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FUEL CELL POWER SYSTEMS FOR REMOTE APPLICATIONS

Phase I Final Report and Business Plan

Prepared By: Teledyne Brown Engineering, Energy Systems, Hunt Valley MD
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City of Palm Desert, Palm Desert CA

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PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY
Under Cooperative Agreeement
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February 10, 1998

Refer to: TBE-ES/WCK-005

Attn: Mr. John P. Motz
U.S. Department of Energy
Golden Field Office
1617 Cole Boulevard
Golden, CO 80401-3393

Ref.: Cooperative Agreement DE-FC36-97GO10217

Dear Mr. Motz:

Teledyne Brown Engineering - Energy Systems is pleased to submit this Final Report and Business Plan covering the work accomplished under the referenced Cooperative Agreement. We and the other members of our team wish to express our appreciation for the opportunity to participate in the Hydrogen Feasibility Studies Program.

We believe our Phase I effort to examine "Fuel Cell Power Systems for Remote Applications" has determined that the product envisioned at the onset of the project is feasible; the market potential is high and the ultimate target price to capture a significant piece of that market is attainable. Coincidentally, Energy Systems expects to introduce a state-of-the-art engine- generator set into the same market place this year, beginning with several beta sites. We have discussed the fuel cell product being pursued in this program with beta site candidates and have a high found level interest. One candidate in particular is the Alyeska Pipeline Company with offices in Fairbanks, Alaska.

We remain confident that completion of the program through Phases II, III and IV will provide the necessary incentives to ultimately proceed with commercialization.

We look forward to continuing this exciting work and to a positive decision/response on the part of the Department of Energy. If you have any questions or comments, please do not hesitate to contact me.

Sincerely,

William C. Kincaide

William C. Kincaide
General Manager

pld

cc: Dr. Sigmund Gronich, DOE-HQ/EE-13
Dr. Neil Rossmeissei, DOE-HQ/EE-13

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Abstract

The goal of the Fuel Cell Power Systems for Remote Applications project is to commercialize a 0.1-5 kW integrated fuel cell power system (FCPS). The project targets high value niche markets, including natural gas and oil pipelines, off-grid homes, yachts, telecommunication stations and recreational vehicles. Phase I includes the market research, technical and financial analysis of the fuel cell power system, technical and financial requirements to establish manufacturing capability, the business plan, and teaming arrangements. Phase I also includes project planning, scope of work, and budgets for Phases II-IV. The project is a cooperative effort of Teledyne Brown Engineering - Energy Systems, Schatz Energy Research Center, Hydrogen Burner Technology, and the City of Palm Desert.

Phases II through IV are designed to utilize the results of Phase I, to further the commercial potential of the fuel cell power system. Phase II focuses on research and development of the reformer and fuel cell and is divided into three related, but potentially separate tasks: A, B and C. Budgets and timelines for Phase II can be found in section IV of this report. Phase II includes:

- Task A - Develop a reformate tolerant fuel cell stack and 5 kW reformer. The deliverable at the end of Phase II, Task A will be a research report.

- Task B - Assemble and deliver a fuel cell that operates on pure hydrogen to the University of Alaska or another site in Alaska. The fuel cell would be based on the design currently utilized in the SERC hydrogen powered fuel cell vehicles. The University of Alaska would gain experience in the utilization of fuel cells for electrical generation, in preparation for technology validation of future fossil fuel reformers and reformate fuel cell power systems.

- Task C - Provide support and training to the University of Alaska in the setting up and operating a fuel cell test lab. This will be done by SERC personnel.

Phase III is for technology validation. A reformate tolerant fuel cell stack will be built by SERC and integrated with a fuel flexible fuel processor built by Hydrogen Burner Technology. This α-prototype technology validation unit will be ready for delivery by April, 2000.

Phase IV would follow the technology validation phase with the development and installation of four β-prototype systems. Negotiations are currently underway to place at least one prototype on the Alyeska pipeline in Alaska. Phase IV will also include updated production, manufacturing, and business planning leading to the production of a system that meets customer requirements.

Designing the FCPS to operate with a reformer and natural gas and/or propane is an excellent intermediate technological step in the development of fuel cell technology. A reformer coupled with a fuel cell allows the utilization of the existing fuel infrastructure while still moving toward cleaner and more efficient energy generation. Currently, hydrogen gas is not widely available. Hydrogen fueled power systems will not attain the market share necessary for commercialization until hydrogen gas is available. On the other hand, hydrogen gas will not be sold widely until there is a greater demand. Reformers address this problem by allowing fuel cells to easily utilize available fuel stocks.

The Phase I research examined the market for power systems for off-grid homes, yachts, telecommunication stations and recreational vehicles. Also included in this report are

summaries of the previously conducted market reports that examined power needs for remote locations along natural gas and oil pipelines. A list of highlights from the research can be found in the executive summary of the business plan. Following are a few of the major findings from the market research:

- The FCPS will need to meet the current retail price of either $0.13/kWh (generator), $0.29/kWh (battery/shore power) or $0.50/kWh (PV) for the consumer markets.

- Fuel cell power systems, not including a reformer, currently could produce electricity at a wholesale price of $0.44/kWh. In the best case scenario, with a 50% stack cost decline, 100% fuel cell performance increase and $12/GJ hydrogen costs, a FCPS could provide power at $0.23/kWh.

- There are approximately 100,000 remote homes in the U.S., almost all of which use a remote power generator. Remote home owners can be classified as early innovators, accustomed to unique power generators. There could potentially be a market here, but the price would have to be comparable to PVs. Most remote home owners prefer more than 5 kW of power.

- There could be a market in FCPSs for 30-40 foot sailboats. 15,000 new boats of this size were built in the last 9 years. They currently carry propane onboard. However, the price would need to be comparable to battery or shore power.

- RV's might offer a potential market for 10,000 units per year if the price was comparable to engine generators.

- People interviewed in the sailboat, remote home and the RV market stated that they could better assess their interest in the FCPS if they could see a demonstration model. They also stated that they might be willing to pay more for the FCPS if they observed the benefits of clean and quiet energy generation.

- Approximately 75% of the remote power systems market under 30 W is at gas distribution sites, with 32,044 units sold in 1995. This market is growing and the current price paid for power (batteries) in this market is $120/W.

- There are greater than 2 million existing land wellheads worldwide whose equipment will eventually need replacement.

- The telecommunications arena is changing rapidly and further study is needed to understand the potential in this market.

Research indicates that people in these markets have an interest in a clean, quiet energy generation systems. The price will need to be comparable to other energy generation systems, but it could possibly be higher given the benefits of the FCPS of less pollution, less noise and greater fuel efficiency. There is a need for a prototype fuel cell power system to demonstrate the advantages this system has over conventional energy generators. Phases II-IV of this project will further the development of the fuel cell and reformer, bringing them closer to commercialization. The project will build on the experience of the partners in both technological advancement and distribution of remote power systems and make this technology a reality today.

I. Summary Description of the Proposed Project

A. Technical Approach

The goal of the Fuel Cell Power Systems for Remote Applications project is to initiate commercialization of a 0.1-5 kW integrated hydrogen fuel cell power system. The four phase project targets high value niche markets, including natural gas and oil pipelines, off-grid homes, yachts, telecommunications stations, and recreational vehicles. The project is a cooperative effort of Teledyne Brown Engineering - Energy Systems (TBE), Schatz Energy Research Center (SERC), Hydrogen Burner Technology (HBT), and the City of Palm Desert.

The work of phase I is summarized in this report and includes a market, technical and financial analysis of the fuel cell power system (FCPS), technical and financial requirements to establish manufacturing capability, a business plan, and teaming arrangements. Phase I also includes project planning, scope of work and budgets for Phases II-IV.

Phases II through IV are designed to utilize the results of Phase I to further the commercial potential of the FCPS. The major tasks and deliverables for each of these phases are detailed in the summary Gantt chart (Figure 1) following this section and are summarized below:

- Phase II – This phase focuses on technology development. SERC will carry out research and development of a reformate tolerant fuel cell stack, while HBT will work to simplify and reduce the size of their fuel reformer. A complete report detailing the efforts and accomplishments of the phase will be the deliverable.

- Phase III – This is the technology validation phase. The advances made in phase II will be applied to build and integrate a reformate tolerant fuel cell stack with a reformer running on natural gas or propane. A control system will be developed, and peripheral components will be chosen. An α-prototype of a 3 kW FCPS will be delivered at the end of the phase, along with a detailed report.

- Phase IV – In this phase, the technology will be further refined for marketability and volume production. A detailed technical and financial plan for commercial production will also be developed, including manufacturing methods and costs, component vendor candidates, and marketing strategy. The deliverables will be four β-prototype demonstration FCPSs, to be installed at selected field test sites, including at least one site on the Alyeska pipeline; the commercialization plan; and a final project report.

Designing the FCPS to operate with a reformer and natural gas and/or propane is an excellent intermediate step in the development of fuel cell technology. A reformer coupled with a fuel cell allows the utilization of the existing fuel infrastructure while still moving towards cleaner and more efficient energy generation. Currently, hydrogen gas is not widely available. Hydrogen fueled power systems will not attain the market share necessary for commercialization until hydrogen gas is available. On the other hand, hydrogen gas will not be sold widely until there is a greater demand. Reformers address this problem by allowing fuel cells to easily utilize available fuel stock.

B. Business Plan for Phases II-IV

TBE, the lead agency in this project, has been manufacturing and selling small thermoelectric power sources for remote applications for the past thirty years. TBE's partner SERC has considerable experience researching, developing, and field testing fuel cell power systems. The lab has built working fuel cell power systems for both stationary and mobile applications. The second technical partner, HBT, has been developing reformer systems for various applications over the past six years and will improve and modify their patented underoxidized burner technology for purposes of this project. The City of Palm Desert, with its rare combination of financial strength and commitment to fuel cell technology will provide consulting services and a venue for the manufacturing operations.

This consortium proposes to enter the market for 0.1 to 5kW remote power systems, initially by providing 1 to 3 kW FCPSs for primary power along natural gas and oil pipelines. These systems could also be used in other applications, such as trickle-charging a battery backup system for remote homes or sailboats, powering instrumentation at telecommunications sites, or providing backup power to a photovoltaic system lighting a highway sign.

The goal for the system is to address the most often-voiced customer demands: reliability, low maintenance, simplicity of design and repair, and competitive front-end costs. Marketing and sales will be directed at the representatives and distributors in regional/district locations for the oil and gas industries, pipeline operators, and engineering and consulting firms.

Phase II has three possible options. In phase IIA, the partners propose to conduct the research and development necessary to produce a reformate-tolerant fuel cell stack and a reformer to complement that stack, allowing use of the current fuel infrastructure. This research will be conducted over a 1 year period, and at the end, the consortium will be prepared to begin integrating the fuel cell and reformer systems into one unit.

In phase IIB, the partners propose to build, deliver, and install a fuel cell power system at the University of Alaska or another site in Alaska within seven months of the start of the project. The system will be palletized in a single, compact unit and will contain all of its own safety and control hardware and software. It will run initially on hydrogen. The partners will also train on-site personnel in maintenance and operation, and analyze the results of the work.

In phase IIC, the partners propose to provide support to the University of Alaska in setting up a fuel cell testing laboratory. SERC, especially, is well qualified to set up a program where professors and graduate students exchange visits between the University of Alaska and Humboldt State University, where instruction on test bench configuration, fuel cell testing methods, and result analysis can occur. Consulting on test bench design and construction will occur on site in Alaska as well.

In phase III, the partners will build on the research from phase II to design, build, and deliver an integrated fuel cell power system that contains a fuel flexible fuel processor (reformer), allowing use of propane or natural gas as the feed stock. This reformer will produce a hydrogen-rich supply of gas that is appropriate for the fuel cell. The fuel cell will incorporate reformate-tolerant membrane, as well as simplified controls and subsystems. This unit will be delivered to Teledyne and tested within a year of the phase III start date.

Finally, in phase IV, the partners will produce four beta test units for locations along natural gas or oil pipelines. At least one of the prototypes will be installed on the Alyeska pipeline. At the same time, plans for manufacturing the units will be made, including a full production plan building upon earlier planning and using the beta design as a basis. Each detail, component, subsystem, and finally the top assembly will be defined in terms of how it is to be obtained (made or purchased). This effort will be lead by the TBE Manufacturing Engineering Department, working with the Engineering Department, SERC and HBT to produce design recommendations that will enhance producibility without compromising performance. The team will also produce a business plan that includes funding for manufacturing and marketing this product, marketing strategies, and product support. Phase IV is an 18 month effort that will culminate with achievable business goals and the formal introduction of the product.

ID	Name	Start	Finish
1	**PHASE IIA - Reformer & Reformate Tolerant FC R&D**	**4/1/98**	**3/30/99**
2	new test stations completed, reformate tolerant cell testing comme	8/25/98	8/25/98
3	design modifications and testing completed	3/16/99	3/16/99
4			
5	**PHASE IIB - Hydrogen FCPS for Remote Village**	**4/1/98**	**11/3/98**
6	palletized system completed (no reformer)	9/22/98	9/22/98
7	system delivered & installed	10/6/98	10/6/98
8			
9	**PHASE IIC - Fuel Cell Testing Support to U. of A.**	**1/1/98**	**1/1/98**
11			
12	**PHASE III - Integrated Reformer/FCPS Development**	**4/1/99**	**3/30/00**
13	prototype reformer received and installed	5/10/99	5/10/99
14	alpha-prototype FCPS completed & delivered	12/30/99	12/30/99
15			
16	**PHASE IV - Field Testing & Mfg. Plan Development**	**4/3/00**	**9/28/01**
17	four beta-prototype systems completed	11/17/00	11/17/00
18	all four systems installed in the field	3/23/01	3/23/01
19	manufacturing plan completed	8/10/01	8/10/01
20	final manufacturing plan and report submitted	9/28/01	9/28/01

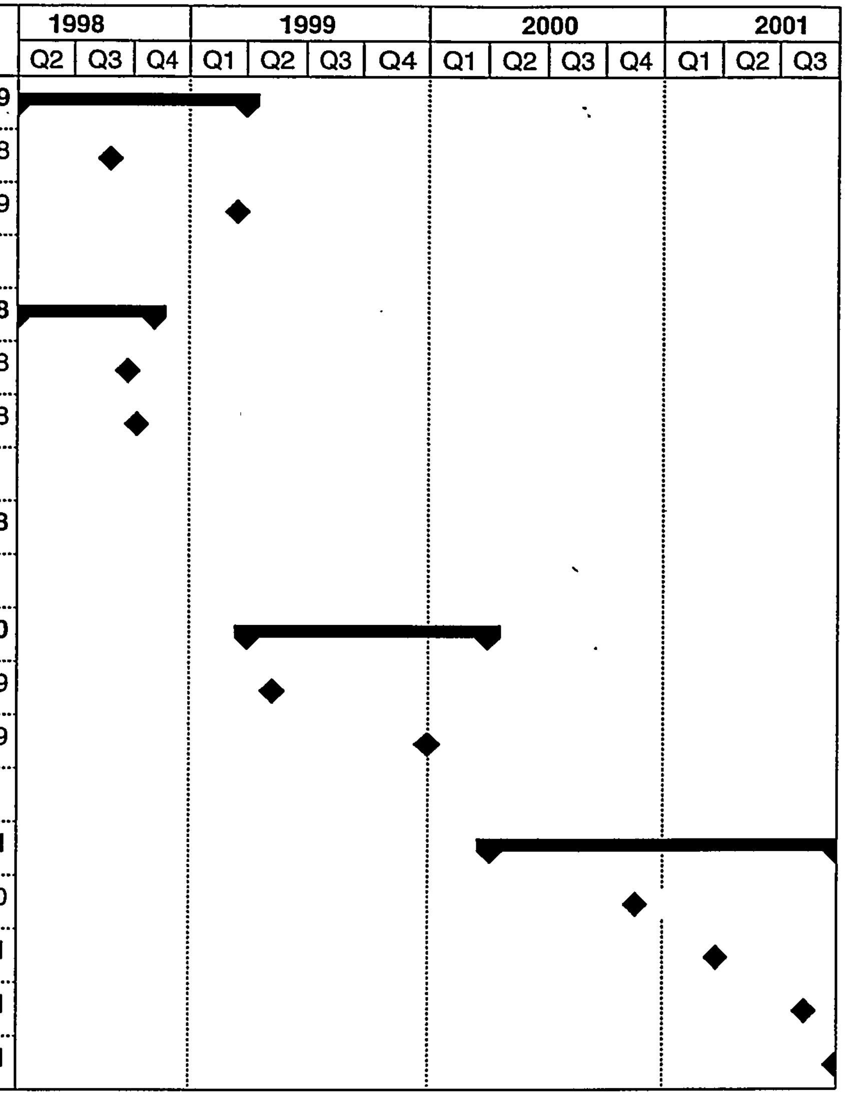


Figure 1. Summary Gantt Chart

C. Budget Requirements for Phases II - IV

The Partners estimate the budget requirements for Phases II - IV to be as shown in Table 1. The budget is based on the work plans detailed in Chapter IV and the schedule shown in Figure 1, page 8. The time span requirement estimated for completion of Phase II is 12 months. Phase III is also 12 months and Phase IV, 18 months. The budget totals include Phase IIA and Phase IIB as independent development efforts. Our plan for the three phases of work has neither overlap or gaps except that Phase IIB ends about four months prior to the start of Phase III. Phases III and IV build upon the technology development efforts completed under Phase IIA.

The overall budget for Phase IIA is $2,536,100. Of this amount, the Partners have agreed to cost share 35% leaving the proposed Federal share as $1,658,100. Similarly the cost share proposed in Phase IIB is 40% with the Federal share as $552,400. In Phase III, the Partner's cost share is proposed to be 35%, with the remaining Federal share as $1,077,900. In Phase IV, which includes demonstration and pre-manufacturing, the Partners propose a cost share of 51% leaving the Federal share at $2,050,800. Details of the cost sharing sources as well as the Federal amounts requested, may be found in Chapter VI. Phase IIC, described as a possible option, has not been budgeted.

TABLE 1

PHASES II - IV PROJECT BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
PARTNERS															
Teledyne Brown Engineering	186,100	0	186,100	66,700	126,400	193,100	134,900	22,600	157,500	373,500	373,500	747,000	761,200	522,500	1,283,700
Schatz Energy Research Ctr.	1,320,400	877,000	2,197,400	485,700	237,000	722,700	894,000	556,600	1,450,600	1,561,800	1,615,800	3,177,600	4,261,900	3,286,400	7,548,300
Hydrogen Burner Tech.	150,000	0	150,000	0	0	0	40,000	10,000	50,000	100,000	100,000	200,000	290,000	110,000	400,000
City of Palm Desert, CA	1,600	1,000	2,600	0	0	0	9,000	3,800	12,800	15,500	15,500	31,000	26,100	20,300	46,400
Totals	1,658,100	878,000	2,536,100	552,400	363,400	915,800	1,077,900	593,000	1,670,900	2,050,800	2,104,800	4,155,600	5,339,200	3,939,200	9,278,400
Percent of Cost Sharing		35%			40%			35%			51%			42%	

II. Technical Approach

A. Integrated System Performance Parameters

The focus of this project is the development of a 3 kW fuel cell power system based on a PEM fuel cell and a fuel-flexible fuel processor (reformer) that produces hydrogen from natural gas or propane feedstock. This is intended to be a fully integrated system suitable for installation and unattended operation in a variety of applications. An α prototype will be built and tested in the lab, and several demonstration units will be β–tested in the field. Finally, a detailed technical and financial plan for commercial production will be completed.

A schematic diagram of the proposed integrated fuel cell power system is shown in Figure 2. The heart of the system is a proton exchange membrane (PEM) fuel cell stack sized to deliver a nominal 3 kW AC output. This will be a 70 cell stack, with 300 cm^2 of active area per cell. The fuel cell subsystems include a low pressure, high volume air blower to provide the oxidant feed, and a water circulation system for cooling the stack and humidifying the incoming air and reformate streams. A partial oxidation (POX) reformer will be used to generate hydrogen rich fuel for the stack from natural gas or propane feedstock. The electrical output of the fuel cell will be conditioned by a DC/DC voltage converter to 48 VDC for use by the blower and water pump, as well as for input to a 4 kW inverter. The inverter will invert and transform the 48 VDC input to a 110 VAC output for use by the applied load. A second voltage converter will step the stack voltage down to 24 VDC to power the balance of the subsystem components (relays, solenoid valves, etc.) as well as the control computer. The control computer manages operation of the fuel cell system, collects operating data, and provides a user interface. A starting battery is included in the system to power the control computer and subsystem loads at start-up. Once the fuel cell receives air and hydrogen it quickly comes on line, taking over the parasitic loads and recharging the starting battery.

The performance of the integrated system is expected to be as follows:

System Net Power	3 kW
System Voltage	120 VAC
Fuel Cell Voltage	42-70 VDC
Fuel Cell Stack Temp.	60 °C
Reformate Flowrate	100 slm max
Reformate CO Content	< 50 ppm

B. Development of Individual Components or Subsystems

1. Developmental Status of Component or Subsystem Technologies

Fuel Cell

This project will utilize a PEM fuel cell stack designed and built by SERC. SERC has produced four similarly sized (64 cell) stacks to date which have worked well under "real world" conditions. These stacks have been installed into golf cart chassis and tested extensively. One of these carts was retained by SERC, the other three are in daily use in Palm Desert, California as part of the Palm Desert Renewable Hydrogen Transportation System Project. Another larger (96 cell) stack is currently undergoing bench testing prior to installation into a neighborhood electric vehicle (NEV) for the same project. These stacks have met their target current densities and been reliable in service.

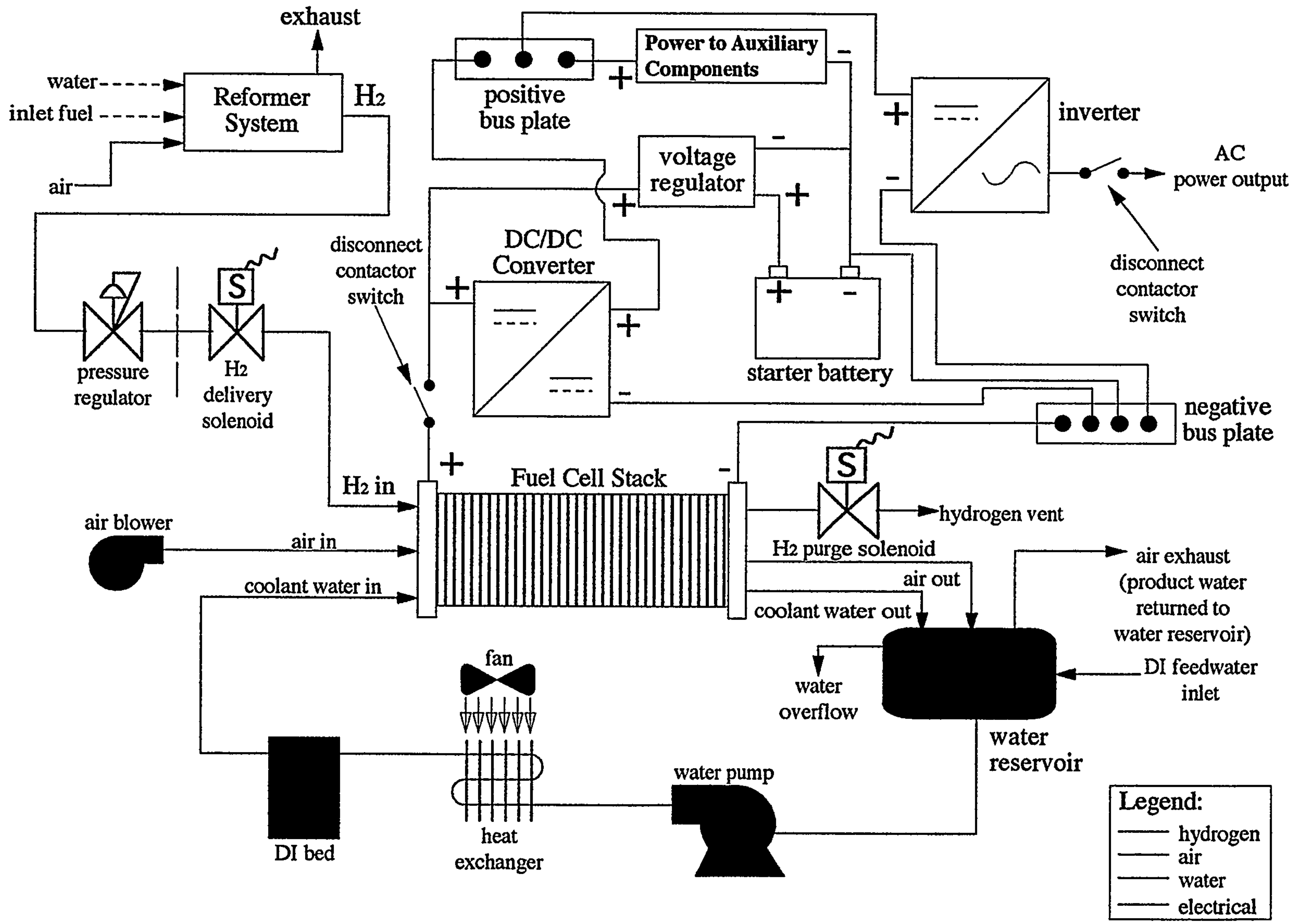


Figure 2. Schematic of Palletized Fuel Cell Power System

The SERC stack is designed for operation at very low reactant pressures, which minimizes system complexity and parasitic loads, and maximizes net system efficiency. For example, a simple, efficient air blower may be used for oxidant supply, rather than a much more power consumptive air compressor. Further, the low pressure means that stack sealing is less problematic, allowing the use of a relatively simple, o-ring based sealing system. The stacks are further simplified by being operated with the hydrogen feed dead-ended, which removes the need to control the flow rate or humidify the gas.

Reformer

The reformer for this project will be developed by HBT. This will be a partial oxidation (POX) reformer based on technology incorporated in HBT's currently marketed 500 and 3500 scfh units. The CO level in the product gas of these is less than 2 ppm, which is good enough for use in a fuel cell with Pt/Ru catalyst, but is achieved with the addition of a pressure swing adsorption (PSA) purification device, which adds bulk and complexity. The flow rate of the smaller unit is at least double that required by the 3 kW system, and it is far too large to be incorporated into a reasonably sized palletized power unit. HBT will develop a prototype reformer with similar product gas quality without the use of a purification step, approximately one half the flow rate, and at least an order of magnitude smaller in overall volume.

Control System

A control system is required to manage the operation of the fuel cell and its subsystems, to monitor key operating parameters and to effect a system shut-down in the event of an abnormal condition. All SERC fuel cell systems to date have included control systems which incorporated very detailed control functions as well as extensive data collection capabilities. These have been based on PC type motherboards, with software developed in-house. This has resulted in very capable and flexible systems, well suited to the needs of an ongoing R&D effort. However, these systems are unnecessarily complex and expensive for the type of commercialized applications envisioned in this project. The lessons learned in those earlier efforts will be incorporated into a new, much simpler, and less expensive control system based on PicStic™ industrial control computers.

Balance of System Components

The rest of the system will be made up of subsystem components, such as a water pump, air blower, inverter, etc., which are standard, off-the-shelf units. All are mature technologies which will be utilized in applications for which they are designed.

2. Technology Development Requirements for Component Technologies

Fuel Cell

All of SERC's stacks to date have been built to operate on pure hydrogen. One of the key goals of this project will be to develop a fuel cell stack that operates on the product gas of a partial oxidation (POX) reformer. Because of the impurities in the reformate stream, the current practice of dead-ending and not humidifying the anode gas will have to be abandoned. If the reformate were dead-ended, the CO and other impurities would build up in the stack, and could not be adequately removed by a simple periodic purge. Instead, the reformate will have to flow through the stack, which will necessitate the addition of a reformate humidification section to prevent the flow from drying out the cell membranes. It is also probable that the flow field of the anode collector plates will have to be redesigned to accommodate the new flow rate.

The other area of concern in running a fuel cell on reformate is the catalyst. When pure hydrogen is the fuel, fuel cells perform best with platinum (Pt) catalysts in their membrane electrode assemblies (MEAs). When operated on reformate though, Pt is not suitable because it is quickly poisoned by the CO in the reformate stream. Catalysts of platinum/ruthenium (Pt/Ru) alloy have been shown to have a higher tolerance for CO, allowing good performance at up to 5 ppm CO. Incorporation of a small (1-5%) air bleed into the inlet fuel stream may increase the tolerance to as much as 50 ppm. These issues, as well as the longevity of Pt/Ru MEAs operated on reformate, will be investigated.

To carry out the above testing, two new test stations will be built. These will include the capability of mixing synthetic reformate to test various CO levels. One will be used for performance testing of MEAs, as well as evaluating stack design changes and operating parameters. The second test station will be devoted to longevity testing of the Pt/Ru MEAs. An existing test station will be modified for testing of the completed 3 kW stack with a reformer.

Reformer

Currently available POX reformers are capable of producing fuel cell quality hydrogen from a natural gas or propane feedstock with the aid of one or more additional purification devices. These units are physically too large and, with a PSA device, complex to be acceptable for this project. HBT will develop a POX reformer with a capacity and product gas quality suited to the fuel cell, and with physical dimensions which will allow it to be reasonably integrated into the final palletized system.

HBT's smallest marketed reformer has approximately twice the required capacity. By developing a unit of just the required capacity, and by minimizing the size of components and arranging those components into the minimum practical volume, the overall size of the unit will be substantially reduced. HBT will further reduce the unit size by developing and "tuning" reformer operation so as to produce acceptable gas quality without the use of a PSA device. It will also be designed to minimize the required start-up/warm-up time and to be responsive to changes in demand.

Control System

Since the power system being developed in this project is eventually to be commercialized, the control system will be as simple, robust, and inexpensive as possible. SERC will develop a control system based on PicStic™ industrial control computers.

The PicStic™ is a low cost, subminiature control computer which incorporates digital I/O, analog inputs, real-time monitoring, and serial communication in a single 0.85 in^2 module. Individual units may be networked together for increased capability. PicStic™ technology is fully mature, and is gaining favor in industry over motherboard based systems or programmable logic controllers (PLCs).

Previous SERC control systems have been based on a PC type motherboard, with C language programming and with more control and data collection functions than are required for this system. In developing the new system, SERC will rethink the control and monitoring strategies from a minimalist viewpoint. While much of the control software will be developed from scratch for this system, it will build on the experience gained in previous control systems, parts of which will likely be usable.

C. Development of the Integrated System

A major integration issue is the coupling of the fuel cell and the reformer. The reformer output will have to respond quickly to changes in demand as the load on the fuel cell varies, while maintaining a consistently low CO level. Since the reformer will have its own control computer separate from the power system control computer, it will be imperative that the two are set-up to communicate with each other. For example, the power system will have to notify the reformer when to begin or stop delivering reformate, and the reformer will have to notify the power system if it is unable to deliver for any reason.

The electrical components, particularly the DC/DC converter and the inverter, will have to be carefully chosen to ensure that their input specs are compatible with the fuel cell over the full range of expected voltages and currents. However, this will be no more than normal engineering practice. More critical is the proper coordination of these components by the control computer, but most of the required algorithms have already been successfully developed in previous SERC systems.

The final stage of the project will be to assemble the various components into a compact, palletized unit. This unit should be as small as possible, but also be designed for efficient manufacturing, shipping, and service in the field. The final design will be reviewed by a registered safety engineer to ensure its safety in normal use. The goal is to provide a reliable, compact power source that the user may install and operate with relative ease and a minimum of ongoing maintenance.

D. Identification of Barriers

Cost and Customer Acceptance

The most serious barrier to the commercialization of fuel cell power systems is the cost of the fuel cell stack itself. At current prices, fuel cells are far more expensive than competing technologies. This is because they are an emerging technology in which individual units are built by hand. The most important components of a PEM fuel cell, and also the most expensive, are the MEAs. Yet these are composed not of exotic materials, but of carbon cloth or carbon paper based electrodes and membranes which are a derivative of common Teflon®. As shown in the business plan, fuel cell systems will become competitive when they are simplified and produced in volume. This project will include hardware development as well as detailed manufacturing planning aimed at attaining competitive costs.

Customer acceptance of a new technology is influenced heavily by cost factors, but other factors play a role as well. Key in the case of fuel cell systems is hydrogen safety. Even if these systems are designed and built to careful safety standards, as discussed above, a certain level of customer reluctance may persist due to a lack of familiarity with hydrogen fueled systems. By installing and operating β-test units in the field, this project will offer potential customers the opportunity to gain that familiarity and to recognize first hand the advantages of these systems. These advantages, such as low maintenance, low noise levels, and low or nonexistent pollutant emissions may in some cases outweigh the relatively high system cost, even in the near term.

Technical Barriers

There are several technical barriers that will have to be overcome in order for this project to be completely successful. These have been discussed in detail in the technical section, but are briefly summarized below:

- Designing a fuel cell stack that runs efficiently on reformate, which will require changes to the anode gas flow path, addition of anode gas humidification, and CO tolerant catalysts.
- The development of a fuel reformer with an acceptably low concentration of CO and small enough to be reasonably incorporated into the palletized power system.
- Integration of the reformer and fuel cell system such that the overall system responds to start-up and transient conditions quickly and smoothly.

Safety Issues with Hydrogen Gas Systems

Introduction

The fuel cell system has been designed, and must be operated and maintained, with safety in mind. The primary hazards are associated with the flammability of the fuels used in the system and the potential for electrical components to act as an ignition source. If a reformer is used there are additional pressurized gas, high temperature, and toxic gas (CO) safety issues to consider.

Hydrogen gas is already used safely as a fuel in industrial settings. Proper design, use, and maintenance practices can allow hydrogen to be used safely in other settings, including homes, campers, and boats.

When handled properly, hydrogen gas is no more dangerous than other common fuels. Hydrogen has some properties that are different from such fuels as gasoline, propane, and natural gas. It is important to recognize these differences and respond to them appropriately.

Numerous authors have written about safe practices for the use of hydrogen gas systems. These literature sources, the appropriate ASME, CGA, and NFPA design codes, and the accumulated experience of the participating agencies will be used to ensure that the safety issues associated with the fuel cell system are addressed properly.

Hydrogen Environmental and Public Health Issues

Hydrogen gas is a colorless, odorless, tasteless, and non-toxic substance. It will not contaminate the air, water, or soil. Other than the flammability hazard, the only significant hazard posed by human exposure to hydrogen gas is asphyxiation, which can occur if hydrogen displaces oxygen in a contained area. This can be easily avoided with proper ventilation.

Hydrogen Flammability Issues

Hydrogen gas is extremely flammable. This property makes it a good fuel, but also necessitates safe practices to prevent fires. The important hydrogen properties with respect to flammability are the ignition energy, buoyancy, diffusiveness, flammability limits in air, and combustion energy.

Hydrogen gas has a very low ignition energy, which makes it easier to ignite than gasoline, natural gas, or propane. The ignition energy of hydrogen is 1/10 the energy required to ignite gasoline, and 1/15 the energy required to ignite natural gas. It is worth mentioning, however, that the ignition energy for all of these fuels is very small, so that ignition of a combustible mixture of any of them is relatively assured even from a weak ignition source.

Hydrogen is flammable over a wide range of mixtures: from 4% to 75% hydrogen gas in air. This compares to a range of 5-16% natural gas in air and 1.4- 7.6% gasoline vapor in air.

Hydrogen has 2.4 times more stored combustion energy per unit mass than either natural gas or gasoline. However, on a volume basis, hydrogen has much less energy. It has 25% of the explosion energy of natural gas and 0.3% of that of liquid gasoline per unit volume at standard temperature and pressure. The amount of stored energy in small hydrogen systems is frequently less than a single gallon of gasoline.

On the positive side, hydrogen is very diffusive and buoyant. These properties help make it easier to prevent a combustible mixture, and when a combustible mixture does occur it usually is short lived. Hydrogen is four times more diffusive than natural gas, and eight times more diffusive than gasoline vapor.

The first strategy for avoiding hydrogen fires is based primarily on reducing the possibilities for creating a combustible mixture. This requires a tight plumbing system to reduce the leak potential.

When a leak does occur, hydrogen will disperse quickly unless it is contained. The second key to safe design practices for hydrogen systems is an allowance for adequate ventilation. Adequate ventilation can reduce, or in some cases effectively eliminate, the area over which a combustible mixture can occur. It also reduces the time period over which the combustible mixture might be present in the event of a leak.

The third priority in safe hydrogen system design is the minimization of ignition sources. Static discharges, open flames, hot surfaces (temperatures greater than 585°C), and sparking electrical equipment are all potential ignition sources. Provisions must be made to reduce or eliminate these hazards. It is important to keep in mind that the energy required to ignite a combustible mixture of hydrogen gas is very small.

The equipment used in the stationary FCPS will be designed, installed, and maintained in accordance with these guidelines for avoiding fire hazards. The flammability hazards of hydrogen are different from, but no greater than, those posed by other common fuels. Hydrogen gas can be used safely and efficiently, provided that the proper precautions are observed.

Safety Issues for Fuel Cell Power System Components

There are several specific safety issues associated with FCPS components. These are outlined below. All of the safety issues are addressed through careful design, installation, and maintenance practices.

<u>Hydrogen Gas Plumbing</u> The hydrogen gas plumbing for the fuel cell system will be at low pressure (≈ 5 psig). The amount of hydrogen gas stored at any given time is minimal (less than one standard liter). The stored combustion energy will be less than one milliliter of gasoline energy equivalent.

The hydrogen plumbing will be designed in accordance with the applicable codes. These include, but are not limited to, CGA G-5 (1991) *Hydrogen*, CGA G-5.4 (1992) *Standard for Hydrogen Piping Systems at Consumer Locations*, CGA G-5.5 (1996) *Hydrogen Vent*

Systems, CGA S-1.3 (1995) *Pressure Relief Device Standards - Part 3 - Stationary Storage Containers for Compressed Gases*, ASME B31.3, *Chemical Plant and Petroleum Refinery Piping*, and NFPA 50A, *Gaseous Hydrogen Systems at Consumer Sites*. The design will include provisions that help reduce the possibility of leaks and ignition sources. The installation site will allow for adequate ventilation in order to disperse any leaks that occur.

Equipment used to minimize pressure hazards will include a pressure relief device and a pressure switch. The pressure relief device will open if the pressure exceeds a safe limit, and vent the gas to a safe location. The pressure switch will send a signal to the control system in an over pressure situation, which will shut the system down.

The hydrogen used by the system may be supplied through a number of methods. These include reformate from a fossil fuel source, high pressure hydrogen storage in cylinders, liquid hydrogen storage, or renewable electrolytic hydrogen in a low pressure storage tank. Each of these hydrogen delivery systems has some hazards associated with it. The hazards of each should be considered when choosing a method for delivering the hydrogen. All of the systems can be used safely and efficiently if they are properly designed, operated, and maintained.

Fuel Cell Stack The fuel cell stack combines hydrogen with air to form electricity and water. A small amount of hydrogen is present in the stack at any given time (2 standard liters, less than 1 milliliter of gasoline energy equivalent). This poses only a minor safety hazard.

A membrane rupture can lead to a cross leak of hydrogen into the air stream of the fuel cell. This may create a combustible mixture inside the stack. The platinum catalyst may act as an ignition source, creating a fire inside the fuel cell stack. This can damage the fuel cell, but it will not pose a danger to people. The fire will be contained inside the stack, as the stored combustion energy is small. The fuel cell performance will drop rapidly in the event of a fire; the control system will recognize the ensuing low voltages and shut down on a fault. This stops the flow of hydrogen, allowing the fire to burn itself out.

The fuel cell can pose a shock hazard. A 70 cell fuel cell stack can operate at voltages up to 70 Volts DC. At lower voltages (40-55 VDC) high currents (up to 150 Amperes) may be present. The fuel cell will be enclosed in a vented container to protect the user from the shock hazard. The exposed electrical contacts will be insulated with a non-conductive material to minimize the shock hazard.

Electrical Equipment The electrical equipment used in the fuel cell system consists of conventional, off the shelf components. These will be selected to meet the appropriate code requirements for a system that includes a flammable gas hazard. The applicable codes include, but are not limited to, NFPA 50A, *Gaseous Hydrogen Systems at Consumer Sites*, NFPA 70, *National Electrical Code*, NFPA 497A, *Classification of Class I Hazardous Locations for Electrical Installations in Chemical Process Areas*, and others.

The electrical components are a potential source of ignition for a combustible mixture of hydrogen gas. To address this, non-sparking or explosion proof components will be used as required by the applicable code. Additionally, exposed connections such as battery terminals will be covered with a non-conductive material to prevent sparking during maintenance. These precautions will minimize the potential ignition hazard.

Some of the electrical components can also pose a shock hazard. The majority of the system components operate at 24 Volts DC. This voltage is low enough that the shock hazard is marginal. Several other components, including the battery, fuel cell, and the DC to DC converter operate at higher DC voltages (40 - 70 VDC). These components will be properly insulated and labeled to lessen the shock hazards.

The battery in the system is a 40 Volt DC sealed lead acid battery. The sealed design eliminates the hazards associated with the sulfuric acid electrolyte and minimizes the dangers of outgassing.

The output electricity is a 30 Ampere, 120 Volt AC outlet. The hazards associated with this power are identical to those for household electrical service.

<u>Control System</u> The FCPS will use a simple controller to coordinate its subsystems. This controller will also have some safety related functions, which are outlined here.

The control system will include several safety interlocks that will allow the system to shut down if a fault occurs. The safety interlocks will include a pressure switch to prevent over pressure in the hydrogen plumbing, voltage measurements of fuel cell stack voltage to monitor performance, and a 'watchdog' timer circuit to shut the system down if the control computer crashes. The safety features of the control system should prevent operation of the system if a fault occurs.

<u>Reformer System</u> If a reformer is used to provide hydrogen, several safety issues must be considered. The reformer is a complex system that requires an automated control system for safe operation. Normally, the potential hazards are minimized through careful control. A number of sensors are used in the system for safety monitoring and control. Redundant sensors are required in many cases. If the system begins to operate outside of the safe limits, the control system recognizes the fault and shuts the system down safely.

This type of complex control instrumentation is used commonly in industrial settings and in automobile engines. Despite the complexity, systems can be designed to be operated safely and efficiently. However, small scale reformers are an experimental technology, and a significant amount of testing will be required to ensure that prototype units are safe and reliable.

Two flammable fuels will be present in the reformer system. These are the input fuel and the hydrogen gas product. The safety issues associated with the reformer's input fuel will depend on the fuel type (natural gas or propane) and the amount of fuel stored on site.

The product of the reforming process is primarily hydrogen gas. A small amount of hydrogen gas is stored in the reformer and associated plumbing. If a ballast is used to allow for fuel cell use during reformer warm-up, then the minor safety issues associated with the stored hydrogen fuel must be addressed.

Small quantities of carbon monoxide gas are produced in the reforming process. During normal operation this gas is oxidized and is not a hazard. However, if a leak were to occur in the process stream prior to CO oxidation, people could be exposed to poison gas.

An additional potential hazard is related to the temperature conditions in the reformer. The reformer operates at high temperature (up to 3,000°F). The reformer will be insulated so that the outside shell is cool enough to touch. The high internal temperature could be a hazard in the event of a leak or if a control failure led to overheating and rupture. For example, steam is used to cool the high temperature gas. A leak in the quenching process area could lead to a pressurized jet of high temperature steam, which would be a significant safety hazard.

In summary, the reformer system is substantially more complex than the other components in the fuel cell power system. There are several hazards, including flammable gas, toxic carbon monoxide gas, and high temperature. During normal operation the control system will keep the reformer within safe operating bounds. If operation leaves these bounds, the control system will respond by shutting the system down. The main danger lies in the dependence on a complex control system for safety, as a failure of the control system could lead to a hazardous situation. For this reason prototype models will be thoroughly tested prior to use in a demonstration unit.

Conclusion

The fuel cell system described in this document will pose few hazards during normal operation. A control system will be used to maintain safe operation. If the operation strays outside safe parameter limits, the control system will respond by shutting the system down. The design of the fuel cell system will minimize the number of hazardous situations that could occur from the failure of a single system component. In addition, the control system prevents many hazardous situations that could occur from the simultaneous failure of multiple system components.

The primary safety hazard, that of the flammability of hydrogen gas, is limited due to the small amount of hydrogen stored in the system at any given time. In addition, a number of safety features are included to further reduce the hazard. The electrical hazards posed by the system are commonplace. They can be easily addressed by following the appropriate code guidelines. The hydrogen used by the system may be supplied through a number of methods whose hazards should be considered when choosing a method for delivering the hydrogen. With proper design, operation, and maintenance, the FCPS can be made safe and efficient.

III Business Plan Development

A. Business Plan Development

1. Description of Business Planning Computer Software

The business planning software used for the Fuel Cell Power Systems for Remote Applications Project is BizPlan Builder by Jian. BizPlan Builder is a strategic business and marketing plan software package, designed to be a complete template for business managers developing a business plan. The software treats the business plan as a series of separate but interrelated documents. Each addresses different aspects of strategic development: the company's mission, the owner's experience, market conditions, the customer profile, competitors, marketing plans, financial strength, and financial need.

BizPlan was deliberately designed to be informational and/or organizational 'overkill' for most businesses. The intent was to cover every aspect of the business plan, offering the user more than enough material with which to work. The software is designed to assist the business manager in development of a professional business plan in order to procure bank loans and/or to interest investors.

The sample table of contents from BizPlan includes the Executive Summary, Company Vision/Mission, Company Overview, Product Strategy, Market Analysis, Marketing Plan, Financial Plan and Supporting Documents. Each of these categories has a template with which the user can fill in appropriate information concerning their business. The templates are general in nature and exhaustive in content, designed to describe any company.

2. Methodology and Assumptions Used to Develop the Business Plan

Bizplan was the model upon which this business plan was designed. An example of how Bizplan was adopted to be utilized by this business plan can be seen in the executive summary chapter. Bizplan suggests an executive summary that includes a summary of the company vision/mission, company overview, product strategy, market analysis, marketing plan, financial plan and conclusion. This would make for a long, exhaustive executive summary, which would demand that the reader sort through much written information before they could find the interesting facts about the potential markets being researched. The executive summary for this business plan followed the Bizplan outline to some extent, but focuses on the most important facts about the market conditions found in the research and financial analysis and puts less emphasis on company mission, overview, and current product strategy. TBE has already shown that remote power generation is within the scope of their company mission. The company is mostly concerned with the market potential and cost considerations of a fuel cell power system. This is just one example of how Bizplan was regarded a model for this business plan, but was not used directly as a template.

BizPlan was utilized to design the market analysis questionnaire for the four designated markets. A copy of this questionnaire can be found in Appendix 1 of this report. These questions were asked of manufacturers, consumers and trade association employees. This was augmented with research about these markets on the internet, in magazines and in books. Not every question was answered for each potential market, but an attempt was made to characterize the consumer's purchasing ability and energy interests, how power is used by the consumer within each market, price paid for power purchased, operation and maintenance issues and the consumer's opinion about this power choice.

Once the raw information was gathered through the market survey (appendix B), the next step was to transfer the information into the template format offered by the software. The templates were designed to bring a young business or an existing business into a new product and market opportunity. Exploring opportunities for a new technology in established markets demanded a different approach.

The tools used in the financial section were a learning curve analysis, a study on the cost of fuel cell power system components purchased in large volume, and an engineering economic analysis of stack energy costs. The learning curve analysis is a traditional and accepted tool. We used a 15% learning curve, which would indicate that an item costing $100 for the 100th unit would only cost $85 for the 200th unit. The learning curve for the semiconductor industry is historically 20%. If we assume a conservative 15% learning curve for SERC's first 4 kW fuel cell power system, which initially cost $45,000, we will see a cost decline to $10,000 just after the 512th unit, and $2,000 at the 525,000th unit.

Dr. Robert Nowak of the Advanced Research Projects Agency in Arlington, Virginia suggested that an analysis of fuel cell power system costs could be done by costing out the components, analyzing the maturity of the industry producing the component, estimating the likelihood of the cost of the component declining as the industry matures, and determining the potential effect of volume discounts or mass production on the cost of each component. This method was utilized in the analysis of the fuel cell power system for this market study and business plan.

In the engineering economic analysis, today's fuel cell stack performance, stack capital cost, and liquid hydrogen cost were used as a base case scenario. The study varied these three parameters to determine their effect on the price per kWh of fuel cell stack electricity.

B. Results and Evaluation of Business Plan

The goal of the Fuel Cell Power Systems for Remote Applications project is to initiate commercialization of a 0.1-5 kW integrated hydrogen fuel cell power system. The research targeted the following high value niche markets: off-grid homes, recreational vehicles, yachts, and telecommunications stations. This research was a cooperative effort of TBE, SERC, and the City of Palm Desert. Also included for planning purposes is previously researched information on the market for small, remote power systems for devices in the petroleum production and gas transmission industries.

The work was conducted over a nine month period. TBE provided administrative oversight and information on their remote power business interests and new product decision logic. SERC researched the technical and financial requirements to build and manufacture a FCPS, including the present state of the technology, the required components, current cost of producing a 3 kW (net) system, a learning curve analysis, projected volume costs of fuel cell materials, and the total energy cost under various assumptions. The City of Palm Desert worked cooperatively with the firm KMC Financial Corporation to research the current energy usage, cost of power, and potential interest in the FCPS of the target markets. KMC and the City also examined the business climate in Palm Desert. BizPlan software was utilized as a guide for writing the business plan.

Research indicates that consumers in these markets have an interest in clean, quiet energy generation systems. The exact premium that these markets would be willing to pay for the benefits of the FCPS is difficult to determine with no model available for demonstration. The current costs of competitive energy generation technologies are $0.13/kWh for generators, $0.29/kWh for the battery/shore power systems that yacht owners would use, and $0.50/kWh for photovoltaics. Using current technology and manufacturing processes, the FCPS could provide power for $0.44/kWh. In the best case scenario with component and labor cost reductions of 50%, fuel cell performance increases of 100%, and a liquid hydrogen cost of $12/GJ the fuel cell could provide power for $0.23/kWh. The cost of energy production of the FCPS was calculated with liquid hydrogen as the fuel. Current cost estimates of hydrogen produced with a small scale POX reformer are only projections and vary widely, depending on the source. With a learning curve of 20%, the FCPS with a reformer reaches the target cost of $1,500/kW at the 260,000th unit. Without the reformer this target is reached at the 50,000th unit.

Consumers in the off-grid home market are early adopters of new technology and interested in reliable, clean, quiet energy generation. There are approximately 100,000 remote homes in the U.S., many of which use a remote power generator. Most remote home owners require less than 5kW for daily needs, but prefer to have more power available to run power tools, etc. An area for further research into this potential market would be for a small FCPS, approximately 1 kW or less, designed to trickle charge a battery bank.

The recreational vehicle (RV) market has a potential of 10,000 units yearly. If the price of the FCPS were comparable to that of current generators and the benefits of the FCPS could be demonstrated, RV manufacturers would be interested in incorporating the new systems into their units. Two RV manufacturers estimated that consumers would be willing to pay a premium of $500 - $700 per unit for the FCPS benefits .

A possible market exists in 30-40 foot sailboats. 15,000 new boats of this size were built in the last 9 years. Sailboat owners are accustomed to high shore power and marine generator costs. An FCPS for this market would be designed for marine conditions and paucity of space. Most sailboats of this size carry propane onboard for cooking, so owners are not apprehensive about carrying fuel tanks.

The main power uses in telecommunications are for air conditioning systems, radio transmitting equipment, cellular and personal communications services and microwave equipment. Field research indicates that even though many of the telecommunications sites are on the grid, power failures are frequent and the sites require large battery or generator backup systems. Repeater stations, which relay or 'repeat' the signal for various telecommunications industry applications are often located in remote places and require highly dependable DC power. Currently, the repeater stations utilize photovoltaic panels and batteries. Sites vary greatly in power usage and the telecommunications arena is changing rapidly, but there appears to be a large potential in this market.

Market studies previously commissioned by TBE examining the gas industry indicate potential markets for small FCPSs (less than 1 kW in size) for remote terminal units, cathodic protection, and electronic flow controllers, and for medium power units (less than 5kW) for wellhead monitoring, control, etc. Approximately 75% of the remote power system market under 30 W is at gas distribution sites, with 32,044 units sold in 1995. This market is growing and the current price paid for power (batteries) in this market is $120/W. Serious consideration should be given to the market for units smaller than 30 W. Such a market might be appropriate for a very small fuel cell power system using bottled hydrogen, especially since material costs for fuel cell stacks are a large portion of FCPS costs, and these would be minimized. There are greater than 2 million existing land wellheads worldwide whose equipment will eventually need replacement.

For the balance of the project, the partners will prepare for production of units to serve the above-mentioned markets. They have chosen to concentrate initially on 1 to 3 kW remote power systems for natural gas and oil pipelines. After the R&D work of phases II and III is completed, the consortium will build and test beta units, perform a detailed producibility study, and formalize the business plan that allows the product to be manufactured and marketed. The task of building and testing the beta test units will be lead by SERC, with support by HBT and TBE. The producibility study will be lead by TBE, with the support of SERC and HBT. The detailed business planning will be lead by TBE, with the support of the City of Palm Desert.

The task of building and testing FCPS beta units begins with the definition of system performance and product specifications to be developed by TBE as part of Phase III. At the onset of Phase IV, SERC will develop an overall system design and sufficient schematics to manufacture parts and procure components. Stack materials and other long lead items will be identified and ordered as soon as possible, as shown in the Gantt chart for phase IV. The goal is to deliver and install four beta units at sites identified in Phase III by the fourth quarter of the year 2000.

Once the beta unit design has defined the configuration, TBE will take over responsibility for the drawing package, developing it to the detail necessary to complete the manufacturing study. The fuel cell stack design will evolve to correct problems identified as a result of beta testing and the manufacturing study.

The task of completing a detailed and final producibility/manufacturing plan and business plan will begin immediately. Building upon earlier planning and using the beta design as a basis, each detail, component, subsystem and finally the top assembly, will be defined in terms of how it is to be obtained, i.e., make/buy. If make, as in the case of fuel cell stack elements, a manufacturing plan will be defined and costs determined. If buy, vendors will be identified and prices obtained. This effort will be lead by the TBE Manufacturing Engineering Department, working with the TBE Engineering Department, SERC and HBT to produce design recommendations which will enhance producibility without compromising performance. The team will:

1. Minimize the number of individual operations, i.e., machine set-ups, multiple machine operations, intermediate steps in total process flow, involved in the fabrication of detail parts.

2. Design for components and feed stock materials that can be purchased as close to finished dimension/configuration as possible.

3. Assure dimensional tolerances are consistent with end product requirements and are necessary for the proper fit and/or function of related parts and components.

This producibility engineering activity will include the identification of the tooling that will assure that all tooling necessary to the production of a quality product at minimum cost is identified, priced, and planned for phasing into the project in a logical fashion, commensurate with forecasted sales.

It is anticipated that the effort to actually get into production will be commensurate with the formal introduction of the product and accessories and a realistic and conservative forecast of orders and sales. We can expect initial sales to be difficult to come by, consisting for the most part of single unit orders by early technology adopters. It is highly likely that these limited production units, if less than a dozen or so in the first year, will be partially assembled (stack) by SERC, with final assembly in a temporary facility, while permanent facilities are being readied.

Funding for manufacturing and marketing this product is expected to be within the internal resources of Allegheny Teledyne Corporation, with support from the community of Palm Desert. The exact method of and timing of capitalization and funding startup costs is yet to be determined. However, similar projects/products have been recently successfully executed.

Other issues that will be addressed as a part of the business planning activity include: 1) the definition of strategies for marketing, i.e., direct sales and/or sales through representatives and distributors, 2) product support, i.e., commissioning, service and training and 3) pricing philosophy. It is likely that the first sales will have to be made as so called loss leaders. Hopefully, this can be limited to a small number of units. However, much depends on the final cost profiles that result from the producibility/manufacturing effort.

C. Technical and Financial Requirements to Establish Manufacturing Capability

Establishing a manufacturing capability for fuel cell power systems is a vital step in bringing the cost of these systems down to competitive levels. This project will culminate in the development of a detailed plan for the commercial production of fuel cell power systems similar to the β-prototypes built in phase IV. In order to progress to volume production, a number of manufacturing issues will have to be addressed. These include, but are not limited to, selection of fabrication techniques, in-house versus out-sourced production, level of plant automation, and estimation of plant capital cost.

The fuel cell stacks SERC has built to date, and will build in this project, are comprised mostly of parts machined in plastic (polypropylene) and graphite. Machining these parts is a very efficient way to produce experimental or prototype stacks, since design changes may be incorporated quickly and cheaply. For production, though, machining is generally not preferred because it is more consumptive of time and materials than such techniques as molding, stamping, or extruding. The machining of plastic sheet materials for proper thickness and surface finish is particularly time consuming, and must be completed before any parts can be cut from the sheet. This requirement would be the most severe impediment to basing manufacturing primarily on machining, even assuming the use of modern, high speed, CNC machine tools.

The strongest alternative to machining of the plastic parts is injection molding. Injection molding allows large volumes of relatively complex plastic shapes to be produced rapidly and at low per piece cost. On the other hand, design changes are discouraged because of the cost of the required molds. A set of molds for the plastic parts in the SERC stack would represent an investment of at least $75,000. Further, it is not clear whether the molded parts would be usable directly or would require some finish machining to meet the required dimensional and finish tolerances. If this path were to be pursued, SERC would have to work closely with an injection molding company to develop a part design optimized both for the fuel cell application and production by molding.

Finding an alternative to machining of the graphite parts is more difficult. Some other stack developers have employed molded graphite, but this technique has not been demonstrated in volume production. Further, because graphite powder is mixed with a nonconductive resin binder in order to produce a moldable material, stack performance is degraded by the resulting higher electrical resistivity of the finished parts. Replacing the graphite parts with comparable metal parts produced by stamping may also be possible. The base metal would almost certainly have to be plated or coated with some noble metal or alloy which would be conductive yet not corrode, even under the moist, high voltage conditions encountered inside a fuel cell stack. Because both of these alternatives would require research and development efforts outside the scope of this project, it will be assumed that the graphite parts will be employed and will be manufactured by machining.

The fuel cell stack MEAs will almost certainly be out-sourced. W.L. Gore & Associates (Gore) has positioned itself to be a sole-source provider of finished MEAs. Their products have demonstrated excellent performance and are delivered accurately die cut to size and shape as per customer drawings, and ready to install. Gore is prepared to increase production capacity as required to meet demand, and understands the importance of lowered MEA costs to the successful commercialization of fuel cell power systems.

Assembly of fuel cell stacks must be done carefully and in a clean environment to ensure good performance. A "clean room" is not necessary, but clean surroundings in which to lay out the parts and assemble the stack are important. The current practice is to assemble the stacks by hand, literally by stacking the parts sequentially one on top of another. For a 70 cell stack, this process will take one or two people approximately four to six hours. Clearly automation of stack assembly would be advantageous, but, owing to the variety of parts involved, some of which are rather fragile, may prove to be difficult.

The reformer technology will be provided by HBT. It is unknown at this time whether HBT will establish manufacturing capacity to serve as a sole-source provider, or will license its technology to TBE for manufacturing in-house.

Final assembly of the FCPS will be a relatively straight forward process, well suited to common "assembly line" techniques. The subsystem components will likely all be provided by selected vendors or manufacturers, with final system assembly and pre-delivery testing occurring in-house. This testing will require a test station capable of measuring system operating parameters, a load bank, and a natural gas or propane supply.

Issues such as in-house versus out-sourced production, level of plant automation, and estimation of plant capital cost are closely interrelated. If production is largely out-sourced, capital investment is minimized but control of production scheduling and quality assurance is reduced. By keeping all production in-house, full control is retained at the expense of much higher capital cost. Both options are viable, the preferred choice depends on expected annual production volume, available start-up capital, cash flow requirements, assumed discount rates, etc. Similarly, plant automation can dramatically reduce per unit production costs, but only by accepting very high initial capital costs. It is unlikely that early FCPS demand will support a great deal of automation beyond the use of CNC machine tools. However, the automation of MEA production, fuel cell stack assembly, and reformer construction would have perhaps the greatest impact on reducing the unit cost, and thus increasing the marketability, of these systems. These issues will be addressed in detail in phase IV.

Detailed manufacturing plans will be established in Phase IV. The Coachella Valley, CA is the location tentatively designated for the Phase IV manufacturing evaluation site. The City of Palm Desert, located in the valley,s has taken a leadership role in the development and commercialization of fuel cells. The city currently maintains the largest fleet of operational fuel cell vehicles in the world.

The city has established incentives which are attractive for the first plant to manufacture small fuel cell power systems for remote applications. The benefits, tax incentives and projected cost information for a Coachella Valley location are presented in Appendix C.

IV. Project Planning for Phases II - IV

A. Phase II - Technology Development

There are three possible options for phase II:

Phase IIA (4/1/98 - 3/16/99)

In phase IIA, SERC will conduct the research and development necessary to produce a reformate tolerant fuel cell stack.

Task 1 - Modify or Redesign Stack for Reformate Operation (4/1/98 - 8/4/98)

This task includes all of the redesign necessary to produce a fuel cell stack intended to run on reformate. Such redesign includes modifying the hydrogen flow path to run the stack "open-ended"(in order to allow the exit of gas stream impurities) and adding anode gas humidification. SERC will also obtain Gore MEAs that are reformate tolerant, fabricate, assemble, and test two 50 cm^2 stacks (each of at least four cells), and analyze and document the results.

Task 2 - Build Two Test Stations (4/1/98 - 9/1/98)

In order to have the ability to test experimental stacks on reformate mixed in the lab or reformate directly from a reformer, SERC will design and build two test stations. This activity entails building and installing benches; obtaining the appropriate hardware and software; identifying, purchasing, and installing the appropriate electronic and monitoring equipment and the plumbing hardware for the air, water, hydrogen, reformate, and synthetic reformate systems. SERC will develop the operating program using LabView software. Finally, SERC will test (in the absence of a fuel cell stack), debug and document all test bench systems.

Task 3 - Modify Test Station 3 to Operate on Reformate (9/2/98 - 12/15/98)

In order to have the ability to test a 3-5 kW stack and reformer under variable loads, SERC will modify an existing test station for operation on reformate. SERC will design modifications, and purchase and install the necessary hardware. This includes adding plumbing for 1)reformate as it leaves an actual reformer and 2)synthetic reformate that has been mixed in the lab to reformer manufacturer specifications. Other changes include adding monitoring equipment for CO and CO_2, and modifying the current LabView software. Finally, SERC will test (in the absence of a fuel cell stack), debug and document all test bench systems.

Task 4 - Begin Development of BASIC Stamp Based Control System (4/1/98 - 3/2/99)

SERC will develop a no-frills control system based on PicStic™ technology. This includes obtaining and programming a PicStic™ industrial controller. SERC will specify the minimum required control and monitoring functions, and design the development system. SERC will obtain control and monitoring hardware and electronics, develop control algorithms and code, and assemble, test, and debug the breadboard system. The breadboard system will be tested with a fuel cell stack and documented.

Task 5 - Test Small Stacks on Synthetic Reformate (7/29/98 - 3/16/99)

SERC will test, on the test stations from Task 2, the two 50 cm^2 stacks from Task 1 on reformate mixed in-house for performance, durability, and maximum CO tolerance. All results will be analyzed and documented.

Task 6 - Produce Final Report for Phase IIA (3/17/99 - 3/30/99)

TBE and SERC will produce and deliver to DOE a final report summarizing the activities and results of phase IIA.

Phase IIB (4/1/98 - 11/3/98)

In phase IIB, SERC will build and deliver to the University of Alaska or another site in Alaska a palletized 5 kW hydrogen fuel cell power system.

Task 1 - Build 5 kW (net) Fuel Cell Stack (4/1/98 - 8/18/98)

SERC will obtain the materials for a 5 kW stack, fabricate the parts, and assemble and test the stack. All test results will be analyzed and documented.

Task 2 - Develop Palletized Fuel Cell Power System (4/1/98 - 11/3/98)

SERC will design all fuel cell subsystems (air, water, hydrogen, and electrical), obtain subsystem components, and design the layout of the components on a pallet. SERC will design and construct a user interface and perform a safety analysis on the designed system. After assembly, testing, and debugging in a brassboard configuration, the system will be assembled, tested, and debugged on a pallet. SERC will deliver and install the system in a remote village, train on-site personnel in maintenance and operation, and analyze operating results.

Task 3 - Produce Final Report for Phase IIB (10/21/98 - 11/3/98)

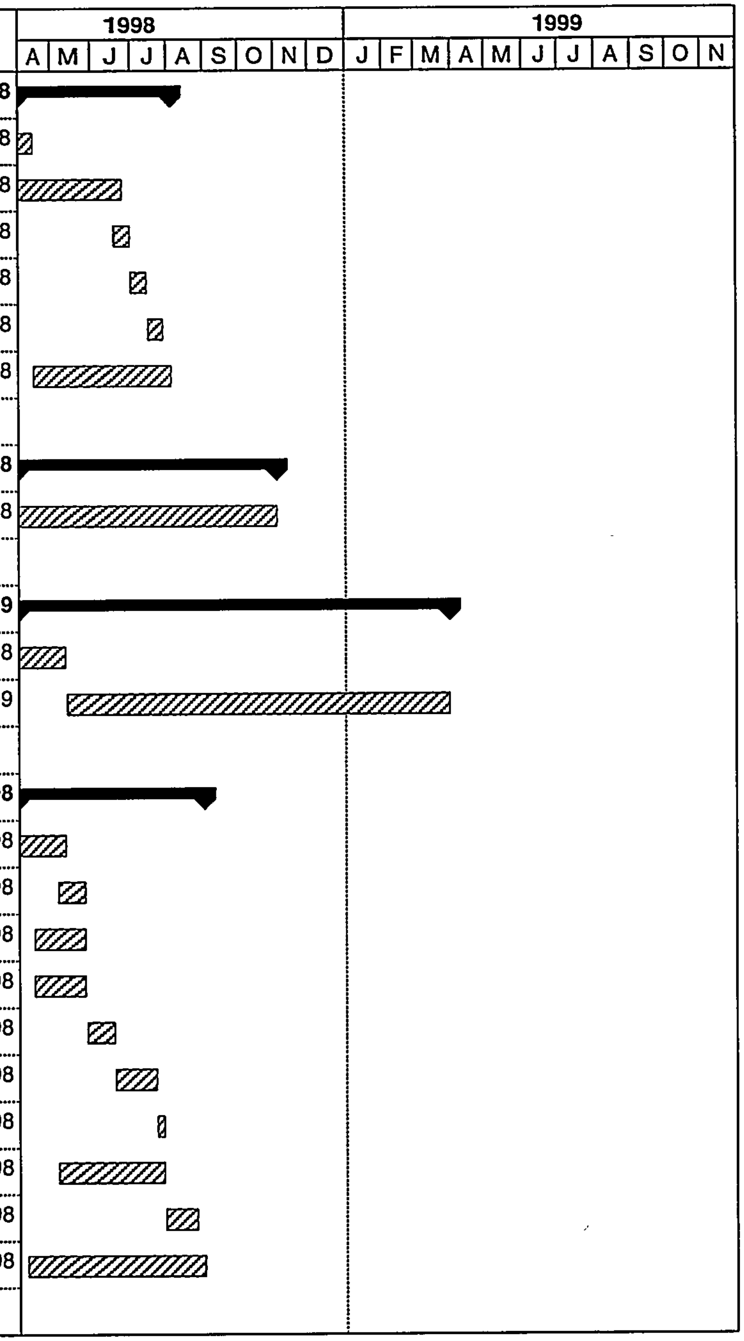
TBE and SERC will produce and deliver to DOE a final report summarizing the activities and results of phase IIB.

Phase IIC - Test Station Support to the University of Alaska

SERC and TBE will provide support to the University of Alaska in setting up a fuel cell testing laboratory. After a general introduction to the test benches at SERC facilities, researchers from both universities will determine the goals and objectives of the Alaska facility. Next, they will specify the resources (funding and personnel) available from both locations to design, build and install, and operate and maintain the Alaska facility. Together they will draw up a general plan for the Alaska facility that includes a budget for labor and materials, a timeline, and a statement of work. This plan will also include provisions for University of Alaska professors and students to spend time at SERC becoming familiar with SERC test benches, testing protocol, and data analysis. Once the plan, personnel, and funding are in place, work can begin at the University of Alaska and at Humboldt State University.

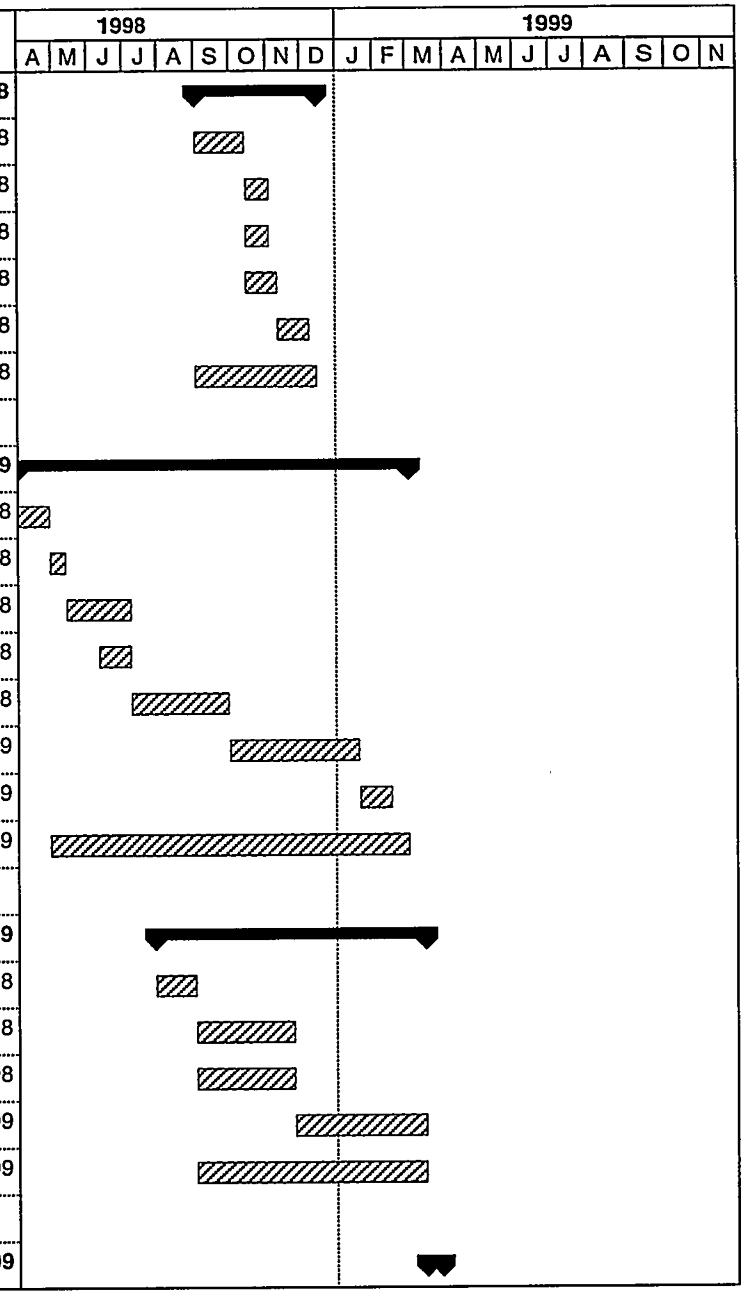
Phase IIA Gantt Chart

ID	Name	Duration	Start	Finish
1	**Modify or Redesign Stack for Reformate Operation**	**90d**	**4/1/98**	**8/4/98**
2	balance h2 flow length in stack	10d	4/1/98	4/14/98
3	obtain materials, MEAs	12w	4/1/98	6/23/98
4	fabricate parts for two four cell, 50 cm2 stacks	10d	6/17/98	6/30/98
5	assemble & test with cathode humidification & H2 (TS2)	10d	7/1/98	7/14/98
6	add anode gas humidification & test on H2 (TS2)	10d	7/15/98	7/28/98
7	analyze and document results	16w	4/15/98	8/4/98
8				
9	**Alaska Fuel Cell Power System Demonstration**	**155d**	**4/1/98**	**11/3/98**
10	design, build, install, & test 5 kW H2 FC system for Alaska	155d	4/1/98	11/3/98
11				
12	**Develop Reformer**	**260d**	**4/1/98**	**3/30/99**
13	negotiate reformate specs with Gore & HBT	30d	4/1/98	5/12/98
14	development of reformer at HBT	230d	5/13/98	3/30/99
15				
16	**Build Two New Test Stations**	**110d**	**4/1/98**	**9/1/98**
17	design test stations & prepare space	6w	4/1/98	5/12/98
18	obtain or build & install benchs	15d	5/6/98	5/26/98
19	obtain LabView package and National Instruments hardware	30d	4/15/98	5/26/98
20	obtain computers, electronic loads, and balance of hardware	30d	4/15/98	5/26/98
21	install plumbing for air, water, H2, reformate, & synthetic reformate	15d	5/27/98	6/16/98
22	install electronics, monitoring devices, & wiring	25d	6/17/98	7/21/98
23	install monitoring equipment for H2 & CO levels in room	5d	7/22/98	7/28/98
24	develop operating program in LabView	12w	5/6/98	7/28/98
25	test and debug without fuel cell	20d	7/29/98	8/25/98
26	documentation	105d	4/8/98	9/1/98
27				



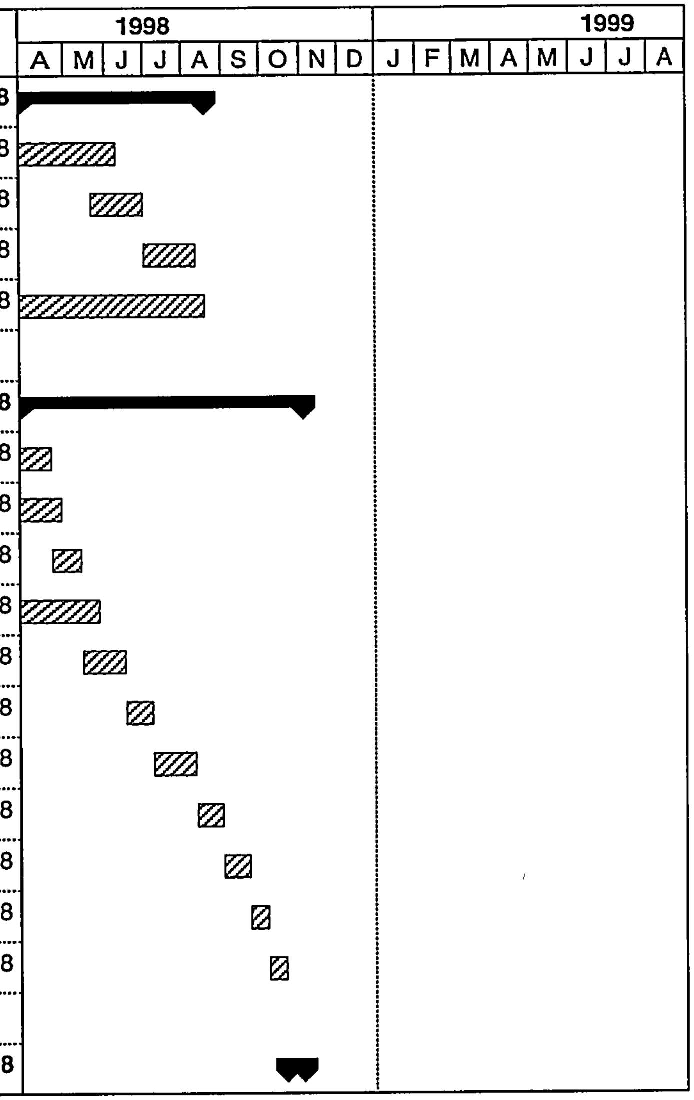
Phase IIA Gantt Chart

ID	Name	Duration	Start	Finish
28	**Modify Test Station 3 for Operation on Reformate**	**75d**	**9/2/98**	**12/15/98**
29	design modifications and obtain hardware	6w	9/2/98	10/13/98
30	add plumbing for reformate & synthetic reformate	15d	10/14/98	11/3/98
31	add monitoring equipment for CO, CO2 content	15d	10/14/98	11/3/98
32	modify LabView program from task 21 as required	4w	10/14/98	11/10/98
33	test and debug without fuel cell	20d	11/11/98	12/8/98
34	document all changes	75d	9/2/98	12/15/98
35				
36	**Begin Development of BASIC Stamp Based Control System**	**240d**	**4/1/98**	**3/2/99**
37	obtain PicStic™ computer system	4w	4/1/98	4/28/98
38	specify minimum required control & monitoring functions	10d	4/29/98	5/12/98
39	design & build development system	8w	5/13/98	7/7/98
40	obtain control & monitoring hardware & electronics	4w	6/10/98	7/7/98
41	develop control algorithms & code	12w	7/8/98	9/29/98
42	assemble, test, & debug breadboard system	16w	9/30/98	1/19/99
43	test breadboard system with 300 cm2 stack	4w	1/20/99	2/16/99
44	document system and software	220d	4/29/98	3/2/99
45				
46	**Test Small Stacks on Synthetic Reformate**	**165d**	**7/29/98**	**3/16/99**
47	obtain reformate tolerant MEAs from Gore	5w	7/29/98	9/1/98
48	test for performance and longevity on "HBT" composition reformate (TS4)	12w	9/2/98	11/24/98
49	test for maximum CO tolerance (TS5)	12w	9/2/98	11/24/98
50	make stack and/or MEA changes as required & test	16w	11/25/98	3/16/99
51	analyze and document results	140d	9/2/98	3/16/99
52				
53	**Produce and Submit Final Report for Phase IIA**	**10d**	**3/17/99**	**3/30/99**



Phase IIB Gantt Chart

ID	Name	Duration	Start	Finish
1	**Build 5 kW (net) Stack**	**100d**	**4/1/98**	**8/18/98**
2	obtain stack materials, MEAs	10w	4/1/98	6/9/98
3	fabricate stack parts	6w	5/20/98	6/30/98
4	assemble and test	6w	7/1/98	8/11/98
5	analyze and document test results	100d	4/1/98	8/18/98
6				
7	**Develop Palletized Fuel Cell Power System**	**155d**	**4/1/98**	**11/3/98**
8	design fuel cell subsystems	3w	4/1/98	4/21/98
9	obtain subsystem components	4w	4/1/98	4/28/98
10	design pallet & component layout	3w	4/22/98	5/12/98
11	design & construct control system & user interface	8w	4/1/98	5/26/98
12	Perform safety analysis	5w	5/13/98	6/16/98
13	assemble system brassboard	3w	6/17/98	7/7/98
14	test & debug brassboard system	5w	7/8/98	8/11/98
15	build system pallet, assemble system on pallet	3w	8/12/98	9/1/98
16	test & debug completed system	3w	9/2/98	9/22/98
17	deliver & install system	2w	9/23/98	10/6/98
18	test installed operation, train on-site personnel	2w	10/7/98	10/20/98
19				
20	**Produce & Submit Final Report for Phase IIB**	**10d**	**10/21/98**	**11/3/98**



Phase III (4/1/99 - 3/30/00)

In phase III, SERC will build a 3 kW, reformate-tolerant fuel cell stack with 300 cm^2 active area, install an HBT reformer, develop a PicStic™ BASIC stamp control system, and develop, test, and deliver to TBE the integrated palletized system.

Task 1 - Develop a 3 kW (net) fuel cell stack. (4/1/99 - 12/29/99)

The stack will be built in three stages: first with four cells, then with thirty-five cells, and finally with seventy cells. In between each scale-up, the stacks will be tested on reformate. Stack building and testing will be documented.

Task 2 - Install HBT Reformer (4/1/99 - 5/31/99)

SERC will prepare lab space for an HBT reformer, plumb natural gas lines into the lab, receive and install the reformer, plumb the reformer to the test station on which it will be operated, and train employees in its use.

Task 3 - Develop PicStic™ Control System (4/1/99 - 8/4/99)

SERC will develop a cell voltage monitoring subsystem, define an input/output list, obtain control and monitoring hardware and electronics, develop control algorithms, write software code, and finally assemble, test, and debug the breadboard system.

Task 4 - Interface SERC and HBT Control Systems (4/1/99 - 6/16/99)

After determining the functions and capabilities of the reformer's control system, SERC will identify an input/output list for communication between the reformer and fuel cell system. SERC's control system will then be updated with the appropriate functions. Finally, SERC will test and debug the integrated operation and document the system.

Task 5 - Modify Test Bench 3 to Test Palletized System (4/1/99 - 5/12/99)

SERC will obtain and install a variable AC load for test station 3 and make any changes that are necessary to the current data monitoring system.

Task 6 - Develop Palletized Fuel Cell Power System (6/24/99 - 12/16/99)

SERC will design the air, water, hydrogen, and electrical systems, obtain the components for these systems and design a layout on the pallet for them. Next, SERC will design and construct a user interface, signal and power/subsystem wiring, and balance of system components, and then perform a safety analysis. These will be assembled in a brassboard configuration along with the control system from Task 3. After testing and debugging the brassboard system, SERC will assemble the system, along with the reformer, on the pallet. Finally, SERC will test and debug, as well as document, the system.

Task 7 - Deliver and Test System (12/17/99 - 3/30/00)

SERC will deliver and install the completed system at TBE, as well as train personnel in its use. Together, TBE, SERC, and HBT personnel will test and evaluate the unit.

Task 8 - Preliminary β-Test Site Planning (1/3/00 - 3/30/00)

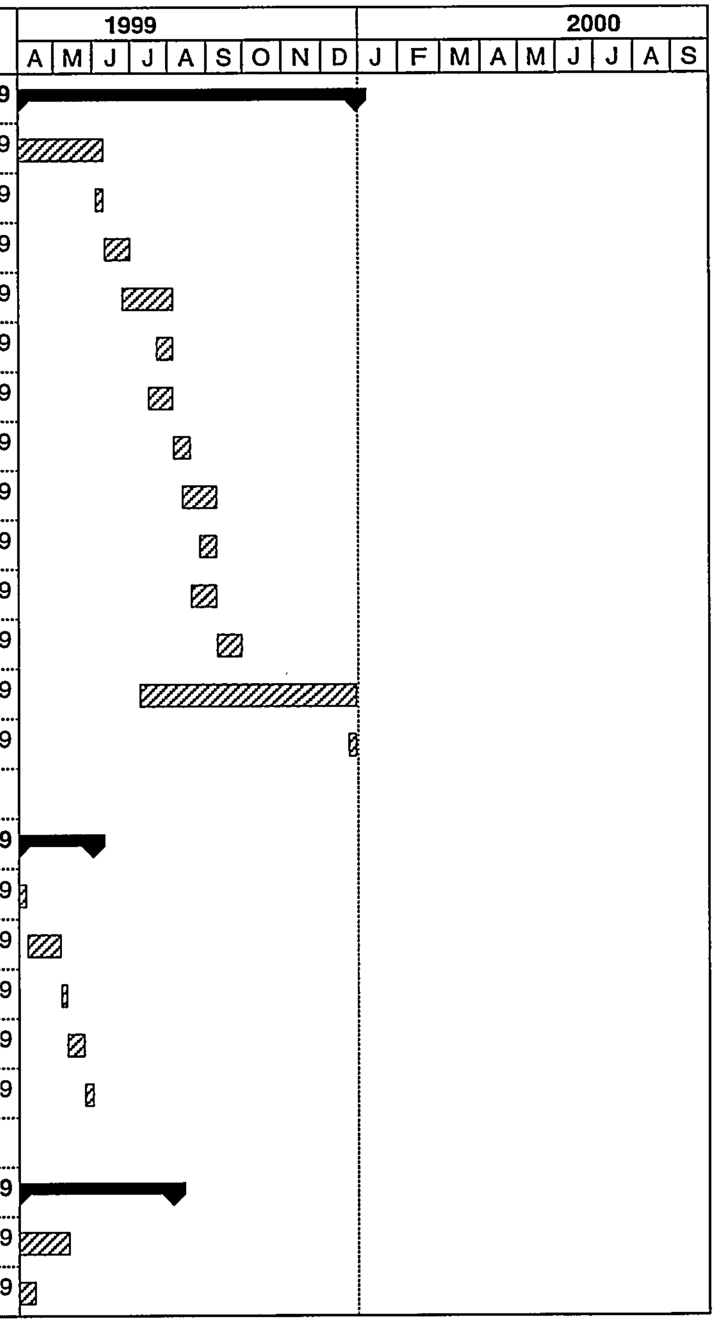
TBE will locate, evaluate, and select potential sites for FCPS β-testing in phase IV.

Task 9 - Produce Final Report for Phase III (3/17/00 - 3/30/00)

TBE and SERC will produce and deliver to DOE a final report summarizing the activities and results of phase III.

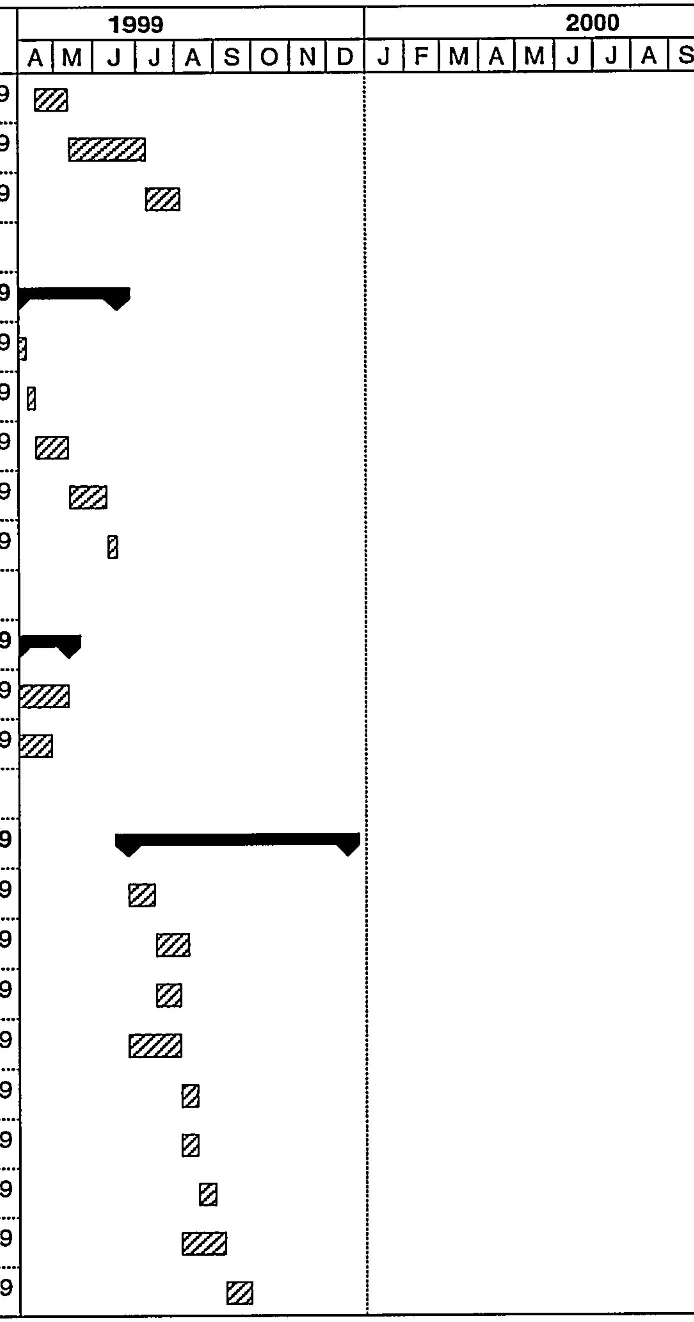
Phase III Gantt Chart

ID	Name	Duration	Start	Finish
1	**Develop 3 kW (net) Stack**	**195d**	**4/1/99**	**12/29/99**
2	obtain materials, MEAs for 4 cell, 300 cm2 stack	10w	4/1/99	6/9/99
3	fabricate parts for 4 cell, 300 cm2 stack	5d	6/3/99	6/9/99
4	assemble and test on reformate	15d	6/10/99	6/30/99
5	make cell design changes as required	30d	6/24/99	8/4/99
6	obtain MEAs to increase stack to 35 cells	10d	7/22/99	8/4/99
7	fabricate parts to increase stack to 35 cells	15d	7/15/99	8/4/99
8	assemble and test on reformate	10d	8/5/99	8/18/99
9	make cell design changes as required	20d	8/12/99	9/8/99
10	obtain MEAs to increase stack to 70 cells	10d	8/26/99	9/8/99
11	fabricate parts to increase stack to 70 cells	15d	8/19/99	9/8/99
12	assemble and test on reformate	15d	9/9/99	9/29/99
13	analyze and document test results	25w	7/8/99	12/29/99
14	document final stack configuration	5d	12/23/99	12/29/99
15				
16	**Install HBT Reformer**	**43d**	**4/1/99**	**5/31/99**
17	prepare reformer space	1w	4/1/99	4/7/99
18	prepare natural gas plumbing and electrical service	4w	4/8/99	5/5/99
19	receive and install reformer	3d	5/6/99	5/10/99
20	plumb reformer to TS3, modify TS3 as required	2w	5/11/99	5/24/99
21	commission reformer, train users	1w	5/25/99	5/31/99
22				
23	**Develop PicStik™ Based Control System**	**90d**	**4/1/99**	**8/4/99**
24	develop cell voltage monitoring subsystem	6w	4/1/99	5/12/99
25	define I/O list for palletized system	2w	4/1/99	4/14/99



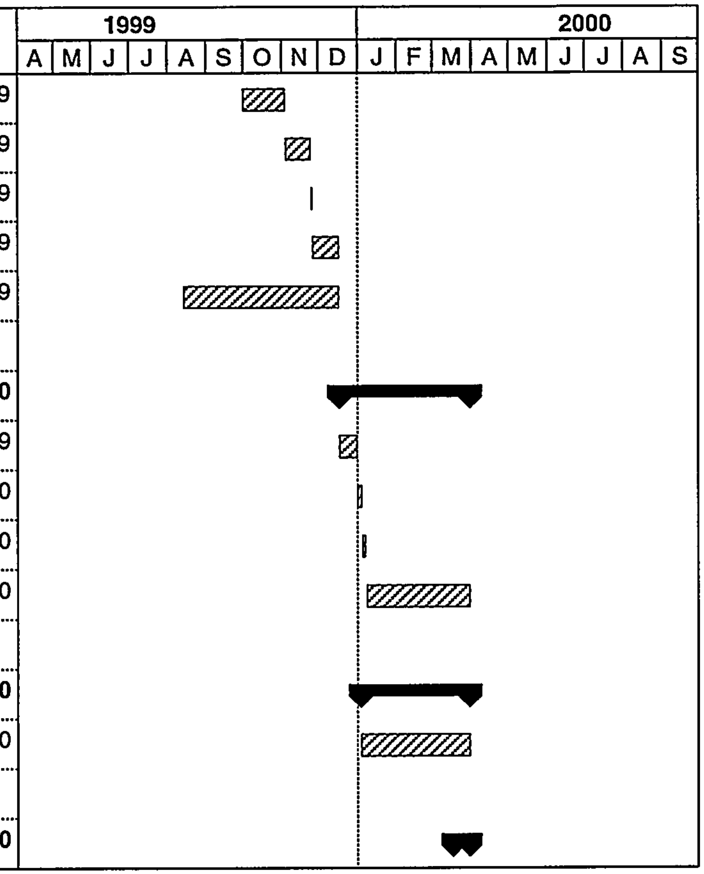
Phase III Gantt Chart

ID	Name	Duration	Start	Finish
26	obtain control & monitoring hardware & electronics	4w	4/15/99	5/12/99
27	develop control algorithms & code	8w	5/13/99	7/7/99
28	assemble, test, & debug breadboard system	4w	7/8/99	8/4/99
29				
30	**Interface SERC and HBT Control Systems**	**55d**	**4/1/99**	**6/16/99**
31	determine functions and capabilities of HBT control system	1w	4/1/99	4/7/99
32	determine I/O list for communication between systems	1w	4/8/99	4/14/99
33	add functions to SERC control system (safety, additional control, etc.)	4w	4/15/99	5/12/99
34	test integrated operation and debug	4w	5/13/99	6/9/99
35	document final configuration	1w	6/10/99	6/16/99
36				
37	**Modify TS3 to Test Palletized system**	**30d**	**4/1/99**	**5/12/99**
38	obtain and install variable AC load	6w	4/1/99	5/12/99
39	design and install data monitoring interface	4w	4/1/99	4/28/99
40				
41	**Develop Palletized Fuel Cell Power System**	**126d**	**6/24/99**	**12/16/99**
42	design fuel cell subsystems	3w	6/24/99	7/14/99
43	obtain subsystem components	4w	7/15/99	8/11/99
44	design pallet & component layout	3w	7/15/99	8/4/99
45	design & construct user interface	6w	6/24/99	8/4/99
46	design signal harness	2w	8/5/99	8/18/99
47	design power and subsystem wiring	2w	8/5/99	8/18/99
48	obtain BOS materials	2w	8/19/99	9/1/99
49	Perform safety analysis	5w	8/5/99	9/8/99
50	assemble system brassboard, with BASIC Stamp control system	3w	9/9/99	9/29/99



Phase III Gantt Chart

ID	Name	Duration	Start	Finish
51	test & debug brassboard system	5w	9/30/99	11/3/99
52	build system pallet, assemble system on pallet	3w	11/4/99	11/24/99
53	set-up on TS3 for testing	1d	11/25/99	11/25/99
54	test & debug completed system	3w	11/26/99	12/16/99
55	document final configuration and testing results	90d	8/13/99	12/16/99
56				
57	**Deliver & Test System**	**75d**	**12/17/99**	**3/30/00**
58	deliver completed system to TBE	2w	12/17/99	12/30/99
59	install and commission system	2d	12/31/99	1/3/00
60	train TBE personnel	3d	1/4/00	1/6/00
61	test and evaluate system	12w	1/7/00	3/30/00
62				
63	**Preliminary Beta-Test Site Planning**	**64d**	**1/3/00**	**3/30/00**
64	locate, evaluate, and select potential beta-test sites	64d	1/3/00	3/30/00
65				
66	**Produce Final Report For Phase III**	**10d**	**3/17/00**	**3/30/00**



Phase IV (4/3/00 - 9/28/01)

In phase IV, SERC will build and deliver four 1-3 kW FCPS β-prototypes for demonstration and testing under field conditions. TBE and SERC will produce a detailed financial and technical plan for establishing commercial production.

Task 1 - Build Four 1-3 kW FCPS Demonstration Units (4/3/00 - 11/17/00)

SERC will build four 1-3 kW FCPS β-prototypes. These will be complete, palletized systems with HBT reformers. Each will be lab tested to prior to delivery.

Task 2 - Field Test Completed Systems (11/6/00 - 9/28/01)

SERC will deliver, install, and commission each system, provide O&M training to on-site personnel, and oversee the testing and evaluation of the systems.

Task 3 - Develop Manufacturing Plan (4/3/00 - 9/28/01)

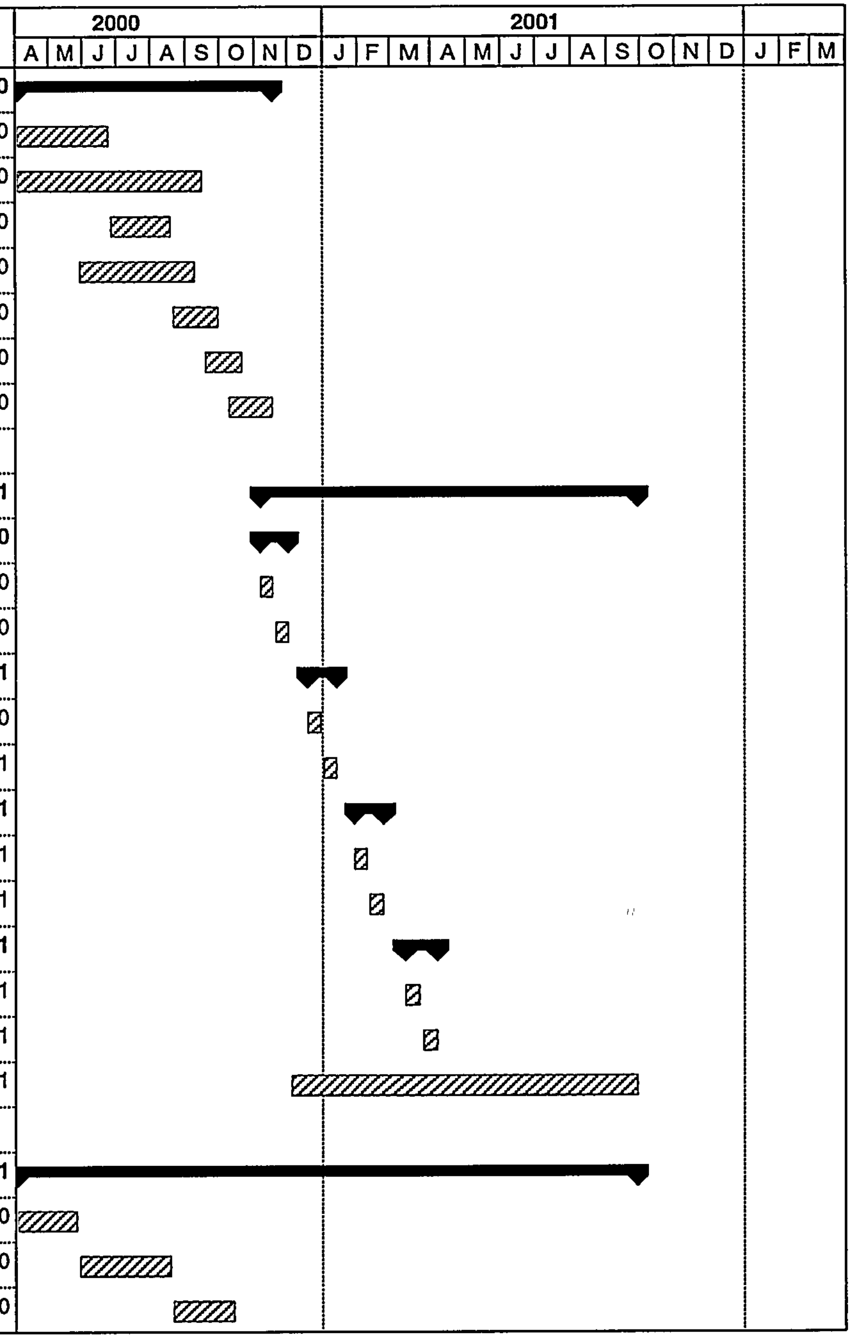
TBE, SERC, and the City of Palm Desert will select a target application and production volume upon which to base the manufacturing plan. Manufacturing methods and equipment suited to FCPS production will be researched and selected, and equipment costs will be estimated. Materials and component suppliers will be identified and contacted to negotiate price and delivery times. Work and material flows will be analyzed, and used to estimate labor requirements and plan the layout of the manufacturing plant. Potential plant sites will be visited and a preferred location selected. Finally, siting, capital, and operating costs will be estimated for input to a financial analysis to determine the break-even point and profitability of the plant. The final business plan will be developed, including financing requirements.

Task 4 - Produce Final Manufacturing Plan and Report (8/6/01 - 9/28/01)

TBE, SERC, and the City of Palm Desert will produce and deliver to DOE a report summarizing the activities and results of phase IV and includes the final manufacturing plan.

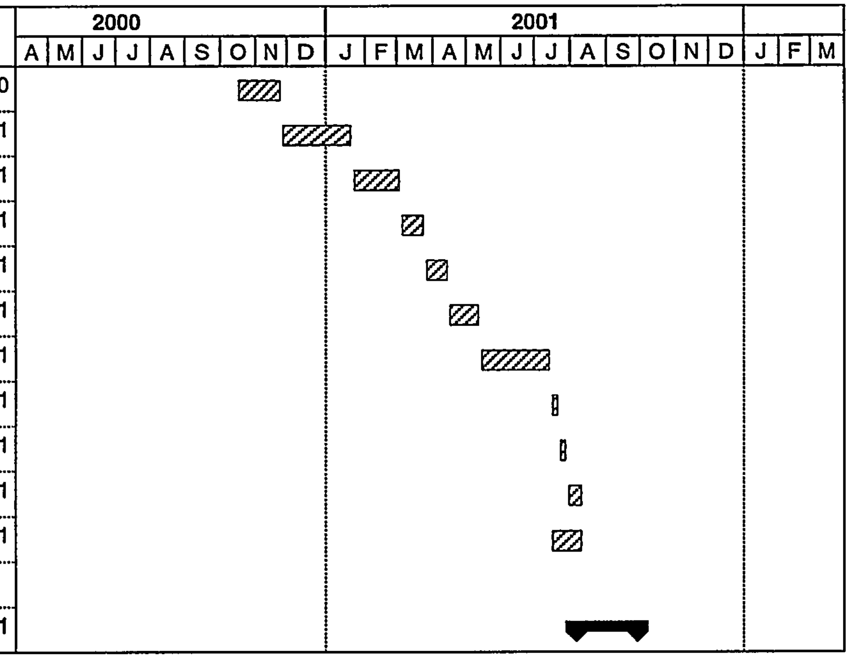
Phase IV Gantt Chart

ID	Name	Duration	Start	Finish
1	**Build & Field Test Four 1-3 kW FCPS Demonstration Units**	**165d**	**4/3/00**	**11/17/00**
2	obtain materials, MEAs for four fuel cell stacks	12w	4/3/00	6/23/00
3	obtain subsystem components and reformers	24w	4/3/00	9/15/00
4	build control systems and user interfaces	8w	6/26/00	8/18/00
5	fabricate stack parts	15w	5/29/00	9/8/00
6	assemble and bench test stacks	6w	8/21/00	9/29/00
7	build system pallets, assemble systems on pallets	5w	9/18/00	10/20/00
8	test & debug completed systems	6w	10/9/00	11/17/00
9				
10	**Field Test Completed Systems**	**235d**	**11/6/00**	**9/28/01**
11	**system #1**	**20d**	**11/6/00**	**12/1/00**
12	deliver, install and commission	2w	11/6/00	11/17/00
13	train personnel at test site	2w	11/20/00	12/1/00
14	**system #2**	**20d**	**12/18/00**	**1/12/01**
15	deliver, install and commission	2w	12/18/00	12/29/00
16	train personnel at test site	2w	1/1/01	1/12/01
17	**system #3**	**20d**	**1/29/01**	**2/23/01**
18	deliver, install and commission	2w	1/29/01	2/9/01
19	train personnel at test site	2w	2/12/01	2/23/01
20	**system #4**	**20d**	**3/12/01**	**4/6/01**
21	deliver, install and commission	2w	3/12/01	3/23/01
22	train personnel at test site	2w	3/26/01	4/6/01
23	test, evaluate, and document systems	43w	12/4/00	9/28/01
24				
25	**Develop Manufacturing Plan**	**390d**	**4/3/00**	**9/28/01**
26	select target application(s) & production volume	8w	4/3/00	5/26/00
27	research production methods, select preferred methods	12w	5/29/00	8/18/00
28	analyze & select manufacturing equipment, estimate costs	8w	8/21/00	10/13/00



Phase IV Gantt Chart

ID	Name	Duration	Start	Finish
29	identify materials and component suppliers	6w	10/16/00	11/24/00
30	negotiate materials and component prices & delivery with suppliers	8w	11/27/00	1/19/01
31	analyze work and material flows, including waste disposal/recycling	6w	1/22/01	3/2/01
32	estimate labor requirements	3w	3/5/01	3/23/01
33	plan plant layout, estimate space requirements	3w	3/26/01	4/13/01
34	evaluate balance of plant requirements, estimate costs	4w	4/16/01	5/11/01
35	evaluate potential plant sites, estimate siting & labor costs	9w	5/14/01	7/13/01
36	estimate plant capital costs	1w	7/16/01	7/20/01
37	estimate plant operating costs, including labor	1w	7/23/01	7/27/01
38	perform financial analyses to determine break-even point & profitability	2w	7/30/01	8/10/01
39	develop final business plan	4w	7/16/01	8/10/01
40				
41	**Produce Final Manufacturing Plan and Report**	**40d**	**8/6/01**	**9/28/01**



V. Teaming Arrangements for Phase II - IV

A. Identification of Team Members and Rationale for Selection.

The team members for this project are Teledyne Brown Engineering-Energy Systems (TBE), the Schatz Energy Research Center (SERC), Hydrogen Burner Technology (HBT), and the City of Palm Desert.

TBE is well-qualified to head this collaborative effort. For the past thirty years the company has been manufacturing and selling small thermoelectric power sources for remote applications. In these applications, utility power is not available, but gaseous fuels are, or can be provided. For the most part, these power sources are considered prime power for the site, so high reliability and long service intervals are of greatest importance to the customer. Most units are used by the oil and gas industry along pipelines and on platforms for cathodic protection and data acquisition/transmission.

TBE has developed a worldwide reputation for dependability and quality in electrical power sources for remote applications and industrial hydrogen gas generators. Using a strategic network of more than 33 representatives and distributors, TBE has the complete capability to design, develop, manufacture, service and sell its products.

SERC has significant experience building fuel cell power systems. SERC is qualified to perform research and development, integration, and assembly of remote power units. SERC and TBE have already worked on a collaborative program to investigate the performance of an electrolyzer powered by a photovoltaic energy system at the Schatz Solar Hydrogen Project in Trinidad, California. The program included data acquisition and analysis, the development of a computer model to simulate electrolyzer behavior and extensive measurement and analysis of photovoltaic performance, as well as, a thorough safety plan. Through this work with TBE, SERC has produced the nation's first fully operational hydrogen fuel cell facility.

SERC has also designed and built four fuel cell/battery conversions on golf cart chassis. Three of these are in daily use by city staff in Palm Desert, California. SERC is currently working on a conversion of a Kewet El-Jet 3. All of these vehicles incorporate SERC's own PEMFC stacks and operating software and are tested in-house on specially built test benches. Power levels have increased from 3 kW in the golf carts to 10 kW in the Kewet. The installed stacks are reliable and have exhibited good performance; development is ongoing to increase power density, improve manufacturability and lower costs.

Hydrogen Burner Technology was chosen to provide the reformer. The company is currently working on a design optimization effort directed at stationary building applications in the 25 to 50 kW capacity ranges. Natural gas and/or propane will fuel these units. One critical issue being addressed through these efforts is the ability of the fuel processing subsystem to achieve the 5 to 50 ppm level of carbon monoxide (CO) required by the PEM fuel cells. Resolution of this issue will have a direct impact on the success of fuel cell power systems for remote applications.

During the summer of 1994 the City of Palm Desert initiated plans to invest in the development of a PEM fuel cell industry and to support development of prototype fuel cell powered vehicles operating on the streets of Palm Desert. The City contracted with SERC to perform a feasibility study and in 1996 became the site of the Renewable Hydrogen Transportation System. Officials at the City of Palm Desert intend to one day establish a fuel cell marketing or manufacturing industry within the community. This task requires the rare combination of financial strength, desire, and business environment of a city such as Palm Desert.

B. Team Member Capabilities

- TELEDYNE BROWN ENGINEERING - ENERGY SYSTEMS

Teledyne Brown Engineering is a company of Allegheny Teledyne Incorporated (ATI), a federation of technology-based businesses with a significant concentration in advanced specialty metals complemented by aerospace and electronics, industrial and consumer products.

Allegheny Teledyne, formed by the merger of the Allegheny Ludlum Corporation and Teledyne, Inc., is a diverse corporation with more than 24,000 employees and more than $4B in annual sales. ATI is composed of four business segments: specialty metals, aviation and electronics, industrial products, and consumer products and services. Teledyne Brown Engineering (TBE), headquartered in Huntsville, Alabama, is the largest component of the aviation and electronics segment. TBE is composed of a number of diverse companies, including Brown Engineering and several commercial units: Control Applications, Marine Products, Hastings Instruments, Engineering Services, Environmental Services, and Energy Systems, located in Hunt Valley, Maryland. In addition, TBE maintains field offices in Colorado Springs, Colorado; Shalimar and Cape Canaveral, Florida; Albuquerque, New Mexico; and Arlington, Virginia, and production facilities in Jackson and Slocomb, Alabama.

Teledyne Brown Engineering - Energy Systems is located near Baltimore, Maryland. Energy Systems is in the heart of the Mid-Atlantic region, with ready access to rail, ocean, and air transportation facilities. Its trained staff and a new 68,000 square foot engineering and manufacturing facility are being used to address opportunities and solve tomorrow's problems.

Teledyne Brown Engineering - Power Systems provides hardware and services to the US Government and many commercial customers. It produces several different types of thermo-isotope fuel as heat sources, and develops various self-powered electrical appliances using improved thermoelectric conversion techniques. New and improved methods of energy conversion are being developed in preparation for future customer needs. Power Systems is testing long-life, high-reliability, conventional electric power generators for introduction into remote power markets.

Teledyne Brown Engineering - Hydrogen Systems operations focus on the engineering, manufacturing, and sale of a full line of hydrogen/oxygen generators. Using electrolysis of water, these generators meet a wide range of customer needs for the on-site production of high-purity gases. Applications include power plants, semiconductor fabrication, optical fiber production, argon purification, metal processing, and meteorological applications. Its current product line provides up to 800 standard liters per minute (slm). A planned new product will significantly increase the range to 2000 slm. Many hardware options are also available. These include water treatment, gas purity instrumentation, area safety monitoring, gas compression, and gas storage. Complete facility design services are also available.
Energy Systems recognizes that it can and should be involved in the evolution of hydrogen as a strategic energy carrier. Its participation in this program reflects that interest as it develops equipment for energy related applications for both commercial and consumer applications.

- THE SCHATZ ENERGY RESEARCH CENTER

The Schatz Energy Research Center (SERC) is located at Humboldt State University (HSU) in Arcata, CA. The mission of SERC is to promote the use of clean and renewable energy in our society. SERC meets its mission by performing research on renewable energy systems; designing, building, operating, and demonstrating clean and renewable energy technologies; providing training for students in renewable energy technologies; educating the public about the advantages of clean and renewable energy technologies; and disseminating information concerning the Center's activities.

During the past seven years, SERC has designed, built, and operated a stand-alone photovoltaic-hydrogen-fuel-cell energy system at Humboldt State University's marine laboratory. The system consists of a 9.2 kW photovoltaic (PV) array coupled to a 7.2 kW bipolar, alkaline electrolyzer. The regeneration technology is a proton exchange membrane (PEM) fuel cell, built in-house. SERC has carefully monitored and reported system performance, developed a simulation program to design such systems, and developed and calibrated a separate electrolyzer thermal model for use in the simulation. In addition, the PV array was used to study mismatch losses and the array designed to minimize them.

Recently SERC has been involved in the Palm Desert Renewable Hydrogen Transportation Project. This project includes producing a fleet of fuel cell powered electric vehicles and a solar hydrogen refueling station for the City of Palm Desert in southern California. The refueling station consists of an ASE Americas 11.7 kW PV array that powers a Teledyne Energy Systems alkaline electrolyzer. The resulting hydrogen is compressed, stored, and delivered to vehicles at a safe and convenient dispensing island. Design for this station is complete and has been reviewed by a registered safety engineer. A design package was delivered to the Office of the State Architect for approval, and ground breaking is scheduled for early 1998.

Through this work, SERC has developed extensive experience in the design and operation of systems which utilize hydrogen as a storage medium for solar electricity. From our work with safety professionals, fire marshals, and local building officials, center personnel are familiar with codes, standards, and safe practices in dealing with DC electrical circuitry and hydrogen gas. In addition, SERC has built and installed a number of small to medium sized (0.6-5.0 kW) PEM fuel cells and has developed sophisticated test equipment to measure their performance. We have in place the design tools and experienced personnel to implement a renewable energy hydrogen system.

SERC has demonstrated an ability to attain scientific and planning goals, improve fuel cell technology, integrate fuel cells into a variety of applications combining hardware, software, and electronics, build test benches, and establish a machine tool shop. The group members have a wide variety of skills, including machining and welding, electronics, programming, design engineering, as well as, financial, management, and technical and business writing expertise.

In phases II - IV, SERC will perform further research and development on fuel cells to increase power density and decrease cost, integrate the various components of the fuel cell power system (reformer and fuel cell), and participate in setting up a fuel cell manufacturing facility.

- HYDROGEN BURNER TECHNOLOGY

Hydrogen Burner Technology has been developing a non-catalyzed reforming approach over the past six years. This approach has many advantages including complete fuel flexibility and interchangeability, tolerance to impurities, simple design and construction, low cost fabrication, rapid response and direct control. Since being formed in 1990, HBT has been prototyping experimental hardware and testing both gas and liquid fueled reformers. Today, the US. Patent Office has granted HBT six fundamental patents, which cover the critical features of its underoxidized burner (UOB™) technology. These features are required for a successful, high efficiency reformer that operates with or without catalyst and that uses ambient air as the oxidant source.

Today, HBT, through a subsidiary company, Phoenix Gas Systems, is marketing on-site hydrogen generation equipment to the process gas industry for industrial facilities. This equipment provides 99.9% hydrogen and <1 ppm CO purity at capacities from 500 SCFH to 3,500 SCFH (~25 to 200 kW). Although this technology meets and far exceeds the purity requirements for PEM fuel cells, the pressure swing adsorption technology used does not appear to have direct application to small, remote power applications.

Last year HBT was awarded two major DOE development programs related to the UOB™ technology for fuel cell system applications. The proposed efforts will utilize much of the technology being developed under these efforts. The first program is the development of a 50 kW fuel-flexible fuel processing (F^3P) subsystem directed primarily at gasoline and ethanol fuels for transportation applications. The laboratory test verification of this unit is scheduled for the summer and fall of 1998, while pre-commercial hardware delivery is scheduled for the late summer of 1999. The second effort is a design optimization effort directed at stationary building applications in the 25 to 50 kW capacity ranges. Natural gas and/or propane will fuel these units. One critical issue being addressed through these efforts is the ability of the fuel processing subsystem to achieve the 5 to 50 ppm level of CO required by the PEM fuel cells.

Hydrogen Burner Technology's role in the proposed project will be the supplier of the fuel processing subsystem. HBT will coordinate with TBE and SERC to review the product specification and develop a suitable specification for the small scale PEM fuel cell demonstration hardware. HBT will construct and qualify a prototype subsystem and deliver it to SERC for integration into the PEM fuel cell system. HBT will provide support for the integration and demonstration activities.

The design of the hardware will be based on HBT's patented technology and advancements derived from the parallel developments. The design and testing of small scale, stationary fuel processing equipment has been ongoing at HBT over the past seven years. Development of a small scale subsystem for both SOFC and PEM fuel cell applications is also part of HBT's internal program development activities.

- THE CITY OF PALM DESERT

An important factor in producing technological progress is a location where the technology can be usefully employed, effectively demonstrated, and rigorously tested. The City of Palm Desert is such a venue. The City has exhibited, through its legislation and its policies, a commitment to promote the development of environmentally benign technologies. This commitment has already manifested itself in several ways: 1) The California legislature, through Assembly Bill #1229, has established Palm Desert as a test locale in which golf carts used as PUV's are street legal; 2) Resolution number 94-63 was passed by the City Council in order to encourage research and development in the areas of alternative energy and alternative transportation and to attract related industry; 3) The public transportation system servicing the City, SunLine Transit, is the only one in the country that is completely fueled by compressed natural gas; and 4) The local community college, College of the Desert, has the only compressed natural gas mechanics training program in the nation. The Redevelopment Agency has also coordinated with the Coachella Valley Economic Partnership in the application for and administration of grant funds to establish a DOD sponsored Alternative Propulsion Systems Research Institute to be placed at the City.

The City's role in this project is to perform survey and marketing research analyses. In subsequent phases, the City will be involved in the business aspects of setting up a fuel cell manufacturing facility, and will provide a venue for this activity.

C. Qualifications and Experience of Key Personnel

- TELEDYNE BROWN ENGINEERING - ENERGY SYSTEMS

WILLIAM C. KINCAIDE
William Kincaide received a BS in Mechanical Engineering with a Power Option from Michigan Technological University in 1959. After graduation, he joined the NASA Manned Spacecraft Program, rising to the position of Manager of the Apollo Space Suit Program. In 1969, Mr. Kincaide joined the Allis Chalmers Advanced Electrochemical Products Division as Manager of Design and Documentation for fuel cell and electrolysis products. The division was sold to Teledyne where Mr. Kincaide became Product Manager for Electrochemical Systems and where he currently holds the position of General Manager of Energy Systems. He is the author of numerous papers on Space Life Support Systems, Hydrogen Production and Energy Storage, and Thermoelectric Power Generation. He is a senior member of the American Institute of Aeronautics and Astronautics.

ALFRED H. LaPORTE
Al LaPorte received a degree in Aeronautical Engineering from the Academy of Aeronautics. After graduating, he joined the Martin Marietta Corp. Working in both the Aerospace and Nuclear Systems Division he attained the position of Program Technical Director. He joined Teledyne when the Nuclear Systems Division was sold and served in a number of Project Engineering positions on space power systems including the Pioneer 10 and 11 deep space probes. He has held the position of Manufacturing Manager for Energy Systems since 1973. He has authored a number of technical papers relating to power systems design and product design for cost reduction.

WILLIAM E. KING
William King received a BS in Industrial Engineering from Johns Hopkins University in 1965. He held various engineering and administrative positions with Martin Marietta Aero-space division from 1953 to 1967. In 1968 he established the Administration Department of the Nuclear Division just before its sale to Teledyne. He currently holds the position of Administration Manager and Site Controller of Energy Systems Division.

JAY B. LASKIN
Jay Laskin received a BS in Mechanical Engineering from the University of Wisconsin in 1963. He holds an Industrial Marketing Strategy Certificate from Northwestern University, J. L. Kellogg Graduate School of Management awarded in 1984. After working as a systems engineer for NASA on the Apollo Space program until 1968,
Mr. Laskin joined the Allis Chalmers Manufacturing Co.'s Advanced Electrochemical Products Division as Manager of Mechanical Design. The division was sold to Teledyne in 1971 where he became a Project Engineer for Hydrogen Systems products and where he is currently the Manager of Marketing, Sales and Service for the Energy Systems group.
Mr. Laskin is a Registered Professional Engineer and is the author of several papers on Hydrogen Production. He is a member of the American Society of Mechanical Engineers, the International Association of Hydrogen Energy and the National Hydrogen Association where he is currently Vice Chairman of the Board of Directors.

WILLIAM R. MENCHEN
William (Bob) Menchen received a Bachelor of Mechanical Engineering degree from Cooper Union and then joined North American Aviation as an Aerothermodynamicist and Wind Tunnel Test Engineer. In 1960, he moved to Martin Marietta's Baltimore Division Propulsion group, working in advanced programs and on the Gemini launch vehicle propulsion system. He received his MS in Mechanical Engineering from Drexel University in 1964. In 1966 Mr. Menchen joined the Hittman Corp. where he rose to Department Head, managing a

multidisciplined staff in studies of energy and environmental issues. In 1976, Mr. Menchen began work at Teledyne Energy systems where he has been a Program Manager on many different power system projects, both government and commercial. Currently he pulls together new business opportunities, often coupled with in-house R&D effort. He is a Registered P.E. and the author of numerous publications and reports in the energy conversion field.

SILAS T. CHRISTENBURY
Silas (Ted) Christenbury received a BS in Nuclear Engineering from North Carolina State University. After graduating, he joined the Nuclear Division of the Martin Company as an engineer in the thermal hydraulic test laboratory in support of portable light water nuclear reactors where he earned an MS in Physics from Drexel University. In 1965 Mr. Christenbury began his 32-year radioisotope thermoelectric generator career as a systems analyst eventually rising to Program Manager of the long-running HPG MOD-3 program. In 1995, Mr. Christenbury assumed the role as manager of the Power Systems Department of Energy Systems.

EMIL T. CHARYSZYN
Emil Charyszyn received a BS in Metallurgical Engineering from Polytechnic Institute of Brooklyn in 1963 and an MA in Modern Studies from Loyola College in 1991. He joined Teledyne in 1974 as a Quality Engineering Supervisor and after a short time with the Westinghouse Electric Company, he rejoined Teledyne where he was promoted to Manager of Product Assurance in 1993. Mr. Charyszyn is currently responsible for all company product quality and compliance to customer specifications. Additional duties include Environmental and Product Safety Compliance.

CHARLES F. WILLIAMS
Charles (Chuck) Williams received a BS in Physics from Pennsylvania State University and an MS in Physics from Trinity College. In 1962 he went to work for Pratt & Whitney Aircraft on the fuel cell for the Apollo program. In 1964 at Allis Chalmers he contributed to the development of a fuel cell for manned space missions. The missions included Space Lab, and the Manned Orbiting Laboratory. In 1967 he went to work for TRW and developed a CO2 removal system for use on F1-11 aircraft. In 1969 he returned to Allis Chalmers to lead the design of a fuel cell for the US Navy (DSSV program). In 1971 at Teledyne, Mr. Williams established a program to develop an electrolysis system for use on Trident Class Submarines. This equipment generated sufficient oxygen for all members of the crew. At present he is developing the largest hydrogen generator offered by Teledyne.

- SCHATZ ENERGY RESEARCH CENTER

PETER A. LEHMAN
Peter Lehman is the director of the Schatz Energy Research Center and professor of Environmental Resources Engineering at Humboldt State University. He received a BS in chemistry from the Massachusetts Institute of Technology and a Ph.D. in physical chemistry from the University of Chicago. He then served as a postdoctoral fellow at the University of California, Berkeley where he conducted research on the aerochemistry of photochemical air pollution. Before coming to HSU, he has been a member of the faculties of Sacramento State University, California State University, Northridge, and Deep Springs College.

While at HSU, Dr. Lehman has served as chair of the Environmental Resources Engineering Department, co-chair of the International Technology Development masters program, and faculty advisor to the Campus Center for Appropriate Technology. His research interests include renewable energy systems, especially solar thermal and photovoltaic technologies. Through the Schatz Center, he is involved in development of solar hydrogen generation systems and in the research and production of proton exchange membrane fuel cells. The

Center is currently involved in developing and producing fuel cell-powered personal utility and neighborhood electric vehicles.

CHARLES E. CHAMBERLIN
Charles Chamberlin is co-Director and technical coordinator at the Schatz Center and professor of Environmental Resources Engineering at Humboldt State University. He received a BS in Civil Engineering from Washington University in St. Louis and a Ph.D. and MS in Environmental Engineering from Harvard University. Dr. Chamberlin teaches courses in data collection and analysis and transport phenomena at the undergraduate and graduate level. He has worked on models of photovoltaic hydrogen production and has participated in the design, development, and operation of the Schatz Solar Hydrogen Project. He also participates in the Schatz Fuel Cell Research Project .

• HYDROGEN BURNER TECHNOLOGY
DAVID MOARD
David Moard serves as President of HBT. He conceived, co-patented and led the development of the Underoxidized Burner (UOB™) technology. Mr. Moard has extensive experience throughout the energy industry, and has successfully guided the development and international marketing of numerous advanced energy technologies. He has been responsible for creating and guiding successful implementation strategies for cogeneration, alternative energy vehicles and clean combustion programs that have resulted in significant market penetration and more than $50 million in annual sales.

Mr. Moard's expertise is widely acknowledged and respected, as evidenced by his previous position as Manager of Fuel Cells at Southern California Gas Company and his participation in the Executive on Loan Program in which he served as Manager of Fuel Cells for the Gas Research Institute. At Southern California Gas Company he was responsible for a $10 million budget and the establishment of commercial on-site cogeneration using fuel cells. The manufacturer alliance he created continues to be utilized today. At the Gas Research Institute he managed and directed the use of a $50 million budget, and was responsible for field testing, final product development and the commercialization of fuel cells.

LEONARD GREINER
Leonard Greiner serves as Vice President of Research and Development. He brings to the position more than 30 years of experience in a wide variety of energy related fields. Mr. Greiner has pioneered the research and development of numerous low emission methanol projects and was the co-inventor of the Underoxidized Burner (UOB™). His preeminent position in the energy field is well known, and is attested to by the more than 35 patents he has been awarded.

Mr. Greiner's accomplishments are significant and several. He invented and developed a chemical heat pump and the related solar collectors for all encompassing residential heating and cooling. Mr. Greiner also introduced a facility for synthesis of methanol from air and water to eliminate global CO_2 greenhouse warming and invented the chemical means to cool nose cones during the reentry of space vehicles into the earth's atmosphere.

In the area of vehicle energy use, Mr. Greiner successfully created unique approaches to methanol fueled auto engines and methanol diesel engine operation. These actions resulted in a 20 percent increase in mileage for methanol engines.

RICHARD WOODS
Richard Woods serves as Vice President of Operations. He has more than 16 years experience in the Fuel Cell Industry and an additional six years of research with electro-chemical systems.

Prior to joining HBT in 1996, Mr. Woods was the Executive Advisor and Marketing Manager for M-C Power Corporation, one of the leading molten carbonate fuel cell manufacturers in the United States. From 1980 through 1991, Mr. Woods was with the Gas Research Institute, where he was Manager of GRI's phosphoric acid fuel cell programs during the 1980s and conducted various analytical studies for GRI's Power Generation Department. Between 1973 and 1979 he worked for Life Systems Inc. where he researched electrochemical systems for NASA space vehicles.

Mr. Wood's extensive knowledge of these industries is evidenced in the patents he holds in the fields of heat driven cooling cycles and Fuel Cell Technology. He earned a BS in Engineering from Case Western Reserve University with a major in Macro-Molecular Science and a minor in Bio-Medical Engineering.

JOSHUA MAUZEY
Joshua Mauzey serves as a Test Engineer. Mr. Mauzey brings to his position a BS in Mechanical Engineering from the University of California, Irvine. He has previously worked as an Undergraduate Research Assistant at the UCI Combustion Laboratory focusing on NASA's High Speed Civil Transport program. Mr. Mauzey also has owned and operated a small business for the last eight years.

SHAWN BARGE
Shawn Barge serves as a Test Engineer. He brings to his position a BS in Mechanical Engineering from the University of California, Irvine. Mr. Barge has previously worked as a Project Leader for the Heat Exchanger Design and Constructions Team at UCI. In addition, he spent two years working for Metrolaser performing holographic and interferomic research.

- THE CITY OF PALM DESERT

PAUL SHILLCOCK
Paul Shillcock is currently the Economic Development Director at the City of Palm Desert Redevelopment Agency. Mr. Shillcock has been employed by the City of Palm Desert since 1989 and has also served as Assistant City Manager/Economic Development Director During his tenure with the City, he has managed numerous projects including the $3.9 million DOE funded alternative energy project focusing on hydrogen powered fuel cells, which are being produced by the Schatz Energy Research Center.

Mr. Shillcock received an MS in Urban Planning and Program Development from Rutgers University, New Brunswick, New Jersey. He also attended the Graduate Studies, MBA program in Quantitative Analysis from Seton Hall University, New Jersey; and has completed Post Graduate Studies from Kean College, Fairmont College, Bakersfield College and College of the Desert. He is a member of the City/County Communications and Marketing Association, Board of Directors; the American Planning Association, the American Economic Development Council and the American Institute of Certified Planners. Mr. Shillcock is also the Chair of the Coachella Valley Economic Development Association and the Co-Founder of the Coachella Valley Economic Partnership.

D. Team Member Facilities and Equipment

- TELEDYNE BROWN ENGINEERING - ENERGY SYSTEMS

Teledyne Brown Engineering's primary facilities, located in Cummings Research Park, Huntsville, Alabama, is comprised of more than 524,000 square feet of administrative and engineering space. TBE's manufacturing and testing facilities occupy 299,000 square feet. An additional 5,000 square feet is devoted to research laboratories, including TBE's Optics Laboratory and Environmental Test Laboratory.

Teledyne Brown has approximately 2,400 personnel assigned to various organizational entities across the United States. There are over 1,000 full-time professionals engaged in the technical activities of the Company. Over 80% of TBE's technical professionals are engineers, physicists, mathematicians, computer scientists, or specialists in other technical fields.

Teledyne Brown Engineering - Energy Systems has been part of Teledyne and now Allegheny Teledyne since 1968. Located near Baltimore, Maryland, Energy Systems is in the heart of the Mid-Atlantic region, with ready access to rail, ocean, and air transportation facilities. Energy systems develops and delivers hardware in two main product areas. Within its Power Systems area, it produces unique electrical power systems for space, terrestrial, and subsea use. Within Hydrogen Systems, it designs and builds advanced electrolytic gas generators for the safe and efficient production of industrial hydrogen and oxygen.

TBE's trained staff of over 100, working in a new 68,000 square foot engineering and manufacturing facility, develops products for both Government and Commercial customers. TBE has recently been ISO 9001 registered.

Energy Systems has developed a worldwide reputation for dependability and quality in electrical power sources for remote applications and industrial hydrogen gas generators. Using a strategic network of more than 33 representatives and distributors, Energy Systems has the complete capability to design, develop, manufacture, service and sell its products described in the following paragraphs.

Power Systems provides hardware and services to the US. Government and many commercial customers who need reliable power. It produces several different types of thermoelectric power generators using both conventional fossil fuels and radioisotope fuels as heat sources. It continues to develop various self-powered electrical appliances using improved thermoelectric conversion techniques. New and improved methods of energy conversion, including the fuel cell are being evaluated in preparation for future customer needs. Power Systems is also testing long-life, high-reliability, conventional electric power generators for the remote power markets.

In Hydrogen Products, Energy Systems focuses on the engineering, manufacturing, and sale of a full line of hydrogen/oxygen generators. Using electrolysis of water, these generators meet a wide range of customer needs for the on-site production of high-purity gases. Applications include power plants, semiconductor fabrication, optical fiber production, argon purification, metals processing, and meteorological applications. Energy System's electrolysis technology emanated from previous fuel cell work, so it is intimately familiar with the requirements of those electrochemical systems.

- SCHATZ ENERGY RESEARCH CENTER

The Center is staffed with a director (Dr. Peter Lehman), a co-director (Dr. Charles Chamberlin), 13 research engineers, 3 graduate and undergraduate students and an administrative assistant. Grant and contract administration, payroll, and purchasing is handled for the Center by the Humboldt State University Foundation (HSUF), a non-profit organization affiliated with the university. Funding for the Center has been provided mainly through grants from Mr. L. W. Schatz, a retired industrialist and philanthropist. Additional funding has been acquired through the U.S. Department of Energy, the South Coast AQMD, Teledyne-Brown Engineering and HSUF.

Facilities at SERC include the fuel cell laboratory on the HSU campus and the solar hydrogen project at HSU's Telonicher Marine Laboratory in Trinidad, CA. The solar hydrogen project is a stand-alone solar energy system which uses hydrogen as the storage medium and a PEM fuel cell as the regeneration technology. It is the only automatically operating PV-hydrogen-fuel cell energy system in the US. The experience of building, maintaining, and operating the nation's first solar hydrogen-fuel cell facility has prepared SERC well to work with remote fuel cell power systems.

SERC's 1400 square foot fuel cell laboratory houses both the production facility and administrative offices. The lab is equipped with three completely automated fuel cell test stations, compressed air, a hydrogen generator, equipment for MEA manufacture, 12 Macintosh computers connected in a network, and three electronic test stations. Adjacent to the lab is a complete machine shop, including a CNC mill, for fuel cell stack production. The lab follows all applicable codes and contains numerous safety systems.

Over the last year and a half, SERC has built 3 fuel cell powered personal utility vehicles (PUVs) and delivered them to the City of Palm Desert. This process involved designing, building, and testing a 5 kW_p PEM fuel cell as a power plant for the PUVs. It involved designing, building and testing peripherals including the air delivery, fuel storage and delivery, refueling water circulation, cooling and electrical systems. SERC has devised and implemented a control algorithm for the fuel cell power plant in the PUVs. It has designed and built a test bench in which running conditions in the PUVs are simulated and the fuel cell and its peripheral systems are tested. SERC is currently retrofitting a Danish made Kewet with a larger (10 kW_p) fuel cell system.

- HYDROGEN BURNER TECHNOLOGY

The facilities at HBT's corporate headquarters in Long Beach, California consist of approximately 15,000 square feet of industrial space and 7,000 square feet of office space. These facilities include assembly areas, welding areas, machine shop, storage areas, and three test bays. The primary use is for the fabrication, assembly and testing of on-site hydrogen generation systems for industrial applications marketed to the process gas industry. Of importance to this effort are facilities needed to manufacture, fabricate, and test prototype fuel processing hardware. The test facility includes the ability to operate on various liquid fuels such as diesel and gasoline to gaseous fuels such as natural gas and LPG. Oxidants available include ambient air, mixed oxygen/air, and pure oxygen. Our offices also include state-of-the-art administrative equipment, sophisticated software, and the latest hardware.

- THE CITY OF PALM DESERT

The City of Palm Desert offers to the project its membership in the American Economic Development Council, the County Communications and Marketing Association, the California Association for Local Economic Development, the California Redevelopment Agency, and other national organizations.

E. Team Member Statements of Commitment (see attachments)

WILLIAM C. KINCAIDE
General Manager

TELEDYNE
BROWN ENGINEERING
Energy Systems
An Allegheny Teledyne Company
10707 Gilroy Road
Hunt Valley, MD 21031-1325
(410) 771-8600 Fax (410) 771-8620

February 11, 1998

Refer to: TBE-ES/WCK-006

U. S. Department of Energy
Attn: Mr. John P. Motz
Field Office
1617 Cole Boulevard
Golden, Colorado 80401-3393

Dear Sirs:

This is to confirm a commitment by Teledyne Brown Engineering - Energy Systems to be the lead partner in the Fuel Cell Power Systems for Remote Applications Project, Phases II - IV.

In phase IIA, Energy Systems and its partners will perform the research and development necessary to produce a palletized, reformate-tolerant fuel cell power system. In phase IIB, Energy Systems will deliver a compact hydrogen fuel cell power system to a site mutually selected with the Department of Energy.

In phase III, Energy Systems, in conjunction with its partners, will develop a reformate-tolerant fuel cell stack and integrate it with a fuel-flexible fuel processor. This technology validation unit will be ready for delivery in March, 2000.

In phase IV, Energy Systems will build, deliver, and field test four demonstration prototypes at beta sites which typify potential market users. In addition, Energy Systems will work with the partners to produce production, manufacturing and business plan leading to the production of a 1 to 3 kW unit that meets customer requirements.

We are pleased to be able to make this offer, and we look forward to working with the Department of Energy.

Sincerely yours,

William C. Kincaide

William C. Kincaide
General Manager

/ceh

SCHATZ
ENERGY
RESEARCH
CENTER

February 10, 1998

William Kincaide, General Manager
Teledyne Brown Engineering-Energy Systems
10707 Gilroy Road
Hunt Valley, MD 21031-1311

Dear Bill:

This is to confirm the commitment of the Schatz Energy Research Center (SERC) to be a partner in the Fuel Cell Power Systems for Remote Applications Project, Phases II - IV.

In phase IIA, SERC will perform the research and development necessary to produce a palletized, reformate-tolerant fuel cell power system. In phase IIB, SERC will assemble and deliver a compact hydrogen fuel cell power system. In phase IIC, SERC will provide support to the University of Alaska in setting up and operating a fuel cell testing lab. The total cost of SERC's activity in phase IIA and IIB of the project is $2,920,113, of which SERC will cost share $1,113,975. A budget has not been developed for Phase IIC.

In phase III, SERC will build a reformate-tolerant fuel cell stack and integrate it with a fuel-flexible fuel processor built by Hydrogen Burner Technology. This technology validation unit will be ready for delivery by April, 2000. The total cost of SERC's activity in phase III of the project is $1,450,632, of which SERC will cost share $556,626.

In phase IV, SERC will work with HBT and TBE to build, deliver, and field test four demonstration prototypes. In addition, SERC will work with the partners to produce an updated production, manufacturing and business plan leading to the production of a 1 to 3 kW unit that meets customer requirements. The total cost of SERC's activity in phase IV of the project is $3,142,849, of which SERC will cost share $1,601,778.

We are pleased to be able to offer the project the benefit of our experience designing and building fuel cell power systems and we look forward to working with you on this project.

Sincerely yours,

Dr. Peter Lehman
Director

Humboldt State University   Arcata, California 95521-8299   Telephone: (707) 826-4345   FAX: (707) 826-4347

HYDROGEN
BURNER
TECHNOLOGY

January 9, 1998

William Kincaide
General Manager
Teledyne Brown Engineering-Energy Systems
10707 Gilroy Road
Hunt Valley, MD 21031-1311

Dear Mr. Kincaide,

As you are aware Hydrogen Burner Technology has been developing the Under-Oxidized Burner (UOB™) technology over the past several years. During 1997, we have been successful at introducing a skid-mounted, integrated system for hydrogen generation. This activity is conducted through our Phoenix Gas Systems (PGS) subsidiary. PGS is dedicated to the manufacturing and marketing of these on-site hydrogen generation systems for industrial applications. Also, last year HBT was awarded two cooperative agreements with the US Department of Energy. These efforts are directed at advancing our fuel cell related product technology. One activity results in the development and demonstration of a 50kW fuel-flexible, fuel processing (F^3P) subsystem, while the other focuses on the design of an optimum subsystem for building applications. We have also begun a couple of in-house efforts addressing small-scale applications and integration with both PEM and solid oxide fuel cells.

The opportunity to propose a small-scale, fuel processing subsystem for your PEM fuel cell system is appreciated. We are pleased to offer you a prototype demonstration UOB™ subsystem for integration with your system. This unit is timed to take full advantage of our parallel program activities, especially the effort focused at achieving the minimum CO levels required for PEM fuel cells. I am sorry, but we can not offer any direct dollar cost sharing at this time to this proposed effort, because we are currently supporting our 25% cooperative agreement commitment to DOE out of our capital. We will be happy to support you and Schatz Energy Research Center in seeking additional sources of cooperative funding from non-government agencies. Of course with the success of this demonstration, and movement toward commercial scale orders, we will begin our business stage including support for production facilities and commercial market activities.

Again, thank you for the opportunity to supply a prototype UOB™ fuel processing subsystem for integration with your fuel cell technology. We look forward to a successful commercial product.

Sincerely yours,

Richard Woods
Vice President of Operations

cc. David Moard

Palm Desert Redevelopment Agency

73-510 FRED WARING DRIVE, PALM DESERT, CALIFORNIA 92260-2578

TELEPHONE (760) 346-0611 FAX (760) 341-6372

February 9, 1998

Mr. William C. Kincaide
Teledyne Brown Engineering
10707 Gilroy Road
Hunt Valley, MD 21031

Subject: Participation in Efforts Subsequent to the Phase I Feasibility Study on Small Fuel Cell Systems for Remote Power

Dear Mr. Kincaide:

The City of Palm Desert has been a Phase I partner in the DOE-sponsored study investigating the use of small PEM fuel cell systems in remote power applications. We look forward to participating in additional phases of this effort as detailed in our proposal inputs for Phases II - IV.

Our activities in Phase II will be a modest involvement in hardware development so that future planning can be facilitated. This planning input will be enlarged in Phase III to explore appropriate commitments the City would make to establish a manufacturing effort in Palm Desert. In Phase IV, the City will work closely with Teledyne Brown engineering to establish a Beta Site Test Plan, Manufacturing Plan and Marketing Plan for fuel cell power systems.

The City is desirous of assisting in the transfer of this technology to the many applications that will eventually result in a reduction of dependence on fossil fuels and will assist in protecting our environment. It is the desire of the City, and the region, to maintain the leadership position that has been established. Consequently, we look forward to the opportunity to become a Beta Test Site to demonstrate the technology and assist in other pre-commercialization activities.

In conjunction with other efforts that the City has undertaken, including assistance in the establishment of an Alternative Propulsion Systems Research Institute funded by the Department of Defense, continued participation in the commercialization of PEM fuel cells will aid in our attaining the goal of establishing the area as the "Silicon Valley of Alternative Fuels Technology."

Sincerely,

Paul Shillcock
Economic Development Manager

PS:lck

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VI. Resources Requirements for Phases II - IV

The four partners responsible for completing Phases II through IV have estimated their resource requirements. These amounts are shown in Tables 2 thru 6 which follow. The presentation used is a summary (Table 2) followed by tables for each of the partners: Teledyne Brown Engineering, Schatz Energy Research Center, Hydrogen Burner Technology and The City of Palm Desert. Each table has a breakdown by program phase starting with Phases IIA and IIB and continuing through Phases III and IV. Note that the table for each Partner includes the items called out by the format specified in the contract. Summary Table 2, is identical to Table 1 presented in Chapter I, page 10.

The resources for Phases IIA and IIB are independent of each other. Phase IIC, described earlier as a possible option, has not been budgeted. Phases III and IV build on the technology development completed in Phase IIA. There is no overlap or gap between the phases except that Phase IIB ends approximately four months before the start of Phase III. The schedule and major milestones for each phase are shown on the summary schedule presented in Chapter I.

The Partners have agreed to the Non-Federal funding levels shown for each phase. These are respectively, 35%, 40% 35% and 51% of the total resource amounts estimated to be required for Phases IIA, IIB, III and IV.

TABLE 2

PHASES II - IV PROJECT BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
PARTNERS															
Teledyne Brown Engineering	186,100	0	186,100	66,700	126,400	193,100	134,900	22,600	157,500	373,500	373,500	747,000	761,200	522,500	1,283,700
Schatz Energy Research Ctr.	1,320,400	877,000	2,197,400	485,700	237,000	722,700	894,000	556,600	1,450,600	1,561,800	1,615,800	3,177,600	4,261,900	3,286,400	7,548,300
Hydrogen Burner Tech.	150,000	0	150,000	0	0	0	40,000	10,000	50,000	100,000	100,000	200,000	290,000	110,000	400,000
City of Palm Desert, CA	1,600	1,000	2,600	0	0	0	9,000	3,800	12,800	15,500	15,500	31,000	26,100	20,300	46,400
Totals	1,658,100	878,000	2,536,100	552,400	363,400	915,800	1,077,900	593,000	1,670,900	2,050,800	2,104,800	4,155,600	5,339,200	3,939,200	9,278,400
Percent of Cost Sharing		35%			40%			35%			51%			42%	

TABLE 3

TELEDYNE BROWN ENGINEERING
PHASES II - IV BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
SALARIES	26,800	0	26,800	9,400	0	9,400	21,800	5,500	27,300	83,200	83,200	166,400	141,200	88,700	229,900
TRAVEL	4,800	0	4,800	3,700	0	3,700	3,000	800	3,800	2,300	2,300	4,600	13,800	3,100	16,900
EQUIPMENT	0	0	0	0	126,400	126,400	0	0	0	0	0	0	0	126,400	126,400
SUPPLIES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBCONTRACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SERVICES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INDIRECT (including fringe)	154,500	0	154,500	53,600	0	53,600	110,100	16,300	126,400	288,000	288,000	576,000	606,200	304,300	910,500
Totals	186,100	0	186,100	66,700	126,400	193,100	134,900	22,600	157,500	373,500	373,500	747,000	761,200	522,500	1,283,700
Percent of Cost Sharing		0%			65%			14%			50%			41%	

TABLE 4
SCHATZ ENERGY RESEARCH CENTER
PHASES II - IV BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
SALARIES	754,700	184,800	939,500	174,800	90,800	265,600	490,100	237,600	727,700	665,600	442,900	1,108,500	2,085,200	956,100	3,041,300
TRAVEL	40,700	0	40,700	30,200	0	30,200	31,600	0	31,600	78,800	0	78,800	181,300	0	181,300
EQUIPMENT	147400	14,000	161,400	111,600	30,100	141,700	116,300	3,400	119,700	427,600	20,800	448,400	802,900	68,300	871,200
SUPPLIES	11,300	19,100	30,400	15,100	6,800	21,900	14,000	8,300	22,300	20,800	24,800	45,600	61,200	59,000	120,200
SUBCONTRACT	0	0	0	62,000	0	62,000	10,700	0	10,700	54,800	0	54,800	127,500	0	127,500
SERVICES	1,200	308,700	309,900	2,400	37,000	39,400	1,200	25,000	26,200	4,000	721,000	725,000	8,800	1,091,700	1,100,500
INDIRECT (including fringe)	365,100	350,400	715,500	89,600	72,300	161,900	230,100	282,300	512,400	310,200	406,300	716,500	995,000	1,111,300	2,106,300
Totals	1,320,400	877,000	2,197,400	485,700	237,000	722,700	894,000	556,600	1,450,600	1,561,800	1,615,800	3,177,600	4,261,900	3,286,400	7,548,300
Percent of Cost Sharing		40%			33%			38%			51%			44%	

TABLE 5

HYDROGEN BURNER TECHNOLOGY
PHASES II - IV BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
SALARIES	45,000	0	45,000	0	0	0	20,000	5,000	25,000	33,000	33,000	66,000	98,000	38,000	136,000
TRAVEL	6,000	0	6,000	0	0	0	4,400	900	5,300	8,700	8,700	17,400	19,100	9,600	28,700
EQUIPMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUPPLIES	45,200	0	45,200	0	0	0	0	0	0	0	0	0	45,200	0	45,200
SUBCONTRACT	15,000	0	15,000	0	0	0	0	0	0	20,000	20,000	40,000	35,000	20,000	55,000
SERVICES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INDIRECT (including fringe)	38,800	0	38,800	0	0	0	15,600	4,100	19,700	38,300	38,300	76,600	92,700	42,400	135,100
Totals	150,000	0	150,000	0	0	0	40,000	10,000	50,000	100,000	100,000	200,000	290,000	110,000	400,000
Percent of Cost Sharing		0%			N/A			20%			50%			28%	

TABLE 6

CITY OF PALM DESERT, CA
PHASES II - IV BUDGET SUMMARY

	PHASE IIA			PHASE IIB			PHASE III			PHASE IV			TOTAL BUDGET		
	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total	Federal	Non-Fed.	Total
SALARIES	0	700	700	0	0	0	0	2,700	0	0	10,900	10,900	0	14,300	14,300
TRAVEL	200	0	200	0	0	0	2,300	0	0	4,900	0	4,900	7,400	0	7,400
EQUIPMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUPPLIES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBCONTRACT	1,400	0	1,400	0	0	0	6,700	0	6,700	10,600	0	10,600	18,700	0	18,700
SERVICES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INDIRECT (including fringe)	0	300	300	0	0	0	0	1,100	1,100	0	4,600	4,600	0	6,000	6,000
Totals	1,600	1,000	2,600	0	0	0	9,000	3,800	12,800	15,500	15,500	31,000	26,100	20,300	46,400
Percent of Cost Sharing		38%			N/A			30%			50%			44%	

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Appendix A - Business Plan

I. Business Plan Executive Summary

The Fuel Cell Power System (FCPS) is an innovative power generator that is adaptable and modular. The system integrates a fuel processor to reform natural gas or propane feedstock to hydrogen, a PEM fuel cell, and all necessary peripheral components into a clean, quiet, and reliable power generation unit.

Included in the business plan are a description of the current state of fuel cell and reformer technology, Teledyne Brown Engineering - Energy Systems' business strategy, a description of the FCPS, a market research summary, information on competitive energy generation technologies, a discussion of commercially available hydrogen, identification of areas for further research, licensing issues, and a financial analysis.

The market research examined off-grid homes, yachts, telecommunications and recreational vehicles. Also included in this report are summaries from the previously conducted market reports that examined power needs for remote natural gas and oil wellheads and along pipelines. Following are a list of highlights from the research. The full reports can be found in Appendix B

Designing the FCPS to operate with a reformer and natural gas and/or propane is an excellent intermediate technological step in the development of fuel cell technology. A reformer coupled with a fuel cell allows the utilization of the existing fuel infrastructure while still moving towards cleaner energy generation. Currently, hydrogen gas is not as widely available as natural gas or propane. Developing the hydrogen infrastructure will be essential for future clean energy generation, but in the interim, reformers allow fuel cells to utilize easily available fuel stock.

Reformers in a FCPS need further research and development to make them commercially acceptable. Reformers in this system assist in commercialization because of fuel infrastructure problems, but introduce the potential for criteria pollutant emissions, noise and safety hazards. Also, there is no currently operating prototype that meets the criteria of the FCPS described in this market study. These problems are not insurmountable and, with further research and testing, reformer technology will assist in bringing the FCPS to commercial status.

II. Research Highlights

Fuel Cell Power System (FCPS)

• The FCPS will need to meet the current competitive energy generation technology prices of either \$0.13/kWh (generators), \$0.29/kWh (batteries/shore power) or \$0.50/kWh (PVs).

• With current technology and manufacturing processes the fuel cell with gaseous pressurized tank hydrogen could provide power for as little as \$0.44/kWh. In the best case scenario, with component and labor cost reductions of 50%, fuel cell power performance increases of 100%, and a hydrogen cost of \$12/GJ, the fuel cell with a tank of pressurized hydrogen could provide power at \$0.23/kWh.

• Fuel cell electrode material and graphite are the two most expensive components in the fuel cell, together representing approximately 70% of the material costs of the fuel cell. More research is needed in the area of electrodes and graphite manufacturing and/or a replacement material for the graphite. Current graphite production methods do not allow for cost reductions, even when large quantities are ordered.

• The fuel cell is 75% of the FCPS cost, without the reformer. The other 25% is for the peripheral components necessary to make the fuel cell operate, such as the water pump, air blower, etc.

• The learning curve analysis revealed that at the following learning curve (LC) percents and unit number of production, the target cost of $1,500/kW is reached.

To reach the FCPS target cost of $1,500/kW:

System	Learning curve percents	Unit # production
FCPS with a reformer	20%	260,000
	15%	> 4 million
FCPS without reformer	20%	50,000
	15%	2 million

Reformer

• We did not estimate the FCPS delivered power costs, as the scaled down reformer technology is not developed yet and no reformer manufacturer has reliable data on costs. We assumed that a reformer would not be cost effective if it did not deliver hydrogen at a competitive price.

• Quotes for the potential purchase price of reformers, once they are mass produced, range from $16/kW to $500/kW depending on the source. This does not include operation and maintenance costs.

• Fuel stock for a reformer must not contain sulfur, halogens, arsenic, lead or copper due to their poisoning effect on the reformer catalyst.

• For use with currently available proton exchange fuel cell catalysts, CO in the reformate must be reduced to 5-10 ppm, or 50 ppm if the reformate is fortified with 1-5% air.

• A small partial oxidation reformer (POX) that converts fuel stock to the purity necessary for the fuel cell is still in the engineering phase and is not yet commercialized.

• POX reformate is approximately 30-35% hydrogen. The energy conversion efficiency of H_2 out (HHV)/CH_4 in (HHV) is 65-75%. Hydrogen Burner Technology estimates the POX reformer cost to be $200/kW after a few hundred units have been produced.

• The POX reformer system is less expensive to build than the steam reformer, but the steam reformer is more efficient in hydrogen extraction. The overall system cost for either the POX or steam are comparable, once all the factors are taken into account.

Hydrogen Availability

• Cryogenic liquid hydrogen is available nationwide, normally delivered in large quantities. The cost is $12 per GJ. For reference: 1 GJ = 10^9 Joules = 0.95 Million BTU. 1 gallon of gasoline is 130.8 MJ (HHV) At $1.50/gallon, gasoline costs $11.50/GJ.

• Gaseous pressurized industrial grade hydrogen is available nationwide, delivered in smaller quantities. The delivered price for a 220 scf tank of industrial grade hydrogen is about $0.16/scf or $340/GJ. Industrial grade hydrogen is suitable for fuel cells.

Market Research

• Use of a FCPS for remote natural gas pipelines is a near term market. The power level is 600W; this market is now served by organic rankine engines.

• The telecommunications arena is changing rapidly and further study is needed to understand the potential in this market.

• There are approximately 100,000 remote homes in the U.S., almost all of which use a remote power generator. Remote home owners can be classified as early adopters, accustomed to unique power generators. There could potentially be a market here, but the price would have to be comparable to PVs.

• There could be a market for FCPSs for 30-40 foot sailboats. 15,000 new boats of this size were built in the last 9 years. They currently carry propane onboard. However, the price would need to be comparable to battery or shore power.

• The RV market might have a potential OEM market of 10,000 units per year if the price were comparable to that of generators.

• People interviewed in the sailboat, remote home and the RV market stated that they could better assess their interest in the FCPS if they could see a demonstration model. They also stated that they might be willing to pay more for the FCPS if they observed the benefits of clean and quiet energy generation.

• Approximately 75% of the remote power system market under 30 W is at gas distribution sites, with 32,044 units sold in 1995. This market is growing. 85% of the power needs in this market is for electronic flow correctors. The current price paid for power (batteries) in this market is $120/W.

• There are greater than 2 million existing land wellheads worldwide whose equipment will eventually need replacement. Wellheads generally use under 5 kW power at a price of approximately $4/W.

• Further research is needed in the < 1kW market. There is an uptrend in the < 20 W applications. Such a market might be appropriate for a very small fuel cell power system using bottled hydrogen, especially since material costs for fuel cell stacks are a large portion of FCPS costs, and these would be minimized.

III. Company Overview

Teledyne Brown Engineering is an Allegheny Teledyne Incorporated (ATI) company. ATI is a federation of technology-based businesses with a significant concentration in advanced specialty metals complemented by aerospace and electronics, industrial, and consumer products.

Teledyne Brown Engineering (TBE), headquartered in Huntsville, Alabama, is the largest component of the aviation and electronics segment of ATI. TBE is composed of a number of diverse companies, including Brown Engineering and several commercial units: Control Applications, Marine Products, Hastings Instruments, Engineering Services, Environmental Services, and Energy Systems, located in Hunt Valley, Maryland. In addition, TBE maintains field offices in Colorado Springs, Colorado; Shalimar and Cape Canaveral, Florida; Albuquerque, New Mexico; and Arlington, Virginia, and production facilities in Jackson and Slocomb, Alabama.

Teledyne Brown Engineering - Energy Systems has been part of Teledyne and now Allegheny Teledyne since 1968. Located near Baltimore, Maryland, Energy Systems is in the heart of the Mid-Atlantic region, with ready access to rail, ocean, and air transportation facilities. Energy Systems develops and delivers hardware in two main product areas. Within the Power Systems' product area, they produce unique electrical power systems for use in space, terrestrial, and subsea applications. Within Hydrogen Systems, they design and build advanced electrolytic gas generators for the safe and efficient production of industrial hydrogen and oxygen. The trained staff of over 100 develops products for both government and commercial customers. They have recently been ISO 9001 registered.

Energy Systems has developed a worldwide reputation for dependability and quality in electrical power sources for remote applications and industrial hydrogen gas generators. Using a strategic network of more than 33 representatives and distributors, Energy Systems has the complete capability to design, develop, manufacture, service and sell its products.

Power Systems provides hardware and services to the U.S. Government and many commercial customers who need reliable power. They produce several different types of thermoelectric power generators using both conventional fossil fuels and radioisotope fuels as heat sources. They continue to develop various self-powered electrical appliances using improved thermoelectric conversion techniques. New and improved methods of energy conversion, including the fuel cell, are being evaluated in preparation for future customer needs. Power Systems is also testing long-life, high-reliability, conventional electric power generators for the remote power markets.

In Hydrogen Products, Energy Systems focuses on the engineering, manufacturing, and sale of a full line of hydrogen/oxygen generators. Using electrolysis of water, these generators meet a wide range of customer needs for the on-site production of high-purity gases for industry. Applications include power plants, semiconductor fabrication, optical fiber production, argon purification, metals processing, and meteorological applications. The current product line covers the range up to 800 standard liters per minute (slm). A planned new product will significantly increase the range to 2,000 slm. Many hardware options are also available. These include water treatment, gas purity instrumentation, area safety monitoring, gas compression, and gas storage. Complete facility design services are also available. The electrolysis technology emanated from previous fuel cell work, so the company is intimately familiar with the requirements of electrochemical systems.

Energy Systems recognizes that they can and should be involved in the evolution of hydrogen as a strategic energy carrier. Our participation in this program reflects the interest of developing equipment for energy related applications for both commercial and consumer applications.

REMOTE POWER BUSINESS

For the past thirty years, Energy Systems has been manufacturing and selling small thermoelectric power sources for remote applications. In these applications, utility power is not available, but gaseous fuels are or can be provided. For the most part, these power sources are considered prime power for the site with high reliability; long service intervals are of greatest importance to the customer. Efficiency is of lesser importance. Power requirements are typically less than 10 kW. Although the generators have been used in a wide variety of applications, most have been used by the oil and gas industry along pipelines and on platforms for cathodic protection and data acquisition/transmission.

The size of the total market for prime power systems under 10 kW in remote oil and gas applications alone is upwards of $50M a year. This market is currently served by photovoltaics, thermoelectrics, organic rankine systems, and with limitations, engine generator sets. Thermoelectrics have historically been limited to about 20% of the market, due to the size limitations of individual units. In order for Energy Systems to be more competitive in the total market, they seek a technology that offers higher efficiency with a modular unit in the kilowatt range, which still offers high reliability and requires minimal maintenance.

PRODUCT DECISION LOGIC

Energy Systems relies heavily on its network of representatives and distributors to develop trends in customer requirements, the competition and new market directions. They also know, as a result of day to day competition, how they need to improve their products to win jobs lost in the past. Once they identify a market segment or industry that appears to offer an opportunity for growth, they typically contract for a focused study to quantify the size of the market, define discriminators and help develop an entry strategy. They look at the near term (1 to 3 years) for low risk engineering solutions to improve their situation and higher risk solutions for the long term to stay ahead of the competition.

As mentioned earlier, the technical and economic risks associated with long term thrusts are significantly higher, by their very nature, and the modest research and development resources of the company must be carefully managed to bring new products to the market in the short term and grow and stay ahead of the competition in the long term.

IV. Fuel Cell Power System Description

A. System Description

The fuel cell power system consists of a partial oxidation reformer, a metal membrane separator, pressure swing adsorber or a preferential oxidation system and a PEM fuel cell power system, as shown in Figure 1. The fuel source is a natural gas pipeline (either domestic or industrial) or a liquefied petroleum gas (LPG) tank. The output is DC or AC (using an inverter) electricity to power the desired end use.

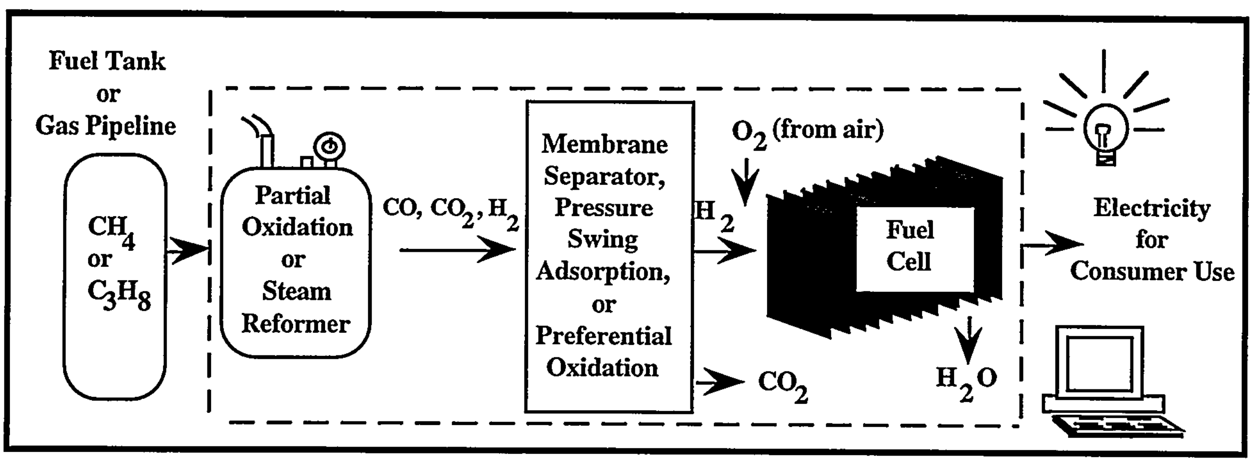

Figure 1. Flow Chart of the Fuel Cell Power System

Fuel Cell Power System Operation

The fuel cell power system consists of a fuel stock, desulfurization, reformer, purification with separator, pressure swing adsorption, or preferential oxidation, a fuel cell and a power conditioner. First the fuel stock is desulfurized. Then the fuel is drawn into the reformer where it undergoes partial oxidation . This produces a mixture of hydrogen, carbon dioxide, and smaller amounts of partially oxidized hydrocarbons, and carbon monoxide. The reformate gases are passed through a metal membrane separator, a pressure swing adsorber or a preferential oxidation system which produces very pure hydrogen; the other gases are exhausted. The hydrogen is fed to the PEM fuel cell system, oxygen is supplied by an air blower, and electricity is produced. The electrical power is then properly conditioned and delivered. This power generator will be designed to run automatically and be convenient for the user. The main benefits of a fuel cell power system are quiet operation and low maintenance. Fuel cells are much quieter than a regular generator of comparable size.

Desulfurization of the Fuel Stock

Sulfur in hydrocarbon fuels can be present in a variety of compounds such as hydrogen sulfide, mercaptans, aliphatic and aromatic disulfides, cyclic sulfur compounds. Maximum limits are set on the sulfur content of the fuel stock because the metal catalysts used in reforming are prone to deactivation by sulfur containing compounds. The desulfurization of the fuel stock occurs before reformation and consists of two basic steps:

1. hydrolysis of organic sulfur compounds to hydrogen sulfide over a cobalt molybdenum catalyst, and
2. absorption of the hydrogen sulfide on a zinc oxide catalyst.

B. Reformer Technology

Partial Oxidation Reformation

The partial oxidation reformer (POX), also called the underoxidized burner reformer, converts methane, propane, gasoline, diesel, and ethanol fuels into hydrogen using air as a combustion oxidant. The hydrocarbon fuel is combusted at high temperature (1425-1650 °C) and underoxidized conditions, forming a partially oxidized product, a combination of water, hydrogen, nitrogen, carbon monoxide, and carbon dioxide. The next step is the water gas shift reaction where water is added to this combustion product to rapidly reduce the gas temperature (to approximately 370 °C) and provide the water required for the next reaction. Since the POX reformer operates at a low stoichiometric ratio of fuel to oxygen, the hydrogen generated is maximized and one of the pollutant by-products of combustion, NO_x, is eliminated. POX reformate is only 30-35% hydrogen. The hydrogen gas stream enters an exothermic catalytic shift reactor where carbon monoxide and water react to form additional hydrogen and carbon dioxide. The carbon dioxide is released and the hydrogen is directed to the fuel cell. Thus it needs a more elaborate post reformer process to achieve a desired purity of the hydrogen product. The energy conversion efficiency [hydrogen out (HHV) / methane in (HHV)] is 65-75%.

There are two types of POX reformation methods, one which utilizes a catalyst and one which doesn't. In the catalytic POX, the exothermic nature of the hydrocarbon/oxygen reaction is combined with the endothermic nature of the hydrocarbon/steam reaction to sustain the reaction without external heat input into the catalyst bed. These are called autothermal reactors, and they are internally insulated, utilizing nickel as the catalyst. Use of a catalyst in the POX increases the hydrogen yield per mole of methane input. The catalytic POX system is fuel specific.

The POX method that does not use a catalyst depends on thermodynamics to overcome the chemical activation energies rather than a specific catalyst; thus this type is fuel flexible. The start up time for non-catalytic POX is approximately 2-4 minutes to full hydrogen production. Hydrogen Burner Technology estimates that POX reformers will cost $200/kW once the technology is mature and hundreds of units are being produced each year.

Reformate Purification

After the fuel has been reformed by partial oxidation, it can be utilized directly by the fuel cell if the impurity level is low enough. Otherwise, it must be further refined. If the reformate is utilized directly by the fuel cell, the concentration of hydrogen seen at the fuel cell anode is about 75% by volume for methanol reformate, 80% for methane reformate and 35% for gasoline reformate. The higher the hydrogen content of the feed gas, the better the performance and power density of the fuel cell. Carbon dioxide and carbon monoxide make up the rest of the reformate. Carbon dioxide is an inert gas but carbon monoxide poisons the fuel cell membrane. Gore fuel cell MEAs can tolerate a maximum of 50 ppm carbon monoxide if there is additional 1% air pumped into the reformate and a maximum of 5 ppm carbon monoxide if no additional air is pumped into the reformate. Additional refining of the reformate is accomplished with either a membrane separator, the pressure swing adsorption method or the preferential oxidation system.

The hydrogen delivered from either the membrane separator, the pressure swing adsorption process or the preferential oxidation system is at least 99% pure and can reach up to 99.999% pure, depending on the technology.

Metal Membrane Hydrogen Purifier

Teledyne Brown Engineering (TBE), as a Phase I cost sharing contribution, agreed to purchase and evaluate a pre-production metal membrane purifier that will yield ultra pure hydrogen from any hydrogen stream. The purifier is made by Teledyne Wah Chang, a sister company to TBE. The purifier was delivered to TBE late in 1997.

The hydrogen-separation membrane is a composite metal membrane that utilizes a thin palladium alloy foil to produce ultra-high purity hydrogen. By minimizing the requirement for expensive palladium alloys, high hydrogen flux can be achieved at reasonable cost. The hydrogen flux through the membrane increases with both increasing temperature and increasing pressure differential across the membrane. For this reason, the composite metal membrane is suited for separating pure hydrogen directly from reformers. Also, the composite metal membrane purifier scales down well, allowing a complete fuel cell power system to be compact.

TBE's R&D plan is to obtain operating and purity data from the prototype Wah Chang purifier membrane stack. Planned tests include cyclic and continuous operation. The system is monitored for flow/pressure performance, leakage, thermal performance, moisture and other impurity levels using instrumentation available at TBE. Depending upon initial test results, more sophisticated impurity data will be obtained.

Pressure Swing Adsorption

In the pressure swing adsorption process, the impurities contained in the hydrogen rich gas are adsorbed on molecular sieves at a low pressure. Operating pressures and temperatures are normally in the range of 147 to 440 psig and 20 to 40 °C. The process operates on a repeated cycle, having two basic steps, adsorption and regeneration, with no change in temperature. To reduce hydrogen losses during depressurization and in order to obtain high performance, the unit uses four or more adsorbers. The use of four adsorbers permits the use of hydrogen remaining in an adsorber at the end of the adsorption step for partial repressurization and purging of the other adsorbers. Each adsorber is cycled through the same adsorption-regeneration sequence, but each is staggered so that at all times one adsorber is on the adsorption step while the other three are in various stages of regeneration. Pressure swing adsorbtion is typically used in large industrial operations.

Preferential Oxidation

The preferential oxidation system involves the gas being passed over a catalyst bed with added air. At a certain temperature and stoichiometric conditions, the reaction of carbon monoxide (CO) with the oxygen, to form carbon dioxide is favored over hydrogen oxidation. The CO is removed to a level of several ppm, which is tolerable by the PEM fuel cell. Preferential oxidation technology is being developed for use with reformers on fuel cell cogeneration systems and/or on-board fuel cell vehicles.

C. The PEM Fuel Cell

A PEM fuel cell is an electrochemical device that converts chemical energy directly into electricity via a modified oxidation process. The fuel cell stack comprises a series of individual cells and the voltage of the individual cells combine to yield the total fuel cell stack voltage. PEM fuel cells are currently designed to operate on a pure hydrogen gas feed stock. At the anode the hydrogen molecules give up electrons and form hydrogen ions, a process made possible by the platinum catalyst. The electrons travel to the cathode through an external circuit producing electrical work as they go through the motor. The hydrogen ions flow through the proton exchange membrane to the cathode, where they combine with oxygen molecules to form water. The hydrogen fuel's natural tendency to oxidize and form water is utilized to produce electricity and useful work. The figure on the right shows a diagram of a single cell in a fuel cell stack and how it operates using hydrogen.

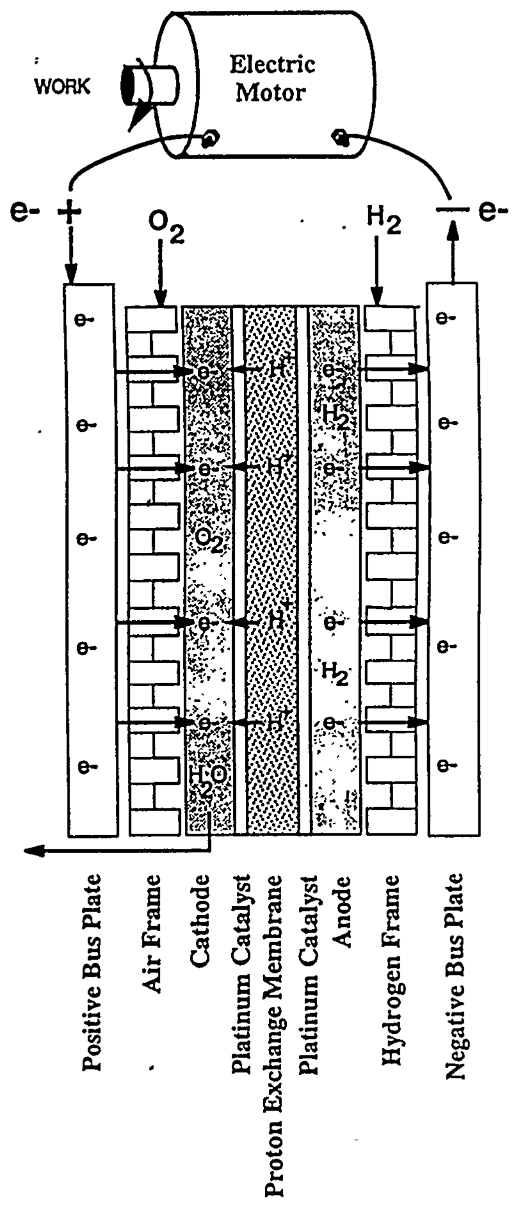

Figure 2. How a PEM Fuel Cell Works

D. Competitive Advantage of Fuel Cells

Fuel Cell

- Quiet operation
- FC itself has no moving parts (the auxiliary systems such as the water pump & air blower do have moving parts)
- Efficient use of energy
- No polluting exhaust
- Higher power density than batteries
- Virtually maintenance free
- Hydrogen fuel can be made domestically - either with solar energy-electrolysis of water; or with reformer technology by making hydrogen from hydrocarbon fuels
- Small size - about the same as a similar powered generator
- Modular, can be designed to fit specific power needs
- No hazardous materials as waste in the manufacturing process, except for the occasional lubricating oil or cleaning fluid
- Some parts are easily recycled
- Quick refueling when used as a vehicle power system (as compared with battery electric which takes hours to recharge)
- Fuel spills do not occur with hydrogen as it is lighter than air

Fuel Cell Power System with a Reformer

- Efficient use of energy
- Higher power density than batteries
- Utilization of the current fuel infrastructure
- Small size, about the same as a similar powered generator
- Modular, can be designed to fit specific power needs

V. Market Research

The potential markets for a fuel cell power system examined in this study include pipelines, remote homes, recreational vehicles, telecommunications and boats/yachts. These markets were chosen because they fit into the 0.1kW to 5 kW range of power usage and the consumers in these markets potentially have the resources and interest to purchase a reliable, fuel efficient, clean, quiet power source. Consumers in this market currently use generators, rankine cycle engines/generators, batteries and sometimes renewable energy systems. Those utilizing photovoltaic energy systems are accustomed to paying an average of $7.00 - $8.00 per watt for an installed system. It is estimated that the fuel cell power system would potentially cost $3.00 - $10.00 per installed watt, possibly less depending on technological and manufacturing advancements.

This section includes assumptions about the fuel cell power system, a review of the demographics and power use details of each market and some conclusions about the potential of the market.

A. Assumptions about the Fuel Cell Power System

Basic assumptions have been made about the fuel cell power system to conduct this market study. These include:

1. The fuel cell will utilize fuel at a more efficient level than currently available power generators.

2. The fuel cell power system will use the existing natural gas and LPG infrastructure and a reformer until hydrogen is readily available.

3. A reformer will be able to convert the currently used fuel (propane or natural gas) into hydrogen to power the fuel cell.

4. The fuel cell is quiet (unlike a noisy generator), and non polluting (only CO_2 from the hydrocarbon fuel reforming).

5. The fuel cell will require less maintenance than conventional power suppliers such as generators and batteries.

6. The fuel cell should last at least 5 years, unlike batteries which have a relatively short lifetime before replacement is required.

7. The refueling process for the fuel cell power system will consist of filling a tank with either propane or hydrogen or utilizing a natural gas source.

8. The fuel cell will be similar to other renewable sources (solar and wind) in that it will cost significantly more per Watt generated than other currently available independent charging devices but its long life expectancy, low operating cost, clean operation, and overall convenience will justify the initial investment.

B. Market Research Process

Research into the potential for fuel cell power systems was accomplished by:

A. Literature Search

1) Internet search for information about:
    a. Existing data on fuel cells for initial reference
    b. Collection of new articles on fuel cells (News Profiles AOL)
    c. Data on competitive power sources (generators, batteries)
    d. Regulations that would apply to a fuel cell power system
    e. Competing technologies/other fuel cell power systems
    f. News groups and forums of RV's, boat owners
    g. RV, boating manufacturer's web sites
    f. Trade association's web sites

g. On-line trade magazines
h. Telecommunication service providers web sites

2) Trade Publications/Associations/Literature Search
a. Home Power Magazine
e-mail and phone conversations with the editor
b. The Independent Home, Michael Potts
included book research and e-mail conversations with the author
c. Thomas Register research for generator/reformer/electrolyzer information
d. Statistics from RVIA (Recreational Vehicle Industry Association)
e. Statistics from the Fleetwood Annual Report and other manufacturers.
f. Family Motor Coach Association
g. Statistics from NMMA - National Marine Manufacturers Assoc.
h. Statistics from the Sailing Company
i. 1996 Fuel Cell Seminar Program and Abstracts
j. Hydrogen Energy Progress IX, 1996
k. Commission of the European Communities Hydrogen Safety Manual

B. Trade Shows/ Manufacturer Research/Phone Conversations

1. Trade Shows
a. National RVIA show in Pomona CA
b. Outdoor and in the water Boat Shows in Long Beach and Oxnard
c. Indoor Boat Trade Show in Long Beach

2. Motor Home Manufacturer Research
a. On site visits to large and small dealers including Travelland U.S.A. which has virtually every major manufacturer represented

3. Phone Conversations
a. Phone conversations with Onan, Generac, Kohler, Quiet Fantastic & Honda generator manufacturers
b. Personal conversations with building contractors & remote home owners in Northern California
c. Discussion with Joan Ogden (Princeton University) concerning reformers

C. Description of Business Planning Computer Software

The business planning software used for the Fuel Cell Power Systems for Remote Applications Project is BizPlan Builder by Jian. BizPlan Builder is a strategic business and marketing plan software package, designed to be a complete template for business managers developing a business plan. The software treats the business plan as a series of separate but interrelated documents. Each addresses different aspects of strategic development: the company's mission, the owner's experience, market conditions, the customer profile, competitors, marketing plans, financial strength, and financial need.

BizPlan was deliberately designed to be information and/or organization 'overkill' for most businesses. The intent was to cover every aspect of the business plan, offering the user more than enough material with which to work. The software is designed to assist the business manager in development of a professional business plan in order to procure bank loans and/or to interest investors.

The sample table of contents from BizPlan includes the Executive Summary, Company Vision/Mission, Company Overview, Product Strategy, Market Analysis, Marketing Plan, Financial Plan and Supporting Documents. Each of these categories has a template with which the user can fill in appropriate information concerning their business. The templates are general in nature and exhaustive in content, designed to fit any company, anywhere.

How BizPlan was utilized to write this Business Plan

Bizplan was the model upon which this business plan was designed. An example of how Bizplan was adopted to be utilized by this business plan can be seen in the executive summary chapter. Bizplan suggests an executive summary which includes a summary of the company vision/mission, company overview, product strategy, market analysis, marketing plan, financial plan and conclusion. This would make for a long, exhaustive executive summary, which might be less effective in that it would demand that the reader sort through much written information before he/she could find the interesting facts about the potential markets being researched. The executive summary for this business plan followed the Bizplan outline to some extent, but tried to focus on the most important facts about the market conditions found in the research and financial analysis and put less emphasis on company mission, overview, and current product strategy. Teledyne has already shown that remote power generation is within the scope of their company mission. They were mostly concerned with the market potential and cost considerations in the development of a fuel cell power system. This is just one example of how Bizplan was regarded a model for this business plan, but was not used directly as a template.

BizPlan was utilized to design the market analysis questionnaire for the four designated markets. A copy of this questionnaire can be found in Appendix 1 of this report. These questions were asked of manufacturers, consumers and trade association employees, along with research about these markets on the internet, in magazines and in books. Not every question was answered for each potential market, but an attempt was made to characterize the consumer's purchasing ability and energy interests, how power is used by the consumer within each market, price paid for power purchased, operation and maintenance issues and the consumers opinion about this power choice.

Once the raw information was gathered through the market survey, the next step was to transfer the information into the template format offered by the software. The templates were designed to bring a young business or an existing business into a new product and market opportunity, but it made little sense to follow each software template completely for a business exploring opportunities in a new technology. Exploring opportunity for a new technology in established markets demanded a different approach.

The financial analysis was conducted similarly to the other chapters of the business plan, where BizPlan was the format, but the templates were not used directly. Again, the problem occurred that the templates were not designed to work with an emerging technology. The economic analysis tools utilized in this business plan were the learning curve, base case scenario, and an analysis of costs and life cycle of the components in the fuel cell power system.

The learning curve analysis is a traditional and accepted tool. We used a 15% learning curve, which would indicate that an item costing $100 for the 100th unit would only cost $85 for the 200th unit. The learning curve for the semiconductor industry is historically 20%. If we assume a conservative 15% learning curve for SERC's first 4 kW fuel cell power system, which initially cost $45,000, we will see a cost decline to $10,000 just after the 512th unit, and $2,000 at the 525,000th unit.

Dr. Robert Nowak of the Defense Advanced Research Project Administration in Arlington, Virginia suggested that an analysis of fuel cell power system costs could be done by costing out the components, analyzing the maturity of the industry producing the component, estimate the likeliness of the cost of the component shifting as the industry matures, and determining the potential effect of volume discounts or mass production on the cost of each component. This method was utilized in the analysis of the fuel cell power system for this market study and business plan.

The BizPlan format and suggested table of contents were the inspiration for this business plan. The questions on the questionnaire were taken directly from suggested questions in BizPlan. The final format of this business plan is the collaboration of BizPlan format and engineering judgment to produce the most appropriate document for this application.

D. Market Research Summary/Consumer Profile

Oil & Gas Industry

TBE has recently evaluated prospects for a 1-5 kW engine generator line for monitoring, control, telecommunications, cathodic protection, and supervisory control and data acquisition (SCADA) along oil and natural gas pipelines. These applications could also be well-served by a FCPS. TBE's experience and marketing network in the engine generator business will be useful in introducing the FCPS. The evaluation indicated that a standardized 500 W model with a price point near $17,000 could compete in this market.

Worldwide potential totaled about 1,000 new devices requiring remote power in 1995 and is forecast to be over 1500 by the year 2000. An estimated 31% of this market could be supplied by alternative remote power systems. Almost half of this potential is among existing onshore wellheads, and about a quarter is in new onshore wellheads. The competing technologies are the power grid, photovoltaics, and thermoelectric generators. The high growth areas in the year 2000 will be in the Former Soviet Union and China. Southeast Asia will also offer opportunity. The markets in Latin America and Africa/Middle East are predicted to be steady while the North American market will grow slightly.

Worldwide, there are more than two million existing land wellheads with potential for retrofit where economics allow. About 48,000 new land wells are drilled annually. Some are exploratory, others are further developments of an existing field. There are more than 8,000 existing unmanned isolated platforms, small and large. Approximately 2,800 offshore wells are drilled annually, with placement of 90-140 new platforms per year.

Demand and potential for growth are strong in the market for systems smaller than 1 kW, especially in the 400 to 600 W range. Cathodic protection usually requires 200-400 W site power, but could exceed that for critical corrosion conditions. Existing pipelines are better candidates for cathodic protection since older lines were largely laid uncoated. Cathodic protection is needed at least every 40 miles. These applications are ideally satisfied (according to many customers) by the use of photovoltaics due to simple, no maintenance installations. The market for 400-600 W power systems has grown significantly since the mid-1980s due to miniaturization of communications, SCADA, remote thermal units, and improved computer and digital communications. Complete systems requiring low maintenance are the most attractive to customers.

Solar panels are appropriate for <1 kW applications typically in the 200-400 W range. For more power, solar arrays become too large to be realistic, thereby limiting them to small power installations. Photovoltaics also more applicable for regions with significant sunlight availability - Latin America, Africa/Middle East. Life cycle costs for solar panels are relatively low compared to that of equipment requiring maintenance. The principal problem is theft and damage in remote locations. Wind power is appropriate only in areas where prevailing winds are constant and predictable. Wind power system capital costs range from $1.80 to 2.70/W.

Customers are very conscious of up-front system cost. They are buying more equipment as packages rather than single-component purchases and there is more dependence on vendors. While price is important, reliability, low maintenance and "no-problem" installations are very critical in remote sites. Energy customers have a propensity to buy more power (larger units) than they need.

Remote Homes

There are approximately 100,000 remote homes in the United States that use renewable energy or a generator as their primary power source. The exact number of remote homes is not officially tracked and depends on if one counts solely remote primary homes, or includes remote cabins used only periodically. A summary of the findings in the Remote Home Market is found in Appendix 2.

On the average, about 25% of off grid homes use a generator for prime power, but even in homes which utilize renewable power for their prime power source, generators are used as back-up power. More people on the east and west coasts use renewable energy sources with remote homes, while mid-westerners traditionally purchase generators for their primary power. Renewables are just becoming a growing industry in the mid-west. There are very few remote homes in the south. Northern California has the largest number of remote home sites per acre in the United States.

Most remote home primary power generators fall in the range of 10-20 kW, while back up power units are 5-15 kW in size. A 1.5 kW generator is required just to keep batteries charged, although a FCPS designed to trickle charge batteries continually could be less than 1 kW. People ordinarily purchase a generator bigger than they need, so they can run their power tools. The market for generators is growing as people, even those hooked up to the grid, experience power outages.

Grid connected households use a total of 2-50 kWh/day, depending on the size of the home, the season and individual electricity use patterns. Remote homes with energy efficient appliances can use as little as 2-11 kWh/day .

Approximately 90% of new off grid homes install photovoltaics (PVs), 20% use wind (many in addition to PVs) and less than 10% use micro-hydro. Greater than 90% of all new remote homes use batteries and inverters.

Currently, remote homes are more like small, efficient normal homes. People are utilizing inverters and 110V AC as opposed to investing in 12 V appliances. Owners of grid connected homes are investing in solar power utilizing inverters and the grid as the storage medium.

Customer Profile

Remote home customers are well educated (16+ years), more wealthy than average ($60k+), in their mid 40's, and are choosing a remote home lifestyle to escape the rat race and feel closer to nature. They are decreasingly technically inclined and generally wish their utility service to be transparent and trouble free.

People who use renewable energy systems on their homes are generally more educated and excited about renewable energy; thus they could be considered 'early adopters.' They have concern for the environment and will pay a slight premium for a 'clean' energy system. A fuel cell power system that operates on reformate with a battery to smooth the power demand would not be considered 'clean' as there is still the problem of exhaust and battery disposal. A fuel cell power system that operates on pure hydrogen would be more attractive to this customer, but the price would have to be comparable to other renewable energy systems and the customer would want to be assured of reliability and maintenance simplicity. The current average renewable power system is approximately 1.0 - 1.5 kW, is cycling about 5 kWh daily and costs between $8,000 - $9,000 installed. Typically, it is designed for four days of energy storage.

Recreational Vehicles
A recreational vehicle (RV) is a vehicle designed as temporary living quarters for recreational, camping, travel or seasonal use. RVs may have their own motor power, as in the case of Class A, B, & C Motorhomes; may be towed by another vehicle, as are fifth wheels, travel trailers, and folding camping trailers; or mounted, as are truck campers. A summary of the findings in the Recreational Vehicle Market is found in Appendix 3 and 4.

A. Class A Motorhomes
The Class A motorhome is the most comfortable, luxurious means of RV travel but with the luxury comes considerable cost in purchase price and fuel. This survey covered lengths ranging from 23 to 45 feet and prices varying from $47,000 to $350,000 with the majority of the units in the $60,000 to $200,000 range. The average price last year was $79,000. Most of the larger and more expensive units over 35 ft have diesel engines and large diesel generators that were from 6.5 kW to 7.5 kW in the units observed. These units typically sell from the low $100,000's to the mid $200,000's. Most of the units under $100,000 use gas and have generators that are generally at least 5 kW due to the large power needs when moving, primarily air conditioning and microwave ovens. Owners of the larger motorhomes typically stay at parks where 30 -50 Amp electric service is available along with cable TV and phone lines in many cases. Propane is used for cooking (the larger units typically have a three burner surface unit and an oven), refrigeration (most of the refrigerators are dual gas and electric), and for heating. The propane tanks range from 20 to 50 gallons depending on the size of the vehicle. They have 2 deep cycle house batteries which are used for the auxiliary power needs and are recharged when the generator is in operation. These batteries are separate from the ones used to start the motor. Many also use inverters for smaller power needs and battery charging.

Class B. Motorhomes - van campers
These camping van conversions offer a fully self-contained living environment. Amenities included are stoves, refrigerators, sinks, toilet, shower, sleeping accommodations and inside living and dining areas. Class B's are the smallest motor homes on the market with lengths ranging from 16-21 feet and prices vary from $32,000 to $53,000 depending upon size and features. Some of the larger units have air-conditioning and microwaves which are run with a small gasoline generator, usually 2.8 kW. The propane tanks (6 to 10 gallons) are used for cooking, refrigeration and heating. Because of the size of these units, components such as holding tanks and propane tanks are rather small so long term dry camping can be a challenge. However a van conversion can serve as a family car when not being used for camping and can be easily parked in almost any campsite.

C. Class C Motorhomes - " Mini's"
Most but not all Class C's are smaller and less expensive than Class A units. Lengths range from 16-31 feet and prices vary from $42,000 to $62,000 with an average price last year of $47,000. A Class C is easier to drive than a Class A because the truck or van cab is narrower than the front of a Class A even though the Class C body is just as wide behind the cab as is a Class A's. Mini's have all the amenities of a Class A (kitchens, bathroom, living, and sleeping areas) but on a smaller scale although larger than a Class B. The units observed had propane tanks in the range of 14 to 20 gallons which are used for cooking (most Class C's have 3 burner stoves and an oven), refrigeration, and heating. Air conditioning, microwave, and other auxiliary power needs are supplied by a gasoline generator (usually 4-5 kW) when moving or when plug in power is not available. The base unit from most manufacturers does not contain a generator, air conditioning, or microwave but these options are usually ordered.

D. Fifth-Wheel Trailers
The smaller fifth wheelers range from 19-24 ft and cost from $10,000 to $15,000. Many of the larger models are towed to a site and left there as a second home. The larger fifth wheelers vary in length from 25 to 41 ft. and prices are from $17,000 to $89,000. The average price of the unit

shipped last year was $22,700, as the smaller units are still the majority that are purchased. Many of the larger new fifth wheelers have slide out rooms that extend the living space when parked. Along with all the normal amenities, some of the larger units have washer/dryer combinations and food freezers. If left at a site, it would typically have plug in power but if not most manufacturers offer an optional propane generator package with sizes from 3.3 kW to 6.5 kW depending on the power needs. The size of the propane tanks are 7 to 20 gallons depending on the size of the units and would be used for the normal cooking, refrigeration, and heating needs in addition to running the generator. A fifth wheeler left at a remote site without plug-ins would be a good candidate for a propane powered hydrogen fuel cell in lieu of a generator for the quiet operation, efficiency, and lower pollution level.

E. Travel Trailers

The smaller trailers (13-27 ft) can be towed by a car, truck, or sport utility vehicle that has sufficient towing capacity and a suitable hitch. The smaller units sell from $6,000 to $19,000 and usually have a fully enclosed bathroom and shower space along with all the other necessary living arrangements. Generators are generally not offered as an option due to cost considerations and one dealer suggested a portable 1.5 kW for backup use. As no one is allowed to ride in these trailers while they are moving, air conditioning is not used during travel. The larger units vary from 27 to 37 feet and prices range from $13,000 to $61,000. Large interiors offer a variety of floorplans for either full time RVers as well as others that spend extended periods of time in one location. The large units like the fifth wheels are typically towed to a location where power is available to run the air-conditioning and microwave. A large travel trailer left at a remote site without plug-ins would be a good candidate for a propane powered hydrogen fuel cell in lieu of a generator for quiet operation, efficiency, and lower pollution level. The majority of the units shipped however are smaller as noted by the $14,200 average price.

F. Truck Campers

The truck camper is the most compact RV available as it is designed to be carried by a pickup truck. The base of the living area is fitted inside the truck bed in the space between the wheel housings. Length's vary from 6 to 11.5 ft , and prices range from $2,000 to $ 20,000 depending on the facilities. The larger units have bathroom facilities, cooking, refrigeration, and optional heating and air conditioning. A unit of this size would have a propane tank of 14 gallons and a 3.4 kW generator.

G. Folding and Camping Trailers

Also known as a pop-up or fold-down trailer, this is a very popular RV for first timers due to its simplicity and lower cost. Many models weigh less than 2,000 pounds and can be towed by all but the most compact small engine cars. Lengths (opened) range from 12 to 26 feet with prices from $4,500- $6,800. Most models have propane stoves, small refrigerators, and portable toilets with sleeping and eating facilities. Power is provided by a battery and a power converter.

H. Van conversions

Van Conversions are similar to Class B Motorhomes except that they do not have bathroom or cooking facilities built in but may have portable facilities. Suburban households use them for general transportation and weekend events

RV - Customer Profile

A 1994 University of Michigan Survey Research Center study for the RV Industry Association (RVIA) found that one out of every 20 vehicle-owning families owns an RV. With some families owning more than one RV, there are more than 5 million RV's on the road. According to RVIA research, 44% of America's RVers are aged 55 and up while 39% are between the ages of 35 and 54. The average RV owner is 48 years old, owns his own home, has a household income just under $40,000, buys in order to travel and camp and is very pleased with the purchase. There are an estimated 25 million RV enthusiasts in the United States. According to RVIA, RV owners annually travel an average of 5,900 miles and spend over 23 days on the road. Another 12 million households intend to buy or rent an RV in the near future. The retail value of RVs produced in 1996 was $12.3 billion. Including the RV rental market, it is estimated that RVs are a $15.75 billion industry.

RV sales are expected to increase in the late 1990s as the massive "baby boom" generation enters the prime RV buying years, age 45-54. After rebounding from the recession year of 1990-91, the recent peak in units was in 1994 with small unit declines in 1995 and 1996. With the improving economy, favorable interest rate environment and demographics, unit sales are expected to increase in 1997 and 1998. Changes in the frequency and duration of vacations also favor the RV industry. Americans are traveling more but over short distances and on weekends with less planning, according to recent studies. For RV owners, this is a natural travel pattern. The growing popularity of RVing parallels the importance of outdoor recreation in the U.S. A survey by the Recreation Roundtable found 77% of Americans view outdoor recreation as a priority in their lives and 67% plan to increase their participation in camping in the 1990's. RVs are a natural focal point for many of these activities, especially camping.

If an RV comes with a power system, the type of power and the configuration of the system is determined by the RV manufacturer. It is offered to the consumer as a standard model with the possibility of one or two upgrades, similar to how cars are sold.

Telecommunications

The telecommunications application in many ways is completely different from the RV and boating application as telecommunications services are needed by virtually all of the population including those on the grid, those in outlying and rural areas, and those traveling through any area who would like telecommunications services.

Remote sites require their own power sources. They would be connected to the grid if available, but generally the cost to run a line extension to these locations is prohibitive. A recent connect by American Tower Systems cost $100,000 per mile. The main power users in telecommunications are the air conditioning systems, radio transmitting equipment, cellular and personal communication services (PCS), and microwave equipment. Because the main telecommunications services (telephone, local radio and television transmitting) are related to population areas, the sites with the major power needs are usually on the grid. With the advent of nationwide cellular service, many of the future sites that provide these services will be off the grid.

Repeater stations which relay or "repeat" the signal for various telecommunications industry applications are often located in remote places and require highly dependable DC power. Solar photovoltaic panels working with batteries are generally the technology of choice to provide power for :

* Microwave repeater stations
* Satellite ground stations
* Telephone cable repeater stations
* Radio - telephone interlink units

Repeater stations not powered by PVs may be powered by the electric grid or by a generator with the major consideration being the cost of running the electrical transmission line to the repeater site. In cases where the repeater is at a remote location, the cost would probably be prohibitive. Generators could be used but they are generally not dependable for unattended operation such as would be required at a remote site. The power requirements vary greatly depending on the number of different carriers, the different kinds of service, the distance from the last tower, and the type of configuration.

Photovoltaics, batteries, and generators are currently used by remote sites, for both primary and back-up power. Our field research indicated that even though many of the telecommunications sites were on the grid, there were significant numbers of power failures which required either large battery backup systems or large generator backup.

The biggest advantages of the FCPS in this application are reliability, less frequent maintenance requirements, and longer life. The efficiency of the fuel cell power system would produce significant fuel savings if a propane reformer is available. The quiet operation and lower pollutant level may not be as significant a factor in a remote site, or in general, as many of the large "on grid" sites are located outside of urban residential areas. Fuel availability is not a major issue, as an existing site would have either a propane or natural gas tank if it needed a generator or arrangements would have been made to bring in diesel or gasoline. Cost, product availability, and power available from the fuel cell are major issues. In order to show that the benefits are worth the higher cost, we need the ability to give an actual demonstration or do an onsite test at one of the facilities that were visited. This request was made by General Telephone & Electronics and American Tower Systems, who manage large multipurpose telecommunications sites around the country.

Telecommunications Equipment Facts

The growth in the telecom equipment market is due to the increased demand by individual, corporate, and government consumers for these services. It will directly affect the amount of new sites created. There are various equipment configurations deployed at these sites. The power needs range from small solar repeater station sites to large multi-purpose sites with different suppliers, where a 50-100 kW backup capacity is needed. It is difficult to determine a typical site configuration or even a class of sites, but the demand for future sites will increase as sales of telecom equipment increase.

The Telecommunications Industry Association released the following information which is derived from U.S. Commerce Department Data. Factory sales in the U.S. of telecommunications equipment for 1996 reached $63.7 billion which was a 20% increase over 1995 sales of 53 billion. The 1994 and 1995 sales breakdown by major categories are as follows:

Value of Telecommunication Sales ($Ms)

	1994	1995
Commercial, Industrial, and Military	20,078	23,124
Broadcast, Studio and related	2,469	2,700
Intercommunications Equipment	283	293
Telephone and Telegraph Equipment	22,557	26,061
Fiber Optic Cable	713	822
Total	**46,100**	**53,000**

1996 was the third straight year that U.S. factory sales have seen double digit growth. The 1996 Telecommunications Act should create new opportunities for growth due to the expected impact of the deregulation on the U.S. economy. The 1996 U.S. trade surplus in telecommunications equipment was $4 billion with exports of $17 billion or slightly over 25% of production .

The type of power system to be installed is decided by either the service provider or the vendor, depending on the situation. Solar is generally preferred for its reliability, if it can generate enough power. The battery bank associated with the PV system is acceptable but wears out fast and is costly to replace, especially in hot climates. Generators are the least preferred due to their low operating efficiency and continuous periodic maintenance, but they are often the only alternative for large power needs.

The stocks of the telecommunications group have been on the defensive over the past several weeks. Concern over valuations and the unsettling events in the SE Asian and Latin American markets is driving the retreat. While deteriorating momentum and growing earnings anxiety suggest that the group will continue to do no better than keep pace with the market, the long-term outlook remains bright. Explosive growth in the small office/home office market, deregulation of the telecommunications industry, demand for increased bandwidth to facilitate high speed data and increasingly complex audio/video transfers and tremendous opportunities to exploit underdeveloped foreign markets should enable the group to post average annual growth of 20%-25% over the next five years.

Yachts/Boats

Sailboats

Sailboats are used extensively for recreation for consumers in water accessible areas with higher utilization in more temperate climates such as Florida, southern California, and the Gulf Coast. Typical use includes day sailing, weekend cruises, inter-island and inter-coastal and even trans-Pacific or trans-Atlantic travel depending on the affluence of the boat owner and the size of the boat. Sailboat production has been consistent with the economic climate dropping from 14,510 units in 1988 to 8,677 in 1991. Production has risen steadily from the 1991 low to a level of 15,939 units in 1996. There is an optimistic projection of a 17% increase in 1997 to 18,643 units. The major concentration is in the smaller boats under 20 ft. A summary of these findings is found in Appendix 5.

Under 30 feet

The majority of the sail boats built yearly (1996 - 85%) and also those that are in service now fall into this category, with the predominant number in this subsegment being under 20 feet. The typical use of these boats is for weekend day cruises, local marina hopping, or inter-island or inter-coastal weekend cruises for the larger boats in this class. Many of the boats under 20 ft. have an outboard motor, while the 25 ft. and up often have gasoline powered inboards. The boats larger than 20 ft. will typically have small cabins which include basic living facilities.

The power needs are supplied by batteries (12V) which are recharged by an alternator, small portable generator, or shore power. The day cruiser's typical power use is for the radio and for lights. Although many contain refrigerators, they are often fortified by buying ice at the start of the day. Cooking is usually done on a small alcohol stove or by hanging a barbecue over the side when anchored or docked. The inboard motors are used primarily to get out of the marina, for propulsion when the wind is too calm to sail, and to charge the battery. Most sailors use them as little as possible due to the gas smell and noise that takes away from the sailing experience.

Because of the relatively minimal power needs and low cost of the boats in this subsegment, it does not appear that it would be an initial target market at this time. There may be a market application here in the future for a small fuel cell powered electric motor to get them out of the marina and for minimal propulsion and other electric needs. See Appendix 6.

30 to 40 Feet

In 1996 there were 1,641 sailboats built in this size range which was slightly over 10% of the total in existence. This size range is projected to increase to 1,852 units, slightly less than the average increase projected for all sailboats.

These boats can range anywhere from $50,000 to $300,000 depending on their size, configurations, appointments etc. This is definitely an upscale market. In addition to the activities mentioned above for the under thirty foot boats, these boat owners may live on board, take longer trips, and entertain guests. The majority have an inboard diesel engine for propulsion when not under sail which is also used with an alternator to charge the battery banks. Usually there are two battery banks, one for starting and one for all other electric power needs. There may be more than one 12V deep cycle battery in each bank depending on the needs and backup batteries are carried for emergencies. Many of the larger boats use some combination of solar panels, wind generators, and trailing water powered generators depending on their electric power needs. Most have propane for cooking (three burner stoves with ovens). The typical tank configuration is one or two 10 lb. containers (2.4 gallons) in a separate locker which would be vented above the water line. Most sailboats of this size do not have a heater or an air conditioner so there would be no need for a generator. At this time none of the major manufacturers make a propane powered generator. A recent article from Cruising World magazine "Surveying your Electrical Needs" showed a sample daily appliance load chart of 150 amp-hrs for a boat of this size using propane for cooking. The major power consumption is for refrigeration, lights, TV/VCR, and microwave. The energy is supplied from the batteries with renewable charging sources such as solar, water, and wind assisting the engine driven charging sources. See Appendix 7.

Since the propane is already on board and only one tank is needed for cooking (a 2.4 gallon tank should supply enough BTU's for a cruising couple for a month and a half), the other tank could be used for powering a fuel cell. This tank could provide up to 900 amp hours which is 6 days supply (based on load chart), assuming that none of the other renewable sources were used and the engine was not run.

It appears that this segment would be receptive to use of a FCPS and would be willing to pay a premium. There were 15,000 units built in this segment over the last 9 years, so a retrofit unit could represent a market. However fewer than 2,000 new units are produced each year, so this is not a sizable market in itself. This may be a market in the future.

Over 40 ft

In 1996 there were only 490 sailboats of this size built, comprising 3% of the market. Of this number 79% were between 40 to 45 ft. The projection for 1997 for this 40-45 ft. subsegment is for 635 units, or a 30% increase, due to improved economic conditions. This is a high end, but small, niche market mentioned in the proposal, but the question is whether these small numbers would justify production The 40- 45 ft. boats might only require a generator under 5kW for heating and air conditioning but the larger "super yachts" have diesel engines and diesel generators with power requirements substantially above 5 kW. The 40 - 45 ft. subsegment has the advantage of being large enough to be able to store two 5 gallon tanks of propane. The three major generator manufacturers Onan, Kohler, and Northern Lights (Alaska Diesel Electric) do not make marine propane generators. Based on the sizes of the diesel generators currently in use, the fuel cell would have to be greater than 5 kW to run the air conditioning and heating functions for this size boat.

Power Boats

Under 30 ft

There are large numbers of small outboard motor boats and inboard runabouts which make up the majority of this subsegment. They are typically gas powered and generally used for day recreation with minimal, if any electric requirements. Many are towed on a trailer to a lake or marina launching site and are towed out after the day use. There may be a market at some point for an inexpensive FCPS to power an electric propulsion motor. The current noise and safety concerns at state and federal government water facilities is directed primarily at personal watercraft but could affect other noisy and polluting water vehicles.

Because of the relatively minimal electrical power needs of this sub segment , it does not appear that it would be an initial target market at this time. A future study might look a extending the range of the electric boats with fuel cell technology as they currently can run up to 10 hrs and then have to be recharged. Another area for future study might be for a propulsion system to be used on small boats currently powered by gasoline inboard or outboard engines.

Over 30 ft with a Cabin Cruisers
In interviews with boat dealers of this type, an aversion to propane based primarily on a fear of explosion and a lack of need was found. Even though the newer large sailboats had propane for cooking, the power boat dealers were not interested.

The smaller boats in this group relied on batteries with various charging devices and typically are used for marina to marina or other day cruises. Owners often do cooking at their destination where they can plug into shore power. If they do dock at an anchorage, they turn on the generator, which can be annoying to others, or they operate off battery power. The battery is charged by the motor while cruising.

The larger and more expensive power boats over 40 ft. run on diesel engines with generators 6 kW and greater. Onan's line of marine generators starts at 6 kW.

There could be an application here for replacing the smaller generators < 5 kW if a diesel reformer was available. This would have the advantage of quieter operation when anchored. However, as most of the current generators in service are > 6 kW , this segment is beyond the scope of the study.

Alternative Electrical Sources for Marine Application

1. Alternator (150 amp)

In order to duplicate the electricity provided by the fuel cell, the engine could turn a 150 amp alternator for an hour and half a day to recharge the batteries to replace the energy used. As many sailboats use their engines, going in and out of marina's, harbors, etc. this would not be a major hardship.

2. Solar power

Solar power would only be used as a supplementary source. Three 50 W panels operating at 12 V and assuming full sun availability for 4 hours would provide approximately 48 amp hrs daily which is about one third of the needs. Less sun accessibility (cloudy days, for example) would reduce the available power.

3. Wind generators

Wind generators are also a supplemental source that could supply between 40 - 80 amp-hrs a day depending on the wind speed and the size of the unit.

4. Water powered generators

A trailing log unit at 5 knot average speed could provide 50 to 100 amp hours daily depending on how long one was cruising.

All of the renewable sources (sun, wind, and water) are only able to provide part of the daily energy requirements. The fuel cell could provide all of the requirements for 6 days or longer (based on the propane availability) with the side benefit of charging the starting battery and back up batteries without running the engine.

VI. Comparing Energy Generation Technologies

Fuel cell power systems can be compared to other energy generating and storage systems such as photovoltaic modules, thermoelectric generators, hydroelectric generators, wind turbines, engine generators and batteries. The following is a summary of positive and negative attributes of these technologies.

Photovoltaic (PV) Modules

PV panels are currently used in remote power situations. They are most appropriate in applications < 10 kW. In larger applications the array may become inconveniently large. PV systems are most applicable to sunny regions, and even in these areas their use is limited to the sunny part of the day. They have low life cycle and maintenance costs, and have an excellent service record. The main problems with PV modules in remote locations are theft and damage. They cost approximately $7/Watt, installed, but this price is dropping approximately 9% per year.

Thermoelectric Generators

Teledyne Brown - Energy Systems is a major supplier of thermoelectric generators (TEGs). TEGs are not commonly used, although customers who are familiar with the technology are comfortable with its application. They convert heat from flameless combustion of gases into electrical energy. They are reliable and adaptable, offering power levels from 5-300 W. TEGs are small and easy to install, but they have a high price, are potentially high maintenance, and have a hot exhaust stack. Prices are high, approximately $30 - $50 per Watt.

Hydroelectric Generators

Hydroelectric power is very appropriate for areas near a year round flowing stream. It is often installed in conjunction with PV and/or wind systems. Hydrosystems utilize batteries for energy storage. Hydropower can cost as little as one tenth that of a PV system, but the cost will depend on the site particulars such as water flow and head, plus the distance from the power generation to the end use. Typical micro-hydroelectric systems produce from 1 kWh to 30 kWh per day.

Wind Power

Wind power generation is most often used in combination with other power generation systems. It is appropriate in areas where prevailing winds are constant and predictable. Cost ranges from $1.80-$2.35 per Watt.

Engine Generators

Engine generators which run on gasoline, propane and/or diesel are the most commonly utilized energy generators for remote sites. Users are very comfortable and familiar with this technology and the fuel is widely available. They are commonly used in conjunction with batteries. Generators' cost range is $0.50 - $1.50 per Watt. They need regular maintenance, are noisy and generate criteria pollutants such as SO_2, CO, NO_x.

Batteries

Batteries can be brought to a remote site to supply previously saved energy or they can serve as on-site energy storage in hybrid energy generation systems. Lead acid is the most common battery technology. It is widely available and people are familiar with its use. The drawback of lead acid batteries is that they need regular maintenance, lose charge over time and constitute hazardous waste. Nickel cadmium (NiCad) batteries are longer lasting and can be recharged more easily, but they are very expensive initially. Lead acid batteries cost about $1.00 per Watt, while NiCads are

3-10 times more expensive. System costs rise when the accessory equipment, such as inverters, charge controllers, etc. are included.

VII. Commercially Available Hydrogen

It is possible that in certain applications or circumstances, a user may prefer to by-pass or delete the onboard reformer and operate an FCPS directly on hydrogen.

Hydrogen is available commercially in either compressed gas or cryogenic liquid form. Compressed gas cylinders are available in several sizes, ranging in capacity from 14 - 220 scf. In this form, the cost to the user is about $577/GJ, including tank rental. Liquid hydrogen is supplied in much larger quantities, with tanks capacities ranging from 1,500 - 18,000 gallons. In this case, cost is on the order of $12/GJ, also including rental charges. For comparison, the energy cost of a gallon of gasoline, assuming a price of $1.50/gal., is $11.40/GJ.

The above figures are based on industrial grade hydrogen (99.95% pure). While higher purity grades are available, up to 99.9995% pure, they are significantly more expensive. The industrial grade has been demonstrated to be entirely satisfactory for use in fuel cells.

The effect of these fuel costs may be illustrated in a brief example comparing the fuel cost to deliver 50 kWh from a gasoline fueled engine/generator versus an FCPS fueled with commercial hydrogen. Assuming a net efficiency of 17% for the engine/generator and 40% for the FCPS, the fuel costs are:

engine/generator	gasoline	$ 12.00
FCPS	compressed H2	$260.00
FCPS	liquid H2	$ 5.40

This brief analysis shows that the fuel cost of generating electic power using liquid hydrogen and a FCPS is less than half that of a gasoline generator.

VIII. Areas for Further Research

This market research has led to knowledge of other potential markets and interesting areas for further research. The following is a discussion of these findings.

Uninterruptible Power Supply

A significant remote power system market can be found in uninterruptible power supply (UPS) systems. Although research in this area is not within the scope of this contract, we give a brief description of the market below.

UPS is the name given to a standby power supply that protects computer systems, many of them containing data that is deemed critical or irreplaceable by a network manager. It may be as simple as a back-up battery, or as complex as a million-dollar support structure.

While a split-second power outage might have gone unnoticed some years ago, today such an event would cause havoc. Examples of problems that might occur include loss of data from credit approvals, airline reservations, EKG readouts, academic transcripts, and stock or trading information. Such events also cause a halt in productivity in the office, store, hospital, or other facility, while the PC or electronic tool stops, reboots, and is re-initialized. Further, power surges may damage the electronic hardware, increasing downtime and decreasing productivity.

Although UPS systems can be costly, the need for reliable power is increasing as we continue to move toward a more information-intensive society. An investment in a UPS is often required to keep a business in business.

Power reliability has become such an important issue that a consortium of 150 firms concerned about continuous power availability has been formed in New York City. It is called The Uninterruptible Uptime Users Group (UUUG). Members include information systems and data center personnel, telecommunications managers, computer technologists and building managers.

The Battery Council International (BCI) estimated the market for UPS systems to be $169 million in 1996, which represented a 13% growth rate over the previous year. This comprised 32% of the 1996 total battery market and is expected to increase to 35% of the market by 2001. This growth is mainly due to the computer industry's expansion of critical applications that demand complete reliability of data, as well as growth of the Internet and networking in general.

UPS devices for networks require adequate and reliable backup batteries, which must be checked and replaced regularly so that they are ready to perform when a network shuts down. One vendor estimates that there are more than 400 manufacturers of UPS devices just for stand-alone personal computers. For network UPS systems, a few of the leading manufacturers include American Power Conversion, and Emerson Computer Power.

UPS systems exist for a large variety of businesses. By design, reliability is a critical issue and firms needing such systems are willing to pay a premium for reliable power. Although we have not identified the quantity of systems in the 0.1 to 10 kW size range, we know that the number of UPS systems is large and growing rapidly.

Telecommunications

The power needs of the telecommunication industry were examined in this report, but time was finite and the research restricted. It was discovered that this market is very broad and is changing very rapidly. More research is needed to understand the market, their power needs and what they would be willing to pay.

Backup Power Systems Necessary Because of Deregulation

As industrial power suppliers become deregulated, confidence in electrical service is diminishing. Evidence of this presents itself in several markets, and was mentioned repeatedly during this market research. People in homes which are on the grid, but are located in regions prone to blackouts, are looking for a back-up power source. As mentioned previously, industrial UPS users are looking for a reliable back-up. This market could be vast.

Systems less than 0.1kW

There is a potential market for small power systems, which are less than 0.1kW. A few recognized markets include electronic flow correctors in gas distribution systems, remote power needs for computers, highway sign lighting, corrosion protection of pipelines and other small remote power needs. These markets generally are very cost tolerant for small amounts of reliable power.

Systems less than 30 W

One high value niche market not included in the current scope of research is the market for small (less than 30 Watt), remote power sources used in the North American petroleum production, gas transmission, and gas distribution industry. The devices requiring power include remote terminal units, electronic flow computers, and remote power units. These make possible collection, processing, storage, and transmittal of data, as well as control of equipment in remote locations.

In 1995, producers, gas transmission firms, and gas distribution companies purchased an estimated 43,000 small, remote power sources for both new installations and replacement units. About 70% of these were stand-alone batteries in the 3 Watt size range, while some solar cells were also purchased. The cost of a photovoltaic system was about $250 per average Watt and the price for stand-alone battery systems was about $120 per average Watt

IX. Licensing

Terms to know

Licensee: the buyer
Licensor: the seller or granter of a license
License: granting of permission or rights to make, use, or sell a certain design, product or process
Intellectual Property: ownership rights given by law to intellectual information such as inventions, patents, trademarks, know-how and trade secrets

General Information

An effective licensing agreement must satisfy four fundamental requirements. First, the party granting the license must have ownership of relevant intellectual property or authority to grant the license. Second, the intellectual property must be protected by law, or at least eligible for legal protection. Third, the licensing agreement should specify what rights are granted with enough precision to avoid disputes. Since a licensing agreement does not transfer ownership of the licensed intellectual property, it normally gives the licensee some, but not all, of the rights in the intellectual property that accompany ownership. Finally, a licensing agreement should state what rights, if any, are reserved by the licensor, whether for its own use or to support future grants to others.

The typical royalty is 1.5-7% of the manufacturer's gross revenue from sales of the patented product. A number of variables determine the actual payment. Often the license agreements involve both a front end fee and a royalty, and in many situations the royalty percentage paid ratchets down over time, as revenue grows. A licensor should investigate the range of agreed royalties for similar intellectual property in the same industry. The remaining work required to bring the intellectual property successfully to market and the business conditions required for its successful commercial use should be carefully examined by both the licensee and the licensor.

Policy of Schatz Energy Research Center and Humboldt State University Foundation concerning licensing of technology

Schatz Energy Research Center is affiliated with the Humboldt State University Foundation (HSUF), an auxiliary non-profit corporation within the California State University system.

Licensing technology from Schatz Energy Research Center involves negotiation with the HSUF. HSUF may also involve a third party in the negotiation.

There are four main procedures in licensing of a technology with HSU Foundation. These include agreement on roles and responsibilities, scope, duration and rate of compensation. Roles and responsibilities can involve further financial arrangements, such as licensor consulting time and fee or any other special arrangements necessary for successful commercialization of the product. The royalty can be based on either gross or net revenue. A net revenue basis for royalty involves more complex auditing procedures.

Details of the Schatz/HSUF licensing policy are found in a policy document published by the Foundation.

X. Financial Analysis

A. An Engineering Economics Analysis of Fuel Cell System Output

Fuel cell efficiency, which is a function of the voltage at which a fuel cell stack is operating, has a significant effect on the economics of the stack. Running a stack at higher voltages produces a higher efficiency and, therefore, lower hydrogen consumption. For a given power output, the choice is between: 1) operating at higher voltages by incorporating more cells in the stack or 2) operating at higher current densities with fewer cells. The former has higher capital costs, the latter higher fuel costs.

Fuel cell component cost and the cost of hydrogen, as well as the efficiency of the stack will together define the cost of electricity ($/kWh) for any particular application. In the following section, we analyze the effect of power density, hydrogen cost, and system component cost on the cost of the electricity produced by the fuel cell power system. The results indicate that in the best case scenario, a 70-cell stack could operate at 33% efficiency, and generate electricity at $0.23/kWh if hydrogen is supplied at $12/GJ. A larger fuel cost (true for renewable hydrogen) would yield a least cost for a stack with more cells which would operate more efficiently.

Figure 1 shows a typical polarization curve for the current stage of fuel cell membrane development. Efficiency is the ratio of electrical power output to fuel input.

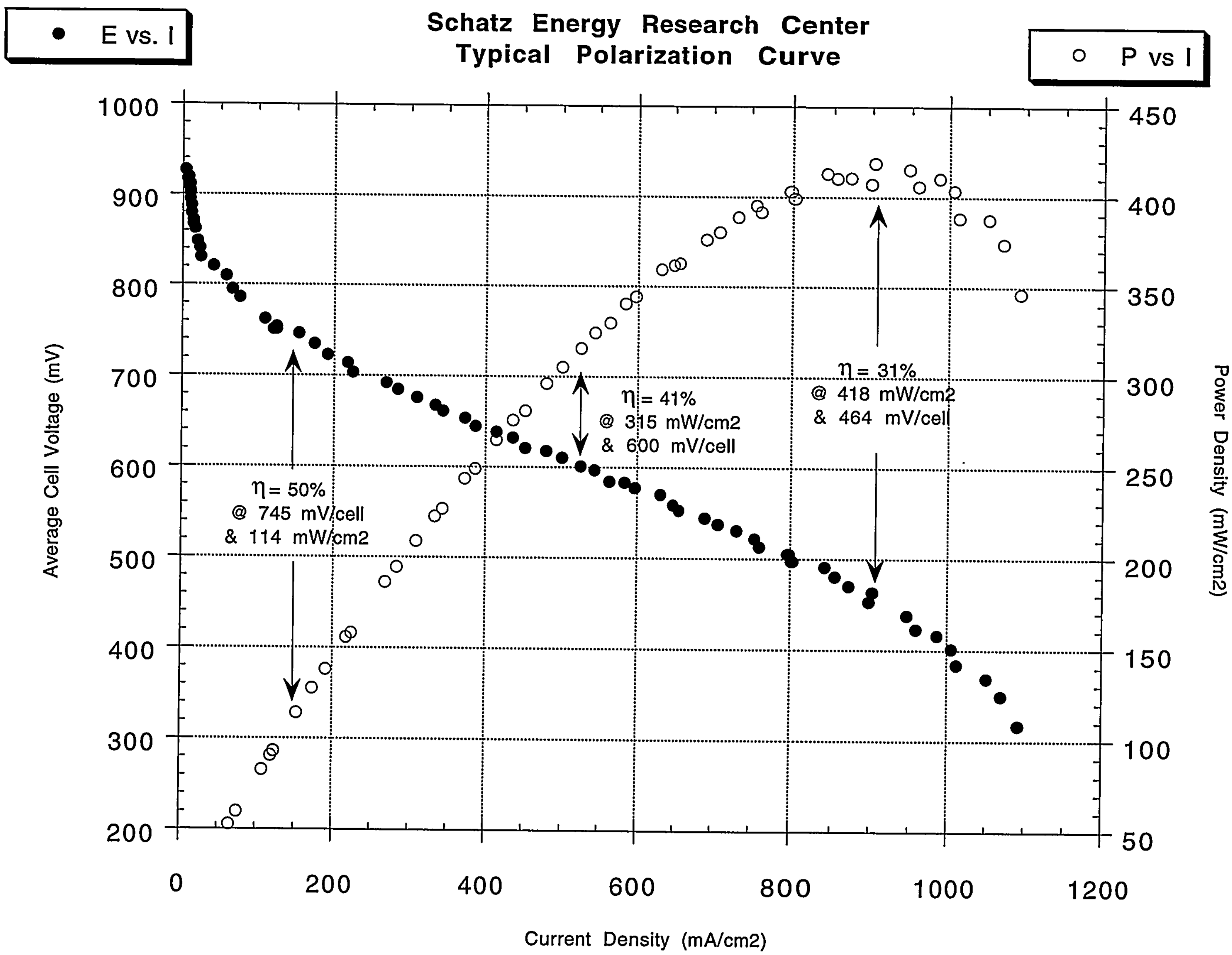

Figure 1. Typical polarization curve showing efficiency (η) at various voltages and power densities.

Combining the principles of Watt's Law and Faraday's Law, we find that fuel cell efficiency is simply the ratio of actual operating voltage to 1.482V (higher heating value), the maximum possible potential resulting from the electrochemical reaction:

$$\eta = \frac{V}{1.482\text{V}}$$

where:

η = the stack efficiency
V = the stack voltage per cell

Note that the efficiency at maximum power is at its minimum, around 30%, while the efficiency at 600 mV per cell, an often-used benchmark, is about 40%, and the efficiency of 50% may be reached at 745 mV per cell. Normally, in the design of a fuel cell system, the first consideration is operating voltage. Achieving this voltage with a greater number of cells in a stack causes a penalty in capital cost, but also increases efficiency and decreases hydrogen consumption. The optimum size for a stack designed to operate at a given voltage and efficiency therefore depends on the relationship between capital and hydrogen costs.

Assumptions:

Hydrogen Cost
We used two sources to determine the cost of hydrogen. Venki Raman of Air Products, Incorporated has predicted the cost of hydrogen to be $2/kg to $7/kg ($14-48/GJ) in the near future, depending on level of capital investment and method of production (large scale steam-methane reformation is the least expensive). Recent quotes from gas companies indicate a wide range of costs. For compressed gas in small tanks, the price was approximately $342/GJ. For liquid hydrogen in commercial quantities, the cost was $7/GJ, with a monthly rental fee for the tank. For purposes of the foregoing analysis, we will assume a cost of $24/GJ, and for our best case scenario, $12/GJ.

Capacity Factor
Clearly the cost of electricity is also dependent on the capacity factor of the system, *i.e.*, the percentage of actual versus possible production of the system. We have chosen in all cases to assume a 90% capacity factor, which allows for constant operation and periodic maintenance. In intermittent operation, the capacity factor would be lower, making the cost of electricity higher.

Useful Life
We assumed a five year useful life for the fuel cell stack. The critical component in a PEM fuel cell with respect to durability is the proton exchange membrane. The same material is used in the chlor alkaline industry, where it is exposed to much harsher operating conditions, and has exhibited lifetimes in excess of 40,000 operating hours (nearly constant operation each day for 5 years). We are confident that the other parts of the stack, such as the graphite and plastic, will last at least this long, and probably much longer.

Constraints
Power production was held constant at 5.2 kWp (gross). With a 90% capacity factor, annual electricity production was 41,000 kWh. We used a typical voltage-current (E-I) curve and a stack with 300 cm^2 of active area. For all comparisons we used the stack that had the smallest present value of fuel and capital costs. Peripheral system costs were held constant at a conservative $20,000. In most designs, the voltage of the stack is a primary consideration. Since we have no

single application in mind, we have allowed a range of voltages. In addition, fuel cell stacks might, in reality, have a longer lifetime operating at a lower current density. We have assumed that, in any case, a lifetime of five years will be possible, irrespective of current density and that a lifetime greater than five years has no value. Finally, we defined improved performance to be double the value of today's current density.

Disregarded Factors

The cost of the reformer was not included. Instead we assumed that hydrogen from a reformer would eventually have to meet the purity and cost standards of currently-available liquid hydrogen in order to be marketable. Parasitic loads of the peripheral components, such as the air blower and water pump (usually about 10 %) also were not included.

Other Assumptions

We assumed a 4% annual interest rate and a 2% annual inflation rate, giving a discount rate of 2%. For the fuel cell cost, we annualized the current stack component cost by using the capital recovery factor given by:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:
CRF = the capital recovery factor
i = the discount rate (2%)
n is the stack lifetime in years (number of periods -- 5).

Using these numbers, CRF = 0.212.

The production cost of electricity, C, is equal to the sum of the annualized capital cost of the stack (ACC) and the annual fuel cost (AFC), divided by the annual electrical production (AEP):

$$C(\$/kWh) = \frac{ACC(\$/yr.) + AFC(\$/yr.)}{AEP(kWh/yr.)}$$

Finally, we have also assumed that operation and maintenance costs (beyond fuel) are negligible.

Results

Table 1. Effect of Various Scenarios on Fuel Cell Electricity Cost.

Scenario	Voltage	Current Density	Hydrogen Cost	Annual Hydrogen Cost	*System Cost	Annualized Capital Cost	Electricity Cost
	(mV)	(mA/cm2)	($/GJ)	($/yr)	($)	($/yr)	($/kWh)
1 - Base Case	522	756	24	9829	38831	8232	0.44
2 - 100% Performance Imp	491	1682	24	10452	29437	6241	0.41
3 - 50% Stack Cost Decline	522	756	24	9829	19416	4116	0.34
4 - 50% H2 Cost Decline	522	756	12	4915	38831	8232	0.32
5 - Best Case	491	1682	12	5226	19416	4116	0.23

*System Cost includes materials, labor, and peripheral system components.

Discussion

The results of our analysis are shown in Table 1 above. We have used current costs of labor, material, and components for this analysis. In choosing our scenarios, we assumed scenarios that may be possible because of volume pricing, better manufacturing methods, and conceivable improvements in technology. The largest cut in cost occurred with a 50% hydrogen cost decline, causing electricity costs to drop from $0.44/kWh to $0.32/kWh, while a 50% stack cost decline had almost the same effect and a 100% performance improvement had very little effect. With all three changes, a significant drop to $0.23/kWh was made possible. The spreadsheet analyses for the base case scenario and scenario II are shown in Figures 2 and 3.

The $0.23/kWh figure represents a wholesale price, but compares quite well to the (retail) lifecycle cost of diesel generators of $0.13/kWh and the cost of a battery/shore-power system paid by yacht owners of $0.29/kWh. This analysis is shown in Figure 4.

For our base case scenario, we chose a point on a current E-I curve that would produce 5.25 kWp with the lowest present value of stack capital costs and annual hydrogen costs. At this point, using $24/GJ, and the current cost of the fuel cell power system, electricity cost was $0.44/kWh.

In scenario II we assumed a 100% performance improvement consisting of a doubling in current density at each voltage. This gave an electricity cost of $0.41/kWh, due to smaller stack costs. The improvement will be greater when labor costs decrease with automation.

In scenario III we assumed a 50% decline in stack capital costs and labor costs. As shown in our prior analysis, this is achievable during the first 2,000 units of production. This yielded an electricity cost of $0.34/kWh.

In scenario IV we assumed a 50% decline in hydrogen costs - from $24/GJ to $12/GJ. Bulk (liquid) hydrogen is available in very large quantities for as little as $10/GJ, so it could possibly be distributed to refueling stations for $12/GJ, even today. This yielded an electricity cost of $0.32/kWh.

In scenario V we assumed all of the above -- double the current fuel cell performance, a 50% decline in stack cost, and a 50% decline in hydrogen cost. This yielded an electricity cost of $0.23/kWh.

Conclusion

Fuel cell component cost, the cost of hydrogen, and the efficiency of the stack will together define the cost of electricity produced by a fuel cell power system. We analyzed the effect of power density, hydrogen cost, and system component cost on the cost of the electricity produced by the fuel cell power system, using scenarios that may be possible in the near future. A 50% stack and labor cost decline had the greatest overall effect on the price of electricity generated. In the best case scenario, a 21-cell stack would operate at 33% efficiency, and generate electricity at $0.23/kWh if hydrogen is supplied at $12/GJ.

Figure 2
Economic Analysis

Stack Size:		variable		Power:		5.25 kW							
Capacity Factor:		0.9		Energy Output:		41,000kWh/yr.							
Active Area:		300 cm2											
Cell Operating Voltage (mV)	Efficiency (η=V/1.482/10)	Operating Current (mA/cm2)	Current (A)	Power (kW)	# Cells in 5.25 kWp Stack	Stack Voltage (V)	Hydrogen Consum Rate (slm)	Ann. H2 Consum (GJ)	H2 Cost ($@$12/GJ)	H2 Cost ($@$24/GJ)	Stack Capital Cost	Capital + Fuel (12) ($)	Capital + Fuel (24) ($)
927	63	4	1.30	0.0012069	4,350	4,032	36	231	2,770	5,540	1,768,876	1,771,646	1,774,416
917	62	7	1.95	0.0017913	2,931	2,688	36	233	2,800	5,599	1,192,079	1,194,879	1,197,678
919	62	8	2.28	0.0020950	2,506	2,304	36	233	2,793	5,586	1,019,420	1,022,212	1,025,005
912	62	10	2.93	0.0026709	1,966	1,792	36	235	2,816	5,633	799,787	802,603	805,420
910	61	8	2.28	0.0020732	2,532	2,304	36	235	2,822	5,644	1,030,122	1,032,945	1,035,767
905	61	10	2.93	0.0026500	1,981	1,792	36	237	2,839	5,677	806,067	808,906	811,744
902	61	10	2.93	0.0026423	1,987	1,792	37	237	2,847	5,694	808,433	811,280	814,127
902	61	10	2.93	0.0026423	1,987	1,792	37	237	2,847	5,694	808,433	811,280	814,127
895	60	10	2.93	0.0026226	2,002	1,792	37	239	2,868	5,737	814,496	817,364	820,232
888	60	12	3.58	0.0031792	1,651	1,466	37	241	2,892	5,784	672,030	674,922	677,814
880	59	12	3.58	0.0031501	1,667	1,466	37	243	2,919	5,837	678,240	681,159	684,078
871	59	14	4.23	0.0036875	1,424	1,241	38	246	2,947	5,893	579,517	582,463	585,410
867	58	14	4.23	0.0036685	1,431	1,241	38	247	2,962	5,924	582,507	585,469	588,431
862	58	16	4.88	0.0042100	1,247	1,075	38	248	2,978	5,956	507,691	510,669	513,647
848	57	20	5.86	0.0049710	1,056	896	39	252	3,027	6,053	430,104	433,131	436,157
841	57	23	6.84	0.0057466	914	768	39	255	3,054	6,109	372,165	375,219	378,274
831	56	24	7.16	0.0059491	882	733	40	258	3,091	6,182	359,526	362,617	365,708
821	55	41	12.37	0.0101498	517	424	40	261	3,129	6,259	211,072	214,201	217,331
810	55	58	17.25	0.0139666	376	304	41	264	3,172	6,344	153,616	156,788	159,960
795	54	66	19.86	0.0157918	332	264	41	269	3,229	6,457	135,957	139,185	142,414
786	53	76	22.79	0.0179132	293	230	42	272	3,266	6,532	119,954	123,221	126,487
762	51	109	32.55	0.0248161	212	161	43	281	3,368	6,736	86,818	90,186	93,554
754	51	124	37.11	0.0279806	188	141	44	284	3,405	6,811	77,093	80,498	83,904
752	51	124	37.11	0.0278900	188	141	44	285	3,417	6,833	77,341	80,757	84,174
751	51	120	36.13	0.0271474	193	145	44	285	3,417	6,835	79,434	82,851	86,268
746	50	153	45.90	0.0342603	153	114	44	287	3,440	6,880	63,114	66,554	69,994
735	50	174	52.08	0.0382951	137	101	45	291	3,492	6,984	56,552	60,044	63,536
723	49	191	57.29	0.0414248	127	92	46	296	3,551	7,102	52,342	55,893	59,444
714	48	218	65.43	0.0467380	112	80	46	300	3,595	7,189	46,486	50,080	53,675
704	47	225	67.38	0.0474336	111	78	47	304	3,648	7,295	45,816	49,464	53,111
692	47	269	80.73	0.0558765	94	65	48	309	3,710	7,420	39,019	42,728	46,438
685	46	284	85.29	0.0584062	90	62	48	312	3,749	7,499	37,365	41,114	44,863
676	46	309	92.77	0.0627204	84	57	49	316	3,798	7,596	34,852	38,649	42,447
668	45	333	99.94	0.0667503	79	53	49	320	3,844	7,688	32,797	36,642	40,486
661	45	343	102.86	0.0680147	77	51	50	324	3,883	7,767	32,203	36,086	39,970
654	44	372	111.65	0.0730094	72	47	50	327	3,927	7,854	30,057	33,984	37,910
645	44	386	115.88	0.0747139	70	45	51	332	3,983	7,965	29,390	33,373	37,355
639	43	415	124.35	0.0794385	66	42	52	335	4,019	8,039	27,691	31,711	35,730
633	43	436	130.86	0.0827729	63	40	52	338	4,059	8,119	26,609	30,669	34,728
621	42	452	135.74	0.0843142	62	39	53	344	4,134	8,268	26,138	30,272	34,406
618	42	480	143.88	0.0888718	59	36	53	346	4,157	8,314	24,840	28,997	33,154
610	41	500	150.07	0.0915628	57	35	54	351	4,208	8,417	24,134	28,343	32,551
601	41	525	157.55	0.0947197	55	33	55	356	4,271	8,542	23,358	27,629	31,899
597	40	544	163.09	0.0973167	54	32	55	359	4,303	8,606	22,756	27,059	31,362
584	39	564	169.27	0.0989073	53	31	56	366	4,394	8,789	22,404	26,798	31,192
583	39	584	175.13	0.1021171	51	30	57	367	4,404	8,807	21,726	26,129	30,533
577	39	597	179.04	0.1033384	51	29	57	371	4,449	8,897	21,479	25,927	30,376
570	38	630	189.13	0.1078168	49	28	58	375	4,504	9,008	20,621	25,125	29,629
559	38	648	194.34	0.1086111	48	27	59	383	4,594	9,189	20,476	25,070	29,665
553	37	656	196.94	0.1088650	48	27	60	387	4,645	9,290	20,430	25,075	29,720
544	37	691	207.36	0.1128914	47	25	61	393	4,716	9,433	19,731	24,447	29,164
538	36	707	212.24	0.1141687	46	25	61	398	4,773	9,547	19,520	24,293	29,066
531	36	732	219.73	0.1166306	45	24	62	403	4,837	9,675	19,125	23,963	28,800
522	35	756	226.89	0.1185394	44	23	63	410	4,915	9,829	18,831	23,745	28,660
514	35	763	228.84	0.1175116	45	23	64	417	5,000	10,000	18,988	23,988	28,989
506	34	798	239.26	0.1209646	43	22	65	423	5,079	10,157	18,470	23,548	28,627
498	34	802	240.56	0.1197609	44	22	66	430	5,158	10,315	18,647	23,805	28,962
491	33	841	252.28	0.1239522	42	21	67	435	5,226	10,452	18,044	23,270	28,496
481	32	854	256.19	0.1231609	43	20	69	445	5,341	10,682	18,155	23,496	28,837
471	32	872	261.72	0.1232125	43	20	70	455	5,454	10,908	18,148	23,602	29,056
464	31	903	270.83	0.1256318	42	19	71	461	5,535	11,071	17,814	23,350	28,885
453	31	898	269.53	0.1221762	43	19	73	472	5,665	11,329	18,295	23,959	29,624
438	30	947	284.18	0.1245963	42	18	75	488	5,856	11,713	17,955	23,812	29,668
423	29	959	287.76	0.1217743	43	18	78	506	6,068	12,135	18,352	24,420	30,488
416	28	986	295.90	0.1231117	43	18	79	514	6,171	12,343	18,162	24,333	30,505
401	27	1006	301.77	0.1211335	43	17	82	533	6,397	12,793	18,445	24,842	31,238
384	26	1012	303.72	0.1165404	45	17	86	558	6,692	13,383	19,139	25,831	32,523
369	25	1051	315.42	0.1163458	45	17	89	580	6,961	13,922	19,170	26,131	33,092
349	24	1071	321.30	0.1122397	47	16	94	613	7,350	14,701	19,841	27,191	34,542
317	21	1093	327.81	0.1039748	50	16	104	675	8,095	16,191	21,352	29,448	37,543

Figure 3
Economic Analysis-ver2

Stack Size:			variable											
Capacity Factor:			0.9											
Power:			5.25 kW											
Energy Output:			41,000kWh/yr.											
Operating Voltage (mV)	Eff	Oper Current (mA/cm2)	Improved Oper Current (mA/cm2)	Current (A)	Power (kW)	# Cells in 5.25 kWp Stack	Stack Voltage (V)	Hydrogen Consum Rate (slm)	Ann. H2 Consum (GJ)	H2 Cost ($@$12/GJ)	H2 Cost ($@$24/GJ)	Stack Capital Cost ($)	Capital + Fuel (12) ($@$12/GJ)	Capital + Fuel (24) ($@$24/GJ)
927	63	4	9	3	0.0024139	2,175	2,016	36	231	2,770	5,540	884,852	887,623	890,393
917	62	7	13	4	0.0035826	1,465	1,344	36	233	2,800	5,599	596,454	599,254	602,053
919	62	8	15	5	0.0041899	1,253	1,152	36	233	2,793	5,586	510,124	512,917	515,710
912	62	10	20	6	0.0053417	983	896	36	235	2,816	5,633	400,308	403,124	405,941
910	61	8	15	5	0.0041464	1,266	1,152	36	235	2,822	5,644	515,476	518,298	521,120
905	61	10	20	6	0.0053001	991	896	36	237	2,839	5,677	403,448	406,287	409,125
902	61	10	20	6	0.0052846	993	896	37	237	2,847	5,694	404,631	407,478	410,325
902	61	10	20	6	0.0052846	993	896	37	237	2,847	5,694	404,631	407,478	410,325
895	60	10	20	6	0.0052452	1,001	896	37	239	2,868	5,737	407,662	410,531	413,399
888	60	12	24	7	0.0063585	826	733	37	241	2,892	5,784	336,429	339,321	342,213
880	59	12	24	7	0.0063002	833	733	37	243	2,919	5,837	339,535	342,453	345,372
871	59	14	28	8	0.0073750	712	620	38	246	2,947	5,893	290,173	293,119	296,066
867	58	14	28	8	0.0073371	716	620	38	247	2,962	5,924	291,668	294,630	297,592
862	58	16	33	10	0.0084201	624	538	38	248	2,978	5,956	254,260	257,238	260,216
848	57	20	39	12	0.0099419	528	448	39	252	3,027	6,053	215,466	218,493	221,520
841	57	23	46	14	0.0114932	457	384	39	255	3,054	6,109	186,497	189,551	192,606
831	56	24	48	14	0.0118981	441	367	40	258	3,091	6,182	180,177	183,268	186,360
821	55	41	82	25	0.0202995	259	212	40	261	3,129	6,259	105,950	109,080	112,209
810	55	58	115	35	0.0279332	188	152	41	264	3,172	6,344	77,222	80,394	83,566
795	54	66	132	40	0.0315837	166	132	41	269	3,229	6,457	68,393	71,621	74,850
786	53	76	152	46	0.0358263	147	115	42	272	3,266	6,532	60,392	63,658	66,924
762	51	109	217	65	0.0496323	106	81	43	281	3,368	6,736	43,823	47,192	50,560
754	51	124	247	74	0.0559611	94	71	44	284	3,405	6,811	38,961	42,366	45,772
752	51	124	247	74	0.0557800	94	71	44	285	3,417	6,833	39,085	42,501	45,918
751	51	120	241	72	0.0542948	97	73	44	285	3,417	6,835	40,131	43,549	46,966
746	50	153	306	92	0.0685205	77	57	44	287	3,440	6,880	31,972	35,411	38,851
735	50	174	347	104	0.0765901	69	50	45	291	3,492	6,984	28,690	32,182	35,675
723	49	191	382	115	0.0828497	63	46	46	296	3,551	7,102	26,585	30,136	33,688
714	48	218	436	131	0.0934759	56	40	46	300	3,595	7,189	23,657	27,252	30,846
704	47	225	449	135	0.0948672	55	39	47	304	3,648	7,295	23,323	26,970	30,618
692	47	269	538	161	0.1117529	47	33	48	309	3,710	7,420	19,924	23,634	27,343
685	46	284	569	171	0.1168125	45	31	48	312	3,749	7,499	19,097	22,846	26,596
676	46	309	618	186	0.1254407	42	28	49	316	3,798	7,596	17,840	21,638	25,436
668	45	333	666	200	0.1335005	39	26	49	320	3,844	7,688	16,813	20,657	24,502
661	45	343	686	206	0.1360294	39	26	50	324	3,883	7,767	16,516	20,399	24,283
654	44	372	744	223	0.1460189	36	24	50	327	3,927	7,854	15,443	19,370	23,296
645	44	386	773	232	0.1494278	35	23	51	332	3,983	7,965	15,109	19,092	23,075
639	43	415	829	249	0.1588770	33	21	52	335	4,019	8,039	14,260	18,279	22,299
633	43	436	872	262	0.1655458	32	20	52	338	4,059	8,119	13,719	17,778	21,838
621	42	452	905	271	0.1686283	31	19	53	344	4,134	8,268	13,483	17,617	21,751
618	42	480	959	288	0.1777436	30	18	53	346	4,157	8,314	12,834	16,991	21,148
610	41	500	1000	300	0.1831255	29	17	54	351	4,208	8,417	12,482	16,690	20,898
601	41	525	1050	315	0.1894393	28	17	55	356	4,271	8,542	12,093	16,364	20,635
597	40	544	1087	326	0.1946334	27	16	55	359	4,303	8,606	11,793	16,096	20,399
584	39	564	1128	339	0.1978146	27	16	56	366	4,394	8,789	11,616	16,011	20,405
583	39	584	1168	350	0.2042343	26	15	57	367	4,404	8,807	11,277	15,681	20,084
577	39	597	1194	358	0.2066767	25	15	57	371	4,449	8,897	11,154	15,602	20,051
570	38	630	1261	378	0.2156335	24	14	58	375	4,504	9,008	10,725	15,229	19,733
559	38	648	1296	389	0.2172221	24	14	59	383	4,594	9,189	10,652	15,247	19,841
553	37	656	1313	394	0.2177301	24	13	60	387	4,645	9,290	10,630	15,275	19,920
544	37	691	1382	415	0.2257827	23	13	61	393	4,716	9,433	10,280	14,996	19,713
538	36	707	1415	424	0.2283374	23	12	61	398	4,773	9,547	10,174	14,948	19,721
531	36	732	1465	439	0.2332611	23	12	62	403	4,837	9,675	9,977	14,814	19,652
522	35	756	1513	454	0.2370788	22	12	63	410	4,915	9,829	9,830	14,744	19,659
514	35	763	1526	458	0.2350233	22	11	64	417	5,000	10,000	9,908	14,909	19,909
506	34	798	1595	479	0.2419291	22	11	65	423	5,079	10,157	9,649	14,728	19,807
498	34	802	1604	481	0.2395218	22	11	66	430	5,158	10,315	9,738	14,896	20,053
491	33	841	1682	505	0.2479045	21	10	67	435	5,226	10,452	9,437	14,663	19,889
481	32	854	1708	512	0.2463219	21	10	69	445	5,341	10,682	9,492	14,833	20,174
471	32	872	1745	523	0.2464251	21	10	70	455	5,454	10,908	9,488	14,942	20,397
464	31	903	1806	542	0.2512635	21	10	71	461	5,535	11,071	9,322	14,857	20,392
453	31	898	1797	539	0.2443523	21	10	73	472	5,665	11,329	9,562	15,226	20,891
438	30	947	1895	568	0.2491926	21	9	75	488	5,856	11,713	9,392	15,249	21,105
423	29	959	1918	576	0.2435486	22	9	78	506	6,068	12,135	9,591	15,658	21,726
416	28	986	1973	592	0.2462235	21	9	79	514	6,171	12,343	9,495	15,667	21,838
401	27	1006	2012	604	0.2422670	22	9	82	533	6,397	12,793	9,637	16,034	22,430
384	26	1012	2025	607	0.2330808	23	9	86	558	6,692	13,383	9,984	16,676	23,368
369	25	1051	2103	631	0.2326916	23	8	89	580	6,961	13,922	9,999	16,961	23,922
349	24	1071	2142	643	0.2244795	23	8	94	613	7,350	14,701	10,335	17,685	25,035
317	21	1093	2185	656	0.2079496	25	8	104	675	8,095	16,191	11,091	19,186	27,281

Figure 4
Life Cycle Cost Analysis

FIVE YEAR LIFE CYCLE COST ANALYSIS – GENERATORS						
INITIAL COST	$1/W					
USEFUL LIFE	3,000 HRS					
SERVICE	EVERY 100 HRS					
RATED POWER	3.7 KW					
			3.7 KW x 3,000 hrs = 11,100 kWh			(lifetime output)
			Assume 5 years of operation (60 months)			(consumption rate)
			unit cost	present value	*EUAC	(over five years)
CAPITAL COSTS			3,700	3,700	796	two generators purchased, year 1/ year 4
OPERATION AND MAINTENANCE						refueling once a month
	FUEL					11/24 natl ave for diesel = $1.193/gal (EIA)
				2,053	442	15% efficiency, $442/yr. for 5 years
	MAINTENANCE (INCLUDE OIL)		3			6 times per year
	LABOR		50			
			53	822	177	$53 x 3.33 times/year, paid upfront
	Costs unaccounted for:					
	FUEL TRUCKING, BARGING					Variable
	INSURANCE					Variable
	CLEAN-UP					Variable
	TRAINING					Variable
	COMPLIANCE					Variable
	NOISE ABATEMENT					
	CO_2($8-200/TON)					National Park Service
	SO_2($0.75/LB.)					Valuations
	NO_X($3.40/LB.)					
Total				6,576	1,415	
Less: Salvage Value				0	0	
Life Cycle Cost				6,576	1,415	
	Total energy generated over five years =11,100 kWh					
	Energy Cost = $1415/11100 kWh = $0.13/kWh					
	This number does not include fuel transportation, insurance, clean-up, training, compliance, noise abatement, or emissions valuation.					
Inflation Rate:	3%	(average, 1991-1996)				
Discount Rate:	5.50%	(11/24 treasury bill rate)				
For a battery storage system on a yacht, the consumer would use shore power at $0.25/kWh, and a storage system consisting of a 600A-h battery bank, battery link, and system monitor (with a total cost of $1060 and lasting about 5,000 kWh).						
The added expense of this system is approximately $0.04/kWh.						
In total, the consumer would pay about $0.29/kWh.						
*Equivalent Uniform Annualized Cost						

B. Volume Pricing of Fuel Cell System Components

One way to assess the potential for cost declines in fuel cell power systems is to examine the commercial availability and volume pricing of fuel cell stack materials and auxiliary components. This technique was recommended to us by Dr. Robert Nowak, team leader for Fuel Cell Power Systems at ARPA in Arlington, Virginia. With this method, essential fuel cell power system components were analyzed for their industry maturity, volume availability, and current / predicted volume pricing. The goal was to identify specific components that will have to be replaced, minimized, or produced differently before fuel cell power systems may be manufactured more cheaply.

Information on the components for a 3 kW net power output fuel cell stack is presented in Table 2. These data show that, at present, the cost of production of a fuel cell power system depends critically on one component: the membrane-electrode assembly (MEA). MEA manufacturing is an emerging industry and should not prove to be limiting, as it will grow simultaneously with fuel cell system development.

Two auxiliary components are made by growing industries. These are the power inverter, and the DC/DC converter. These industries are also not likely to limit fuel cell system development; growth in these industries is rapid and does not depend solely on the fuel cell industry.

Table 2: Availability of Fuel Cell System Components

Sub-System	Component	State of Industry*	Industry Ceiling‡ (# FC Systems)
FC	Graphite	Mature	Zero†
FC	Membrane/Electrode (MEA)	Emerging	5,000§
FC	Other Mat'ls and Hardware	Mature	>20,000
Air	Blower	Mature	>20,000
Hyd.	H2 Plumbing (Swagelok)	Mature	1,000
Water	Water Pump (Gear Type)	Mature	1,000
Water	Heat Exchanger w/ fans	Mature	>20,000
Water	Fan Motor Controller	Mature	>20,000
CCU	System Control Computer	Mature	>20,000
CCU	Man Machine Interface	Mature	>20,000
Elec.	DC/DC Converter (4 kW)	Growing	2,000
Elec.	Inverter (4 kW)	Growing	500
Elec.	Voltage Regulator	Mature	>20,000
Elec.	Battery (Gel Cell Lead Acid)	Mature	>20,000
Various	Enclosures	Mature	>20,000

*State of Industry Categories: Emerging (custom), Growing, Mature, Declining.
‡Industry Ceiling refers to the point at which the manufacturer must make a capital investment or change to a different technology in order to provide lower prices.
†Better Price Not Available at Any Quantity.
§Industry is growing rapidly, this number will increase quickly.

Of greater concern are the mature industries that have a low "industry ceiling." The most important of these industries in terms of system cost is the graphite industry. Graphite production methods for the grade of graphite required for fuel cell stacks do not allow for cost reductions, even when large quantities of the product are ordered. This makes graphite a limiting factor in bringing down system price. Graphite should ultimately be replaced as a stack material in order to attain low cost fuel cell systems if the material continues to be expensive. In the near term some cost reductions may be possible by reducing the amount of graphite used per stack.

There are several other mature industries listed in Table 2 that have a low "industry ceiling." These industries are not likely to be limiting, as alternative designs for fuel cell systems will probably allow for the use of less expensive components when the limits of these industries are reached. Eventually, for fuel cell production to move out of the laboratory and onto the manufacturing floor, most of these auxiliary components will need to be made in large volumes on a custom basis, much like, for example, the radiators for internal combustion engines.

The component and materials costs for fuel cell system production are presented in Table 3. The materials cost for a single prototype fuel cell power system is compared to the cost for production volumes of 2,000 and 20,000 systems per year. It is assumed that the auxiliary systems will be assembled from OEM components for production volumes up to at least 20,000 units.

Clearly, the MEA currently represents the bulk of the fuel cell power system cost. Improvements in MEA production and effectiveness will dictate the path of system cost decline. Graphite is next in importance. Both the capital and the manufacturing costs of graphite plates in fuel cell stacks are high. Use of alternative materials, such as coated metals, or alternative manufacturing techniques for graphite, such as molding graphite parts, could help to reduce these costs.

Eventually, the use of "off the shelf" OEM components for the auxiliary sub-systems will limit the cost of systems. At present, the estimated total cost for the auxiliary components for a production volume of 20,000 units is $4,070, which is about $1,350 per kW. As a comparison, an entire diesel generator costs from $500 to $1,000 per kW for systems under 10 kW. As noted, eventually the cost for the fuel cell system may be brought down by using custom components. A substantial capital investment will be required to do this.

In summary, the fuel cell stack makes up approximately 75% of the system cost. This is true for the prototype unit and for production volumes of 2,000 and 20,000 units. This indicates that for the near term cost reduction strategies should focus on the fuel cell stack, as this makes up the large majority of the system cost.

Table 3: Price Schedule for Principal Fuel Cell System Components

Sub-System	Component	Cost per System	volume cost (number units) 2,000	20,000
FC	Graphite	$8,700	$8,700	$8,700
FC	Membrane-Electrode (MEA)	$20,000	$4,000	$2,700
FC	Other Mat'ls and Hardware	$1,000	$700	$500
	Sub-total for Fuel Cell	$29,700	$13,400	$11,900
Air	Blower	$430	$220	$200
Air	Blower Motor Controller	$125	$60	$35
Hyd.	H2 Plumbing (Swagelok)	$500	$350	$350
Water	Water Pump (Gear Type)	$460	$270	$270
Water	Heat Exchanger w/ fans	$800	$300	$200
CCU	System Control Computer	$750	$400	$150
CCU	Man Machine Interface	$270	$125	$75
Elec.	DC/DC Converter (4 kW)	$1,700	$1,000	$1,000
Elec.	Inverter (3.6 kW)	$1,525	$915	$760
Elec.	Voltage Regulator	$80	$50	$30
Elec.	Battery (Gel Cell Lead Acid)	$180	$100	$100
Various	Enclosures	$1,000	$500	$200
Various	Balance of System	$1,500	$900	$700
	Subtotal for Aux. Comp.	$9,320	$5,190	$4,070
Total	(Excludes Tax & Shipping)	$39,020	$18,590	$15,970

C. A Learning Curve Analysis of the Schatz Fuel Cell

One method of predicting the rate at which an item of new technology becomes affordable is by use of the learning curve.The learning curve, or experience curve, concept was first applied in the 1950's when studies showed that production costs decline by a certain percentage (typically 10 to 30 percent) with each doubling of cumulated output. For example, a 20 percent learning curve indicates that if the thousandth unit of a product costs $1,000, then the two thousandth unit will normally cost $800. Learning curves vary widely from industry to industry; they may be as high as 40 percent, or they may not occur at all.

The main reason for the variations in learning curves is that some products lend themselves better than others to improvements in design and to factory and labor efficiencies. Manufacturing activities reflect steeper curves than raw materials purchasing, marketing, sales, or distribution. In addition, other forces may be reducing costs: exogenous progress (improvements in general technical knowledge and inputs, as well as advances due to feedback from customers) or scale economies may be at work. A learning curve analysis is only part of the process of determining a product's total cost behavior.

The technique used to determine the experience curve is to decompose the manufacturing process into discrete activities and to estimate, on the basis of historical data, the possible cost decrease for each activity. Second, the effects of exogenous progress and scale economies are estimated. The last step is to determine which element of cost behavior is the most prominent. Because the history of fuel cell production is so young, we consider the case of a 20 percent learning curve quoted for the membrane-electrode assembly by Robert Williams, a senior research scientist at the Center for Energy and Environmental Studies at Princeton University. (The membrane-electrode assembly is the most costly component of a fuel cell stack.) We also consider a less optimistic situation using a 15 percent learning cuve.

The fuel cell power system may be an appropriate candidate for the experience curve strategy. It is a manufactured item, which may lend itself well to improvements in design and increased factory and labor efficiencies.The fuel cell industry is an emerging one, so output is likely to double quickly enough for the learning curve to take effect. We have included subsystem costs because over time, subsystems will become simpler and their costs lower.

Battery and generator prices are also subject to experience curve effects, but these will be very small, since doubling times are greater for mature industries than for emerging industries, and cost change decreases with each doubling. For example, 1991 cumulative total battery output is double that of 1974, a seventeen year doubling time, which will increase over time. By 1991, there had been at least eight doublings of cumulative battery production since 1939. Assuming a learning curve ratio of 0.20, the change in price between the seventh and eighth doubling will be $(0.80)^8$-$(0.80)^7$, or -0.04, *i.e.*, the price of batteries will decline only four percent (due to the learning curve) during this 17 year period. Though the learning curve never stops working, its effect weakens as an industry matures. (Compared with the effects of inflation, the learning curve effect on a mature industry can become negligible.) Therefore, it is accurate to compare today's battery and generator prices to tomorrow's fuel cell prices.

In summary, the experience curve relates cumulative production volume to cost and can be an integral part of cost analysis and strategy formulation. History shows, however, that knowledge of how and why it works is critical to success with the curve, and that there are many risks associated with its application. As a manufactured item in an emerging industry, the fuel cell power system is a possible candidate for the use of the experience curve.

In order to perform a learning curve analysis for the SERC fuel cell, we considered learning curve rates of various technologies (semiconductors:20-25%) and considered the rate for the most expensive component (the membrane-electrode assembly) suggested by Dr. Robert Williams of Princeton University (20%). We then listed the costs of each component and estimated labor hours required to manufacture a fuel cell power system using our current method. The actual price structure of the membrane electrode assembly, as delivered from Gore, is shown separately from the general learning curve.

Because the capital cost of generators is generally around $1500/kW, such a target might be useful for fuel cell systems. Our learning curve analysis on a 70-cell fuel cell remote power system (not including a reformer) shows that, with a 20% learning curve, this target is reached at about the fifty thousandth unit and with a 15% learning curve, it is reached at the two millionth unit. Note that we have derated the output of the system and accounted for parasitic loads. This decline in the cost of the system is dependent on the advancement of manufacturing techniques and the identification of substitute materials and components.

For a fuel cell power system that includes a reformer initially costing $50,000, the $1500/kW target is reached at the 260,000th unit with a 20 percent learning curve, and sometime after the 4 millionth unit with a 15 percent learning curve.

These analyses are shown in spreadsheet form in Figures 5 and 6.

Figure 5

Learning Curve Effect on 70-cell Fuel Cell Remote Power System

(with Reformer)

Cume Prod Vol (A2=A1*2)	Stack/Subs Cost ($) (LC=.20) (B2=B1*.8)	Stack/Subs Cost (LC=.15) (B2=B1*.85)	Act MEA Cost ($/stack)	Ref Cost (LC=.20)	Ref Cost (LC=.15)	Sys Cost (LC=.20)	Sys Cost (LC=.15)	$/W (LC=.20)	$/W (LC=.15)	Cume Investment (LC=.20)	Cume Investment (LC=.15)
1	57,190	57,190	14,423	50,000	50,000	121,613	121,613	40.5	40.5	0	0
2	45,752	48,612	14,423	40,000	42,500	100,175	105,535	33.4	35.2	121,613	121,613
4	36,602	41,320	12,796	32,000	36,125	81,398	90,241	27.1	30.1	321,963	332,682
8	29,281	35,122	11,169	25,600	30,706	66,050	76,997	22.0	25.7	425,765	466,498
16	23,425	29,854	10,192	20,480	26,100	54,097	66,146	18.0	22.0	609,800	706,217
32	18,740	25,376	8,565	16,384	22,185	43,689	56,126	14.6	18.7	931,603	1,135,331
64	14,992	21,569	7,426	13,107	18,857	35,525	47,853	11.8	16.0	1,452,146	1,862,171
128	11,994	18,334	6,775	10,486	16,029	29,254	41,138	9.8	13.7	2,317,303	3,118,696
256	9,595	15,584	5,962	8,389	13,625	23,945	35,170	8.0	11.7	3,780,085	5,313,473
512	7,676	13,246	5,311	6,711	11,581	19,698	30,138	6.6	10.0	6,159,302	9,044,724
1,024	6,141	11,259	4,823	5,369	9,844	16,332	25,926	5.4	8.6	10,109,218	15,465,837
2,048	4,913	9,570	4,009	4,295	8,367	13,217	21,947	4.4	7.3	16,744,115	26,578,329
4,096	3,930	8,135	3,684	3,436	7,112	11,050	18,931	3.7	6.3	27,083,829	44,972,404
8,192	3,144	6,915	3,521	2,749	6,045	9,414	16,481	3.1	5.5	45,274,183	77,562,888
16,384	2,515	5,877	2,708	2,199	5,138	7,422	13,724	2.5	4.6	77,129,166	135,030,135
32,768	2,012	4,996	2,708	1,759	4,368	6,479	12,071	2.2	4.0	121,615,821	224,868,545
65,536	1,610	4,246	2,708	1,407	3,713	5,725	10,667	1.9	3.6	212,324,822	395,572,595
131,072	1,288	3,609	2,708	1,126	3,156	5,122	9,473	1.7	3.2	375,208,617	699,082,875
262,144	**1,030**	**3,068**	**2,708**	**901**	**2,682**	**4,639**	**8,458**	**1.5**	**2.8**	**671,317,741**	**1,241,672,480**
524,288	824	2,608	2,708	721	2,280	4,253	7,596	1.4	2.5	1,216,081,537	2,217,317,448
1,048,576	659	2,217	2,708	576	1,938	3,944	6,863	1.3	2.3	2,229,681,284	3,982,397,800
2,097,152	527	1,884	2,708	461	1,647	3,697	6,239	1.2	2.1	4,135,395,647	7,196,001,049
4,194,304	422	1,602	2,708	369	1,400	3,499	5,710	1.2	1.9	7,752,447,697	13,085,058,875

Stack and Subsystems Costs/Assumptions

Material		26,590
Labor:		
FC	15 p-wks	
air, water, h2 subsystems	1 p-wk	
electrical	1 p-wk	
Total	17 p-wks	
17 p-wks x $45/hr/person x 40 hr/wk =		30,600
Stack Cost (not incl. MEA's)		57,190
Initial reformer cost assumed to be $50,000.		

Notes:

Assumed 250 mW/cm2/cell(continuous) x 300 cm2 x 1W/1,000 mW = 75 W/cell

70 cells x 75 W/cell = 5,250 W, gross.

This stack will generate 3 kW (net) reliably.

Parasitic loads = about 10%

Target = $1500/W. This target is reached at the 260,000th unit with the 20% curve, and after the 4 millionth unit with the 15% curve.

Cumulative investment does not include plant costs.

Figure 6

Learning Curve Effect on 70-cell Fuel Cell Remote Power System

(without Reformer)

Cum Prod Vol (A2=A1*2)	Stack/Subs Cost ($) (LC=.20) (B2=B1*.8)	Stack/Subs Cost (LC=.15) (B2=B1*.85)	Act MEA Cost ($/stack)	Ref Cost (LC=.20)	Sys Cost (LC=.20)	Sys Cost (LC=.15)	$/W (LC=.20)	$/W (LC=.15)	Cume Investment (LC=.20)	Cume Investment (LC=.15)
1	57,190	57,190	14,423	0	71,613	71,613	23.9	23.9	0	0
2	45,752	48,612	14,423	0	60,175	63,035	20.1	21.0	71,613	71,613
4	36,602	41,320	12,796	0	49,398	54,116	16.5	18.0	191,963	197,682
8	29,281	35,122	11,169	0	40,450	46,291	13.5	15.4	257,765	279,498
16	23,425	29,854	10,192	0	33,617	40,046	11.2	13.3	373,000	424,442
32	18,740	25,376	8,565	0	27,305	33,941	9.1	11.3	578,323	687,019
64	14,992	21,569	7,426	0	22,418	28,995	7.5	9.7	907,378	1,126,142
128	11,994	18,334	6,775	0	18,769	25,109	6.3	8.4	1,462,058	1,889,632
256	9,595	15,584	5,962	0	15,557	21,546	5.2	7.2	2,424,800	3,242,922
512	7,676	13,246	5,311	0	12,987	18,557	4.3	6.2	4,001,332	5,540,816
1,024	6,141	11,259	4,823	0	10,964	16,082	3.7	5.4	6,664,856	9,522,818
2,048	4,913	9,570	4,009	0	8,922	13,579	3.0	4.5	11,239,846	16,486,778
4,096	3,930	8,135	3,684	0	7,614	11,819	2.5	3.9	18,282,367	27,826,612
8,192	3,144	6,915	3,521	0	6,665	10,436	2.2	3.5	31,196,140	48,423,409
16,384	2,515	5,877	2,708	0	5,223	8,585	1.7	2.9	54,607,732	85,500,133
32,768	**2,012**	**4,996**	**2,708**	**0**	**4,720**	**7,704**	**1.6**	**2.6**	**85,584,275**	**140,673,587**
65,536	**1,610**	**4,246**	**2,708**	**0**	**4,318**	**6,954**	**1.4**	**2.3**	**154,676,548**	**252,446,304**
131,072	1,288	3,609	2,708	0	3,996	6,317	1.3	2.1	282,973,138	455,772,548
262,144	1,030	3,068	2,708	0	3,738	5,776	1.2	1.9	523,742,381	828,048,636
524,288	824	2,608	2,708	0	3,532	5,316	1.2	1.8	979,962,087	1,514,160,069
1,048,576	659	2,217	2,708	0	3,367	4,925	1.1	1.6	1,851,891,065	2,787,032,940
2,097,152	**527**	**1,884**	**2,708**	**0**	**3,235**	**4,592**	**1.1**	**1.5**	**3,530,932,016**	**5,163,883,065**
4,194,304	**422**	**1,602**	**2,708**	**0**	**3,130**	**4,310**	**1.0**	**1.4**	**6,785,306,465**	**9,630,460,241**

Stack and Subsystems Costs/Assumptions

Material		26,590
Labor:		
FC	15 p-wks	
air, water, h2 subsystems	1 p-wk	
electrical	1 p-wk	
Total	17 p-wks	
17 p-wks x $45/hr/person x 40 hr/wk =		30,600
Stack Cost (not incl. MEA's)		57,190

Assumed 250 mW/cm2/cell(continuous) x 300 cm2 x 1W/1,000 mW = 75 W/cell

70 cells x 75 W/cell = 5,250 W, gross.

This stack will generate 3 kW (net) reliably.

Parasitic loads = about 10%

Target = $1500/W. This target is reached at the 50,000th unit with the 20% curve, and at the 2 millionth unit with the 15% curve.

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Appendix

Appendix 1

Market Analysis Questionnaire

I. *Consumer Profile*

(Applications: remote homes, yachts, motor homes, telecommunication sites.)

1) Describe the consumer or types of consumers. Demographics: age, income, gender, family, location, occupation, education.
2) What current economic factors influence the consumer's spending? (psycho graphics: lifestyle, motives, needs, interests, purchase history).
3) What kind of profile does the consumer fit? (Innovator, early adopter, majority adopter, late majority, laggard).
4) What is the basis for the consumer buying decisions? What do they like or dislike about products currently on the market?
5) What features would the consumer like to see in a product for this market?
6) Who influences the final decision to purchase?
7) What motivates people to buy the product? (practical/emotional).
8) What level of service does the consumer require and/or desire?
9) Note (in a separate comment section) general comments made by the consumer about the product or its competition.

II. *The Current Technologies and Market*

1) Describe the current technology: (Find out this information for both generators and batteries).

   Type:
   Power supplies (in kW); AC or DC:
   Amps:
   Volts:
   Temperature range of operation:
   Weight:
   Maintenance Checks (frequency and extent of work):
   Price:
   Number of units in use:
   Number of units purchased yearly:
   How it is used:
   Useful Life (years):
   Features:
   Drawbacks:

2) What is the local availability of fuels? How pure are the available fuels?
3) Does this market segment have any need for the waste heat?
4) Define the size (in number of units and $) and location of the market.

5) What are the key points in defining the market segment: (product feature, lifestyle of target consumers, geographical location, season, etc.).

6) How is the market distributed among major participants?

7) What are the major trends in this market? What do industry forecasters predict for the next two years? Do trends point to growth or decay of the market? if possible, define rate of growth or decay.

8) Are there related industries upon which the market depends? What are these markets?

III. Competition

1) Define the competitive product (s).

2) List and discuss key competitors with regard to product or service, price, location, promotion, innovation, management, and financial position.

3) How are the competitor's products similar to or different from ours?

4) What are the major strengths and weaknesses of the competitors?

5) How do the customers perceive the competitors?

6) What is the current position with respect to price, quality, and reputation?

7) What is the sensitivity of this market with respect to price, quality, and reputation?

8) Does the competitor offer terms or discounts?

9) Which company's product provides the most features and has superior performance? Which is the most often purchased?

10) Does the competition specialize or offer variety?

11) What features of our product are superior in satisfying our target market? (High efficiency, low maintenance, quiet operation).

12) What distribution channels are used for competing technologies?

13) In which publications does the competitor advertise their product? (If it is informative or interesting, place competitors' advertisements and brochures in a Support Document section).

IV. Summary

1) Summarize your view of the potential consumers, current technologies and market, and competitive environment for fuel cell remote power systems.

2) Justify market potential, if it exists, with a logical rationale.

3) Are there market niche opportunities that are not included in the categories of oil and gas pipeline instrumentation, remote homes, yachts, motor homes, and telecommunications site instrumentation? List these unexplored applications, and describe why they qualify for further study.

Appendix 2

Typical Remote Home Power Use

The amount of power used in a remote home depends, of course, on the power use of the occupants. The following is a list of typical use:

Appliance	**Power demand (in Watts)**	**Typical Voltage(DC)**	**Typical Hrs/Day**	**Notes**
Refrigerator	**avrg** - 105 kWh/month **new** - 70 kWh/month **super efficient** - 23 kWh/month	12-24 V. Some are AC and run off of 120 V.	Cycles on and off - see power demand per month	Many people use propane refrigerators as electric are expensive
Lights(each)	15-100	12-24	6-8	Typical house will have 6-20 lights. Not always all on at the same time.
Washing machine	200-500 Wh/load	12-24 V	1	
Vacuum	600-1000 W	needs AC inverter		
Dishwasher	1000-1500	needs AC inverter ?	1	Great chore to do by hand
Electronic Equipment (stereos, TV, VCR, computer)	**Radio** - 50-200 W **TV**- 200-600 W **Computer** - 200-500 W	**Radio** - 12 V(DC) Usually use AC inverter	Varies	
Phantom loads (Cost of having device ready to go at all times)	Approx. 10-20 W per device			Includes VCR, microwave, stereo, clock, answering machine, computer
Power tools Electric Drill	250-750 W			included for general information
Iron	500-1200 W	usually in a AC inverter system	short time 10 min - 1 hr.	Uses much power, but for short times.

Appendix 3

Recreational Vehicles
Statistics by Market Segments (units shipped according to RVIA)

Motorized	**1996**	**1995**	**1994**	**1993**	**1992**
Class A - Full Size	36,500	33,000	37,300	31,900	27,300
Class B - Van camper	4,100	4,100	3,500	3,000	2,900
Class C - Mini's Motor Homes	14,700	15,700	17,300	16,500	16,800
Sub Total	55,300	52,800	58,100	51,400	47,000
Towables					
Fifth wheel	48,500	45,900	48,900	43,900	38,900
Travel Trailers	75,400	75,300	79,100	69,700	63,600
Folding & Camping	57,300	61,100	61,700	51,900	43,300
Truck Campers	11,000	11,900	11,400	10,900	10,600
Towables Subtotal	192,200	194,200	201.100	176,400	156,400
Conversion Vehicles	219,300	228,200	259,600	192,400	179,300
Total	466,800	475,200	518,800	420,200	382,700

Average Price ($)

Motorized	**1996**	**1995**	**1994**	**1993**	**1992**
Class A - Full Size	$ 79,000	83,000	68,500	62,600	64,000
Class B - Van Camper	$ 42,900	40,000	37,400	39,600	37,620
Class C - Mini's	$ 47,100	41,800	40,100	37,800	36,500
Towables					
Fifth Wheel	$22,700	20,700	19,600	18,400	19,300
Travel Trailers	$14,200	13,000	12,100	12,000	12,200
Folding & Camping	$ 5,000	4,800	4,500	4,400	4,400
Truck Campers	$11,100	10,000	9,800	9,400	9,300
Conversion Vehicles	$27,500	27,200	25,100	24,800	25,100

Appendix 4

Recreational Vehicle
INDUSTRY STATISTICS (Market Share)

	Motor Homes (Classes A & C)	**Travel Trailers**	**Folding Trailer**
Fleetwood	27.4%	24.8%	33.6%
Winnebago	16.5%	0.0%	0.0%
Coachmen	11.6%	0.0%	0.0%
Thor Industries	7.9%	14.6%	12.1%
Gulfstream	4.9%	0.0%	0.0%
Skyline	0.0%	7.3%	0.0%
Cobra	0.0%	7.4%	11.5%
Jayco	0.0%	8.0%	29.7%
Palomino	0.0%	0.0%	5.9%
Subtotal	68.3%	62.1%	92.8%
All others	31.7%	37.9%	7.2%

Statistics not available for Class B - Van Conversion campers or Van Conversions.

Appendix 5

Statistics by Market Segment
The Boating Market 1994 - 1996

Power Boats (units sold)	1994	1995	1996
Small Outboards	220,000	231,000	215,000
Inboard Boats-Runabouts	7,200	6,900	6,000
Inboard Boats-Cruisers	4,200	5,460	5,350
Sail Boats (units built)			
under 20 ft	9,083	10,346	11,975
20-29ft	2,204	1,865	1,833
30-40ft	1,357	1,646	1,641
40 ft +	317	464	490
Total Sailboat Production	**12,961**	**14,321**	**15,939**

The information on Power Boats came from the National Marine Manufacturers Association (NMMA). The numbers on personal watercraft (jet ski's) and canoes, which are one of the fastest growing areas, were omitted as they are not relevant to our study.

Data on sailboats sold has not been compiled since 1990, but the Sailing Company keeps record of sailboats built.

Appendix 6

Boating Applications

Summary of power needs

Sailboats Type	Usage	Power Supply	Power Uses & Source of Power: Cooking	Heat	A/C	Aux Elec	Start	Engine
< 30 ft	Day Sailing Weekend Cruising	Batteries - recharged by Alt or shore power	Alcohol or BBQ	N/A	N/A	Batteries 12v	Battery 12v	Gas
30-40ft	Day Sailing, Inter Island & Long Trips Live on	Batteries-recharged by Alt or shore power or Solar or Wind Power	Propane 5-10pd tanks (2.4-4.8 gal)	N/A	N/A	Battery Bank 12v	Battery 12v	Diesel
>40ft	All of the Above	Same as above but 3.5 to 5k generator if A/C and Heating desired	Propane 10 pd tanks (4.8 gal)	Yes Genset	Yes	Battery Bank	Battery	Diesel

Power Boats Type	Usage	Power Supply	Power Uses & Source of Power: Cooking	Heat	A/C	Aux Elec	Start	Engine
<under 30ft	Day Recreation	Batteries	N/A	N/A	N/A	N/A	Battery	Gas
>30ft Cabin	Marina- Marina Island Cruising	Batteries, Diesel Generator 6K+	Elec	Elec	Elec	Elec	Battery	Diesel

Appendix 7

Yacht/Boat Appliance Load Chart

Appliance	avg. current (amps)	avg. use (hrs/day)	avg. consumption (amp-hrs/day)
DC Loads (12 V)			
cabin lights	3.2	4.00	12.8
running lights	2.0	2.00	4.0
anchor light	2.0	10.00	20.0
SW/AM-FM	0.4	.40	0.2
VHF Receiver	0.5	4.00	2.0
transmitter	4.8	.25	5.0
Loran	0.4	2.25	0.9
instruments	0.4	2.00	0.8
tape deck	2.0	2.00	4.0
bilge pump	4.0	0.25	1.0
refrigerator	5.0	12.00	60.0
auto pilot	1.8	2.00	3.6
AC Loads			
TV/VCR	7.0	2.00	14.0
laptop computer	0.8	2.00	1.6
blender	12.0	0.10	1.2
microwave	80.0	0.17	13.6
sewing machine	7.2	0.50	3.6

Total average daily load : 150 amp hrs a day

This chart is from the July 1997 issue of Cruising World in an article entitled "Surveying Your Electrical Needs" by Kevin Jeffrey. This is for a cruising boat 35-40 ft long that does not have air conditioning or heating but has all of the other "necessities" of life.

Research indicates that a 2.4 gallon propane tank could run this boat for approximately 6 days (900 amp hrs) while charging the starting battery and the fuel cell back up battery in off peak times.

APPENDIX B

FEASIBILITY AND MARKET STUDY

SMALL PEM FUEL CELLS

FINAL REPORT

Prepared by

City of Palm Desert

February 1998

FEASIBILITY STUDY and MARKET SURVEY

SMALL PEM FUEL CELLS

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INTRODUCTION

INTRODUCTION

The City of Palm Desert is a member of a consortium, which also includes the Schatz Energy Research Center (SERC) at Humboldt State University, and Teledyne Brown Energy Systems, which has undertaken the responsibility of Phase I of a Cooperative Agreement entitled "Fuel Cell Power Systems for Remote Applications." This effort is sponsored and funded by the Department of Energy.

The project was designed as a nine-month effort that includes a literature search, market survey, identification of competitive technologies, an estimate of market opportunities, developing a market strategy and defining a business plan. The responsibility for individual portions of the overall effort is assigned to the various partners based on levels of expertise. The project completion date is February 13, 1998.

The goal of this project is to study the feasibility of small PEM fuel cells as a power source for existing and future markets with emphasis on auxiliary power needs of the recreational Boating and Recreational Vehicle (RV) industry, and remote and backup power sources for telecommunications sites. The fuel cell system will be in the .1 to 5 kW range.

SCOPE OF CITY OF PALM DESERT'S RESPONSIBILITY

As indicated, the scope of the entire project was divided and assigned to the various members of the consortium based on areas of expertise and ability to dedicate the necessary resources to complete the tasks assigned. The City of Palm Desert has assumed responsibility for the feasibility study portion of the overall project, which includes a thorough Internet and literature search, a market survey and an estimate of market opportunities based on the survey. Results are based on discussions with manufacturers, distributors, and service persons related to the identified potential markets.

The work will be accomplished using a combination of City staff and consulting services provided by a faculty member from the local community college—the College of the Desert.

OBJECTIVES

1. Identify Potential Market Niches

Since the City of Palm Desert and the Schatz Energy Research Center initially began their combined efforts to advance fuel cell technology, it has been a belief that providing fuel cells to niche market applications was an important tool in the commercialization of the technology. Identification and investigation into market potential in applications where there is less cost-sensitivity and clear advantages over competing technologies is an approach that has been successfully utilized by other high-tech products and should be a part of the approach used in the commercialization of fuel cells.

While the identified niche markets of this study did not exhaust the list of possible applications, they clearly meet the parameters of the study and the accepted criteria of niche market opportunities. Further, they are able to take advantage of existing infrastructure thus eliminating the need to address an additional problem. The markets chosen are also characterized as geographically dispersed, less cost-sensitive and are emerging as strong markets as the national economic picture improves and consumer demand increases.

Recreational vehicles, boats, telecommunications and remote homes would all provide opportunities, some greater, some lesser, to introduce the technology and initiate the process of gaining consumer acceptance.

2. Ascertain Competing Technologies

In order to accurately predict potential market penetration, it is imperative to identify and evaluate competing technologies. This includes all possible competition and should be examined in terms of original purchases and "after market" applications.

The niche markets chosen and the parameters of the project regarding size, weight and performance substantially limit the competing technologies.

3. Determining Performance Criteria/Limiting Factors

In order to adequately ascertain the potential for fuel cells to replace the currently utilized competing technologies it is necessary to determine performance criteria for the current users and limiting factors that would enhance the attractiveness of fuel cell technology to the consumer if they could be eliminated. Interviews with manufacturers, salespersons and end users provide the best data for analysis of performance requirements and the shortcomings of competing technologies.

While performance criteria is easy to ascertain, limiting factors are, by necessity, accepted and adapted to by end users. The question arises as to whether fuel cell technology could replace existing technologies <u>if</u> the cost of fuel cell products was significantly higher than competing technologies. While the benefits are easily seen by manufacturers, sales people and end users, the use of competing technologies has been tailored to accommodate the inherent limitations, and the transition to new technologies may be more difficult to market than originally expected.

4. Evaluate Receptivity/Interest by Industry Representatives

Receptivity/interest by those representing the relative industries is key to transitioning from current new technologies. Again, interviews with manufacturers and sales persons provide the best source of information on consumer attitudes as well as primary data on industry receptivity.

There is a universal interest in new and better technology among the target populations for the niche markets chosen. The challenge may be one of encouraging industry representatives to deal with the changes in manufacturing techniques, maintenance, service, guarantees/warranties, etc.

5. Estimate Market Penetration

The identification and evaluation efforts outlined result in the basis for an estimated market penetration in terms of numbers of units that may be demanded in each of the niche applications. All of the factors evaluated as well as numbers of potential applications provide the base in determining this estimated number.

Because of the large number of factors that could affect actual market penetration, the estimate is based on current production figures as opposed to utilizing any production projections by industry. The estimate also considers the current cost of the technology and the cost implications will be dealt with on an application-by-application basis.

PROCESS

The method proposed includes a thorough review of available information in print, and through electronic media, discussions with individuals involved in the manufacture and sale of the niche market products and discussions with end users where applicable.

1. Literature Search

The markets selected include two—RVs and boats—where there is extensive literature available on products, trends, attitudes, etc. of providers, end users and experts involved in the evaluation of these products, trends and attitudes. Periodicals will be reviewed to extract any applicable information. A search will also be made of related publications, periodicals that deal with technology related issues, and any in-depth newspaper reports that are relevant to the project.

2. Internet Research

The Worldwide Web is rapidly becoming a major resource in any research effort. All possible information will be gleaned from Internet resources and E-mail will be utilized for follow-up when possible.

3. Trade Shows

Where scheduling coincides with the project period, trade show attendance will be included in the research effort. These events provide opportunities to meet and talk with manufacturers, suppliers, sales persons and end users. There is also an opportunity to investigate competing technologies to ascertain the improvement that can be anticipated with the commercialization of fuel cell technology.

4. Visits with Industry Representatives

In-person visits with manufacturers and sales representatives are a major source of information and are easily accomplished because of the large number of boat sales and RV sales and manufacturing operations in Southern California. Sales representatives are adept at articulating the concerns, attitudes and buying habits of consumers and this resource should be fully utilized.

5. Focus Groups

Utilizing focus groups as a major information resource is more beneficial than individual surveys. The group setting encourages participation and provides clearer and more focused response to questions regarding product applicability.

ASSUMPTIONS

ASSUMPTIONS

Since this is a marketing research and feasibility study, some basic assumptions are being made in order to speak more authoritatively with industry manufacturers, dealers, replacement equipment manufacturers, and other industry sources:

1. The fuel cell will perform at a more efficient level than current available power sources.

2. The fuel cell will use the existing natural gas and LPG infrastructure until hydrogen is readily available.

3. A reformer will be able to convert the currently used fuel (propane or natural gas) into hydrogen to power the fuel cell.

4. The fuel cell will be quiet (unlike a noisy generator), non polluting (only CO2 from the propane reforming), and while providing auxiliary power needs, can also restore integrated battery capacity when not functioning at peak loads.

5. The fuel cell will have high reliability and require little maintenance as compared to conventional power sources such as generators and should last at least 10 years, unlike batteries and generators, which have a relatively short lifetime before replacement is required.

6. The fuel cell can be recharged in minutes by a refueling process similar to putting gas into your car, unlike batteries used in golf carts, electric boats, and small utility vehicles which require an "overnight charge."

7. The fuel cell will be similar to other renewable sources (solar and wind) in that it will cost significantly more per watt generated than other currently available independent charging devises but its long life expectancy, low operating cost, and overall convenience will justify the initial investment.

MARKETING

RESEARCH

MARKETING RESEARCH PROCESS

A. Literature Search

1. Internet Searches

a. General

1. Existing data on fuel cells for initial reference
2. Collection of news articles on fuel cells (News Profiles AOL)
3. Data on competitive power sources (generators, batteries)

b. Boating Applications

1. Data on products (powerboats & sailboats) that use current power source technology.
2. News groups and forums of boat owners (to be used in future)
3. Trade associations' Web sites
4. On-line trade magazines

c. Recreational Vehicle Applications

1. Data on products' (RV's) current power sources
2. News groups and forums of RV owners (to be used in future)
3. RV manufacturers' Web sites
4. Trade associations' Web sites (RVIA & RVDA)
5. On-line trade magazines
6. FMCA - Family Motor Coach Association

d. Telecommunications Applications

1. Data on telecommunication products' current power sources
2. Telecommunication service providers' Web sites.
3. Trade associations' Web sites (TIA & EIA)
4. On-line trade magazines

2. **Trade Publications** (General with specifics for all)

   a. Review for articles re power sources and uses
   b. Phone and E-mail conversations with editors
   c. Review advertisements for competitive products

3. **Trade Associations**

   a. Boating

   Statistics from NMMA - National Marine Manufacturers Assoc.
   Statistics from the Sailing Company (for Sailboats built)

   b. Recreational Vehicles

   Statistics from RVIA (Recreational Vehicle Industry Assoc.)
   Statistics from the annual reports of RV manufacturers

   c. Telecommunications

   Statistics from TIA (Telecommunication Industry Association) and EIA (Electronic Industry Association)

B. Trade Shows, Manufacturer and Dealer Visits

The information obtained in the literature search was expanded upon by attending trade shows, phone and personal interviews with boating and RV manufacturers and dealers, telecommunications service providers, and telecommunications site managers.

1. Boating

Outdoor and in the water boat shows in Long Beach (7/19/97) and Oxnard (8/3/97). The Indoor Trade Show in Long Beach on 10/25 /97 to observe boat types, configurations, and power needs. Gathered information for survey and made dealer and vendor contacts for follow-up.

2. RV's

National RVIA show in Pomona, CA on October 21, 1997. On-site visits to large and small dealers including Travelland U.S.A. in Irvine, CA (which has virtually every major manufacturer represented) and All American RV in Colton, CA. (where 10 dealers are located). Visit to RV Showcase in Indio, CA with developer of proposed multi-purpose RV development that will include dealers, manufacturer warranty service locations, luxury RV park with golf course, clubhouse, tennis, pools and many other amenities.

3. Telecommunications

Scheduling of events did not allow for any trade show visits.

Local visits to GTE to discuss power needs. Local visits to private radio and telecommunications vendors who provide various telecommunications services to phone companies, cellular, PCS, and long distance vendors.

Phone discussions with American and Allied Tower Systems who create, maintain, and manage multi-purpose commercial sites that are used by different telecommunications service providers.

BOATING

APPLICATONS

Feasibility Study and Market Survey

Boating Applications

I. STATISTICS BY MARKET SEGMENTS

II. BOATING APPLICATIONS - SUMMARY OF POWER NEEDS

III. DETAIL OF POWER NEEDS

A. SAILBOATS
B. POWERBOATS

IV. OTHER ALTERNATIVE ELECTRICAL SOURCES

V. OBSERVATIONS AND CONCLUSIONS

I. STATISTICS BY MARKET SEGMENTS

The Boating Market
1994 - 1996

Units sold for powerboats and Units Built for sail boats

	1994	1995	1996
Power Boats			
Small Outboards	220,000	231,000	215,000
Inboard Boats-Runabouts	7,200	6,900	6,1000
Inboard Boats-Cruisers	4,200	5,460	5,350
Total Power Boats Sold	231,400	243,360	226,350
Sail Boats			
Under 20 ft	9,083	10,346	11,975
20 - 29 ft	2,204	1,865	1,833
30 - 40 ft	1,357	1,646	1,641
40+ ft	317	464	490
Total Sailboat Production	12,961	14,321	15,939

The source of information on Power Boats was NMMA - National Marine Manufacturers Association. The numbers on personal watercraft (jet ski's) and canoes, which are the fastest growing categories, were omitted as they are not relevant to our study. NMMA has not compiled data on sailboats since 1990 and the data source was *Sailing Company*, a publisher of statistics on sailboats and magazines on sailing.

The information on power boats is provided in "units sold" whereas on sailboats it is "units built." The *Sailing Company* only surveys manufacturers based on units shipped and does not track units sold by sailboat dealers. The figures above do give an idea of the relevant population.

The Marketing Services Department of NMMA did not do a formal 1997 sales forecast, but anticipated that the Inboard-Cruiser market, which was identified as the target, will be flat.

The *Sailing Company* forecasts a 17% increase in sailboat building based on manufacturers surveys and the current strong economy.

II. BOATING APPLICATIONS - SUMMARY OF POWER NEEDS

			Power Uses & Source of Power					
Type	**Usage**	**Power Supply**	**Cooking**	**Heat**	**A/C**	**Aux Elec**	**Start**	**Engine**
Sailboats								
< 30 ft	Day Sailing Weekend Cruising	Batteries - recharged by alternator or shore power	Alcohol or BBQ (Charcoal)	N/A	N/A	Batteries 12V	Battery 12V	Gasoline
30 - 40 ft	Day Sailing, Inter Island & Long Trips Live On	Batteries - recharged by alternator or shore power or solar or wind power	Propane 5 - 10 pound tanks (2.4 - 4.8 gallons)	N/A	N/A	Battery Bank 12V	Battery 12V	Diesel
> 40 ft	All of the Above	Batteries - recharged by alternator or shore power or solar or wind power and 3.5 to 5k generator if A/C and heating is desired	Propane 10 pound tanks (4.8 gallons)	Yes Genset	Yes Genset	Battery Bank	Battery	Diesel
Power Boats								
< 30 ft	Day Recreation	Batteries	N/A	N/A	N/A	N/A	Battery	Gasoline
> 30 ft Cabin	Marina-to- Marina trips	Batteries, Diesel Generator 6kW+	Electric	Elect.	Elect.	Elect.	Battery	Diesel

III. DETAIL OF POWER NEEDS

A. SAILBOATS

Sailboats are used extensively for recreation by consumers in water accessible areas with higher utilization in more temperate climates such as Florida, Southern California, and the Gulf Coast. The statistics provided are for the USA only. The typical use includes day sailing, weekend cruises, inter-island and inter-coastal and even trans-Pacific or trans-Atlantic sailing; depending on the affluence of the boat owner and the size of the boat. Sail boat production has been consistent with the economic climate decreasing from 14,510 units in 1988, to 8,677 in 1991. Production has risen steadily from the 1991 low, to a level of 15,939 units in 1996 with the optimistic projection of a 17% increase in 1997 to 18,643 due to the improving economy. The major concentration is in smaller boats, those under 20 ft. in length.

1. Under 30 feet

The majority of the sail boats built annually (1996 - 85%) and those that are currently in service fall into this category with the predominant number of these being under 20 feet. The typical use of these boats is for weekend day cruises, local marina hopping, or inter-island or inter-coastal weekend cruises. Most of the boats under 20 feet have an outboard motor, if any, while the 25 feet and larger often have gasoline powered inboard engines. The boats larger than 20 feet will typically have small cabins which include basic living facilities. The sales price for boats over 20 ft. in length is generally $1000 per foot.

Power needs are supplied by batteries (12v) which are recharged by an alternator integrated into the engine configuration, small portable generator, or shore power. The day cruiser's typical power use is for the radio and for lights used after dark. Although many contain refrigerators (reefers) they are often augmented by ice purchased at the start of the day. Cooking is usually done on a small alcohol stove or by a barbecue when anchored or docked. The inboard motors are used primarily to leave and enter the marina, and when the wind and current is too calm to sail. The inboard motor, if equipped with an alternator, will also be used to charge the batteries. Most sailors use them as little as possible due to the gasoline fumes and noise that detracts from the sailing experience.

There may be a market application in the future for a small fuel cell electric motor similar to those used in electric boats for propulsion and other electrical needs. Due to the relatively low cost of all but the largest boats in this category, it does not appear that there is an initial target market at this time.

2. 30 to 40 Feet

In 1996 there were 1,641 sailboats built in this size range, which represents slightly more than 10% of the total sailboats built. The number of units produced in this size range is projected to increase to 1,852 units, which is slightly less than the average increase projected for all sail boats. These boats range in price from $50,000 to $300,000 depending on their size, configuration, appointments, etc. In addition to the activities outlined above for boats smaller than thirty feet these boat owners often live on-board, take longer trips, and entertain guests. The majority of these boats have an inboard diesel engine for propulsion when not under sail, which will also be used with an integrated alternator to charge the battery banks. Normally there are two battery banks, one for starting the engine and one for all other electric power needs. There may be more than one 12v deep cycle battery in each bank depending on the demand, and "backup batteries" are carried for emergencies. Many of the larger boats use some combination of solar panels, wind generators, and trailing water powered generators depending on their electric power needs.

Most boats of this size have propane for cooking (three burner stoves with ovens) with the typical configuration being one or two 10 pound tanks (2.4 gallons) in a separate locker, vented above the water line. Most sailboats of this size would not have a heater or an air conditioner, consequently there would be no need for a generator. At this time no major manufacturer produces a propane powered generator. Enclosed is a chart from a recent article published in *Cruising World* magazine "Surveying Your Electrical Needs" (Exhibit 1) showing a sample daily appliance load of 150 amp-hours for a boat in this size range with the major consumption being refrigeration, lights, TV/VCR, and microwave oven. The energy is supplied from the batteries with renewable charging sources such as solar, water, and wind assisting the engine driven charging system.

Since the propane is on board and available at marinas, only one tank is needed for cooking (a 2.4 gallon tank should supply enough BTUs for a couple cruising for a month and a half), a second tank could be used for powering a fuel cell. Based on preliminary calculations from the Schatz Energy Research Center, one tank could provide as much as 900 amp-hours which represents a 6-day supply (based on exhibit one) assuming that the other renewable sources and the engine charging system were not used. Additionally, the fuel cell should be able to recharge the starter battery bank and any backup battery bank that might still exist. Exhibit 2 shows the system necessary to provide 150 amp-hours a day and the cost of that system installed.

It appears that this category would be receptive to the fuel cell concept even though current technology is adequate and cost effective. However, the total arrival new units is less than 2,000 which, by itself, would not be a sufficient market to reduce the fuel cell to a reasonable cost and should be viewed as a market for the future.

3. Over 40 Feet

In 1996 there were only 490 sailboats of this category built, or 3% of the total production. Of this number, 385 were between 40 and 45feet. The projection for 1997 for this category is for 635 units (487 for 40-45ft. range), or a 30% increase due to improved economic conditions. While this is the high end niche market that should be targeted, there is a question as to whether this small number alone would justify production. The 40-45 foot boats would only require a generator for heating and air conditioning while the large "super yachts" have diesel engines and diesel generators that produce power substantially above our 5kW limit. The 40-45 foot category without need for air conditioning and heating would have needs similar to the 30-40 foot category and would have the added advantage of being able to easily store two 5-gallon tanks of propane.

Based on power requirements that the diesel generators respond to, it is assumed that a fuel cell would have to be greater than 5kW to provide for the air conditioning and heating functions on a boat of this size.

Summary - Sailboat Applications

1. Under 30 Feet

Because of the minimal power needs and low cost of the boats in this category, it does not appear that it would be a target market at this time.

There may be a market application in the future for a small fuel cell or electric motor similar to those used for electric boats for minimal propulsion and other electric needs.

2. 30 to 40 Feet

Since propane is already used for cooking purposes, with an extra tank usually in reserve, this category would offer potential provided that the cost of the fuel cell/reformer was equal to or slightly more expensive than current alternative energy costs. In addition to providing all the auxiliary electrical needs, the ability to charge the starting battery bank and the backup battery, the fuel cell would very attractive.

Based on the research, it would appear that this will be an attractive market when the cost of the fuel cell competes with existing technology but that the current number of units built each year are not sufficient to justify production. There were 15,000 units built in this category over the last nine years, consequently an aftermarket unit should be investigated as a target market.

3. Over 40 Feet

The majority of the units in this category could be reclassified to the preceding category assuming that there were no air conditioning or heating systems on board. The remaining units have higher power needs than the scope of this study.

B. POWER BOATS

1. Under 30 Feet

The data show that there are large numbers of small outboard motor boats and inboard runabouts which make up the majority of this category. They are typically gasoline powered and used for day recreation with minimal, if any, electric requirements. Many are towed on a trailer to a lake or marina launching site and are towed out after the day use. There may be a market at some point for an inexpensive electric motor, similar to what the electric boats now use, as a way to reduce pollution, noise, and fuel costs. The current noise and safety concerns at state and federally managed water facilities is directed primarily at personal watercraft but may eventually affect other noisy and polluting water vehicles

2. Over 30 Feet with a Cabin (Cruisers)

Based on interviews with boat dealers of this boat type, there is an aversion to the carrying of propane based on a fear of explosion and a lack of need. Even though the newer large sailboats use propane for cooking, the power boat dealers were not interested.

The smaller boats in this group relied on batteries and various charging devises and typically are used for marina-to-marina trips or other day cruises. Owners often cook at their destination where they can access shore power. If they do stop and stay at an anchorage, they run the generator or use battery power. The batteries would have been charged as the motor is always running while cruising, versus the sailboats which would use their motor only when moving in and out of the marina.

The larger and more expensive power boats (over 40 feet) ran on diesel engines with generators rated at 6kW and greater. Onan's product line of marine generators starts at 6kW.

Summary - Power Boat Applications

1. Under 30 Feet

Because of the minimal electrical power needs of this category, it does not appear that it would be a target market at this time.

A future study might investigate extending the range of electric boats utilizing fuel cell technology, as they currently can operate on their batteries for up to 10 hours and then have to be recharged.

Another area for future study might be for a propulsion system to be used on small boats currently powered by gasoline inboard or outboard engines.

2. Over 30 Feet with a Cabin

There could be an application here for replacing the smaller generators (<5kW) using a diesel reformer. This would have the advantage of quieter operation when anchored and would not require the carrying of propane. However, as most of the current generators in service are >6kW, this category is beyond the scope of this study.

IV OTHER ALTERNATIVE ELECTRICAL SOURCES

Based on the numbers generated at the Schatz Energy Research Center, a 2.4 gallon (10 pound) tank of propane could power a 0.5kW fuel cell sufficient to provide 900 amp-hours, or 6 days at 150 amp-hours per day, which is the daily electrical load for a cruising sail boat in the 35-40 foot range. (Exhibit One) Since the other propane tank was dedicated for cooking, there would technically be a requirement to refuel after 6 days, run on battery power, or utilize the propane reserved for other purposes.

Current sources of energy

1. Alternator (150 amp)

In order to duplicate the electricity provided by the fuel cell, the engine could operate an integrated 150 amp alternator for an hour-and-a-half a day to recharge the batteries and replace the energy used. As many sailboats use their engines going in and out of marinas, harbors, etc., this is not of major concern.

2. Solar Power

Solar power would be used only as a supplementary source since three 50-Watt panels would provide approximately 48 amp-hours daily. This represents approximately one third of the needs, and on sun-less days would provide substantially less.

3. Wind Generators

Wind generators are also a supplemental source that could supply between 40 and 80 amp-hours per day depending on the wind speed and the size of the unit.

4. Water Powered Generators

A trailing-log unit at 5 knot average speed could provide 50 to 100 amp-hours daily, depending upon the cruising time.

All of the renewable sources (sun, wind, and water) are only able to provide part of the daily power requirements. The fuel cell could provide all of the requirements for 6 days or longer (based on propane availability) with the side benefit of charging the starting batteries and back-up batteries without running the engine.

V. OBSERVATIONS AND CONCLUSIONS

1. Market Segment Potential

A. Sailboats

The manufacturers of sailboats between 30 and 45 feet should be receptive to this concept once the cost is competitive based on:

1. Alternative fuels for energy needs

Sailboats in this size range already use, or are familiar with, alternative renewable forms of energy such as solar, water, and wind.

2. Propane use

New sailboats of this size typically use propane for cooking and have either two 10 pound (2.4 gallon) or one or two 20 pound (4.8 gallon) tanks.

3. Amenity value

If the engine only had to be used while traveling in and out of marinas, harbors, or anchorages, the sailing experience would be greatly enhanced.

B. Power Boats

The larger power boats have power needs that are beyond the scope of this study. There is an aversion to using propane because of fear of explosion and unfamiliarity with gaseous fuels. If a diesel reformer were available, there may be some interest from owners who use anchorages and would appreciate the quiet operation. The profile seems to be marina-to-marina and day-cruises where shore power and engine generated power are sufficient for their needs.

2. Other Marine Applications

Consideration should be given to investigating alternative boating operations. They include:

A. **Houseboats** - river cruising
B. **Electric Boats** - bay, lake, and recreational day trips

Exhibit One

Sample Appliance Load Chart

Appliance	Average Power (Amps)	Average Use (Hrs/Day)	Average Consumption (Amp-hrs/Day)
DC Loads			
cabin lights	3.2	4.00	12.8
running lights	2.0	2.00	4.0
anchor light	2.0	10.00	20.0
SW/AM-FM	0.4	0.40	0.2
VHF Receiver	0.5	4.00	2.0
transmitter	4.8	0.25	5.0
Loran	0.4	2.25	0.9
instruments	0.4	2.00	0.8
tape deck	2.0	2.00	4.0
bilge pump	4.0	0.25	1.0
refrigerator	5.0	12.00	60.0
auto pilot	1.8	2.00	3.6
AC Loads			
TV/VCR	7.0	2.00	14.0
laptop computer	0.8	2.00	1.6
blender	12.0	0.10	1.2
microwave	80.0	0.17	13.6
sewing machine	7.2	0.50	3.6

Total average Daily Load: 150 Amp-hrs/Day

Source: July 1997 issue of *Cruising World* from an article entitled "Surveying Your Electrical Needs" by Kevin Jeffrey.

Information provided for a cruising boat, 35-40 feet long without air conditioning or heating systems.

Exhibit Two

Power System for the Representative Boat

Equipment Category	Suggested Equipment
Renewable Charging Sources	Two 50-watt solar panels ($650) One 200-watt pole mounted wind generator ($1250) One water conversion kit for the wind unit ($320) Charge control for the above ($200) Mounts for all of the above ($300)
Engine-driven Charging Sources	One 125 to 150 amp high output alternator ($300) Charge controls for the above ($160)
AC Power Source	One 1500-watt inverter-charger ($900) One Shore power inlet ($200)
Battery Bank	600 amp-hour house bank with single engine starting battery. ($700)
Battery Link or Combiner	One 2-bank, 150 amp capacity battery link or combiner ($160). Allows multiple battery banks to be charged independently.
System Monitor	Single Bank digital system monitor ($200)
Efficient Appliances	Efficient Lighting ($150)
Estimated Cost of the System	$5490

Information provided for a 35-40 foot sail boat without air conditioning or heating systems.

RECREATIONAL

VEHICLE

APPLICATIONS

Feasibility Study and Market Survey

Recreational Vehicle Applications

I. RV DEMOGRAPHICS

II. DESCRIPTION OF MARKET SEGMENTS

III. STATISTICS BY MARKET SEGMENTS

IV. RV APPLICATIONS - SUMMARY OF POWER NEEDS

V. MANUFACTURER AND DEALER SURVEY

VI. MARKET SHARE STATISTICS

VII. OBSERVATIONS AND CONCLUSIONS

I. RV DEMOGRAPHICS

A University of Michigan Survey Research Center study for RVIA, found that one in every ten vehicle-owning families owns an RV (this includes van, pickup truck and sport utility conversions). That number rises to one in nine among households headed by 35- to 54-year-olds. With some families owning more than one RV, there are more than 9 million RVs registered in the United States. RV owners are divided between empty-nesters, aged 55 and over, enjoying the freedom of frequent travel; and 35- to 54-year-old couples raising families, who like the convenience, economy and enjoyment of RV vacations.

According to a recent University of Michigan study, 44% of America's RV'ers are aged 55 and up, while 39% are between the ages of 35 and 54. The average RV owner is 48 years old, owns his own home, has a household income just under $40,000, buys in order to travel and camp and is very pleased with the purchase, according to RVIA research. There are an estimated 25 million RV enthusiasts in the United States. According to RVIA, RV owners annually travel an average of 5,900 miles and spend over 23 days on the road. An additional 12 million households intend to buy or rent an RV in the near future. The retail value of RVs produced in 1996 was $12.3 billion. Including the RV rental market, it is estimated that RVs represent a $15.75 billion industry.

With more than 16,000 public and privately owned campgrounds nationwide, RV'ers are free to roam America's highways and back roads for a weekend or weeks on end. Privately owned RV parks and campgrounds are found near popular destinations, along major tourist routes, and even in city environments. These campgrounds appeal to traveling families by offering a variety of activities to keep children busy. Swimming pools, game rooms, playgrounds and snack bars are practically standard. RV travelers seeking a resort atmosphere with facilities such as tennis courts, golf courses and health spas flock to the new breed of luxury RV resorts. Facilities at public campgrounds tend to be simple, but offer great scenic beauty. Public lands are popular for hiking, fishing, white water rafting and many other outdoor recreational opportunities.

RV sales are expected to increase in the late 1990's as the massive "baby boom" generation enters the prime RV buying years (age 45-54). After rebounding from the recession year of 1990-91, the recent peak in units sold was in 1994 with small declines in 1995 and 1996. With the improving economy, favorable interest rate environment and demographics, unit sales are expected to increase in 1997 and 1998. Changes in the frequency and duration of vacations also favor the RV industry. Americans are traveling more but over short distances and on weekends with less planning, according to recent studies. For RV owners, this is a natural travel pattern. The growing popularity of RV'ing parallels the importance of outdoor recreation in the U.S. A survey by the Recreation Roundtable found 77% of Americans view outdoor recreation as a priority in their lives and 67% plan to increase their participation in camping in the 1990's. RVs are a natural focal point for many of these activities, especially camping.

II. DESCRIPTION OF MARKET SEGMENTS

A recreational vehicle (RV) is a vehicle designed as temporary living quarters for recreational, camping, travel or seasonal use. RV's may have their own motor power (as in the case of Class A, B, & C Motorhomes); may be towed by another vehicle (as are 5th wheels, travel trailers, and folding camping trailers); or mounted (as are truck campers).

A. Class A Motorhomes

The Class A motorhome is the most comfortable, luxurious means of RV travel. However, with the luxury comes considerable cost in initial purchase price and fuel consumption. This survey covered motorhomes ranging from 23 to 45 feet in length and with a price range from $47,000 to $350,000. The majority of the units were in the $60,000 to $200,000 range. The average price for a Class A unit last year was $79,000. Most of the larger and more expensive motorhomes (over 35 ft) that were observed during the study have diesel engines and large diesel generators providing power in the range of 6.5kW to 7.5kW. These units typically sell from the low $100,000's to the mid $200,000's. Most of the Class A units under $100,000 use gasoline and have generators that are generally 5kW due to the large power needs, primarily air conditioning and microwave ovens. Owners of the larger motorhomes typically stay at parks where 30-50 amp electric service is available along with cable TV and phone lines in many cases. Propane is used for cooking (the larger units typically have a three burner surface unit and an oven), refrigeration (most of the refrigerators are dual gas and electric), and for heating. The propane tanks range from 20 to 50 gallons depending on the size of the vehicle. All Class A motorhomes have "house batteries" which are banks of deep cycle batteries used for the auxiliary power needs that are recharged when the generator is in operation. These batteries are separate from the ones used to start the motor. Many motorhomes also use inverters for smaller power needs and battery charging.

B. Class B Motorhomes (van campers)

These camping van conversions offer a fully self-contained living environment. Amenities included are stoves, refrigerators, sinks, toilet, shower, sleeping accommodations and inside living and dining areas. Class B's are the smallest motor homes on the market with lengths ranging from 16-21 feet and prices varying from $32,000 to $53,000 depending upon size and features. Some of the larger units have air-conditioning and microwaves which are powered by a small gasoline generator, usually 2.8kW. The propane tanks (6 to 10 gallons) are used for cooking, refrigeration and heating. Because of the size of these units, components such as waste holding and propane tanks are rather small. A van conversion can serve as a family car when not being used for camping and can be easily parked in almost any campsite. The fuel economy of 16-18 mpg. is about twice that of a Class A motorhome.

C. Class C Motorhomes (mini's")

Most but not all Class C's are smaller and less expensive than Class A units. Lengths range from 16-31 feet and prices vary from $42,000 to $62,000 with an average price of $47,000. A Class C is easier to drive than a Class A because the truck or van cab is narrower than the front of a Class A even though the Class C body is just as wide behind the cab as is a Class A. Mini's have all the amenities of a Class A (kitchens, bathroom, living, and sleeping areas) but on a smaller scale. The units observed had propane tanks in the range of 14 to 20 gallons which are used for cooking (most Class C's have 3 burner stoves and an oven), refrigeration, and heating. Air conditioning, microwave, and other auxiliary power needs are supplied by a gasoline generator (usually 4-5kW) when plug-in power is not available. The base unit from most manufacturers does not contain a generator, air conditioning, or microwave but these options are usually ordered.

D. Fifth-Wheel Trailers

This type of trailer is very similar to a conventional travel trailer except that it includes a raised "gooseneck" area in the front that contains a permanent bed. The separated sleeping area and the fact that the "rig" must be towed by a pickup truck (the gooseneck fits into a hitch in the open bay of the pickup truck) are the major differences between fifth-wheels and conventional trailers. Smaller units under 4000 pounds can be towed by compact or ½ ton pickups . The smaller "fivers" range from 19-24 ft and cost from $10,000 to $15,000. Because fifth-wheel hitches can handle more weight than conventional hitches, they can be much larger than other types of trailers. Many of the larger models are towed to a site and left there as a second home. The larger "fivers" vary in length from 25 to 41 feet and are priced from $17,000 to $89,000. The average price of the unit shipped last year was $22,700 as smaller units are still the majority of all purchases. Many of the larger new "fivers" have slide out rooms that extend the living space when parked. Along with all the normal amenities, some of the larger units have washer/dryer combinations and food freezers. If they were left at a site, it would typically have plug in power, but if not, most manufacturers offer an optional propane generator package with sizes from 3.3kW to 6.5kW depending on the power needs. The size of the propane tanks are seven to 20 gallons depending on the size of the units and would be used for the normal cooking, refrigeration, and heating needs in addition to running the generator. A fifth wheeler left at a remote site without plug-ins would be a good candidate for a fuel cell in lieu of a generator for the quiet operation, efficiency, and lower pollution level.

E. Travel Trailers

The smaller trailers (13-27 ft) can be towed by a car, truck, or sport utility vehicle that has sufficient towing capacity and a suitable hitch. The smaller units sell from $6000 to $19,000 and usually have a fully enclosed bathroom and shower space along with all the other standard living accommodations. Generators are usually not offered as an option due to cost considerations (one dealer suggested a portable 1.5kW for backup use). As no one is allowed to ride in these trailers while they are moving, air conditioning is not used during travel. The larger units vary from 27 to 37 feet and prices range from $13,000 to $61,000. Large interiors offer a variety of floor plans for either full time RV'ers or others who spend extended periods of time in one location. The large units, like the fifth wheels, are typically towed to a location where power is available to run the air conditioning and microwave. A large travel trailer left at a remote site without plug-ins would be a good candidate for a fuel cell in lieu of a generator for the quiet operation, efficiency, and lower pollution level.

F. Truck Campers

The truck camper is the most compact RV available as it is designed to be carried by a pickup truck. The base of the living area is fitted inside the truck bed in the space between the wheel housings. The upper structure may extend over the sides of the truck bed and forward in a section called the cabover which contains the main sleeping area. Lengths vary from 6 to 11.5 feet, and prices range from $2000 to $20,000 depending on the amenities. The larger units have bathroom facilities, cooking, refrigeration, and optional heating and air conditioning. A unit of this size would normally have a propane tank of 14 gallons and a 3.4kW generator.

G. Folding and Camping Trailers

Also known as a pop-up or fold-down trailer, this is a very popular RV for first-timers due to its simplicity and lower cost. Many models weigh less than 2000 pounds and can be towed by all but the most compact cars. Lengths (opened) range from 12 to 26 feet with prices from $4500 to $6800. Most models have propane stoves, small ice boxes (occasionally refrigerators), and portable toilets with sleeping and eating facilities. Power is provided by a battery and a power converter.

H. Van Conversions

Van Conversions are similar to Class B Motorhomes except that they do not have bathroom or cooking facilities built-in. Suburban households use them for general transportation and weekend events as well as camping expeditions.

III. STATISTICS BY MARKET SEGMENTS

(Units Shipped According to RVIA)

Motorized	**1996**	**1995**	**1994**	**1993**	**1992**
Class A - Full Size	36,500	33,000	37,300	31,900	27,300
Class B - Van camper	4,100	4,100	3,500	3,000	2,900
Class C - Mini's	14,700	15,700	17,300	16,500	16,800
Sub Total Motor Homes	55,300	52,800	58,100	51,400	47,000
Towables					
Fifth wheel	48,500	45,900	48,900	43,900	38,900
Travel Trailers	75,400	75,300	79,100	69,700	63,600
Folding & Camping	57,300	61,100	61,700	51,900	43,300
Truck Campers	11,000	11,900	11,400	10,900	10,600
subtotal Towables	192,200	194,200	201.100	176,400	156,400
Conversion Vehicles	219,300	228,200	259,600	192,400	179,300
Total	466,800	475,200	518,800	420,200	382,700

Average Price ($)

Motorized	**1996**	**1995**	**1994**	**1993**	**1992**
Class A - Full Size	79,000	83,000	68,500	62,600	64,000
Class B - Van Camper	42,900	40,000	37,400	39,600	37,620
Class C - Mini's	47,100	41,800	40,100	37,800	36,500
Towables					
Fifth Wheel	22,700	20,700	19,600	18,400	19,300
Travel Trailers	14,200	13,000	12,100	12,000	12,200
Folding & Camping	5,000	4,800	4,500	4,400	4,400
Truck Campers	11,100	10,000	9,800	9,400	9,300
Conversion Vehicles	27,500	27,200	25,100	24,800	25,100

IV. RV APPLICATIONS - SUMMARY OF POWER NEEDS

			Power Uses & Source of Power					
Type	**Usage**	**Power Supply**	**Cooking/Ref**	**Heat**	**A/C**	**Aux House**	**Start**	**Engine**
Class A Motor Home	Full Time Living 2nd Homes and Weekend Trips	Generator 5-17kW plus batteries, solar and 30-50 amp plug in	LPG 10-30 gallon. Also Electric Refrigeration	LPG	Gasoline/ LPG Generator	Batteries Deep Cycle (4 - 6 volt)	Battery 1 or 2 12V	Gasoline or Diesel
Class B Van Campers	Weekend Camping, Short Trips	Batteries - recharged by alternator or plug in power; Optional generator 2.8kW	LPG 5-10 gallon	LPG	Plug in or Gasoline Generator	Auxiliary Battery 12V	Battery 12V	Gasoline
Class C	All of the Above	Same as above 4 to 5kW generator for A/C	LPG 10-15 gallon	LPG	Gasoline Generator	Auxiliary Battery 12V	Battery 12V	Gasoline
Fifth Wheel Trailers	Long Term Living, Longer Trips	Site Plug-in and/or LPG generator (3-4kW)	LPG 5-10 gallon	LPG	LPG Generator	Auxiliary Battery	N/A	N/A
Travel Trailers	Long Term Living, Longer Trips	Site Plug-in or Portable generator	LPG 5-10 gallon	LPG	Plug-in	Auxiliary Battery	N/A	N/A
Truck Campers	Weekend Camping, Short Trips	Batteries 15 amp power converter	LPG 5 gallon	N/A	N/A	Auxiliary Battery	N/A	N/A
Folding Camping	Weekend Camping, Short Trips	Batteries 15 amp power converter	LPG 5 gallon	N/A	N/A	Auxiliary Battery	N/A	N/A

V. MANUFACTURER AND DEALER SURVEY

The fuel cell concept created much interest due to the following benefits (versus a standard generator):

- Quiet Operation—Can be run for 24 hours—not subject to campground noise regulations
- Better Operating Efficiency (45 % versus - 15% for internal combustion engine)
- Longer Life
- Lower Maintenance (no moving parts)
- Less Pollution—no pollution if using hydrogen fuel. No CO.
- Lower weight than same size generator (110 lb. vs. 216 lb.) Onan Emerald-Plus 5kW

The concerns expressed were as follows:

<u>Cost</u> - In production could be $ 2-3 per Watt. At $1.00 per Watt cost would be $5000 for a 5kW versus an Onan 5kW generator at $2500-$2800 . When asked the question "<u>What premium are the benefits worth ?</u>" the executives at Fleetwood and Coachmen (two of the three largest manufacturers of motorhomes) both suggested numbers of $500 to $700. They believe the market is very price sensitive, especially at the medium and lower price levels, and that the upscale RV'er that typically stay in the luxury parks with plug-ins might not be interested since there are no appreciable fuel savings burning propane versus gasoline.

<u>Safety</u> - RVIA recently required propane cylinders to be equipped with "stop fill" valves to prevent overfilling. These valves will prevent the propane tank from filling beyond 80 percent of its capacity, thus allowing for propane expansion as the ambient temperature increases. While industry sources indicate that RVIA probably overreacted, the hydrogen concept was immediately questioned on this basis. The Hindenberg incident was mentioned even though most of the fires in RVs are caused by electrical shorts not propane or any other fuel.

<u>Fuel Availability and Usage</u> - Although propane is available at most truck stops and many gas stations, the current usage and tanks (20 gal) are sufficient for running the propane appliances (stove, refrigerator, and water heater) for a longer time than the traditional gas fill up. If a propane powered fuel cell was used to replace a generator to run the air conditioner, it would probably result in more frequent refueling unless the size of the tanks was increased. This is in comparison with gasoline or diesel generators whose tanks are substantially larger as they supply fuel for the engine as well as the generator. According to the Schatz Energy Research Center, propane usage would be slightly more than gasoline (0.9 vs. 0.75 gallons per hour).

Product Availability - Despite some of the above concerns, manufacturers and dealers were anxious to see the product and were disappointed when told that a prototype would not be available for many months. They would be interested in meeting again when the product is available.

Configuration Issues

Size and Location - A fuel cell could be put in the same space that the generator currently occupies.

Weight - If the size of the propane tanks were increased due to increased consumption of propane by the fuel cell, it would partially or fully offset the weight advantage that the fuel cells have and would require some reconfiguration.

Replacing a Gasoline Generator - Generators shut off if the gas tank level gets too low. The fuel cell would eliminate that problem. Many of the diesel motor home owners are not happy about using propane for some of their needs as it requires two fueling stops.

Running Two A/Cs - Air conditioning units have become efficient enough that a 5.5 kW generator can run two 13,500 BTU units on one of the larger motor homes by cycling them based on the thermostatic control. The initial power surge is handled by the house batteries in addition to the generator. As air conditioning is the major energy draw that requires a generator, it is assumed that a fuel cell of 5kW in combination with the house batteries could satisfy these requirements

LPG Generators - These are used primarily on diesel motor homes and fifth wheels as neither would have a gasoline engine or gasoline storage tank. Most travel trailers do not have generators as the relatively low selling price would not justify it and most of these units are used at a site where plug-ins are available. If any of the towables were left at a remote site a fuel cell would be a good option.

VI. MARKET SHARE STATISTICS

Motor Homes (Classes A & C)

Fleetwood	27.4%
Winnebago	16.5%
Coachmen	11.6%
Thor Industries	7.9%
Gulfstream	4.9%
Sub Total	68.3%
All others	31.7%

Travel Trailers (Including Fifth Wheels and Truck Campers

Fleetwood	24.8%
Thor Industries	14.6%
Jayco 8.0%	
Cobra 7.4%	
Skyline	7.3%
Sub Total	62.1%
All others	37.9%

Folding Trailer Market

Fleetwood	33.6%
Jayco 29.7%	
Thor Industries	12.1%
Cobra 11.5%	
Palomino	5.9%
Sub Total	92.8%
All others	7.2%

Statistics not available for Class B Van Conversions.

VII. OBSERVATIONS AND CONCLUSIONS

1. Key Issues

a. Cost

Fuel cell cost must be less than $1.00 per watt rather than the $3.00 per watt estimated for a propane powered fuel cell. At this price the fuel cell would still be more expensive than powered generators but the offsetting benefits could be attractive to the competing RV buyers. The manufacturer would probably take a financial loss on initial production in order to market the product.

b. Safety

For purposes of this study, we are assuming that the existing fuel would be used. Since the applicable categories currently use propane this would not be a major concern

c. Product Availability

The benefits in theory are very attractive. The RV manufacturers need to see a working prototype. Consumer acceptance could be achieved very easily if they could hear the quiet operation, notice the lack of emissions, and see that it really could provide their electrical needs.

2. Applicable RV Market Segments

a. Motorized

The approximately 40,000 Class A's and C's that are currently gasoline powered would be the primary target market. They would require outfitting with larger propane tanks but would see increased gasoline mileage as their air conditioning units would now be powered by the fuel cell. The Class B's would probably be interested for the quiet operation but the extra propane capacity might be a problem as the smaller Class B's do not have room for a generator.

The larger diesel units have 6.5kW and larger diesel generators and, as noted earlier, some would prefer to eliminate propane. Most of these higher priced units will generally camp where there are hook-ups provided.

b. Towables

Many of the 5th wheels and a few of the more expensive travel trailers have propane generators to power their air conditioning units and other systems when they are at remote sites without plug-ins. A propane fuel cell system would be very attractive in this situation to eliminate the noise and pollution thereby enhancing the camping experience.

When a portable version is available and affordable, it would be attractive to some of the lower priced trailers and other towables.

3. Other opportunities

Other opportunities that came up but were beyond the scope of this study were:

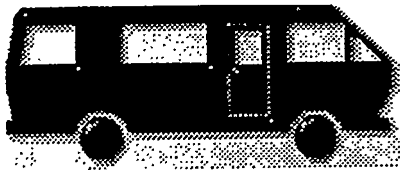
a. RV rally fields

RV clubs and associations have rallies where large numbers of RV'ers gather. Typically power is not available and has to be brought in using large portable 50-75kW generators which are noisy and polluting.

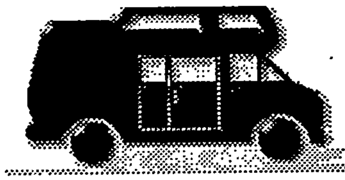
b. Propulsion

If a fuel cell could power the actual RV at a reduced operating cost, as well as provide the necessary electrical power when the vehicle was stopped, the sale of fuel cells would greatly increase. With the recent announcements from the big three US automakers and Mercedes-Benz regarding fuel cell powered cars, it would appear that this will be an option sometime in the next decade.

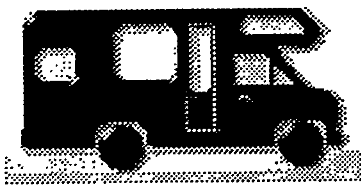
RV MANUFACTURER'S SHOWROOM



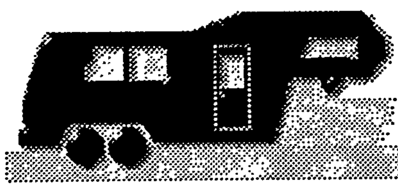
CLASS A MOTORHOMES



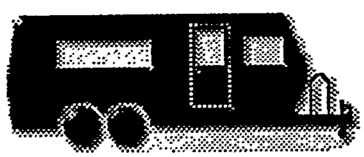
CLASS B MOTORHOMES
(Van Campers)



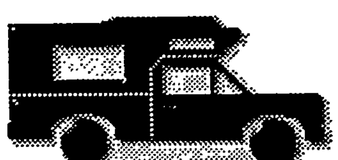
CLASS C MOTORHOMES



FIFTH WHEEL TRAILERS



TRAVEL TRAILERS



TRUCK CAMPERS

POP-UP CAMPERS

TELECOMMUNICATIONS

APPLICATIONS

Feasibility Study and Market Survey

Telecommunications Applications

I. TELECOMMUNICATIONS EQUIPMENT DEMOGRAPHICS

II. INTRODUCTION - TELECOMMUNICATIONS SITES

III. TYPES OF TELECOMMUNICATIONS APPLICATIONS

IV. OBSERVATIONS AND CONCLUSIONS

I. TELECOMMUNICATIONS EQUIPMENT DEMOGRAPHICS

Advances in the telecommunications equipment market will directly affect the number of new equipment sites created resulting from increased demand by individual, corporate, and government consumers for these services. There are a myriad of combinations of various equipment deployed at a number of different kinds of sites. The needs range from small solar powered repeater station sites to large multi-purpose sites where a 50-100kW capacity is needed. While it is difficult to determine a typical site configuration, or even a class of sites, it is clear that the demand for future sites will increase as sales of telecommunications equipment increase. Due to the many mergers and partnerships that are taking place, it is also expected that many of the single-use sites owned by one vendor will be expanded to become multi-use sites with cost sharing or co-management arrangements.

The TIA (Telecommunications Industry Association) has released the following information which has been derived from U.S. Commerce Department Data.. United States factory sales of telecommunications equipment for 1996 reached $63.7 billion, which was a 20 percent increase over 1995, when sales were reported at 53 billion. While more detailed information for 1996 is not available yet, the 1994 and 1995 sales breakdown by major categories is as follows:

	1994	1995
Commercial, Industrial, and Military	20,078	23,124
Broadcast, Studio and related	2,469	2,700
Intercommunications Equipment	283	293
Telephone and Telegraph Equipment	22,557	26,061
Fiber Optic Cable	713	822
	46,100	53,000

The year 1996 was the third straight year that United States factory sales have seen double digit expansion. The 1996 Telecommunications Act will create new opportunities for growth due to the expected impact of the deregulation on the U.S. economy. The 1996 U.S. trade surplus in telecommunications equipment was $4 billion with exports of $17 billion, or slightly over 25% of production.

While the traded stocks in the telecommunications group on Wall Street have been on the defensive for the last few months due to concern over the unsettling events in the Asian and Latin American markets, the long-term outlook remains bright. Explosive growth in the soho (small office/home office) market, deregulation of the telecommunications industry, demand for increased bandwidth to facilitate high speed data, and increasingly complex audio/video transfers and opportunities to exploit underdeveloped foreign markets should enable the group to post average annual growth of 20%-25% over the next five years.

II. INTRODUCTION - TELECOMMUNICATIONS SITES

The telecommunications site application in many ways is completely different from the RV and boating application as telecommunications services are needed by virtually all of the population including those on the "grid", those in outlying and rural areas and even people traveling through these areas that require telecommunications services. RVs and boats are used by segments of the population for part-time recreational pursuits and in some cases are short-term living arrangements.

There are some common aspects, which is the reason telecommunications was integrated as part of this study. The remote sites (those not connected to the grid) require their own power sources, similar to the RV or boat when they are not connected to "shore power." Remote sites would be connected to the grid if available, but generally the cost to extend service to these locations is prohibitive (a recent connect by American Tower Systems cost $100,000 per mile), and alternative power sources must be used. Similar to the RVs and boats, the main power users are the air conditioning systems, radio transmitting equipment for radio, cellular and PCS (personal communication services), and microwave equipment. Because the predominant telecommunications services (telephone, local radio and television transmitting) are provided in populated areas, the sites with the major power needs are usually on the grid. With the advent of nationwide cellular and PCS service, many of the future sites that provide these services will be off the grid and will, by necessity, be provided by towers located at remote sites.

Repeater stations which relay or "repeat" the signal for various telecommunications industry applications are often located in remote places and require highly dependable DC power. Solar Photovoltaic panels working with batteries are generally the technology of choice to provide power for :

- Microwave Repeater Stations
- Telephone Cable repeater stations
- Satellite ground stations
- Radio-telephone interlink units.

Repeater stations may be powered by the electrical grid or by a generator, with the major consideration being the cost of extending the electrical transmission line to the repeater site. In cases where the repeater is at a remote location, the cost is often prohibitive. Generators could be used, but they are generally not dependable for unattended operation such as would be required at a remote site. The power requirements vary greatly with some of the variables being the number of different carriers, the different kinds of service, the distance from the last tower, and the nature of the equipment configuration.

Three major sources of electrical power—photovoltaics (solar), batteries, and generators—are used by these remote sites, with the choice based on the power requirements and access restrictions of the individual site. Those sources are also used as backup (primarily batteries and generators) for sites on the grid in the event of power failures. Field research indicated that even though many of the telecommunications sites were on the grid, there were significant numbers of power failures which required either large battery backup systems or generator backup.

The greatest advantages of the fuel cell in this application would be the reliability, the lower maintenance, and the longer life. The efficiency factor provided by SERC indicate significant fuel savings if a propane driven fuel cell was used. The quiet operation and lower pollutant level may not be as significant a factor in a remote site, or in general, as many of the large "on grid" sites are located outside of urban residential areas. Fuel availability is not a major issue, as an existing or proposed site would have either a propane or natural gas storage tank if designed with a generator, and arrangements would have been made to deliver fuel. Cost, product availability, and size of the fuel cell (based on the limits of this study) are issues. In order to demonstrate that the benefits justify the higher cost, an actual demonstration or an onsite test at one of the facilities is necessary. This request was made by several of the motorhome manufacturing companies, by GTE and by American Tower Systems (manager of large multi-purpose sites around the country).

III. TYPES OF TELECOMMUNICATIONS APPLICATIONS

1. Power for Remote Sites

Remote communications links are required in very diverse environments, from mountain tops and large hills to long stretches of prairie and desert. Throughout the mountainous areas of the U.S. and Canada, a number of microwave repeater stations use generators to operate television and radio transmitting equipment. Smaller sites that require DC power use solar panels with batteries. Siting facilities in this manner enables communications signals to reach areas that otherwise are located in topographical "shadows." These repeater sites are also used to send signals across long stretches of prairie and desert.

If the solar photovoltaic system (solar panels combined with batteries) can provide the power requirements, it is generally preferred. PV offers high reliability, eliminates fuel or water delivery requirements, matches efficiently the requirement for power to load, and boasts low maintenance requirements. Generators are not dependable for unattended operation and require periodic fueling and maintenance.

The predominant existing remote telecommunication applications are:

- Radio and Television Repeater Stations
- Telephone Microwave Stations
- Telephone Cable Repeater Stations
- Cellular Towers to achieve remote coverage
- PCS sites - although many of these are low level building top sites on the grid
- Emergency Services Communications
- Military Communication Services
- Satellite Ground Stations

Other related remote Power Needs

- Environmental Monitoring
- Navigational Aids (airplanes)
- Buoys and Lighthouses (Marine)
- Remote Airstrip Landing Lights

2. Backup Power for Sites on the Grid

A. Multi-purpose Commercial Communications Sites

As telecommunications applications have increased in recent years, there are a number of private commercial vendors who specialize in developing full service communications sites with antennas, towers, equipment storage buildings, grid connections, and standby power equipment that are available for use by different types of telecommunication service providers. These companies, essentially, are real estate acquisition and property management companies with their expertise being in the telecommunications field. They provide site acquisition, site development, site marketing, and site management. The majority of these sites are large power users and generally on the grid, although many companies are looking into remote sites for nationwide cellular and PCS applications.

A typical site (if there is such an animal) includes a tower and an equipment building containing 3-4 PCS sites, some cellular sites, and a dozen paging company sites. Various telecommunications companies rent space at these sites. This concept has proven popular since the emerging telecommunications technologies, while different, all need a site with a tower and power and economies are realized when vendors share with others rather than building their own. Prior to deregulation, most of the telecommunications service providers built and maintained their own sites necessary to provide basic services for their territories and local areas. With the rapid increase in types of service and service providers, the local land use regulatory authorities have rejected the proliferation of towers in favor of one larger complex that can serve many different needs. Many of the sites have substantial radio transmitting equipment generating heat while operating, requiring air conditioning and associated large power needs.

A site of this size would normally be on the grid but would have backup generator capacity typically in the range of 45 to 100kW. The generators are either diesel or propane, with propane being the preferred fuel due to the problems and regulations involved with storing diesel fuel. Propane tanks installed on these sites store up to 500 gallons and usually last for a year. The generators are manufactured by either Onan, Generac, or Kohler. Generac has a specific division dedicated to Telecommunications Power Systems. The generators are run weekly on a test basis to insure that they are maintained and ready in the event of a problem with the grid.

Most sites have a transfer switch that shuts off the grid power and immediately starts the generator. If the generator does not start, the switch connects again to grid power. Most of the tenants at these sites maintain emergency backup batteries in their equipment storage areas in the event that the generators malfunction. Some of the generators in larger sites are tested daily, and reliability problems and maintenance are a major concern of these site managers.

B. Single Purpose Telecommunications Sites on the Grid

Prior to the expansion of telecommunications services in the mid 1980's (cellular, paging, multiple long distance carriers, and now PCS) and the deregulation following the AT&T breakup, most of the telecommunication service providers acquired, developed, and managed their own sites which were all on the grid. The largest application was telephone service with backup power being provided by batteries.

Field interviews and on-site central office visits with GTE resulted in the determination that <u>all</u> of their sites are on the grid and <u>all</u> backup power is provided by massive battery banks. In extreme emergency occasions, they will transport portable generators to their sites to recharge the batteries Battery life expectancy and cost is a major concern in extreme climate conditions either hot or cold.

C. Mobile Telecommunication Applications

Mobile generator power to provide remote communications is more in demand than ever before for a variety of applications for civilian, emergency, and military. Examples are on-the-spot reporting by news crews, emergency communications during fires or other natural disasters, and remote military training exercises. Users need a reliable, user friendly power source that can accommodate a variety of demands. Mobile generators typically start at 2kW and are as large as 20kW with various fuel options of diesel, gasoline, and liquid propane.

IV. Observations and Conclusions

The power needs of telecommunications service providers vary greatly depending on the type of service and configuration of equipment provided at the sites :

- Repeater and other small off-the-grid remote sites—low power needs usually provided by solar equipment or batteries.
- Larger remote towers with radio transmitters—frequently will have a generator, usually diesel, however propane is becoming more popular.
- Single vendor sites—usually on the grid with battery backup.
- Multi-purpose commercial sites managed by a independent company where various service providers rent tower and equipment storage space. These sites are typically on the grid with large generator backup. With the increasing demand for nationwide telecommunications service, specifically cellular and PCS, there will be an increased demand for remote off-the-grid multi-purpose sites in order to have continuous coverage areas. After the tower location is determined, an evaluation will be made whether the cost to connect to the grid is feasible, or if a remote site with alternative power creation makes sense.

If the electric grid is available, that would naturally be the first choice. If a remote location is desired, there are companies and software programs available that, given the exact specifications of the electronic equipment being used, the type of service, and the service level desired, can evaluate and determine the correct power system. These models would evaluate the economics, suggest system configurations, and summarize performance levels of different combinations of photovoltaics, batteries, and generators.

Unlike the boating and RV applications survey, market segments for remote or even on-grid sites could not be easily identified due to numerous variables relative to service provided, type of service, equipment configuration, single use or multi-use site, etc. It is clear that the large multi-purpose sites on the grid would have backup power needs that exceed the scope of this study, but would have interest in a reliable and efficient alternative to their current backup systems. Other sites that require 5kW or less would consider an alternative to their expensive batteries, photo-voltaic systems, and unreliable and maintenance-intensive generators. The majority of the smaller sites would have either batteries or photo-voltaic systems.

In discussions with the various service providers, it was clear that the number of existing sites would be hard to determine based on the reasons previously stated. Estimates of large multi-user sites ranged from 2000 to 3000 throughout the country with single-user vendor sites at 5000 to 7000. The majority of the sites with significant telecommunications equipment are currently on the grid, with backup power needs representing their main concern.

This portion of the study, once again, underscored the need for an actual product to demonstrate. GTE, Compact Radio, and American Tower Systems specifically expressed interest and a desire to test a prototype. Their power needs are all different, but a working prototype would enable potential users to establish some benchmarks both in reliability and efficiency.

Based on the initial assumptions, a prototype should create interest due to the proposed reliability, low maintenance, and projected fuel efficiency of the fuel cell. Cost numbers could then be factored against the fuel savings, the lower equipment maintenance costs, and lower service personnel and related overhead costs over a period of time. In addition the quiet operation and low pollution levels, while not as relevant in this application, would probably allow for some premium which could be included in the calculation.

The fuel cell will cost significantly more per watt generated than currently available power sources, but its longer life expectancy, increased reliability, and lower operating costs could justify a higher initial investment. This number can be determined and refined as actual production draws closer. Until the product is available, it is impossible to estimate a market for this industry due to the rapid changing technology and site configurations which could be significantly different in two years.

Additional investigation into emergency communications equipment might result in a further estimate of market potential but, again, until a prototype is available to compare against existing technology, this cannot be adequately determined.

SUMMARY

Summary

To determine the feasibility of small PEM fuel cells as a power source for the markets in this study, it is necessary to consider the benefits to and concerns of the target markets, identify segments of these markets that would be potential consumers, determine what the existing and competing technology is, and calculate the market potential.

Benefits

1. Quite Operation

The RV users that camp in a campground without hookups would rank this as the most important benefit. The remote telecommunications site would probably rank this as the lowest priority. Sailboat users would rate this benefit highly, but in many cases they would utilize batteries if anchored at a remote location where shore power was not available.

2. Efficiency

All segments would rank this highly, especially remote telecommunications sites where improved fuel efficiency would reduce fueling trips. Although there is easier access to fuel for boats and RVs , more efficient operation would reduce costs and might encourage new users.

3. Lower Maintenance

Remote telecommunications sites would rank this either first or second, as maintenance is a major concern due to location and accessibility. As RVs and boats are used more on a recreational basis, they generally do not require as much maintenance on existing systems and would often be serviced before a long trip or cruise.

4. Less Pollution

This would be a high ranking benefit for both the RVs and boats as an enhancement of the recreational experience. Remote telecommunications sites wouldn't be as concerned with this aspect.

5. Lighter Weight

This is an added benefit that could reduce overall fuel consumption in RVs and boats, but would not be a significant factor for remote telecommunication sites.

Concerns

1. Cost

The projected cost of $2-3 per watt is substantially higher than the current cost of generators, batteries, and other forms of alternative energy. The recent proposed cost of 79 cents per watt for the fuel cell cars, once they are in mass production, would be more competitive with the existing current technologies. This would certainly be the major concern in the boating and RV industries where there are a number of competing companies and cost considerations offset proposed benefits. The recent publicity regarding fuel cell powered cars should be a positive in gaining market acceptance. Cost is also a big issue with the telecommunications companies, but the trend to large multi-purpose sites results in larger power demand than the scope of this study allows for consideration.

2. Product Availability

The benefits realized by manufacturers and sales persons created interest in the proposed product which typically wanes when there is no product to demonstrate. The telecommunications people that were interviewed were extremely interested in testing a prototype, either at a site or on a simulated test basis. The same request was received from the major RV manufacturers where it would have been tested in their research labs.

3. Fuel

With the exception of the power boat segment which uses diesel or gasoline, all of the other market segments studied are already using propane. There were some concerns expressed by the RV and sailboat market about using hydrogen, and also about availability. This issue will disappear if a hydrogen infrastructure is developed to support fuel cell powered automobiles.

4. Safety

There is some concern about adding more propane capacity or hydrogen in the future by the RV and sailboat markets.

Market Potential

1. Boating

The majority of the power boats that use generators have needs that require units over 5kW, which puts them outside the scope of this study. In addition, they all use diesel or gasoline—as there is an aversion to propane—and currently none of the major generator manufactures make a marine propane generator.

Based on the 1996 production numbers, there were approximately 2000 sailboats produced over 30 feet, with 500 of those over 40 feet. The units between 30 and 40 feet typically do not have generators, and their electrical needs can be supplied by batteries which are quite often recharged by running the engine for an hour a day (often while motoring in or out of a marina), or other acceptable alternatives. The sailboats over 40 feet would be the higher priced cruising yachts which would typically use shore power, either at their home base or at their destination, with minimal use of the generators unless there were major temperature fluctuations. The sailboats that did go on long cruises would probably have diesel or gasoline generators larger than the scope of this study. As this is primarily a recreational market, the estimate is that only 10%, or 50 of the larger sailboats would be interested in this technology.

At this time we believe that there is no substantial market potential in the recreational boating area, as the current electric power sources are adequate and the projected cost of a fuel cell would be too high, even with some of the proposed benefits. Once the price becomes competitive with batteries and other alternatives, this market can be examined again. At this point the high initial investment would not be offset by the projected benefits.

2. Recreational Vehicles

The market potential here would be in the Class A and Class C motorhomes, most of which currently use gasoline generators, and use propane for cooking, refrigeration and heating. The high-end diesel-powered motor homes have larger than 5kW generators that are used primarily for air conditioning during travel from one destination to another. These RV enthusiasts usually park where hookups are available, and would not be interested in remote camping where the noise factor from existing competing technology would be a concern.

Of the approximately 50,000 units of Class A and Class C motorhomes shipped in 1996, 40,000 would be priced under $100,000 and would fit into the target market. Many of these units would go to parks with plug-ins. It is assumed, however, that at least 25% would utilize remote locations and National Parks, where plug-ins are not available and noise restrictions would prohibit generator use after certain hours. If a quieter system was available this percentage would increase substantially.

Despite the proposed benefits of the fuel cell system, the main obstacle to this market would be cost. Generators installed in new units cost approximately 50 cents per kW with aftermarket generators costing slightly more. As this is a recreational product used only occasionally, many generators—if maintained properly—will last almost as long as the projected vehicle life.

It is our belief that there is a market potential here of 10,000 units per year if the cost can be reduced, and a prototype can be produced which would demonstrate to major RV manufacturers the quiet operation, improved fuel efficiency, and lower maintenance. Once the RV manufacturers were convinced, and began production of new units with fuel cells, aftermarket demand would appear as existing owners would desire the same benefits. This market segment should be helped by all of the recent publicity regarding the fuel cell powered cars.

3. Remote Telecommunications Sites

As we have discussed earlier, market segments for remote or on-grid sites could not be easily identified or quantified due to all the variables relative to service provided, types of service, equipment configuration, and single use or multi use site. The TIA (Telecommunications Industry Association) was unable to provide site information, and only had available information regarding sales of different kinds of equipment. It is clear that the multi-purpose sites would have larger requirements than the scope of this study.

At this time the majority of the single and multi-purpose sites are still utilizing grid power, with the fuel cell application seen as a backup power replacing either large battery banks, generators, or small photo-voltaic devices. The proposed benefits of higher operating efficiency, lower fuel cost, and lower maintenance which would be an offset to the expected higher cost, did create interest in the parties surveyed. The key issue here is product availability. A prototype unit that could be evaluated in comparison to a generator, battery bank, or photo-voltaic system would enable the telecommunication service providers to assess the cost versus the benefits of the technology.

It is impossible at this time to estimate a market potential for the product in the telecommunications industry. The technology the industry uses is changing so rapidly that projecting use two years into the future when the fuel cell would be available, cannot be done.

4. Aftermarket Applications

Based on the results outlined, it appears that the only significant aftermarket application would be in the RV segment. Once manufacturers had successfully added an optional fuel cell generator, an aftermarket would appear for kits to replace existing generators with fuel cell units. This would be especially true for those vehicles bought within the last five years by "early adapters" who were interested both in the benefits of new technology, and also had a vehicle that still maintained sufficient value to make an investment of this size reasonable.

It is estimated that approximately 5000 RVs per year, on average, would convert; with the number increasing each year. This estimate would increase if the benefits are as projected, as user acceptance would induce the less adventurous to try it, particularly those that are interested in remote locations but disenchanted by the noise of generators.

At some point in the future, when the fuel cell is a proven energy source in RVs, some of the boating "early adapters" who first utilized solar and other alternative energy sources would have an interest, but the numbers would be significantly smaller.

Once the product is available, there should be some interest in the telecommunications market as it would not require any special configuration as may be needed in the RV and boat market. At that point, if the projected benefits are attainable and the cost was competitive, these companies would be able to justify the higher initial investment.

APPENDIX C

ESTABLISHING A FUEL CELL MANUFACTURING FACILITY IN THE COACHELLA VALLEY

1. Benefits

The Coachella Valley currently maintains a permanent population of approximately 300,000 residents. Only 25% of the land is developed and land costs are a fraction of those in Los Angeles, Orange or San Diego counties. Complete build out for the valley is not expected until the year 2030, at which time a population of 800,000 is projected. In addition to the low land costs, there is an ample water supply, a motivated and capable work force and utilities are available at competitive rates--especially in the eastern end of the valley where the State of California designated Enterprise Zone is located.

The valley also provides easy access to major markets. The Los Angeles, San Diego and Orange County metropolitan areas are within a 2 1/2 hour drive, and the Phoenix and Las Vegas metropolitan areas are within 4 hours. The clean air, abundant recreational opportunities, lower crime rates, and reduced urban congestion are attractive to businesses and to the professionals that would staff those businesses. Once the facility is operational, it is expected that the local educational institutions will establish a curriculum that would result in qualified personnel being available at the local level.

The City of Palm Desert, located in the geographical center of the valley is one of the world's top resort destinations but has also taken a leadership role in the development and commercialization of fuel cells, currently maintaining the largest fleet of operational fuel-cell vehicles in the world. The College of the Desert in Palm Desert has an established ETTC (Energy Technology Training Center) and curriculum, is developing a Tech-prep program to initiate an alternative energy training in the local high schools, and an alternative fuels curriculum is expected when the Coachella Valley branch of the California State University system is established in Palm Desert in the year 2000.

The Coachella Valley has received a " Clean Region" designation because of its leadership in alternative fuel applications. The local transit system, SunLine Transit, has converted all of its buses to CNG from diesel and gasoline, and is currently experimenting with mixtures of hydrogen and CNG. Fuel cell busses are expected to be integrated into their fleet by the year 2001. In addition, one of the major school districts, Desert Sands, has converted from diesel buses to CNG with other school districts to follow. The region has received a Research & Development contract through the National Automotive Center to establish an Alternative Propulsion Systems Research Institute and a grant from the National Science Foundation to train students to service and maintain fuel cells.

2. Tax Incentives

The State of California designated Enterprise Zone is located North and East of Palm Desert. There are a number of California State tax credits that would be applicable to the proposed facility if located in this Enterprise Zone.

a. Enterprise Zone Sales Tax Credits

Businesses may claim a state income tax credit equal to the sales and use taxes paid on the first $20 million of qualified new machinery and equipment purchased each year. Equipment used to manufacture fuel cells would qualify for this credit.

b. Business Expense Deduction

The cost of qualified business property (tangible personal property used exclusively for business) purchased for use in an enterprise zone may be deducted as a business expense in the first year it is placed in service. The maximum deduction is the lesser of 40% of the cost or $40,000.

c. Hiring Credit

A tax credit of up to 50% of qualified wages with a maximum of $19,000 per employee is available. This credit is reduced each year of employment, however excess credit can be carried forward to future years.

d. Net Operating Loss Carry-over

Net Operating Losses can be carried over to future years to reduce the amount of taxable income for those years.

State and Local government also provides incentives whether the business is located in an Enterprise Zone or not.

a. State of California Investment Tax Credits

In addition to Enterprise Zone benefits, manufacturers may receive a six percent state tax credit for purchases of qualified machinery and equipment. This credit can be carried forward for at least seven years.

b. Recycling Market Development Zone

Much of the Coachella Valley is included in a RMDZ. These zones provide special opportunities for businesses that recycle materials or use recycled materials in their manufacturing processes. The major benefit is low interest loans for buildings, equipment and working capital.

c. Research and Development Tax Credits

Businesses engaged in R & D receive a credit to apply against their tax liability of up to 12%.

d. Miscellaneous Local Incentives

Local governments have the legal authority to rebate taxes, reduce or waive fees, defer fees, assist with infrastructure improvements, provide rent subsidies, etc. The decision on these actions is made by the applicable unit of local government. Besides the state and local tax incentives, the close proximity of the Enterprise Zone to the Palm Desert area where the major educational resources are located, would make this the logical location for a new manufacturing facility.

3. Projected Cost Information

a. Site

It was assumed that a start-up assembly operation would require 5000 square feet of space, 4000 square feet for manufacturing or assembly and storage, and 1000 square feet for administrative and office staff. Estimated cost would be $0.30 per square foot for manufacturing, or $1200 per month, and $0.60 per square foot for administrative space, or $600. Total cost would be approximately $2000 per month, which includes a charge for common areas and provided services (janitorial, security, trash, etc.) of $200 per month.

b. Personnel (Local rates for assumed job classifications)

Realizing that personnel is determined by the size and output expected from the business, the information provided includes the annual cost by category of positions expected at start up.

Category	Hourly	Monthly	Annually
Engineer		$6,000	$72,000
Tech Assistant		$2,600	$31,200
Assembler (entry level)	$8.00	$1,400	$16,600
Assembler (experienced)	$12.00	$2,080	$25,000
Clerical	$9.00 (avg.)	$1,560	$18,700

Standard benefits represent 33% of the gross income for each employee.

c. Utilities

Local utility service would provide for the expected needs of a high-tech manufacturing or assembly business. Electrical service is available at competitive rates (less than 8 cents per kW hour), state-of-the-art telecommunications facilities are maintained by GTE which will provide high-speed modem, ISDN and T-1 lines. Fiber optic high speed cable modems will be available in the near term. Even though the environment is classified as desert, plentiful water supplies are available to meet the needs of any manufacturing or assembly operation.

d. Office Overhead

Office furniture and equipment, office supplies, telephone, postage, overnight parcel service and miscellaneous office expenses would be similar to other areas of the country.

e. Transportation Availability

Air freight, trucking and rail services are available in the Coachella Valley at competitive rates. The 5kW unit will weigh approximately 110 pounds and will be approximately 3.5 cubit feet.

(1) Air Freight Overnight Delivery Options

(a) Airborne - Largest package limited to 260 pounds, with maximum size of 5.5 cubic feet.

(b) UPS - Largest package limited to 150 pounds.

(c) FedEx - Largest package limited to 150 pounds but offers a bulk shipping division if more than one unit needs to be shipped.

(2) Trucking

If overnight delivery were not required, either a freight forwarding company could be used for multiple units; or a local trucking company could be used for shipping single units. The delivery time would depend on the destination. Major trucking companies available in the Coachella Valley include:

(a) Bedford Freight - An LA based freight forwarder that could be used for multiple unit deliveries or full truckloads from the manufacturing site to a purchaser.

(b) Conway Western Express - A local Indio-based company would deliver individual units only, with the units being transferred to other truckers in their system.

(3) Rail Freight

Service is available at two locations in the Coachella Valley. This option would be used for shipping multiple units.