NPV ($)	7,008,000	5,704,700	2,598,800	2,797,600
Scenario NPV w/o Incentives ($)	4,892,300	2,089,700	939,600	1,450,200

Federal tax incentive credit: 30% of capital cost for fuel cells and microturbines

California incentive: $4.5/watt for systems <1000 kW; $2.25/watt for systems 1,000 to 5,000 kW

Hydrogen Production 300 kW MCFC

WWTP Location	California	Connecticut	New Jersey	New York	Ohio
Estimated WWTP Size (MGD)	9.38				
Estimated Population Served (persons)	93,762				
Biogas Used (scf/year)	34,223,081				
Total Energy Produced (kW-hr/yr)	2,146,200				
Total Hydrogen Produced (lb/yr)	111,062				
Overall Grid Energy Savings (MW-hr/yr)	2,146.20				
Overall Natural Gas Savings (MMBtu/yr)	1,984.42				
NO_x Emission Savings (ton/yr)	131.87	132.27	132.57	132.63	135.46
CO Emission Savings (ton/yr)	4.20	4.20	4.20	4.20	4.20
CO_2 Emission Savings (ton/yr)	837.46	895.18	850.76	1,059.33	1,994.88
SO_2 Emission Savings (ton/yr)	178.94	179.34	180.88	182.53	194.99
CH_4 Emission Savings (ton/yr)	6.53	6.53	6.53	6.53	6.53
Overall Emission Savings (ton CO_2 equivalents/yr)	802.10	859.81	815.39	1,023.97	1,959.51

Fuel Cell Value Proposition and Market Opportunity for WWTPs

- Fuel cells offer to the end user:
  - **High electrical efficiency** yielding significant **electricity savings**
  - **Natural gas or fuel savings** from utilizing waste heat
  - Significant **emission reductions** as compared to the grid
  - Ability to **generate hydrogen** from a renewable source
  - Help meet utilities' **RPS requirements**
  - Capture a **renewable fuel** and convert waste to energy and heat
- Fuel cells offer **value** in states with incentives, high cost of electricity and fuel, and regulations on emissions. For e.g., California, Connecticut, New York, New Jersey, and Hawaii,

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Appendix H: The High Volume Manufacture Cost Analysis of 5 kW Direct Hydrogen Polymer Electrolyte Membrane (PEM) Fuel Cell for Backup Power Applications

THE HIGH VOLUME MANUFACTURE COST ANALYSIS OF 5 KW DIRECT HYDROGEN POLYMER ELECTROLYTE (PEM) MEMBRANE FUEL CELL FOR BACKUP POWER APPLICATIONS

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Table of Contents

1 INTRODUCTION 1
2 APPROACH 3
2.1 Overview of Cost Analysis Methodology 3
2.2 System Specifications to 2015 5
2.3 System Design to 2015 8
2.4. Stack Materials, Manufacturing, and Assembly Process Overview 12
2.5 Manufacturing Cost Assumptions to 2015 14
2.6 Limitations of the Design Approach and Analysis 18
3.0. COST ANALYSIS RESULTS 20
3.1 "As Is" 2010 System Cost Analysis Results 20
3.2 2012 System Cost Analysis Results 23
3.3 2015 (100,000 Units) System Cost Analysis Results 27
3.4 DFMA Insights into Stack Cost Reduction 30
4.0 SENSITIVITY ANALYSIS 33
4.1 Sensitivity Analysis Assumptions 33
4.2 Sensitivity Analysis Results 33
5.0 CONCLUSIONS 36

List of Figures

Figure 1 - Manufacturing Cost Analysis Methodology 3
Figure 2 - Custom Model Application in Boothroyd-Dewhurst Estimating Software 5
Figure 3 - 2010 "As Is" 5 kW Direct Hydrogen PEM System Schematic 10
Figure 4 - 2012 and 2015 5 kW Direct Hydrogen PEM System Design Schematic 11
Figure 5 - Stack Manufacturing Process Overview 13
Figure 6 - 2010 (2,000 Units) System Cost Breakdown by Major Manufacturing Area..... 20
Figure 7 - 2010 (2,000 Units) Stack Component Manufacturing Cost Breakdown 21
Figure 8 - 2012 (10,000 Units) System Cost Breakdown by Major Manufacturing Area 24
Figure 9 - 2012 (10,000 Units) Stack Component Manufacturing Cost Breakdown 25
Figure 10 - 2015 (100,000 Units) System Cost Breakdown by Manufacturing Area 27
Figure 11 - 2015 (100,000 Units) Stack Component Manufacturing Cost Breakdown 29
Figure 12 - 2010 (2,000 Units) Sensitivity Analysis 34
Figure 13 - 2012 (10,000 Units) Sensitivity Analysis 35
Figure 14 - 2015 (100,000 Units) Sensitivity Analysis 35

List of Tables

Page
Table 1 - Stack Operational Characteristics for 2010, 2012, and 2015 6
Table 2 - Stack Construction Details for 2010, 2012, and 2015..... 8
Table 3 - Production Process Assumptions 14
Table 4 - Scrap Rates for Production..... 15
Table 5 - Capital Cost Assumptions 16
Table 6 - Operations Cost Assumptions 16
Table 7 - Manufacturing Line Specifications for 2,000 Units in 2010..... 17
Table 8 - Equipment Required for Various Production Volumes..... 17
Table 9 - Capital Cost Assumption by Production Volume 18
Table 10 - 2010 (2,000 Units) Total System Costs with Mark-up 20
Table 11 - 2010 (2,000 Units) Stack Manufacturing Cost Breakdown by Component..... 21
Table 12 - 2010 (2,000 Units) System BOP Summary..... 22
Table 13 - 2010 (2,000 Units) System Manufacturing Line Utilization..... 23
Table 14 - 2012 (10,000 Units) Total System Costs with Mark-up..... 24
Table 15 - 2012 (10,000 Units) Stack Manufacturing Cost Breakdown by Component..... 25
Table 16 - 2012 (10,000 Units) System BOP Cost Summary 26
Table 17 – 2012 (10,000 Units) Manufacturing Process Line Utilization..... 26
Table 18 - 2015 (100,000 Units) Total System Costs with Mark-up..... 27
Table 19 - 2015 (100,000 Units) Stack Manufacturing Cost Breakdown by Component..... 28
Table 20 - 2015 (100,000 Units) System BOP Cost Summary 30
Table 21 - 2015 (100,000 Units) Manufacturing Process Line Utilization 30
Table 22 - Summary of Costs for Varied Production Levels to 2015 for 5 kW Direct Hydrogen PEM Fuel Cells for Backup Power Applications 36

1 INTRODUCTION

This report provides cost estimates for the manufacturing of 5 kW direct hydrogen polymer electrolyte membrane (PEM) fuel cells designed for backup power applications at varying production volumes. This cost analysis identifies the projected costs for stationary PEM fuel cells at higher volumes of production using mass manufacturing techniques, the main drivers for system cost, and potential opportunities for cost reduction from a design for manufacture perspective. This analysis has been performed to help the U.S. Department of Energy (DOE) establish technical targets for the manufacture of stationary fuel cell systems to 2015.

An air-cooled 5 kW_{net} PEM fuel cell system for backup power applications is considered in this cost analysis. The system inputs are high purity bottled hydrogen and ambient air. The system configuration was chosen after completing a review of literature and patents pertaining to current stack and system technologies and through dialog with industry members on possible design improvements to their systems and the expected market demand for their products by 2015. The system design does not reflect any one manufacturer's design, but a composite design created by Battelle engineers based on industry inputs and our expertise in fuel cell system design and system integration. The design was vetted with stack and system manufacturers as a viable design for backup power applications.

This cost analysis can be considered an update to the analysis done by Battelle in 2005. The most substantial changes in the system design relative to the previous cost analysis are the change in cooling from a liquid-cooled stack to an air-cooled stack, and the consideration of a direct hydrogen system as opposed to a reformer-based system. There are products on the market for telecommunications applications that successfully use both cooling approaches. There are many tradeoffs between the two cooling approaches and a superior approach is not clear.

The cost analysis examines high volume manufacturing costs for three production volumes to 2015 and considers improvements to the system design in the out years. The "as is" system design is based on current technology in 2010 and a market demand of 2,000 units annually. The projected technology system designs in 2012 and 2015 are based on a market demand of 10,000 and 100,000 annual units respectively. Changes to the manufacturing methods at different production volumes are not considered as it is unlikely that companies will adopt alternative manufacturing techniques after making initial investments in specific high volume equipment.

Cost reduction is expected to be primarily achieved through changes in design based on technological advancements. A secondary factor contributing to cost reduction is economies of scale. Primary changes considered for systems in 2012 and 2015 are an increase in current density, an increase in the membrane utilization, and a decrease in the number of bipolar plates. The increase in current density is expected to come from research advances in membranes and catalysts. The increase in membrane utilization is attributed to improvements in the design and manufacturing capabilities. The reduction in bipolar plates is realized by combining the cathode air and cooling air process streams into a single process air flow and thereby eliminating the need for separate cooling air channels.

A design for manufacture and assessment (DFMA) methodology is used to prepare the cost estimates. The system specifications, the cost analysis methodology, and results of the cost analysis are presented below.

2 APPROACH

2.1 Overview of Cost Analysis Methodology

There are four steps to our cost analysis methodology: system design, cost modeling, sensitivity analysis, and analysis refinement based on industry feedback (Figure 1).

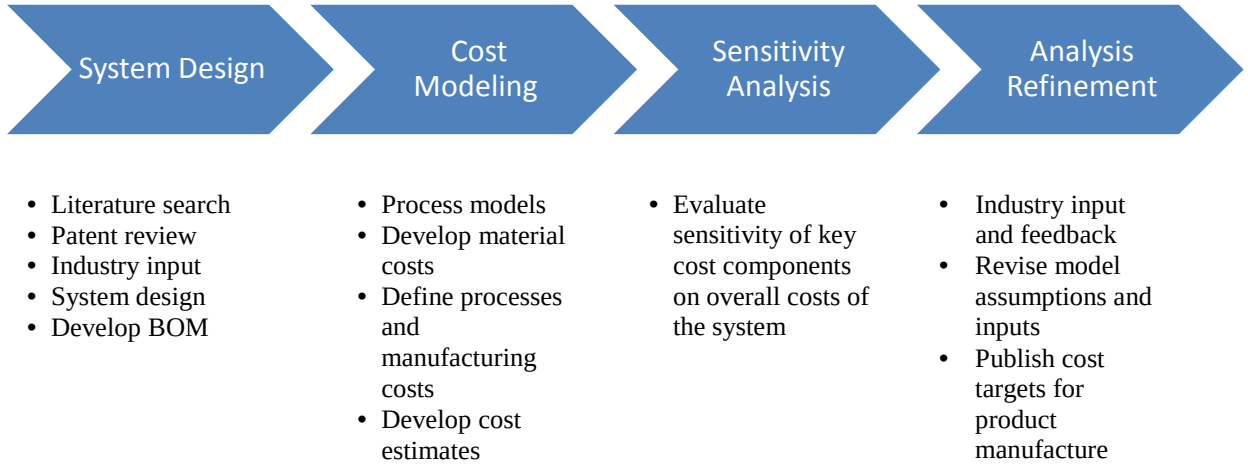


Figure 1 - Manufacturing Cost Analysis Methodology

Step 1 System Design – The first step in our methodology is to create the system design and the associated bill of materials (BOM). Relevant background information is collected from literature (patents, journal articles, and conference proceedings) and through interviews with fuel cell system and component manufacturers on current system design, component design, technologies in use, state of development, and expected near-term improvements in fuel cell technology. This information is used to determine the preliminary "as is" design of the direct hydrogen PEM fuel cell stack and system for the future years of interest (2012 and 2015). The overall system design is used to generate the BOM for the main components of the system. The system design and configuration is then refined and updated multiple times based on iterative feedback from industry.

The 2010 system is specified to reflect the current state of technological advancement of products ready for mass production and not advanced manufacturing developments or cutting edge research advancements that have been demonstrated only in limited testing. Improvements to the design and construction are assumed for the years 2012 and 2015.

The production quantities considered were developed through industry dialog with an optimistic view of market demand to 2015. Annual quantities of 2,000, 10,000, and 100,000 units in the years 2010, 2012, and 2015 respectively are considered in this study. These quantities reflect the total market demand and not the specific production of any one manufacturer. Knowing that a transition to high-volume manufacturing was anticipated within five years the decision was made

to conduct the cost analysis using high volume production manufacturing approaches for all years considered.

Step 2 Cost Modeling – The cost modeling step focuses on gathering material costs, developing process models, estimating the costs to manufacture the stack, gathering costs for the balance of plant (BOP), estimating capital equipment costs, and finally integrating the information to estimate overall system costs. This cost analysis considers the manufacture of the stack as well as system assembly and acceptance testing as in-house operations. Manufacturing methods are selected based on the industry practices and considerations for achieving desired durability and costs. These methods are further refined based on feedback from industry and based on cost modeling.

The cost of production of the stack and the system assembly and testing was estimated using custom models developed from the manufacturing process definitions, implemented in the Boothroyd-Dewhurst Design for Manufacture and Assembly (DFMA)™ software (Figure 2). DFMA™ software strives to reduce product cost by simplifying its design. The process includes, for example, increasing the number of functions every part accomplishes, reducing the number of parts in an assembly or product, and reducing the number of assembly steps required. The DFMA™ design process can be applied to manufacturing and assembly processes as well as to hardware parts.

Vendor quotations and estimates are solicited for raw materials, BOP components, and capital equipment. Whenever possible, multiple vendor quotes are gathered and compared to create an overall composite cost for the subject item. These costs are then integrated with the DFMA™ manufacturing costs to determine the total cost for all three system scenarios. Quotations for manufacturing equipment were based on estimates of component design and did not include specific site and operational requirements.

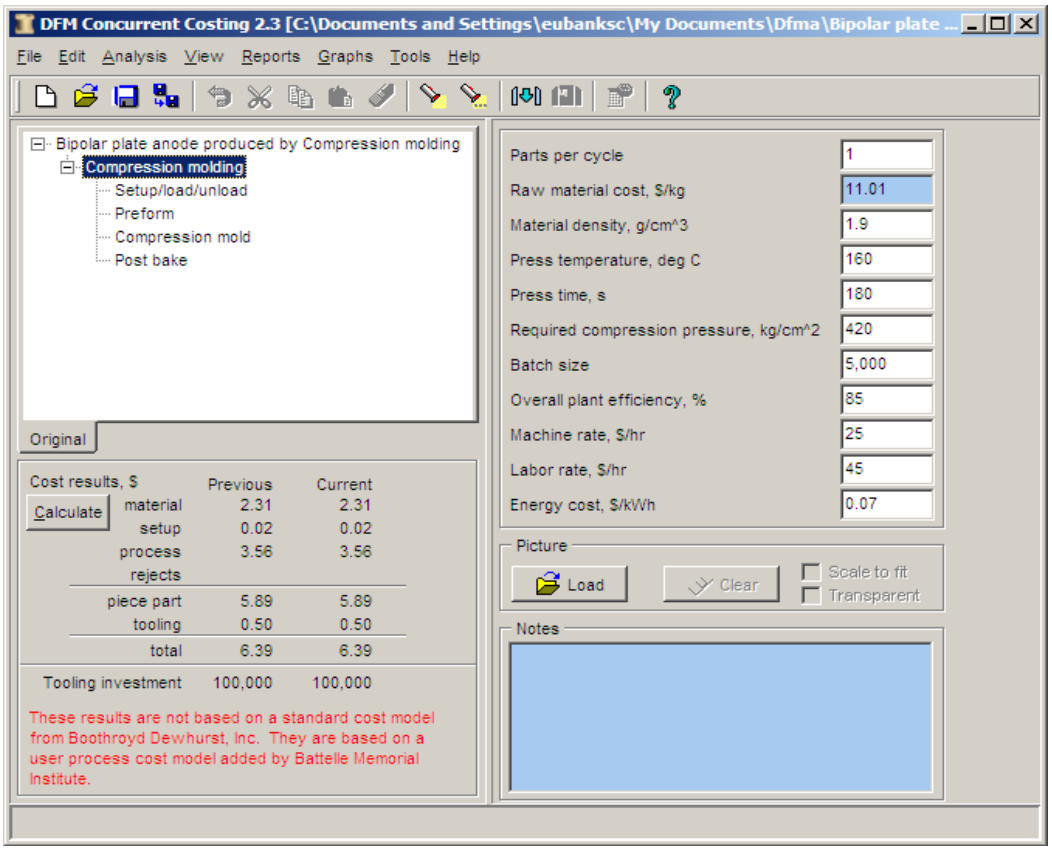


Figure 2 - Custom Model Application in Boothroyd-Dewhurst Estimating Software

Step 3 Sensitivity Analysis – Single factor sensitivity analysis is conducted by varying components that most influenced the cost of the system. Tornado diagrams are generated to demonstrate which components will most impact the cost of the system. This information is used to identify areas for cost reduction in future designs of systems.

Step 4 Analysis Refinement – Preliminary results of the cost analysis are presented to industry and the DOE. Feedback received is incorporated, the cost analysis is updated, and cost targets for product manufacture are published.

2.2 System Specifications to 2015

A comparison of the operational characteristics of the three systems analyzed in this study are presented in Table 1. The operational characteristics were determined by considering the application requirements, current design status, technological advances, and manufacturability.

The net power output of 5kW is defined by the application specification. The system inputs are high purity bottled hydrogen and ambient air. An air-cooled system was chosen for the analysis. This is reflective of many commercially available PEM systems for backup power applications. Compared to a water-cooled system, an air-cooled system offers a reduction in BOP components and advantages in reliability, transport, and durability. An air-cooled system is generally operated at a lower current density than a water-cooled system which in turn requires more

active membrane area for an equivalent power output. Due to equipment limitations, particularly with respect to thermal management, an air-cooled system also is limited on the stack size.

Cell voltages between 0.6 and 0.7 VDC are typical. The median cell voltage of 0.65 VDC was selected. A full-power stack voltage of 50 VDC was selected. As the stack is operated at reduced power the stack voltage will increase. For all operating conditions the stack is expected to operate in excess of the target 48 VDC output enabling a simpler buck DC/DC converter, rather than a buck/boost converter, to be used. These selections remained constant for all years considered in the cost analysis.

Using an assumed DC/DC converter efficiency of 90% and an approximate tally of the power requirements for the BOP and system losses, the gross power output was estimated to be 7kW. The gross power output remained constant for all years considered in the cost analysis. It is reasonable to expect there will be improvements in either the basic efficiency of the BOP components or their implementation within the system that will lower parasitic power losses and thereby decrease the gross power requirement. But the specific improvements could not be quantified with enough confidence to know their magnitude or date of implementation.

The ratio of stack to cell voltage determines the number of cells in the stack. The membrane electrode assembly (MEA) active area is determined by the gross power output, the stack voltage, and the current density. The total membrane area is the MEA active area divided by the membrane utilization ratio.

Table 1 - Stack Operational Characteristics for 2010, 2012, and 2015

	2010	2012	2015
Net Power Output (W)	5,000	5,000	5,000
Gross Power Output (W)	7,000	7,000	7,000
Nominal Operating Voltage (VDC)	50	50	50
Stack Temperature (C)	80	80	80
Power Density (W/cm^2)	0.455	0.52	0.65
Current Density (A/cm2)	0.7	0.8	1
Cell Voltage (VDC)	0.65	0.65	0.65
Active Area Per Cell (cm2)	200	175	140
Overall Membrane Dimensions (cm)	33 x 10	31 x 8.3	25 x 7.1
Overall Membrane Area (cm2)	330	257	178
Membrane Utilization (%)	61%	68%	79%
Number of Cells (#)	77	77	77
Catalyst Loading (mg/cm2, total)	0.4	0.35	0.25

Improvements to the current density, catalyst loading, and the membrane utilization ratio are considered to 2015. The 2010 system has a current density of 0.7 A/cm^2. Technological advances are assumed that increase the current density to 0.8 A/cm^2 in 2012 and 1.0 A/cm^2 in 2015. Catalyst loading was assumed to decrease from 0.4 mg/cm^2 to 0.25 mg/cm^2 in 2015.

The membrane utilization ratio refers to the ratio of active area relative to the entire membrane size. It is of importance as the roll-to-roll fabrication process yields an MEA that is uniform over

its entire area; the catalyst and gas diffusion layer (GDL) are applied to the entire MEA and not just the active area. There is a wide range in membrane utilization ratios currently being used depending on the type of manufacturing processes adopted. For example, MEAs are often fabricated today in batch processes in which the catalyst and GDL are applied only to the active area. As such, the cost penalty for a low utilization ratio is not as severe and optimization is a lower priority. Manufacturers may have significant investment in tooling based on a particular stack geometry and a small reduction in MEA costs is not sufficient to offset the expense in changing tooling. Finally, given the above constraints and the magnitude of the cost reduction, there has not been a lot of emphasis on optimizing the membrane utilization ratio relative to the many other cost reductions, performance improvements, and durability enhancements manufacturers are currently pursuing. The membrane utilization ratio is about 60% in 2010 and improves to nearly 80% by 2015.

Stack construction details are presented in Table 2. The stack has a typical PEM construction consisting of an alternating pattern of bipolar plates and MEAs sandwiched between thick endplates. There are a total of 77 cells in the stack. Tie rods passed through the endplates hold the stack together and apply mechanical loading to ensure sealing between cells and the endplates. Injection molded Viton FKM gaskets are used for sealing. Material thicknesses were chosen based on values typically used in these applications, industry recommendation, and potential availability. The membrane is 0.2mm thick Teflon reinforced PFSA, a suitable choice for the specified operational parameters of the stack. The catalyst ink is rolled on to the entire membrane area. The GDL is 0.3mm thick carbon paper coated with Teflon for water management. A microporous layer comprised of a blend of carbon, graphite, and Teflon is applied to one side. A hot-press operation is used to fabricate the MEA from the catalyst-coated membrane and GDL layers. Bipolar plates are compression molded from a graphite polymer mix. The geometry for the plates has larger flow channels suitable for an air-cooled stack. .

Table 2 - Stack Construction Details for 2010, 2012, and 2015

	2010	2012	2015
Number of Cells (#)	77	77	77
Membrane Base Material	PFSA0.2 mm thickPTFE Reinforced	PFSA0.2 mm thickPTFE Reinforced	PFSA0.2 mm thickPTFE Reinforced
Catalyst Loading	Total Loading = 0.4 mg/cm2 Cathode is 2:1 to 4:1 relative to Anode	Total Loading = 0.35 mg/cm2	Total Loading = 0.25 mg/cm2
Catalyst Application	Catalyst ink prepared, rolled on, heat dried	Catalyst ink prepared, rolled on, heat dried	Catalyst ink prepared, rolled on, heat dried
GDL Base Material	Carbon Paper 0.30 mm thick	Carbon Paper 0.30 mm thick	Carbon Paper 0.30 mm thick
GDL Construction	Carbon Paper, PTFE coating for water mgmt, carbon/graphite/PTFE microporous layer	Carbon Paper, PTFE coating for water mgmt, carbon/graphite/PTFE microporous layer	Carbon Paper, PTFE coating for water mgmt, carbon/graphite/PTFE microporous layer
MEA Construction	Catalyst applied to membrane, GDL placed on either side, hot press operation to join.	Catalyst applied to membrane, GDL placed on either side, hot press operation to join.	Catalyst applied to membrane, GDL placed on either side, hot press operation to join.
MEA/Bipolar Plate Seal Material	Viton FKM 0.3 mm thick	Viton FKM 0.3 mm thick	Viton FKM 0.3 mm thick
MEA/Bipolar Plate Seal Construction	Injection Molded	Injection Molded	Injection Molded
Number of Bipolar Plates	155	78	78
Bipolar Plate Material	Composite (Graphite Polymer) 3mm nominal thickness	Composite (Graphite Polymer) 3mm nominal thickness	Composite (Graphite Polymer) 3mm nominal thickness
Bipolar Plate Details	Anode side has parallel serpentine paths 1mm wide and 1mm deep. Cathode has parallel paths 2-3 mm wide and 2mm deep	Anode side has parallel serpentine paths 1mm wide and 1mm deep. Cathode has parallel paths 2-3 mm wide and 2mm deep	Anode side has parallel serpentine paths 1mm wide and 1mm deep. Cathode has parallel paths 2-3 mm wide and 2mm deep
Bipolar Plate Construction	Compression molded	Compression molded	Compression molded
Coolant and End Gaskets	Viton FKM	Viton FKM (no coolant gasket)	Viton FKM (no coolant gasket)
End Plates/Compression System	1" Thick die cast Aluminum plates with tie rods	1" Thick die cast Aluminum plates with tie rods	1" Thick die cast Aluminum plates with tie rods

2.3 System Design to 2015

2010 "As Is" Design

The "as is" system schematic is shown in Figure 3. Hydrogen passes through a dual-stage regulator and is supplied to the stack at 2 psig. The stack is operated in dead-head mode with a periodic purge to flush the anode. Hydrogen recirculation is a significant BOP cost and the application requirements do not dictate a need for it. A pressure switch and relief valve ensure the stack is operated at an appropriate anode side pressure. Air enters the system enclosure through a particulate filter. The cathode air stream is drawn from inside the system enclosure. It

passes through a second filter (chemical and particulate), blower, flow meter, and stack before exiting the enclosure. Cooling air is also drawn from inside the enclosure. Two blowers provide the cooling for the stack. A centrifugal blower provides cooling air through channels in the bipolar plates. An axial fan draws air over the outside of the stack to assist in the cooling. Stack sensors (current, voltage, temperature) and other system sensors provide feedback to the control module which ensures the stack is operated correctly. The electrical output of the stack is sent through a DC/DC converter where it is adjusted to the desired output voltage of 48 VDC.

The most substantial change in the system design relative to the previous cost analysis conducted in 2005 by Battelle[1] is the change in cooling from a liquid-cooled stack to an air-cooled stack. There are currently products on the market for backup telecom applications that successfully use both approaches. There are many tradeoffs between the two cooling approaches and a superior technology is not clear.

Compared to a water-cooled system, an air-cooled system offers a reduction in BOP components and advantages in reliability, transport, and durability. For example, rather than having a coolant loop with a pump, sensors, filter, radiator, and radiator fan, the air-cooled system needs only an air filter and one or two blowers. The air-cooled system is also able to handle freezing conditions better since there is not a dedicated liquid loop. The air-cooled system is easier to transport and install as there are no complications from the coolant media, either protection from freezing of a factory filled liquid system during shipment or filling during the installation. Furthermore, an air-cooled system more easily facilitates a merger of the cathode and cooling process streams which enables a cost reduction by the elimination of some bipolar plates.

While the air-cooled system offers many advantages, the air-cooled system generally operates at a lower current density than a water-cooled system. The lower current density increases the membrane area required to achieve an equivalent power output which in turn increases the system cost. Finally, it can be very challenging to maintain suitable and uniform membrane temperatures in an air-cooled stack, particularly as power exceeds the 4-5kW range.

Another significant change in the overall system is the elimination of all humidification. Improvements in MEA technology coupled with the requirements for stationary backup power applications have enabled many fuel cell manufacturers to eliminate humidification. In general, the simplification of the BOP is an area where fuel cell manufacturers have made focused efforts on reducing cost and have made significant progress. The elimination of humidification is one of the largest cost reductions and most visible changes.

[1] Battelle. 2005. Interim Report on the Economics of Stationary Proton Exchange Membrane Fuel Cells. Report to the DOE. DOE Contract No. DE-FC36-03GO13110.

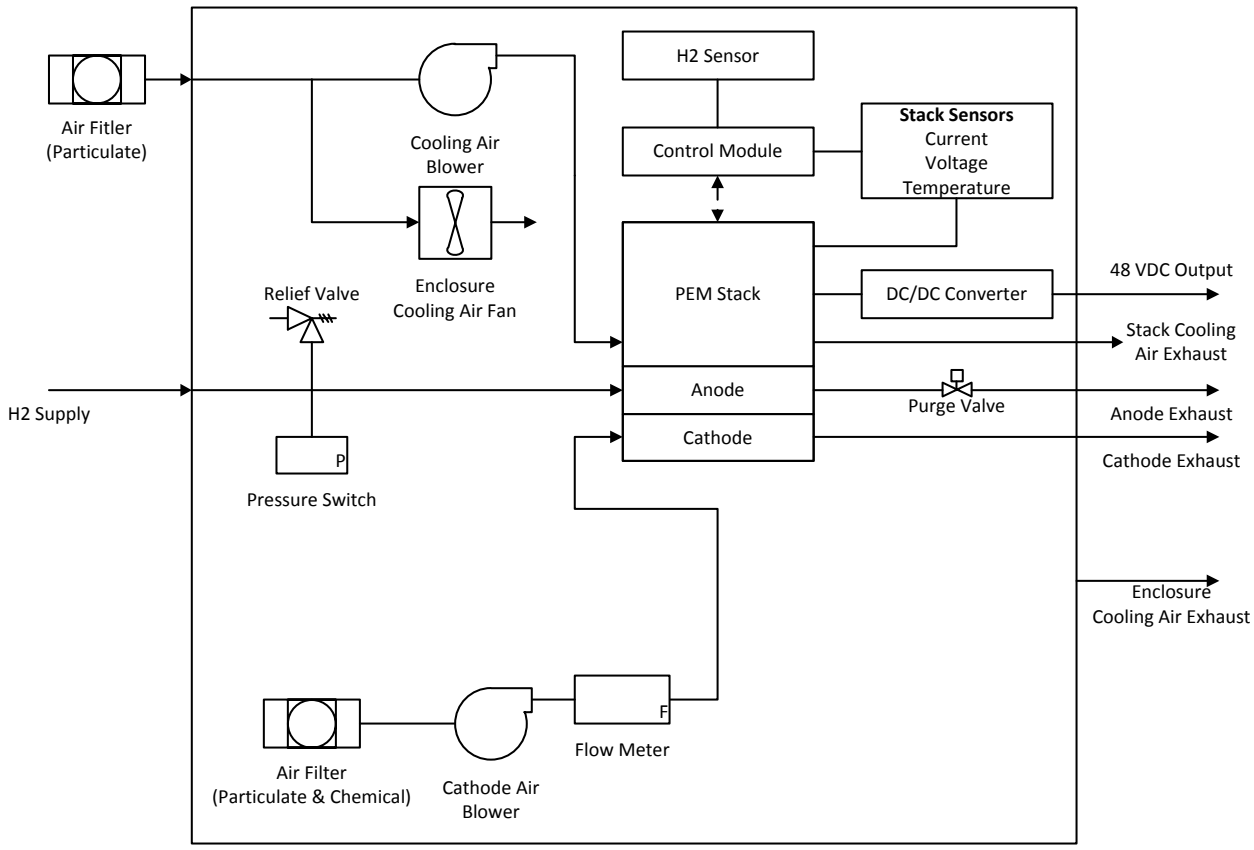


Figure 3 - 2010 "As Is" 5 kW Direct Hydrogen PEM System Schematic

2012 and 2015 System Design

The 2012 system design schematic is shown in Figure 4. Relative to the 2010 schematic, a technological improvement has been assumed. The cooling air and cathode air have been combined into a single process stream. The most significant impact is that there no longer needs to be separate channels for cooling between bipolar plates. Therefore the number of bipolar plates required in the stack can be cut in half. The blower for the 2012 and 2015 systems supplies air for both the cathode and cooling. As such, the blower will be required to supply more air at an increased pressure drop and, therefore, needs to be a slightly more advanced blower than the single cathode blower or single cooling blower in the 2010 design. Since the technological improvements assumed for 2015 affect only the stack detail design (and not the overall system design) the 2015 system design is identical to the 2012 system design.

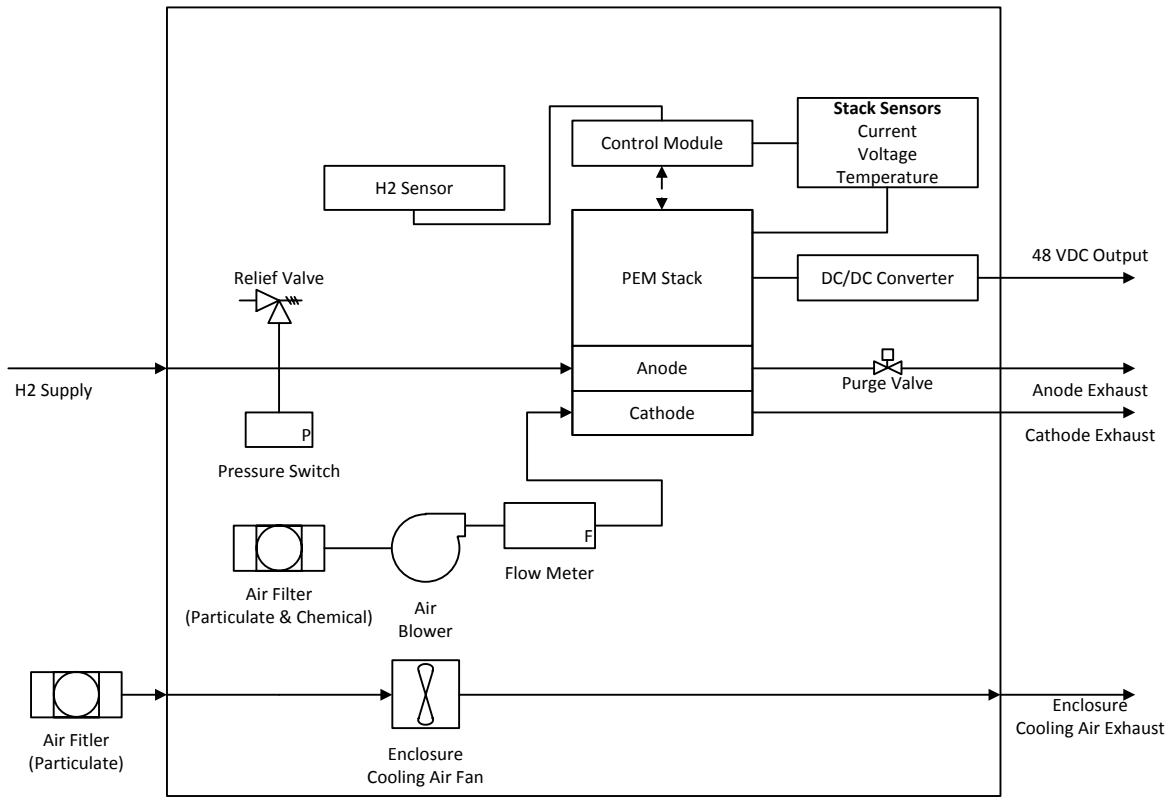


Figure 4 - 2012 and 2015 5 kW Direct Hydrogen PEM System Design Schematic

Balance of Plant Assumptions

The system specifications are used to derive the requirements for any specific BOP component. Suitable components that met the requirements are identified from multiple manufacturers. The costs for balance of plant equipment were obtained by soliciting quotes or price estimates from each manufacturer. The quotes were requested to reflect costs for a single year commitment to purchase and not as part of a long-term strategic alliance.

The assumption at the outset is that suitable BOP components are readily available, commercially produced items. For the majority of items, the current production volumes are adequate for all years considered in this analysis and a volume quotation is easily obtained. For a few items like the blowers, regulators, and DC/DC converters, commercial products are produced, but not in quantities of tens or hundreds of thousands. The manufacturers generally are able to offer budgetary pricing even when the forecasted production quantity exceeds current production capacity.

There are three components for which the assumption of readily available commercial items is not valid: the electronic control unit (ECU), cathode flow meter, and DC/DC converter. The ECU is a custom electronic item tailored to each individual system design. The specification of the required components, connectors, and implementation is more detailed than the system cost analysis facilitates. Pricing for small quantities is obtained from one commercial vendor of fuel cell ECUs and Battelle's general experience with designing and building system control ECUs. No suitable off-the-shelf item was identified for the cathode flow meter. Scientific instruments

for measuring air flow are generally not suitable for system implementation due to cost and physical limitations (size, pressure drop, etc.). PEM systems currently on the market typically use an automotive air flow sensor configured as an OEM part for the system. Since the configuration is proprietary and not commercially available, cost estimates for this part were obtained using retail prices for replacement automotive parts and suitable quantity scaling factors. The DC/DC converter was the most difficult BOP component to match to a suitable commercially available product. There are multiple manufacturers of DC/DC converters that could be used with this application. However, the converters either have capabilities that far exceed the requirements of the application (and therefore cost much more than necessary) or are produced in quantities much lower than the 2,000 units annually making a volume cost estimate difficult. The cost was estimated using the low quantity cost for suitable converters, assumptions for the volume cost reduction possible, and feedback from fuel cell system manufacturers.

2.4. Stack Materials, Manufacturing, and Assembly Process Overview

The manufacturing of cell stack components, stack assembly, system assembly, and test and conditioning are all performed in-house and contribute to the manufacturing costs. An overview of the stack manufacturing process is shown in Figure 5.

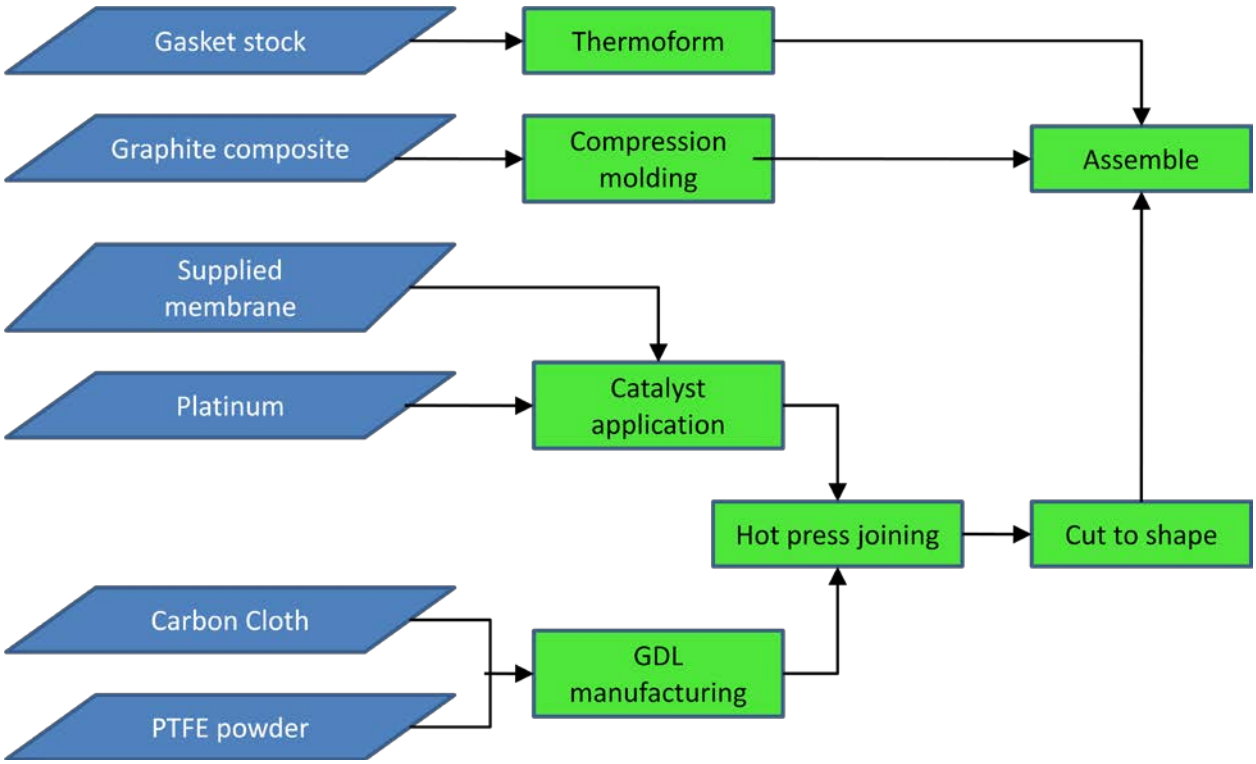


Figure 5 - Stack Manufacturing Process Overview

All the gaskets are thermoformed from raw material. The bipolar plates are a graphite composite compression molded to the required shape. For both the GDL and the membrane the substrate material (carbon cloth and Teflon®-reinforced PFSA respectively) are supplied by external vendors. Catalyst is applied to the membrane by a roll application process. Battelle considered inkjet printing as alternative application processes for the catalyst. This process offers

significant improvement in catalyst utilization due to the ability to print only on the active area as well as customize the catalyst distribution over the active area. However, this technology has not yet reached a suitable stage of development for scaling to mass production. Coatings are applied to the GDL to form the microporous layer and for water management. The GDL and MEA are hot-pressed together. The MEA is cut to the required shape and assembled with the bipolar plates and the gaskets.

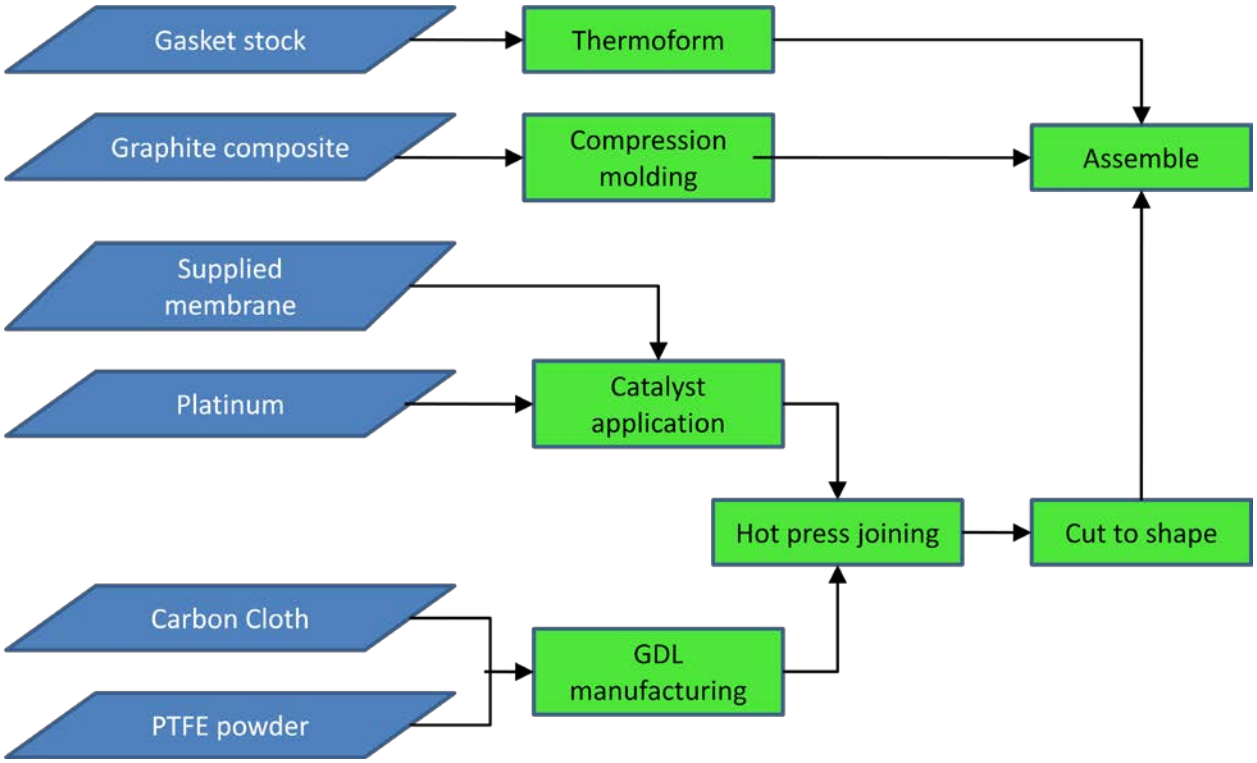


Figure 5 - Stack Manufacturing Process Overview

Battelle considered manufacturing a reinforced PFSA membrane from raw materials. Industry feedback indicated that the material supplier's preference is to supply a finished membrane product rather than the raw materials. The cost of purchasing the membrane as a finished product was comparable to the cost of manufacturing from raw materials.

With the high-level manufacturing model established, each step in the manufacturing process for fuel cell stack components was evaluated in detail – starting with the MEA production. Manufacturing processes used in previous DOE cost analysis reports were used as the basis for the Battelle approach.[2] Due to the proprietary nature typical of these processes, Battelle received little revising feedback in comparison to the previously published information. The existing process and equipment generally was supported by Battelle's manufacturing knowledge and by feedback from industry. Battelle incorporated a few changes to the manufacturing process. If a

[2] DTI Inc. 2009. Mass Production Cost Estimation for Direct H2PEM Fuel Cell Systems for Automotive Applications.

change was made, adding a tension control for example, its impact was small enough as to have negligible impact on the intent or cost of the process. The most substantial change noted was adding quality inspection equipment to the lines. However, such equipment has low power consumption (and thus processing cost) and even at a high capital cost does not affect system cost significantly.

2.5 Manufacturing Cost Assumptions to 2015

Production Assumptions

The cost of production was estimated using models developed from the manufacturing process definitions, implemented in the Boothroyd-Dewhurst DFMA™ software. Standard models for processes or machinery existing in the software were used whenever possible. A custom model was programmed, using fundamental mechanical principles and published machinery specifications or data gathered from vendors, when a standard model was not available. Basic cost assumptions are detailed in Table 3.

Table 3 - Production Process Assumptions

Parameter	Value
MEA manufacturing process	Roll-to-roll
Process line speeds:	
Catalyst application	10 m/min
GDL fabrication	5 m/min
MEA hot pressing	0.5 m/min
Roll length	1000 ft
Membrane roll width	1 m
Carbon cloth width	1 m
Overall plant efficiency	85%
Inspection steps included in processing	None
Labor cost	$45/hr
Machine cost	$25/hr
Energy cost	$0.07/kW-h
Setup operations per roll	1
Operators on membrane line	3
Operators on all other lines	1

Assumptions were developed from previously published information, discussions with vendors, using standard values defined in the software, and by engineering estimates.

Scrap rates for the stack manufacturing processes vary and in some cases represent a tangible portion of the process cost. As with the manufacturing process definition itself, much of this information is considered proprietary in industry. The values used for the Battelle analysis are representative of ranges for similar processes and engineering estimates were made based on Battelle's manufacturing knowledge. Table 4 below delineates the scrap rates, which were held constant over all the forecasted years. These rates capture not only scrap resulting from initial production of material, but also excess material consumed during stack rework as part of test and conditioning.

The remainder of the fuel cell system components, including balance of plant and structure (frame) and enclosure, are purchased or outsourced. The assembly, integration, testing, and

conditioning of all these items are done in-house. Stack assembly and test costs are included in the stack estimate while the cost of system assembly and test is included at that level.

Battelle approached manufacturing by defining a business model where the fuel cell stack components, stack assembly, system assembly, and test and conditioning are all performed in-house. Doing so means acquiring and operating all necessary machinery as well as buildings and associated infrastructure such as electric distribution, heating and cooling, cleanliness control, lifting and transportation of materials, and storage. System components falling outside the defined core will be purchased or outsourced. As a result, no equipment or facilities are included for production of commercially-available off-the-shelf items, such as blowers and pressure regulators, nor are any resources allocated to commercially common processes like metal machining or plastic molding.

Table 4 - Scrap Rates for Production

Scrap/Reject Rates	
Catalyst application	30%
GDL fabrication	30%
MEA hot Pressing	5%
Slit to width	0.5%
Slit and cut	0.5%
Compression molding - Pre-form	0.5%
Compression molding - Mold	1%
Compression molding - Post bake	1%
Die casting – End plate	0.5%
Die casting - Thread tapping	0.5%
Testing and conditioning	5%

Since a transition to high production volumes was anticipated well before the lifetime of the manufacturing equipment, high-volume equipment was identified and used at the outset. The manufacturing processes utilize roll-to-roll style processing (instead of batch processing). This approach results in excess manufacturing capacity initially, but as production volumes increase over time the capacity is eventually exceeded. More equipment is bought as those limits are reached, phasing the cost of the manufacturing capital expenditures.

Cost estimates were developed for each piece of machinery in the manufacturing process. Quotes were gathered from vendors when possible, from published pricing information, resale listings, internet searches, and by engineering estimate when necessary. The same price was used across the various manufacturing line itemizations if a machine appears in multiple process lines.

Capital Cost Assumptions

Capital expenditures for production and equipment are amortized over a 20 year period and the annual amortized cost is distributed over production volume for that year. Capital cost assumptions are presented in Table 5 and operating cost assumptions are presented in Table 6. Equipment line costs were calculated by evaluating the type of equipment needed for various processes (Table 7), estimating line utilization at various production volumes (see Section 3), and calculating the number of pieces of equipment necessary for various production volumes (Table 8). Other financial assumptions are consistent with the DOE H2A model where it is

assumed 100% is financed at10% interest rate, and 40% tax rate, 10% decommissioning, and 10% depreciation apply.

Table 5 - Capital Cost Assumptions

Capital Cost	Unit Cost	Units	Total Cost (2010$)	Assumption/Reference
Factory Total Construction Cost	250	$/sq.ft.	4,034,780	Area based on line footprint plus 1.5x line space for working space, offices, shipping, etc. Includes Electrical Costs ($50/sq.ft.)
Production Line Equipment Cost	varies by component		6,847,500	Baseline Production = 2,000 units. As production increases, additional capital expenditures are needed. Manufacturer discussions and quotes. See Below for details
Additional Production Line Equipment Cost (Years 2-6)	varies by component		11,820,000	See below for details
Forklifts	25000	$/lift	50,000	Assumes 2 forklifts with extra battery and charger.
Cranes	66000	$/crane	198,000	5 ton crane, 20' wide per line
Real Estate	125,000	$/acre	125,000	Assumes 1 acre of vacant land, zoned industrial Columbus, OH
Contingency	10% Total Capital Cost		1,125,528	Construction Estimation Assumption
Total			***12,380,800 - 24,200,800***	**Baseline CC - Total CC**

Table 6 - Operations Cost Assumptions

Operations Cost	Unit Cost	Units	Total Cost (2010$)	Assumption/Reference
Forklift Maintenance and Battery Recharge	4	$/day/forklift	2,000	Assumes 250 Working days
Forklift Maintenance and Battery Recharge	4	$/day/forklift	2,000	Assumes 250 Working days
Crane Maintenance	3300	$/year	9,900	Assumes 5% CC, DOE H2A model assumes 4%CC for trucks
Insurance & Property Tax	2% Total Capital Cost		varies by production volume	DOE H2A model
Average Line O&M	9% of Line CC		616,280 - 1.68M	Average maintenance line component cost reported in DTI report
Total			***875,800 - 1.94M***	**Baseline OM - Total OM**

Table 7 - Manufacturing Line Specifications for 2,000 Units in 2010

Process Line	Item Description	Quantity Required Per Line
Membrane	Unwind stand with brake and tensioner	1
	Infra-red Oven	2
	alt: Microwave dryer	1
	Tension control	2
	Boiling water hydration tank	1
	Air dryer	1
	Rewind stand	1
Catalyst Application	Membrane coater	1
GDL production	Unwind stand with brake and tensioner	1
	PTFE solution bath	1
	Oven	1
	alt: Microwave dryer	1
	Spray depositer	1
	IR oven	1
	alt: Microwave dryer	1
	IR oven	1
	Rewind stand	1
Hot press	Unwind stand with brake and tensioner	3
	Hot pressing station	1
	Rewind stand	1
Cutting & Slitting	Unwind stand with brake and tensioner	1
	Slitter	1
	Guide rolls	4
	Cutters	3
	Stackers	3
Bipolar Plate Mfg	Compression molding press	1

Table 8 - Equipment Required for Various Production Volumes

	2010		2012		2015	
	# Units	Cost	# Units	Cost	# Units	Cost
Membrane mfg						
Catalyst application	1	1,575,000				
GDL mfg	1	3,175,000				
membrane slit	1	220,000				
GDL slit	1	257,500				
MEA mfg (hot press)	1	260,000			1	260,000
MEA slit and cut	1	535,000			1	535,000
Bipolar plates mfg	1	750,000	1	750,000	10	7,500,000
Gaskets	Outsourced					
Assembly	1	25,000	2	50,000	27	675,000
Testing	2	50,000	7	175,000	75	1,875,000
Total CC/year		**6,847,500**		**975,000**		**10,845,000**

Capital costs are amortized over 20 years and over the production volumes. Table 9 presents the capital costs for production based on volume. For example, when producing 2,000 units, approximately $570 of the total system costs are capital costs associated with manufacturing. Capital costs represent a diminishing portion of the fuel cell system cost with increasing production volume.

Table 9 - Capital Cost Assumption by Production Volume

Production Level (Units)	2010$/unit
2,000	540
4,500	270
10,000	120
21,000	80
46,000	50
100,000	25

2.6 Limitations of the Design Approach and Analysis

The approach for the analysis is to create a generic system that is representative of current industry technology and practice. The generic system is made from the merged non-proprietary input from multiple industry representatives and is defined at a high level. There are numerous tradeoffs to be considered when choosing a specific design feature or system specification characteristic. Since the decisions made to define the design and specification are the basis for the cost analysis, it is worthwhile to explicitly consider the impact, limitations, and justification for the choices made.

- Automotive market - The emergence of the automotive market will have huge impact throughout the fuel cell industry. The analysis was conducted assuming no significant automotive market existed for PEM fuel cells for two reasons: consistency in the cost analysis and the unknown details of the impact on the stationary market. Firstly, it is unlikely that a significant automotive market will be present in the years 2010 and 2012. Assuming that no automotive market existed in 2015 allows for a comparison of the cost projections based solely on the economies of scale for the target system. Secondly, when a substantial automotive market is realized, it is likely that economies of scale will propagate aspects of the automotive design through all PEM products. The design of a PEM system for automotive applications is different due to the prioritization of compact size, low weight, high power, and rapid response. For example while an automotive MEA may not be ideal for a stationary backup power application, it may still be implemented if technically acceptable since the production volume will offer a significant cost advantage. Since the exact technologies that would transfer and their associated costs are still to be determined, the analysis was done assuming no significant automotive market.

- Production quantities - The quantities of systems produced in 2010, 2012, and 2015 are representative of the entire industry and not of a single manufacturer. There is currently not a dominant manufacturer in terms of market share; the 2010 sales volume is split among the handful of manufacturers. As such the volume pricing of commodities and

materials is slightly lower than what any individual manufacturer may realize when purchasing smaller quantities (i.e. 400 units in 2010 for a single manufacturer rather than 2,000 units considered in the analysis). The differential in cost is more significant for items very specific to this fuel cell application like the hydrogen regulator or DC/DC converter. The difference in cost between 400 and 2,000 units for common, mass-produced items like fittings and valves is rather small. It is unknown whether a dominant manufacturer will emerge by 2012 or 2015 or if the manufacturers will continue to have similar market shares. As with 2010, the cost analysis considered production quantities that represent the entire market so any individual manufacturer may not realize quantity discounts to the degree shown in the cost analysis.

- High volume manufacturing - Having established the production quantities, the cost analyses are performed from the perspective of building a manufacturing operation capable of producing the quantities in the years specified. Since mass production quantities are achieved well before standard equipment lifetimes are reached, it is logical to select high-volume equipment at the start of operations. The cost analysis shows the equipment is underutilized for the 2010 quantities and to a lesser extent for the 2012 quantities. However it does not make sense to make any significant investment in equipment more suited for smaller batch manufacturing if it will be inadequate within a few years. The assumption of high volume manufacturing techniques will tend to underestimate the 2010 cost of the system compared to what manufacturers currently realize. This is attributable to several factors. Firstly, although high volume production approaches may be used for several of the components (membrane, GDL, etc.), the fabrication currently involves some level of more labor intensive batch manufacturing (catalyst application, MEA hot press, etc.). Secondly, this cost analysis has the advantage of building the production facility from scratch. The ideal high volume production equipment to produce the quantities desired is chosen. Many manufacturers have already made a significant investment in equipment in prior years without the luxury of the assumption that high production volumes will come to fruition. The existing equipment may not be as cost-effective as the high volume production equipment or the need to recover the capital investment may inhibit the manufacturer's ability to implement changes. Finally, the cost analysis assumes a production of 2,000 identical systems in 2010. In actual practice there is a fast-paced evolution of core technologies for fuel cells. To deliver a *better* product, manufacturers are continually developing and refining their materials and design.

- Fuel cell design - The variety of products currently on the market for the target application indicates there are several alternate stack and system designs, each with their own merits and drawbacks. The cost analysis is performed using a single general fuel cell system design suitable for the target application. The chosen design is representative of one of many valid design approaches.

3.0. COST ANALYSIS RESULTS

3.1 "As Is" 2010 System Cost Analysis Results

Total System Costs

The total system cost, pre-markup, for 2010 (2,000 units produced) is $6,896 (Table 10), $1,379 per kW. A breakdown of this cost is presented in Figure 6. The system cost is dominated by the stack and balance of plant, 38% and 49% of the total respectively. The costs for capital equipment and final assembly are minor contributors. With mark-up of approximately 50% total system costs are $10,345 or $2,069 per kW.

Table 10 - 2010 (2,000 Units) Total System Costs with Mark-up

2010 sales volume:	2000
Total stack manufacturing cost, with scrap	$ 2,636
Stack manufacturing capital cost	$ 540
BOP, less structure	$ 3,403
System assembly, test, and conditioning	$ 318
Total system cost, pre-markup	**$ 6,896**
System cost per KW_{net}, pre-markup	**$ 1,379**
Sales markup	50.0%
Total system cost, with markup	**$10,345**
System cost per KW_{net}, with markup	**$ 2,069**

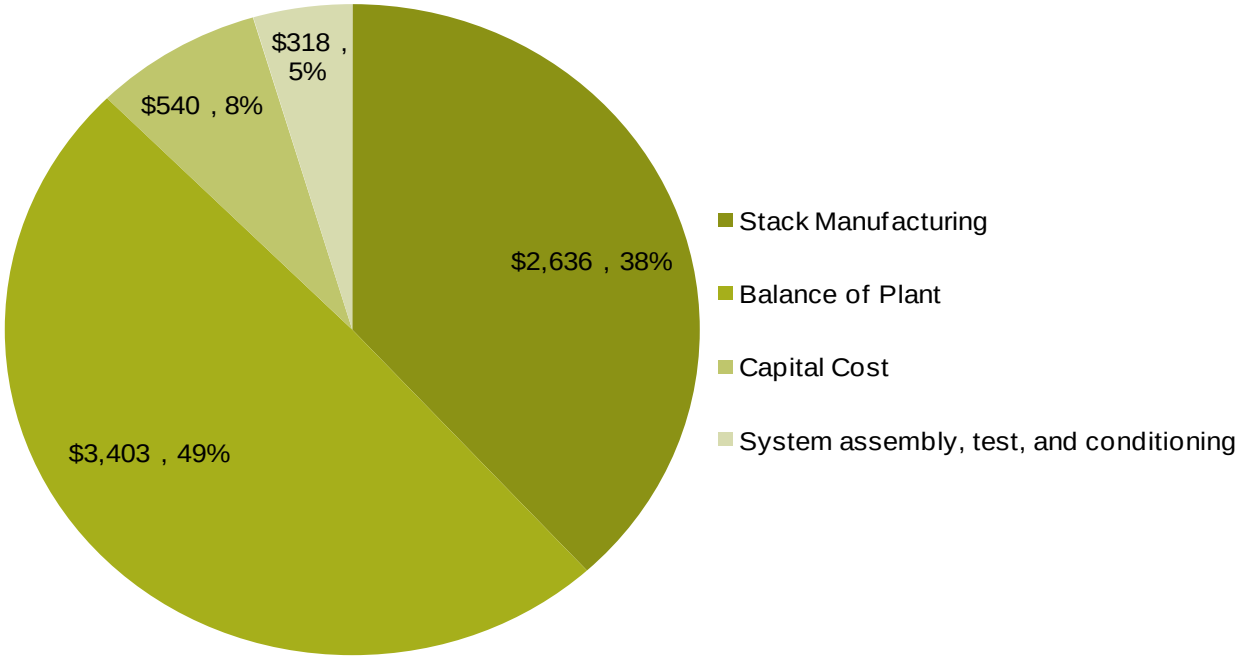


Figure 6 - 2010 (2,000 Units) System Cost Breakdown by Major Manufacturing Area

Stack Manufacturing Costs

The stack manufacturing costs for the fuel cell stack are broken down by component in Table 11. The major contributors to the stack costs are the bipolar plates and the MEA, contributing 33% and 57% of the total stack cost respectively.

Table 11 - 2010 (2,000 Units) Stack Manufacturing Cost Breakdown by Component

Stack Component	2010 cost per 5 kW stack	Qty per stack	Qty per cell	2010 Unit Cost
Bipolar plates	$862	155	2	$5.56
MEA	$1,513	77	1	$19.64
Cathode side gasket	$49	77	1	$0.64
Anode side gasket	$52	77	1	$0.68
Cooling gasket	$49	77	1	$0.64
End gaskets	$1	2		$0.64
Tie rods and hardware	$40	8		$5.00
End plates	$28	2		$14.11
Stack assembly	$41	1		$40.89
Total	**$2,636**			

The component costs shown in Table 11are further broken down by manufacturing process to identify the fundamental drivers of cost. This breakdown is shown in Figure 7. In general, raw material costs are the largest contributor to the component cost. Processing and tooling costs are much smaller. Only in the case of the compression-molded, composite, bipolar plates are the costs somewhat equally distributed among raw materials, processing, and tooling.

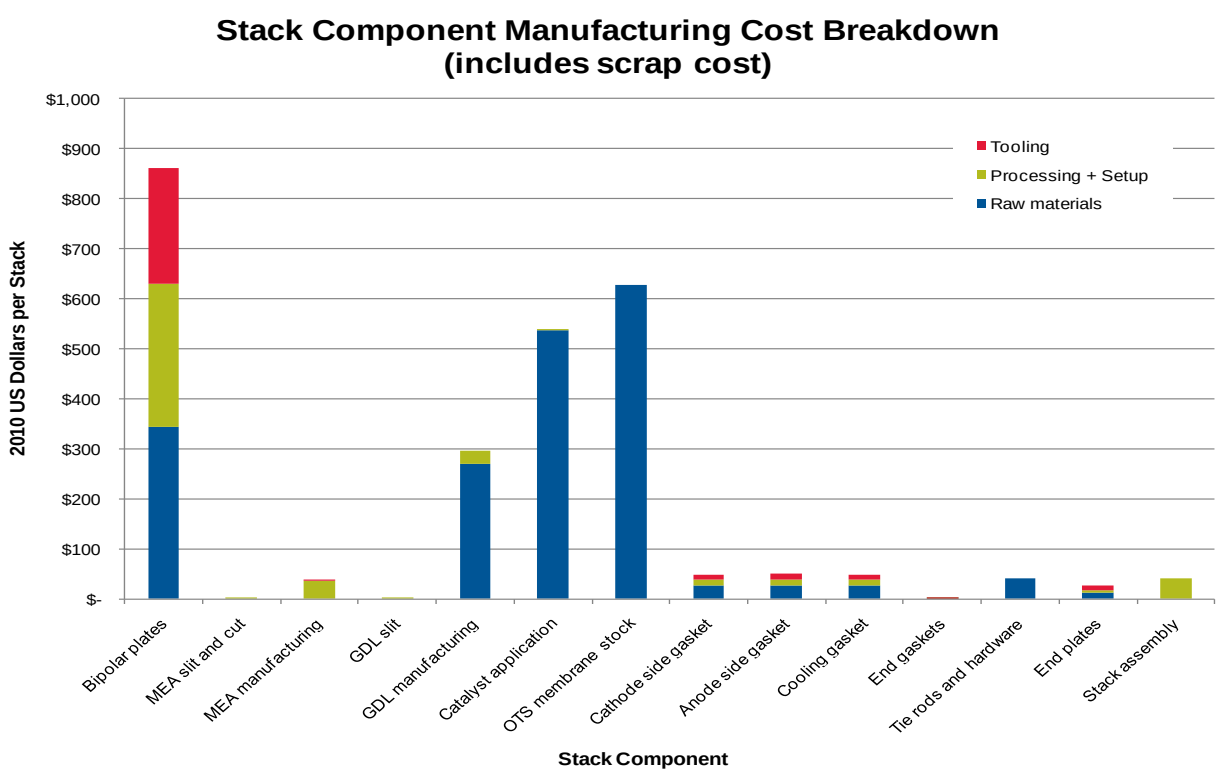


Figure 7 - 2010 (2,000 Units) Stack Component Manufacturing Cost Breakdown

The BOP costs are tabulated in Table 12. The DC/DC converter is the single largest cost item comprising 37% of the total cost of BOP components. Fans, blowers, and the ECU are the next highest cost items. The cost for the cooling air fan (exterior of stack) and blower (interior of stack) for quantities of 2,000 units annually totals $305. The system configuration for 2010 has cooling channels between two bipolar plates. The system could be water cooled with the same configuration. To enable that, the cooling fan and blower would be replaced with a coolant pump and a radiator/fan. That change in BOP components is not expected to have a significant impact on the total system cost.

Table 12 - 2010 (2,000 Units) System BOP Summary

BOP Component	Unit Cost
Air Filter (Cooling Air)	$28
Fan (Cooling Air)	$155
Blower (Cooling Air)	$150
Air Filter (Cathode Air)	$83
Blower (Cathode Air)	$320
Flow Meter (Cathode Air)	$99
Relief Valve	$130
Anode Purge Valve	$40
Stack Temperature Sensor	$18
Stack Current Sensor	$15
Stack Voltage Sensor	$60
DC/DC Converter	$1,250
Fuel Cell ECU	$380
H2 Shutoff Valve	$55
Enclosure Heater	$30
Enclosure Heater Relay	$3
Assorted Plumbing/Fittings	$160
Buss Bar	$16
H_2 Sensor	$124
Wiring and Connectors	$50
Assembly Hardware	$30
Frame	$207
Total	**$3,403**

Manufacturing Process – Line Utilization

At initial and low-volume production, much of the capacity of the manufacturing equipment goes unused. In some cases, the entire year's production can be run in a few calendar days. However, by business model definition, the equipment purchase at the beginning is justified by the rapidly increasing production quantities over the five year period of study. Despite much of the machinery's production capacity potentially going unused in the first few years, the unused capacity represents, by way of capital costs allocated to each unit, a small portion of the system cost.

Battelle defined line utilization as the number of machine hours necessary to produce the annual quantity, divided by the total number of annual machine hours available, express as a percentage.

The annual machine hours available are the number of machines times 24 hours (3 8-hour shifts) in a day. A summary is presented in Table 13.

Line utilization is useful for identifying process bottlenecks. From the results presented in Table 13, system test and conditioning is an obvious bottleneck, requiring two test stations running for a large number of the available hours. The fundamental driver of the utilization is the assumption that each stack requires 4 hours of test and conditioning. That assumption was generally supported by industry feedback, along with a recognition that the time for conditioning will drop considerably as production quantities increase. Although it is somewhat of a bottleneck, test and conditioning is not a large issue since its overall contribution to the total system cost is low (5%, Figure 6). Bipolar plate forming is likely to become a bottleneck once higher quantities are produced. For this, and any of the manufacturing processes, the bottleneck is readily addressed by implementing additional manufacturing equipment. Since the stack cost is largely determined by materials and not capital equipment, adding manufacturing equipment has a relatively small impact on system cost.

Table 13 - 2010 (2,000 Units) System Manufacturing Line Utilization

Manufacturing Process	Quantity	Utilization (%)
Membrane slit-to-width	1	0.4
Catalyst application	1	0.8
GDL fabrication	1	1.7
MEA hot press	1	17.6
Bipolar plate forming	1	68.4
Stack assembly	1	9.9
Test and conditioning	2	83.3

3.2 2012 System Cost Analysis Results

Total System Costs

The total system cost, pre-markup, for 2012 (10,000 units produced) is $5,082 (Table 14) ($1,016 per kW). With mark-up, the total cost of the system is $7,624 ($1,525 per kW). This is a reduction of $1,814 from the 2010 system total cost. A breakdown of this cost is presented in Figure 8. As with 2010, the system cost is dominated by the stack and balance of plant (31% and 61% of the total respectively). The costs for capital equipment and final assembly remain minor contributors.

The actual cost of both the stack and balance of plant decreased from 2010 to 2012. On a percentage basis, for both 2010 and 2012, stack and balance of plant comprise approximately 90% of the total system cost. The split between the two changed from 40/50 stack/BOP in 2010 to 30/60 in 2012. Since many of the balance of plant components are used in a wide variety of industries, their production quantities are sufficiently high that the economies of scale are already realized. Minimal reductions in pricing are offered as part of a volume purchasing agreement.

Table 14 - 2012 (10,000 Units) Total System Costs with Mark-up

System	Costs	
Total stack manufacturing cost, with scrap	$1,556	
Stack manufacturing capital cost	$ 120	
BOP, less structure	$3,089	
System assembly, test, and conditioning	$ 318	
Total system cost, pre-markup	**$5,082**	
System cost per KW_{net}, pre-markup	**$1,016**	
Sales markup		50.0%
Total system cost, with markup	**$7,624**	
System cost per KW_{net}, with markup	**$1,525**	

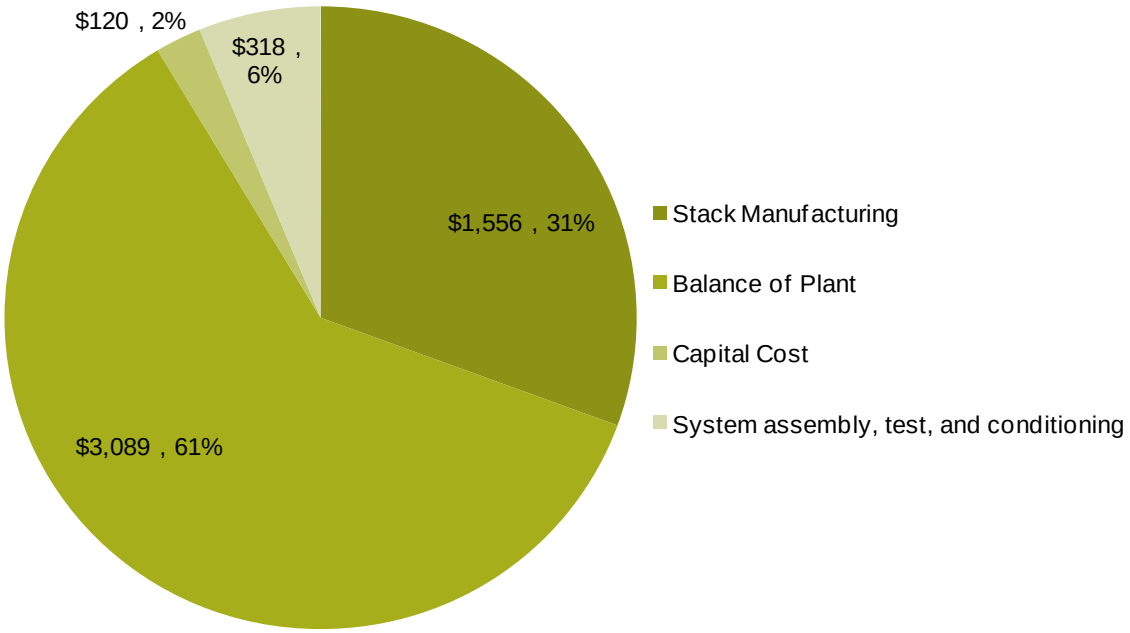


Figure 8 - 2012 (10,000 Units) System Cost Breakdown by Major Manufacturing Area

Stack Manufacturing Costs

The stack manufacturing costs for the fuel cell stack are broken down by component in Table 15. The major contributors to the stack costs are the bipolar plates and the MEA, contributing 24% and 63% of the total stack cost respectively.

Relative to 2010, the total cost for bipolar plates dropped by nearly $500. The unit cost dropped by $0.86 from 2010 to 2012. Increased production quantities therefore account for about $67 of the $500 reduction. The rest of the reduction is achieved by combining the cooling and cathode air streams and reducing the number of bipolar plates required.

Table 15 - 2012 (10,000 Units) Stack Manufacturing Cost Breakdown by Component

Stack Component	2012 cost per stack	Qty per stack	Qty per cell	2012 Unit Cost
Bipolar plates	$367	78	1	$4.70
MEA	$981	77	1	$12.73
Cathode side gasket	$49	77	1	$0.63
Anode side gasket	$51	77	1	$0.66
Cooling gasket	-	0	0	-
End gaskets	$1	2		$0.63
Tie rods and hardware	$40	8		$5.00
End plates	$27	2		$13.55
Stack assembly	$41	1		$40.89
Total	**$1,556**			

The stack MEA cost also dropped by approximately $500 from 2010 to 2012. About 25% of the reduction is due to increased production quantities. The remaining 75% of the reduction is attributed to the assumed technological advances of higher operating current density, higher membrane utilization, and reduced catalyst loading.

The component costs shown in Table 15are further broken down by manufacturing process to identify the fundamental drivers of cost. This breakdown is shown in Figure 9. As with 2010, raw material costs are the most significant constituent of the total cost. The exception remains the bipolar plates, which are equally split among raw materials, processing, and tooling.

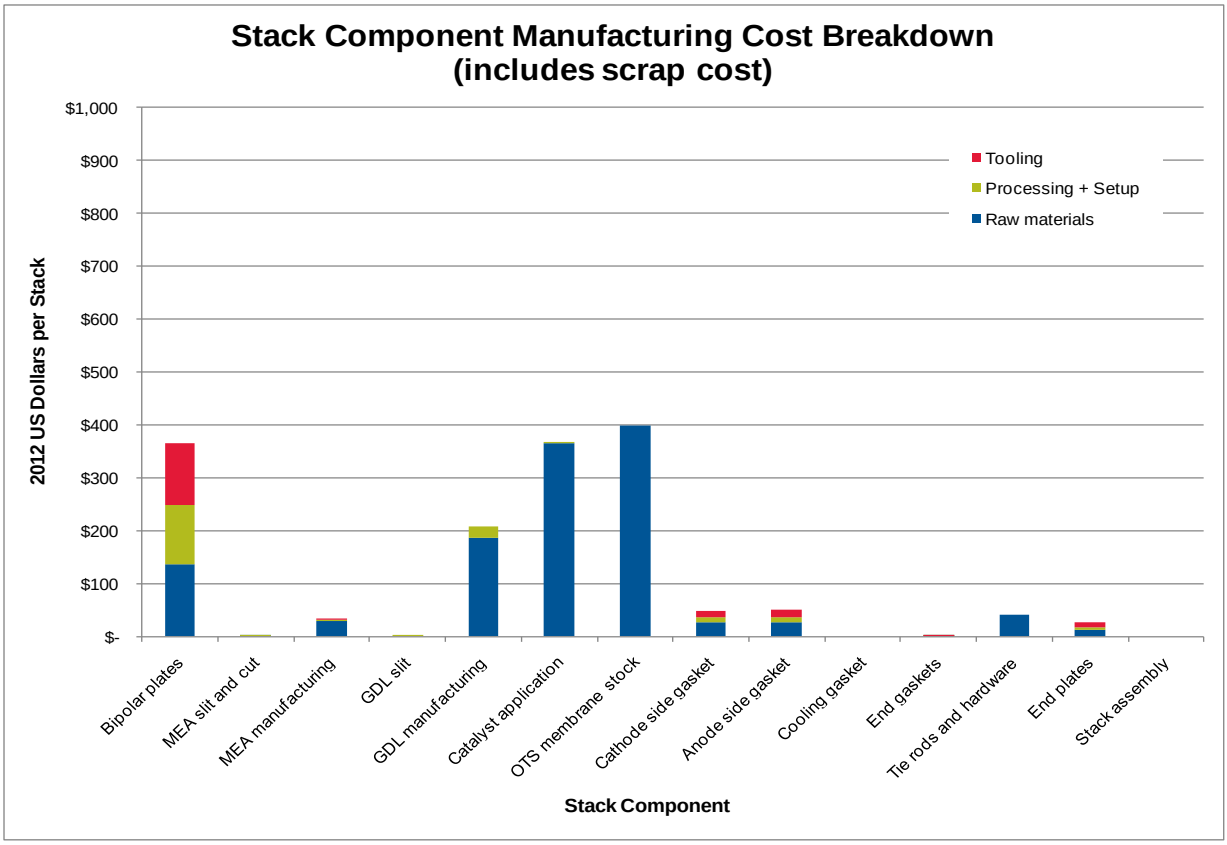


Figure 9 - 2012 (10,000 Units) Stack Component Manufacturing Cost Breakdown

Balance of Plant Costs

The BOP costs for the 5 kW system at production volumes of 10,000 units are tabulated in Table 16. The DC/DC converter is the single largest cost item comprising 36% of the total cost of BOP components. Fans, blowers, and the ECU are the next highest cost items.

Table 16 - 2012 (10,000 Units) System BOP Cost Summary

BOP Component	Unit Cost
Air Filter (Cooling Air)	$23
Fan (Cooling Air)	$142
Blower (Cooling Air)	-
Air Filter (Cathode Air)	$48
Blower (Cathode Air)	$440
Flow Meter (Cathode Air)	$93
Relief Valve	$130
Anode Purge Valve	$35
Stack Temperature Sensor	$17
Stack Current Sensor	$11
Stack Voltage Sensor	$57
DC/DC Converter	$1,125
Fuel Cell ECU	$380
H2 Shutoff Valve	$53
Enclosure Heater	$25
Enclosure Heater Relay	$3
Assorted Plumbing/Fittings	$156
Buss Bar	$12
H2 Sensor	$115
Wiring and Connectors	$50
Assembly Hardware	$30
Frame	$144
Total	**$3,089**

Manufacturing Process – Line Utilization

A summary of the manufacturing line utilization is presented in Table 17. Note that additional lines are implemented on the bipolar plate forming, stack assembly, and test and conditioning processes. The capital costs for these additional lines are included in the 2012 system total.

Table 17 – 2012 (10,000 Units) Manufacturing Process Line Utilization

Manufacturing Process	Quantity	Utilization (%)
Membrane slit-to-width	1	1.7
Catalyst application	1	3.3
GDL fabrication	1	6.6
MEA hot press	1	68.8
Bipolar plate forming	2	57.0
Stack assembly	3	100.0
Test and conditioning	9	92.6

3.3 2015 (100,000 Units) System Cost Analysis Results

Total System Costs

As shown in Table 18, the total system cost, pre-markup, for 100,000 units produced is $4,220 ($844 per kW). Total system with markup is $6,330 ($1,266 per kW) . This is a reduction of $2,676 from the 2010 system total cost. A breakdown of this cost is presented in Figure 10. The system cost is dominated by the stack and balance of plant, 24% and 68% of the total respectively. The costs for capital equipment and final assembly remain minor contributors.

Table 18 - 2015 (100,000 Units) Total System Costs with Mark-up

System	Costs
Total stack manufacturing cost, with scrap	$1,017
Stack manufacturing capital cost	$ 25
BOP, less structure	$2,860
System assembly, test, and conditioning	$ 318
Total system cost, pre-markup	**$4,220**
System cost per KW_{net}, pre-markup	**$ 844**
Sales markup	50.0%
Total system cost, with markup	**$6,330**
System cost per KW_{net}, with markup	**$1,266**

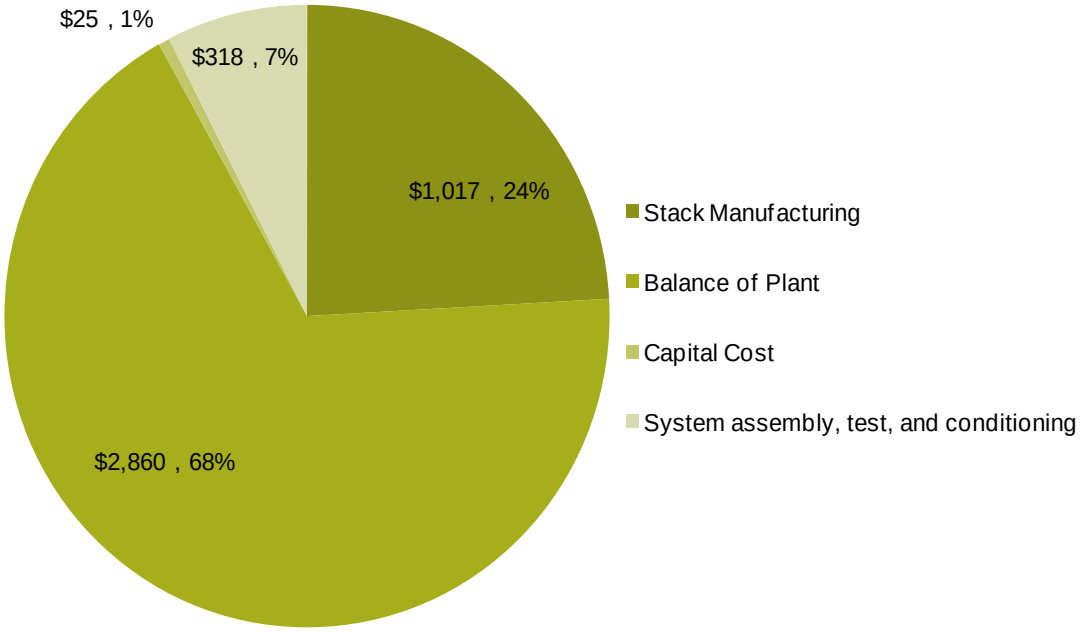


Figure 10 - 2015 (100,000 Units) System Cost Breakdown by Manufacturing Area

The actual cost of both the stack and balance of plant decreased from 2010 to 2012 and again from 2012 to 2015. On a percentage basis, for all years and quantities considered, stack and balance of plant comprise approximately 90% of the total system cost. The split between the two changed from 40/50 stack/BOP in 2010 to 25/65 in 2015. Again this reflects that many of the balance of plant components are already produced in high quantities and little in terms of economies of scale is expected to be realized.

Stack Manufacturing Costs

The stack manufacturing costs for the fuel cell stack are broken down by component in Table 19. The major contributors to the stack costs are the bipolar plates and the MEA, contributing 31% and 49% of the total stack cost respectively.

Relative to 2012, the total cost for bipolar plates dropped by nearly $47. This costs reduction is achieved entirely through increased production volume.

The MEA cost also dropped by over $1,000 from 2010 to 2015. About 25% of the reduction is due to increased production quantities. The remaining 75% of the reduction is attributed to the assumed technological advances of higher operating current density, higher membrane utilization, and reduced catalyst loading.

Table 19 - 2015 (100,000 Units) Stack Manufacturing Cost Breakdown by Component

Stack Component	2015 cost per stack	Qty per stack	Qty per cell	2015 Unit Cost
Bipolar plates	$320	78	1	$4.10
MEA	$497	77	1	$6.45
Cathode side gasket	$47	77	1	$0.61
Anode side gasket	$49	77	1	$0.64
Cooling gasket	-	0	0	-
End gaskets	$1	2		$0.61
Tie rods and hardware	$40	8		$5.00
End plates	$22	2		$11.02
Stack assembly	$41	1		$40.89
Total	**$1,017**			

The component costs shown in Table 19are further broken down by manufacturing process to identify the fundamental drivers of cost. This breakdown is shown in Figure 11. As with 2010, raw material costs are the most significant constituent of the total cost. The exception remains the bipolar plates, which are equally split among raw materials, processing, and tooling.

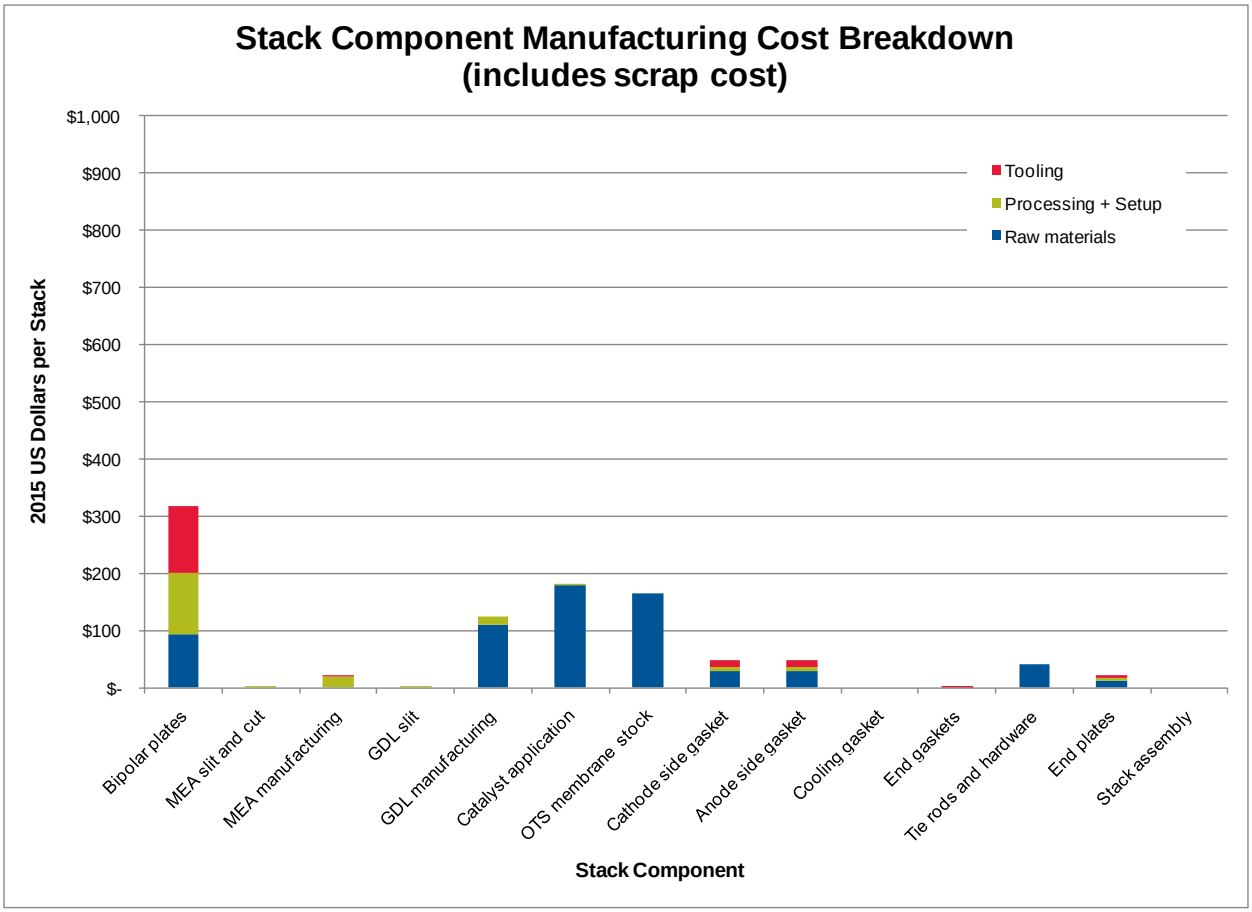


Figure 11 - 2015 (100,000 Units) Stack Component Manufacturing Cost Breakdown

Balance of Plant

The BOP costs are tabulated in Table 20. The DC/DC converter is the single largest cost item comprising 35% of the total cost of BOP components. Fans, blowers, and the ECU are the next highest cost items.

Table 20 - 2015 (100,000 Units) System BOP Cost Summary

BOP Component	Unit Cost
Air Filter (Cooling Air)	$21
Fan (Cooling Air)	$132
Blower (Cooling Air)	-
Air Filter (Cathode Air)	$35
Blower (Cathode Air)	$400
Flow Meter (Cathode Air)	$86
Relief Valve	$130
Anode Purge Valve	$25
Stack Temperature Sensor	$16
Stack Current Sensor	$10
Stack Voltage Sensor	$55
DC/DC Converter	$1,000
Fuel Cell ECU	$380
H2 Shutoff Valve	$51
Enclosure Heater	$25
Enclosure Heater Relay	$3
Assorted Plumbing/Fittings	$150
Buss Bar	$10
H2 Sensor	$107
Wiring and Connectors	$50
Assembly Hardware	$30
Frame	$144
Total	**$2,860**

Manufacturing Process Costs - Line Utilization

A summary of the manufacturing line utilization is presented in Table 21. Note that additional lines are implemented on the MEA hot press, bipolar plate forming, stack assembly, and test and conditioning processes. The capital costs for these additional lines are included in the 2015 system total.

Table 21 - 2015 (100,000 Units) Manufacturing Process Line Utilization

Manufacturing Process	Quantity	Utilization (%)
Membrane slit-to-width	1	11.4
Catalyst application	1	22.8
GDL fabrication	1	45.6
MEA hot press	2	79.1
Bipolar plate forming	12	95.1
Stack assembly	30	100.0
Test and conditioning	84	99.2

3.4 DFMA Insights into Stack Cost Reduction

From a DFMA perspective, ongoing commercial and academic research into fuel cell systems and their components might have a substantial effect on fuel cell cost. In contrast to processes like metal forming or plastics manufacturing where the process to convert a raw material to

finished good is typically well-defined and can be accomplished by a variety of methods, fewer fuel cell and component manufacturing techniques exist in comparison, the processes vary from company to company, and the techniques are rapidly evolving. In many cases, these processes are tailored to the specialized fuel cell materials in use – such as handling of PFSA film. New fuel cell stack materials or technologies could drastically alter the manufacturing steps required and the resultant component cost.

From a standpoint focused purely on manufacturing processes, there are several design improvements that can help reduce costs of the system by simplifying manufacturing processes and reducing material consumption. As these improvements seek to drastically simplify the design and construction, any implementation would need to trade off the possible cost reduction with the associated impact on fuel cell operation. For example, simplifying bipolar plate geometry could reduce costs, but also adversely affect the flow distribution within each cell. These design improvements extend beyond those considered in the cost analyses in this report. Several key design improvements are detailed below –

1. Eliminate separate cooling air stream and integrate with the air fuel supply stream.
   The Battelle fuel cell implements this change in 2012 and 2015 systems. This concept is currently being manufactured in industry and does not require a fundamental PEM fuel cell technology change. Benefits to the system include eliminating one blower, air filter, and associated plumbing, approximately halving the number of bipolar plates and gaskets in the stack, and reducing the number of stack assembly steps.
2. Integrate sealing function into the membrane.
   Reinforced membranes are typically produced on a Teflon substrate. Teflon can also be used as a gasket material. Given the pressures, temperatures, and leak tolerance of the PEM fuel cell application, an integral Teflon seal seems feasible. Benefits to the system include eliminating separate component gaskets and the associated assembly steps.
3. Mathematically optimize the membrane area.
   Use a weighted optimization to ensure that the cell area maximizes power density (considering edge effects, gas distribution), minimizes waste of raw materials (size the cell to maximize whole cells per width and length of roll material), and assembly steps and time.
4. Simplify the bipolar plate geometry.
   From the perspective of function, channeled bipolar plates and the GDL both facilitate a satisfactory gas distribution. Eliminating channels from the bipolar plates and relying solely on the GDL for distribution is attractive because the bipolar plate forming operation is the major cost driver. Industry feedback suggests this is already being done in some cases. Since bipolar plates represent such a large cost in the stack, this is a valuable opportunity.
5. Eliminate reinforcement of the membrane).
   Unreinforced membranes are in use today, however they generally trade durability for simplicity of construction. If possible to achieve system performance requirements with an unreinforced membrane, the manufacturing equipment, process steps, and cost are reduced. Reinforced membranes currently represent a 20-30% premium over their unreinforced counterparts.

6. Improve means of stack alignment and assembly.
   Using through-style compression components (like tie rods) may require that the MEAs, gaskets, and bipolar plates are sized to accommodate these components, which increases component cost due to the larger consumption of raw materials. Considering other approaches to align and constrain the stack layers could allow these components to be reduced in size and cost. Tie rods could still be used to apply the assembly pressure.

4.0 SENSITIVITY ANALYSIS

4.1 Sensitivity Analysis Assumptions

The sensitivity analysis of the costs for a 5 kW system at varying production volumes (2,000 10,000 and 100,000) analyzes the impact of slight variations to the assumptions for the major contributing cost factors and highlights their significance. The cost factors for the analysis were chosen because of their significant contribution to the cost and/or the difficult nature of precisely assessing their magnitude, such as the cost of platinum. The analysis demonstrates the effect to the overall cost of the stack based on reasonable variations to each factor.

The cost factors that were varied for the analysis include:

- Catalyst application scrap rate
  - Assumed to be 30%
  - Varied by +/- 10%
- Platinum loading
  - Assumed to be 0.4, 0.35 and 0.25 mg/cm^2 for 2010, 2012 and 2015 respectively
  - Varied by +/- 0.1 mg/cm^2
- PFSA Cost
  - Assumed to be $247, $202 and $120 per m^2 for 2010, 2012 and 2015 respectively
  - Varied by +/- 10%
- Platinum cost
  - Assumed to be $1,100 per troy ounce
  - Varied by +/- 20%
- GDL scrap rate
  - Assumed to be 30%
  - Varied by +/- 10%
- Bipolar plate material cost
  - Assumed to be $11, $6.75 and $3.75 per kg for 2010, 2012 and 2015 production volumes respectively
  - Varied by +/- 10%
- PTFE cost
  - Assumed to be $18, $11 and $3 per kg for 2010, 2012 and 2015 production volumes respectively
  - Varied by +/- 10%

4.2 Sensitivity Analysis Results

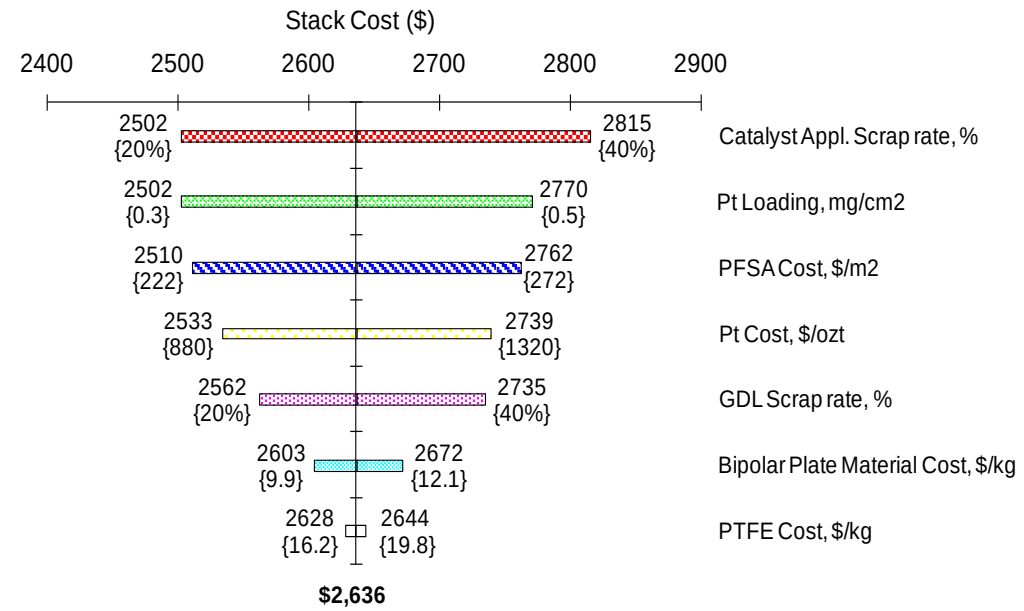
Catalyst application scrap rate is the principal sensitivity factor in the sensitivity analysis at production volumes of 2,000 and 10,000 units and is the second leading sensitivity factor at a production volume of 100,000 (Figure 12, Figure 13, Figure 141, 4-2, and 4-3). A scrap rate of 30% is a reasonable estimate for newer operations. As production volume goes up the experience gained could allow for reductions in scrap rate, presenting an excellent opportunity for cost reduction.

Platinum loading is the second highest sensitivity factor in 2010 and 2012 and the primary factor in 2015. In all years and production volume, lowering the platinum loading is extremely beneficial, but needs to be weighed against achievable current density at the given loading which will drive the necessary active area. Because of the importance of platinum loading levels, water cooled systems potentially become more attractive due to their ability to potentially handle lower catalyst loading for an equivalent current density.

The estimate for the GDL scrap rate is also rather conservative at 30%. Although it has less impact than the catalyst application scrap rate, it still holds great potential for cost reduction, particularly at the higher production volumes.

Platinum cost is somewhat unpredictable. For this analysis it was varied by +/- 20%, but could potentially vary even greater. This also contributes greatly to other major factors such as the catalyst application scrap rate and platinum loading.

The bipolar plate material cost, PFSA material cost, and PTFE cost round out the bottom of the sensitivity analysis, but all three still present a significant opportunity for cost reduction.



X-axis is cost ($) of fuel cell stack. Numbers in brackets are the values of the cost drivers.

Figure 12 - 2010 (2,000 Units) Sensitivity Analysis

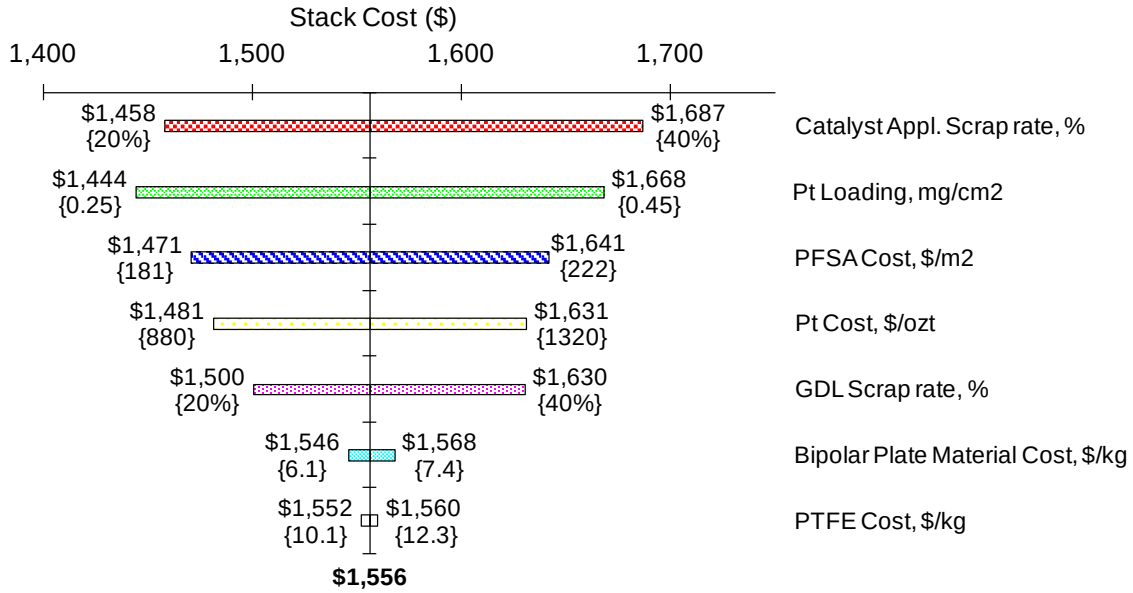


Figure 13 - 2012 (10,000 Units) Sensitivity Analysis

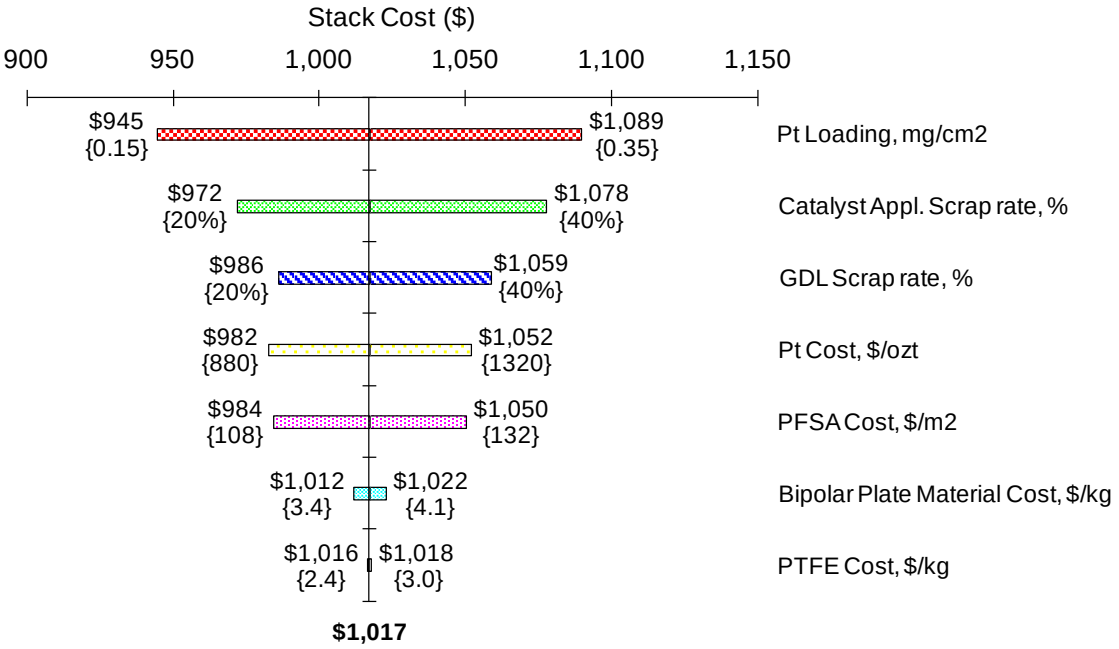


Figure 14 - 2015 (100,000 Units) Sensitivity Analysis

5.0 CONCLUSIONS

A summary of the costs of the different components, assembly, and capital equipment by stack, BOP, and system are presented in Table 22.

Table 22 - Summary of Costs for Varied Production Levels to 2015 for 5 kW Direct Hydrogen PEM Fuel Cells for Backup Power Applications

Components	2010 (2,000 Units) Cost Per Stack	2010 (2,000 Units) Each Cost	2012 (10,000 Units) Cost per Stack	2012 (10,000 Units) Each Cost	2015 (100,000 Units) Cost per Stack	2015 (100,000 Units) Each Cost
Bipolar plates	$862	$5.56	$367	$4.70	$320	$4.10
MEA	$1,513	$19.64	$981	$12.73	$498	$6.46
Cathode side gasket	$49	$0.64	$49	$0.63	$47	$0.61
Anode side gasket	$52	$0.68	$51	$0.66	$49	$0.64
Cooling gasket	$49	$0.64	-	-	-	-
End gaskets	$1	$0.64	$1	$0.63	$1	$0.61
Tie rods and hardware	$40	$5.00	$40	$5.00	$40	$5.00
End plates	$28	$14.11	$27	$13.55	$22	$11.02
Stack assembly	$41	$40.89	$41	$40.89	$41	$40.89
Stack Subtotal	$2,635		$1,557		$1,018	
BOP Cooling	$333		$305		$278	
BOP Cathode	$502		$441		$396	
BOP Anode	$225		$218		$206	
BOP Sensors	$217		$200		$188	
BOP ECU	$380		$380		$380	
BOP DC/DC Converter	$1,250		$1,125		$1,000	
BOP Frame	$207		$144		$144	
BOP Misc. Components (Fittings, Tubing, Wiring, Connectors, etc.)	$289		$276		268	
BOP Subtotal	$3,403		$3,089		$2,860	
Stack Subtotal	$2,635		$1,557		$1,018	
BOP Subtotal	$3,403		$3,089		$2,860	
Capital Cost	$540		$120		$25	
System Assembly, Test, and Conditioning	$318		$318		$318	
System Total	$6,896		$5,084		$4,221	
$/kW	$1,379		$1,017		$844	

The current "as-is" system at production volumes of 2,000 units using high volume manufacturing techniques are approximately $1,379 per kW. Cost can be expected to decline to $1,016 per kW and $844 per kW based on projected design improvements to the proposed "as is" stack and system design and an increase in production to 10,000 units and 100,000 units respectively.

Major design improvements considered included increases in current density from 0.7 A/cm^2 to 0.8 A/cm^2 and 1.0 A/cm^2, membrane utilization from 61% to 68% and 79%, platinum loading from 0.4 mg/cm^2 to 0.35 mg/cm^2 and 0.25 mg/cm^2, and reduction in bipolar plates from 155 to 78 plates respectively.

Major contributors to the system cost are the bipolar plates, MEA, and the DC/DC converter. The main drivers to MEA cost are the raw materials, most specifically catalyst materials. Catalyst application and platinum loading are identified as key opportunities for reducing stack costs. A reduction in scrap rates during catalyst application and preparation of the gas diffusion layer can have a significant impact on costs of manufacturing. System costs are heavily influenced by the BOP costs. BOP costs are driven by the DC/DC converter and the cathode air blower. The lack of a suitable off-the-shelf DC/DC converter is a significant obstacle. Further work to understand the application requirements and the drivers for DC/DC converter cost is recommended.

At initial and low-volume production, much of the capacity of the manufacturing equipment goes unused. In some cases, the entire year's worth of production can be run in a few calendar days. The bottlenecks in production include bipolar plate-forming, stack assembly, and test and conditioning. Despite being limitations to productivity, the system cost impact of these bottlenecks is mostly low since raw material costs are the predominant expense in stack production. Of the group, eliminating the bipolar plate-forming bottleneck will have the most impact on stack cost. This can be achieved by emerging technologies like flat/unformed sheet metal or foils. Industry feedback indicates that test and conditioning time will decrease significantly over the next 5 years, providing a modest opportunity for cost reduction.