Final Technical Report[1]
Part 1

Contract Number: DE-FG36-08GO18113

Award Recipient: South Carolina Hydrogen and Fuel Cell Alliance

Project Title: Development of Hydrogen Education Programs for Government Officials

Project Director: Dr. Shannon Baxter
South Carolina Hydrogen and Fuel Cell Alliance (SCHFCA)
P.O. Box 12302
Columbia, SC 29211
Phone: (803) 727-2897
Email: baxterclemmons@schydrogen.org, baxter@rackcorporation.com

Project Team and Principal Roles on the Project:

South Carolina Hydrogen and Fuel Cell Alliance
- Prime Contractor with DOE
- Education and outreach activities

Greenway Energy, Aiken, SC
- Subcontractor/Technical Subject Matter Expert (Tasks 1-3)

Advanced Technology International (ATI) dba SCRA Applied R&D
- Project Team Leader (Tasks 4-9)
- Program, financial and subcontract management

[1] This final technical report encompasses work conducted across two different sets of tasks, and two different contract vehicles. Contract vehicle #DE-FG36-08GO18113 funded three tasks under the title "Development of Hydrogen Education Programs for Government Officials," and the first six tasks under the title "A Feasibility Study for Producing Hydrogen from Landfill Gas to Operate Fuel Cell Powered Materials Handling Equipment (MHE)." The final task under the title "A Feasibility Study for Producing Hydrogen from Landfill Gas to Operate Fuel Cell Powered Materials Handling Equipment (MHE)" was funded under Contract Vehicle #4F-31542.

Additional Subcontractors to Advanced Technology International (ATI) dba SCRA Applied R&D (Tasks 4-9):

Gas Technology Institute

Technical lead for LFG cleanup and hydrogen production systems Support for Feasibility Study

Ameresco, Inc.

Technical Lead for Feasibility Study

Coordination of site preparation activities for all project equipment

BMW Manufacturing Company

Host site

DOE Managers (Headquarters and DOE Golden Office):

DOE Technology Development Manager (Tasks 1-3): Christy Cooper
E-mail: Christy.Cooper@ee.doe.gov

DOE Technology Development Manager (Tasks 4-9): Pete Devlin
E-Mail: Peter.Devlin@ee.doe.gov

DOE Project Officer (all tasks): Gregory Kleen
E-mail: Greg.Kleen@go.doe

Project Start Date: 1 October 2008

Project End Date: 31 January 2014

Final Technical Report[2]
Part 2

Contract Number: 4F-31542

Award Recipient: Advanced Technology International dba SCRA Applied R&D

Project Title: A Feasibility Study for Producing Hydrogen from Landfill Gas to Operate Fuel Cell Powered Materials Handling Equipment (MHE)

Project Director: Russ Keller
Advanced Technology International, dba SCRA Applied R&D
315 Sigma Drive
Summerville, SC 29483
Phone: (843) 760-4358
E-mail: russ.keller@scra.org

Project Team and Principal Roles on the Project:

Advanced Technology International (ATI) dba SCRA Applied R&D
- Prime Contractor with ANL
- Project Team Leader
- Program, financial and subcontract management

Gas Technology Institute
- Technical lead for LFG cleanup and hydrogen production systems
- Support for Feasibility Study

Ameresco, Inc.
- Technical Lead for Feasibility Study
- Coordination of site preparation activities for all project equipment

BMW Manufacturing Company
- Host site

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DOE Managers (Headquarters and Argonne National Laboratory):

HQ: Pete Devlin [Peter.Devlin@ee.doe.gov]

ANL: Shabbir Ahmed [ahmeds@anl.gov]

Project Start Date: 31 January 2014

Project End Date: 31 August 2014

Final Technical Report – Part 1
1 October 2008 – 31 October 2011

1.0 EXECUTIVE SUMMARY

Background for the project concept. Hydrogen and fuel cell technologies are moving out of the laboratory and into economically competitive niche markets such as cell phone tower back-up power and forklift operations. As hydrogen technologies become competitive in these early markets, communities will need to be educated about the opportunities afforded by hydrogen technologies and about safety concerns associated with them. The Hydrogen 101 program led by the South Carolina Hydrogen and Fuel Cell Alliance (SCHFCA) was designed to raise awareness about hydrogen and fuel cells to community leaders within South Carolina and the Southeast US.

How the research adds to the understanding of the area investigated. This project contributes to achieving five of the critical DOE education milestones from the Education section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Develop set of introductory materials suitable for a non-technical audience.
- Develop materials for community seminars.
- Hold community seminars to introduce local residents to hydrogen.
- Hold "Hydrogen 101" seminars.
- Evaluate knowledge and opinion of hydrogen technology of key target audiences and progress toward meeting objectives.

2.0 PROJECT ACCOMPLISHMENTS VERSUS GOALS AND OBJECTIVES

The over-arching objective of this project was to improve basic understanding among public officials whose responsibilities include developing policies and regulations pertaining hydrogen and fuel cells, improve basic understanding of hydrogen and fuel cell concepts among stakeholders and the general public, and to prepare local communities for the roll-out of hydrogen and fuel cell technologies in those early markets where they offer a value proposition compared with incumbent technologies.

The project consisted of three tasks:

- Task 1: Hydrogen Education for State and Local Government Officials
- Task 2: Hydrogen Education for Codes Officials
- Task 3: Facilitate Cooperation and Best Practices within Southeastern States

Goals within these three tasks included:

- Synthesize objective and technically accurate information that will be made available to a wide audience through the Internet, a national meeting, and training sessions.
- Design and develop educational programs that will clarify the benefits and challenges of moving to a hydrogen economy that avoid over-selling hydrogen technologies.
- Train a group of hydrogen educators at the project team institutions (The South Carolina Energy Office, The State Fire Marshal's Office, the SCHFCA and Greenway Energy) who will be resources on hydrogen and fuel cells to the target audiences.
- Develop relationships with government consortium groups and associations.
- Leverage relationships with project team organizations in South Carolina to deploy hydrogen education materials to government and code officials.
- Institute recurring statewide events to provide public officials with opportunities to view the latest hydrogen and fuel cell technologies.
- Establish direct lines of communication with individual city, county and state officials to disseminate important hydrogen and fuel cell information through project partners existing communication resources.
- Continue to raise public awareness and acceptance of the benefits of hydrogen and fuel cell technologies in order to increase interest in the adoption of hydrogen and fuel cells.

3.0 SUMMARY OF PROJECT ACTIVITIES

3.1 APPROACHES USED:

The project team was comprised of South Carolina-based hydrogen experts having connections to technically accurate information, and civic organizations and associations having the communications networks and events with our target audience already established. The entire team worked together to identify specific messaging of interest to the local audiences and sub-audiences. Based on the feedback we gathered from the civic organizations and other community opinion leaders, we developed education materials and demonstrations.

We conducted the marketing of the project through the existing web sites, e-mail distribution lists and communication networks. We distributed the materials primarily at the events associated with each of the civic associations partnered on the project, although we did conduct several stand-alone events and webinars.

3.2 Project Accomplishments

Key project accomplishments by fiscal year include the following:

- Fiscal Year 2009
  - Created 97 slides and four class demonstrations for use as needed based on the interests of the particular audience being addressed. The materials created were based on audience tastes as indicated by project partner representatives.
  - Reached 120 state and local government officials and d**ecision makers.**

- Fiscal Year 2010
  - Conducted in-person presentations to over 20 groups of targeted South Carolina decision makers.
  - Held eight Webinars to provide information to stakeholders throughout South Carolina.
  - Reached 1,446 targeted additional state and local government officials and decision makers.
  - Created a SlideShare channel through which Webinar presentations can be viewed.
  - Placed hydrogen education videos on the SCHFCA YouTube channel.
  - Developed over 20 topic specific slides that included value proposition for telecommunications, permitting of fuel cells, etc.
  - Produced a tri-fold handout that summarizes key messages with a fun quiz.
  - Maintain a Web site that keeps a running log of industry news and allows access to fact sheets at www.schydrogen.org.
  - Updated fact sheets that are easily understandable for a wide audience and some are targeted to specific audiences.
  - Hosted two "Lunch-and-Learn" activities, one for state educators and another for staff on the state capitol grounds.
  - Made presentations to groups including: the South Carolina Municipal Association, the South Carolina Association of Counties, Councils of Government, law firms, gubernatorial candidates, and mayoral candidates.
  - Utilized Hydrogen 101 materials in wider public education efforts that reached additional stakeholders.
  - Supported through educational efforts the passage of the South Carolina Hydrogen and Fuel Cell Permitting Act that is now law. The law in South Carolina and the movement to win support can serve as a case study for other states that want to implement central permitting authority at the state level, as recommended by industry.

- Fiscal Year 2011
  - In person presentations to over 30 groups of targeted South Carolina decision makers.
  - Held three webinars to provide information to stakeholders throughout South Carolina.

    - Reached 1,744 targeted additional state and local government officials and decision makers.
    - Webinar presentations can be viewed through a SlideShare channel.
    - Videos of educational information on hydrogen are available on the SCHFCA YouTube channel.
    - Developed case studies on early markets for hydrogen and fuel cell technologies including: fuel cell lift trucks, combined heat and power, and telecommunications backup power.
    - Presentations to groups including the National Congressional Candidates, Gubernatorial Candidates, State House and Senate Candidates, Head of the South Carolina Department of Commerce, Agency heads at the South Carolina Department of Health and Environmental Control.
    - Hydrogen 101 materials were utilized in wider public education efforts that reached additional non-decision makers.
    - Educational efforts with South Carolina House and Senate members to demonstrate the effect of state level incentives for fuel cells and renewable technologies on creating viable markets.

- Fiscal Year 2012
    - In person presentations to over 45 groups of targeted South Carolina decision makers.
    - Featured presenter in a DOE webinar: Where the Jobs Are: Hydrogen and Fuel Cells in South Carolina.
    - Reached 21,672 targeted additional state and local government officials and decision makers.
    - Webinar presentations can be viewed through a SlideShare channel.
    - Videos of educational information on hydrogen are available on the SCHFCA YouTube and Greenway Energy YouTube channels.
    - Developed market value proposition case studies on material handling equipment (MHE) early markets for hydrogen and fuel cell technologies.
    - Presentations to groups including: national congressional candidates, staff of national presidential candidates, state house and senate members and staff, Leaders at the SC Department of Commerce, and the Coastal Conservation League.
    - Hydrogen 101 materials were utilized in wider public education efforts that reached additional non-decision makers.
    - Educational efforts with SC House and Senate members to demonstrate the effect of state level incentives for fuel cells and renewable technologies on creating viable markets.
    - Hosted the DOE Secretary Chu visit in South Carolina, which included briefing Congressman James Clyburn.

4.0 CONCLUSIONS AND FUTURE DIRECTIONS

The SCHFCA Hydrogen 101 program met all of its goals and its efforts are having an impact in creating wider support for hydrogen. Education about the effect of state level incentives on the market for fuel cell and other renewable technologies has started to show how states can grow their hydrogen economy.

Final Technical Report – Part 2
1 March 2011 – 31 August 2014

1.0 EXECUTIVE SUMMARY

Background for the project concept. The U.S. Department of Energy (DOE) has been conducting extensive research and analysis of the potential opportunities for biogas feedstocks for fuel cell applications, including both stationary fuel cells in distributed applications and transportation fuel cells. Biogas, the gaseous product of biological anaerobic digestion, is comprised mostly of methane (about 50%-70%) and carbon dioxide (30%-50%), with trace amounts of other particulates and contaminants. Methane is the second largest source of U.S. greenhouse gas (GHG) emissions, contributing about 11% of total GHG emissions, and landfills and wastewater treatment facilities contribute about 30% of U.S. methane emissions.[3]

The methane content of biogas, or bio-methane, is the usable portion of the biogas. The methane potential from landfills, animal manure, wastewater, and industrial, institutional, and commercial organic waste in the U.S. is estimated at about 7.9 million tonnes per year, which is equal to about 420 billion cubic feet or 431 trillion British Thermal Units (BTUs). While this resource potential is small relative to the supply of natural gas, it presents a "win-win" opportunity for the production of renewable energy fuel and GHG mitigation (methane is 21 times more potent a GHG than is carbon dioxide). The majority of biogas resources are situated near large urban areas -- ideally located near the major demand centers for hydrogen generation for fuel cell electric vehicles (FCEVs) and power generation from stationary fuel cells.[4]

Fuel cell manufacturers presently are deploying combined heat-and-power (CHP) applications at several sites using biogas from various sources. These deployments include food processing plants at Gills Onions and the Sierra Nevada Brewery and waste water treatment plants at Tulare, California, and the Orange County Sanitation District (OCSD) in Fountain Valley, California.[5] At OCSD, DOE has been supporting an innovative demonstration project that produces CHP and hydrogen transportation fuel from the anaerobic digester gas collected by the OCSD wastewater treatment plant. This "CHHP" or "trigeneration" facility has been producing 250 kilowatts of electricity and also producing enough hydrogen to fuel up to 50 vehicles daily at an adjacent fueling station.[6]

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[3] U.S. Energy Information Administration, 2009

[4] Additional information is available in the National Renewable Energy Laboratory's "Biogas Potential in the United States" fact sheet, dated October 2013.

[5] National Renewable Energy Laboratory, Biogas and Fuel Cells Workshop Summary Briefing, 12 June 2012.

[6] Additional information is available in the National Renewable Energy Laboratory's "Biogas and Fuel Cells Workshop Summary Report," dated January 2013.

Landfill gas (LFG) also is a potentially an attractive resource for bio-methane. Landfills are estimated to have sufficient bio-methane capacity to fuel about 3.7 million FCEVs on a daily basis.[5] The price of LFG typically is negotiated on a project-by-project basis. Anecdotally, based on SCRA's market research, this price tends to be much less than the price of natural gas – 50% or more below the market price of natural gas. This suggests the potential economics of producing hydrogen from cleaned-up LFG could be competitively attractive versus using utility-delivered natural gas and the same hydrogen production equipment. The economic potential for an attractive hydrogen fuel cost using an on-site source of LFG can be further leveraged by combining both CHP for stationary power and on-site generation of a renewable transportation fuel from the same LFG source.

The BMW Manufacturing Company in Greer, South Carolina has been using LFG from a nearby landfill to fuel four gas cogeneration turbines in a CHP application since 2003, supporting about 25% of the assembly plant's electrical needs (about 4.4 MW) and nearly all of its thermal needs. EPA awarded BMW its Landfill Methane Outreach Program "Project of the Year" for this project. BMW's original LFG project was supported by Ameresco, Inc., the original project developer, and Waste Management, Inc., operator of the Palmetto Landfill located in Wellford, SC. The initial infrastructure allowed for collecting, cleaning and compressing the LFG from the Palmetto Landfill, transporting it through a 9.5-mile pipeline to the BMW plant, removing the siloxanes from the LFG stream, further compressing and then using it as fuel for CHP gas turbine electrical generators.

In 2008, BMW began an internal assessment regarding the potential productivity gains and cost savings that might be achievable should the company design its new assembly facility at the Greer site, which was scheduled to become operational in 2010, to be supported by fuel cell-powered material handling equipment (MHE) as a replacement technology for battery-powered MHE. At that time, battery-powered MHE was deployed throughout the company's existing logistics and assembly facilities. As part of its early due diligence process, BMW reached out to SCRA for an opinion on the feasibility of this technology solution. In response to this request, SCRA provided an overview of the environmental benefits, operator safety issues and potential energy savings, drawn from DOE and other open-source information. A summary is provided in Appendix A.

BMW's due diligence confirmed the expected benefits of fuel cell-powered MHE, and the company moved forward in outfitting its new facility with the appropriate hydrogen fueling infrastructure to support approximately 100 MHE units (e.g., fork lifts, tuggers, etc.) when the new assembly facility opened in September 2010. Subsequent management decisions by BMW leadership have raised the on-site fuel cell MHE inventory to more than 300 units, representing a 100% site-wide conversion from battery power to fuel cell power. While BMW currently is purchasing hydrogen from an established industrial gas supplier, the company expressed a desire

[5] "Renewable Hydrogen Potential from Biogas in the United States," G. Saur and A. Milbrandt, National Renewable Energy Laboratory

to explore a future option where it could produce its own hydrogen, preferably from a renewable source -- and ideally as a follow-on effort to its existing LFG-to-CHP project.

While DOE was conducting its research on the potential opportunities for biogas feedstocks for fuel cells, SCRA identified an opportunity for researching the business case for on-site LFG-to-hydrogen generation through its discussions with BMW. DOE competitively selected SCRA to execute a project concept that would leverage the existing LFG-fueled CHP power plant infrastructure already in operation at BMW to assess the financial and technical viability of on-site generation of hydrogen fuel for fuel cell-powered MHE.

How the research adds to the understanding of the area investigated. Results from this project would be used to provide landfill owners and LFG-to-energy project operators a framework for assessing future projects. This framework would help identify and evaluate the economic tradeoffs between flaring excess LFG not being used for power production, and converting that gas to a transportation fuel for sale or for on-site consumption. The OCSD project validated the feasibility of a tri-generation project using wastewater biogas; this project would validate the tri-generation concept for a LFG feedstock.

The technical effectiveness and economic feasibility of the methods or techniques investigated or demonstrated. This 42-month project successfully validated that:

> (1) a financially viable business case exists for a full-scale deployment of commercially-available equipment capable of converting LFG to hydrogen under the specific operating environment at the host site (i.e., quantity of available LFG, scale of hydrogen demand necessary to fulfill on-site fueling requirements, etc.);
>
>> Specifically, at a production level of 500 kilograms of hydrogen per day, the analysis concluded that the projected cost, based upon equipment vendor quotes obtained at the time, would be approximately $4.85 per kilogram (in 2011 dollars). This cost includes compression, storage and dispensing at 350 bar. The primary cost drivers include the write-off of $4.7 million capital equipment, $4.50/MMBtu LFG input cost (delivery point post-siloxane clean-up at 275 psig and 93 degrees F), and annual O&M costs of $215,000.
>>
>> If the recently-revised (July 2014) federal incentives for renewable transportation fuels are applied, the preceding cost per kilogram of hydrogen could fall to as low as $3.93 per kilogram based upon the three-year average trend for these credits.
>
> (2) as proven at pilot scale, commercially-available gas clean-up and steam-methane reformation (SMR) equipment can convert the host site's LFG stream to hydrogen at purity levels that meet fuel cell industry standards; and
>
> (3) during an operational trial period consisting of 60-80 consecutive run-hours per piece of MHE, fueling the host site's MHE using the LFG-sourced hydrogen from the project equipment revealed no perceptible difference in fuel cell stack performance in the MHE

units as compared with fuel cell stack performance of those same units fueled with the delivered hydrogen source.

How the project is otherwise of benefit to the public. The results of this project reach far beyond the host site and its fuel cell MHE fleet. This process and technology could be useful at many LFG-to-energy projects with access to more LFG than the power production equipment requires. In such cases, the “excess” LFG could provide an additional value stream by converting it to hydrogen for vehicle, fleet vehicle or other applications. From an environmental perspective, widespread adoption of this technology solution could reduce the amount of LFG landfill operators would need to flare (and the costs associated with the requirement for flaring unused LFG), as well as reduce any detrimental environmental impacts associated with flaring.

This project is especially innovative and pioneering because of the focus on hydrogen as a transportation fuel. While LFG biogas has been used in fueling compressed natural gas (CNG) or liquefied natural gas (LNG) combustion engine trucks, this is the first project to focus on reforming biogas to hydrogen for use as a renewable fuel for fuel cell vehicles (i.e., lift trucks) on an industrial scale.

Figure 1 shows the process options for making stationary or motive power from various biogas feedstocks (including LFG).

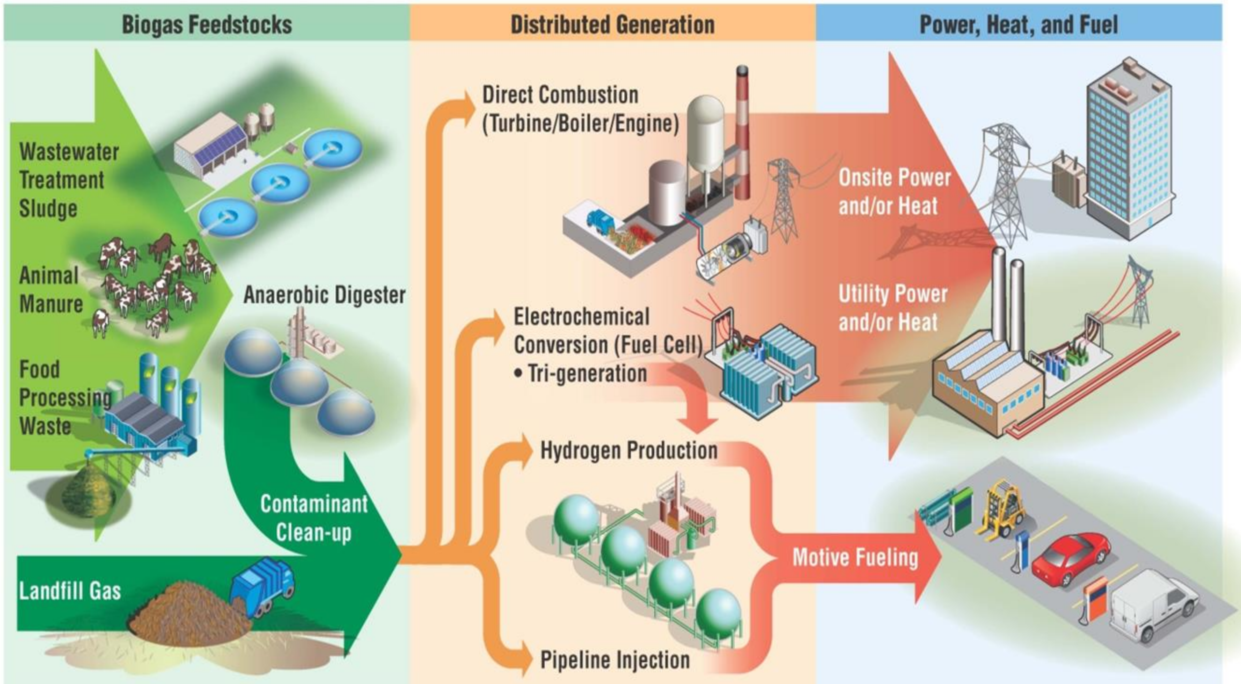

Figure 1: Biogas-to-Energy Process[7]

[7] National Renewable Energy Laboratory, "Biogas and Fuel Cells Workshop Summary Report" January 2013

2.0 PROJECT ACCOMPLISHMENTS VERSUS GOALS AND OBJECTIVES

The over-arching objective of this project was to determine whether there is a viable business case for LFG-to-hydrogen conversion technology, and if so, whether commercially-available equipment can recover hydrogen from an LFG source at sufficient purity to meet the required industry standards for use in fuel cell equipment.

2.1 Goals and objectives for the project. The project was executed in three successive phases, each dependent upon successful accomplishment of the preceding phase as a pre-requisite for moving forward to the next phase.

- The project team examined whether a business case was possible that would permit recovering hydrogen from the existing LFG source, converting it at large scale through an optimized capital equipment investment, and providing that hydrogen via a long term fee-for-services contract to the host site. The analysis compared the "traditional" cost per kilogram of delivered hydrogen versus the cost per kilogram of hydrogen produced on site using the LFG source.

- Next, the project demonstrated the technical feasibility of taking the existing LFG stream that already has been filtered, dried and pre-treated sufficiently for use in gas turbine electrical generator sets and further cleaning and purifying it to remove the remaining trace contaminants. The hydrogen was recovered using commercially-available SMR technology. The purified hydrogen from this process was analyzed and compared with hydrogen being delivered to the host site by a commercial industrial gas vendor for a period of time of sufficient duration (nominally two months) to ensure results were consistent across the normal daily or weekly variations in LFG composition at the source landfill.

- Finally, the hydrogen produced from the LFG source was compressed, stored, and distributed to a single site on the grounds of the manufacturing facility that would permit a performance evaluation using actual fuel cell-powered MHE. The performance evaluation involved:

    - gathering data during an operational trial period for hydrogen produced on-site
    - comparing that with data drawn from MHE using trucked in fuel operating under the same duty cycle
    - drawing conclusions regarding the impact, if any, of using the LFG-sourced hydrogen on MHE fuel cell durability and maintenance requirements

2.2 Actual accomplishments from the project. The project commenced officially on 17 June 2011 and completed on 31 August 2014. Actual project accomplishments are summarized by project phase immediately below.

2.2.1 Phase 1. The first phase focused on determining the feasibility and business case for a fully scaled-up equipment installation that would convert LFG to hydrogen on the host facility site in sufficient quantity to provide hydrogen for 400 MHE units. Because an initial deployment of approximately 100 pieces of MHE occurred before this project began, the host site already had arranged for delivered hydrogen to support these units.

The ultimate output from the study was an equivalent "price per kilogram of hydrogen" that would be charged to the host site in a long term fee-for-services contact sufficient to recover the capital and installation costs for the optimized equipment installation identified in the study. The feasibility study considered two alternatives:

> (1) a hydrogen production quantity equal to the smallest commercially-available SMR unit on the market (50 kilograms per day hydrogen production); and
>
> (2) a hydrogen production quantity sufficient to satisfy the maximum foreseeable hydrogen consumption demand at the host site (500 kilograms per day). This upper limit was based upon the demand signal that would result should BMW convert all its MHE units to fuel cell power, and operate each unit at the weekly "duty cycle" of 120 hours per week. Site-wide empirical data gathered prior to the start of this project showed an average consumption of 1.6 kg of hydrogen per MHE unit per day for the initial deployment of 100 MHE units.

At the time the feasibility study was conducted, the vendor base for "small-scale" hydrogen production equipment (equipment other than the large-scale systems used in the petroleum refining industry) included systems having a capacity from approximately 50 kg/day production up to 800 kg/day production. Because of the host site's specific request that the analysis address the 500 kg/day production rate the team used this value rather than 800 kg/day as the upper end for the study. The team did not investigate a third production level, mid-way between the upper and lower levels, so no conclusions were possible regarding whether the behavior of the cost per kilogram of hydrogen produced between the two analysis points was linear or non-linear.

A copy of the final version of the feasibility study is appended to this report as Appendix B. Specific results and conclusions from the study included:

- At the 500 kg/day level, with the existing LFG supply and equipment at the host facility, on-site production of hydrogen using LFG as the hydrocarbon feedstock would be cost competitive, if not advantageous, versus hydrogen sourced from vendors, produced off-site and transported to the facility.
    - Projected cost, based upon equipment vendor quotes obtained at the time, would be approximately $4.85 per kilogram (in 2011 dollars), which is based upon a LFG input cost of $4.50 per MMBtu. This cost includes compression, storage and dispensing at 350 bar. Other primary cost drivers include the write-off of $4.7 million capital equipment and O&M costs of about $215,000 annually.

- At the 50 kg/day hydrogen production level, on-site production is not cost competitive versus the delivered hydrogen alternative.

    - Projected cost, based upon equipment vendor quotes obtained at the time, would be approximately $18.90 (in 2011 dollars), which is based upon a similar cost for LFG at $4.50 per MMBtu. This cost includes compression, storage and dispensing at 350 bar. Other primary cost drivers include the amortization of $2.2 million capital equipment and O&M costs of about $50,000 annually.

- Technologies exist and are commercially available to achieve the level of clean-up required to meet specifications of hydrogen generation system providers.

- Small scale SMR hydrogen production equipment is available, but is designed for use with pipeline quality natural gas. The additional equipment required to clean-up the LFG before it can be used as a hydrocarbon feedstock for the SMR equipment is commercially-available today.

- Large scale industrial hydrogen production by SMR in the oil refining and petrochemical industry is very mature. The application of smaller scale distribution SMR equipment (< 800 kg/day production) is less mature. Future distributed SMR equipment may benefit from:
    - lower pricing from increased volume and competition within the market
    - more efficient heat reclaim strategies within the SMR process
    - improved catalyst efficiency
    - the ability to withstand hydrocarbon feedstocks with higher concentrations of undesirable constituents

- The conclusions within the feasibility report are based on a 10 year analysis. This analysis length was selected based upon vendor quotes for the expected lifetime of their gas clean-up systems gathered during the study. Data gathered from SMR vendors showed an expected lifetime of 15 years for their equipment. Using longer analysis periods likely would result in a lower cost per kilogram of hydrogen produced, assuming adequate equipment durability. This is due to the benefit of the initial utility infrastructure and installation costs being divided over the longer evaluation period. A post-completion review of this project, conducted by Argonne National Laboratory confirms that a 15-year analysis period would lower the cost of hydrogen to $15.49 and $4.21 per kg of hydrogen for the 50 and 500 kg-H2/day production levels, respectively. This analysis can be found at Appendix E.

The principal conclusion from the feasibility study was that, at hydrogen production levels similar to BMW's anticipated "full scale" hydrogen production requirement (approximately 500 kg/day), the front-end gas clean-up equipment and on-site production of hydrogen using LFG as the hydrocarbon feedstock appear to be cost competitive, if not advantageous, versus hydrogen sourced from vendors, produced off-site and transported to the end user's site.

Implication for DOE Fuel Cell Technology Program: Although the analysis presented within the feasibility study is specific to the upstream LFG equipment and actual LFG constituents at this facility, the basic principles of hydrocarbon feedstock clean-up and reformation to hydrogen should apply to other LFG sources, as well as to agricultural waste streams, wastewater systems, digester gases and other process off-gases.

Phase 1 completed on 25 October 2011.

2.2.2 Phase 2. This phase demonstrated the technical feasibility of taking the existing LFG stream that already has been filtered, dried and pre-treated sufficiently for use in gas turbine electrical generator sets, further cleaning and purifying it to remove the remaining trace contaminants, and then recovering hydrogen using commercially-available SMR technology.

Because variations from the composition of the host site's LFG stream were unknown, this phase provided for two months of testing and analysis of the hydrogen produced by the pilot scale equipment to ensure any temporal variations in LFG composition would not adversely affect the quality of the hydrogen produced on site.

The original plan for this phase envisioned designing and building a gas clean-up system capable of feeding a 15 kg hydrogen production per day SMR/mobile hydrogen production unit. This small capacity was selected to permit fueling 3-5 MHE units during the subsequent phase 3 operational trial, which the project team considered adequate for proof-of-principle. The project equipment laydown would be operated to achieve the SAE J2719 standard for hydrogen purity for use in fuel cell equipment.

- **Gas clean-up equipment.** The project tapped into the host site's LFG system downstream of the siloxane removal equipment, which provided a pressurized incoming gas stream at the inlet to the gas clean-up system. After initial collection in a pressurized "surge tank" the incoming LFG first passed through a moisture separator and fine particle filter to remove any free moisture or particulate materials. Next, the LFG is passed over two beds of activated carbon to reduce hydrogen sulfide and carbonyl sulfide, and to remove any remaining organic silicon compounds. At this point the only constituents remaining are carbon dioxide, nitrogen, oxygen and methane. A series of pressure swing adsorbers (PSAs) was used at this point to reduce the non-methane constituents to a level compatible with the inlet to the SMR equipment.

  Upon completing the design and build of the project equipment the initial gas clean-up system performance did not meet required specifications. In order to achieve satisfactory gas clean-up system performance the project team installed additional equipment, specifically a deoxygenation system, an additional PSA system leased from a different equipment vendor, and an additional compressor to improve the differential pressure across the PSA. Schematics depicting the original and final gas clean-up system components are provided in Figure 2 below.

- **Hydrogen production equipment.** The project team married the gas clean-up system to a previously-developed GTI Mobile Hydrogen Unit (MHU), a trailer-mounted, fully integrated hydrogen production and delivery system containing all necessary equipment to convert natural gas and water into high-purity, high-pressure hydrogen. The MHU was designed originally to facilitate early hydrogen-powered vehicle demonstration programs and increase public awareness about hydrogen infrastructure. The capacity of the MHU was an ideal fit for the anticipated hydrogen production required to execute the final phase of the project (operational trial).

  The MHU contained the following equipment:
  - Natural gas booster compressor
  - Natural gas desulfurizer
  - Water purification system
  - Natural gas fuel processor using high-efficiency SMR and CO shift to make hydrogen (12-15 kg/day capacity)
  - Hydrogen purifier with fuel cell quality hydrogen product gas using state-of-the-art PSA
  - Low pressure hydrogen buffer storage tank
  - High-pressure two-stage diaphragm compressor for hydrogen rated up to 7500 psig with a flow rate of 6 to 8 scfm
  - State-of-the-art high-pressure composite storage rated at 485 bar (7000 psig) arranged in three-bank storage cascade capable of storing 18.6 kg H2

  The MHU components are shown in Figure 3 below.

Phase 2 began on 12 December 2011 and completed on 31 January 2014. Detailed lab analyses confirmed hydrogen purity above the SAE J2719 standard. Specific results and conclusions from this phase included:

- Successfully fabricated a gas clean-up system that met SMR inlet purity requirements (>90% methane, <10% carbon dioxide, <3.5% nitrogen, <0.2% oxygen).

- Successfully produced hydrogen that met or exceeded the fuel cell industry standard (SAE J2719) for hydrogen purity and contaminant concentration using the upgraded on-site clean-up system and the small SMR.

- Demonstrated repeatability of results over a 3-month period (samples from October 2013 and January 2014). Copies of the full slate of gas analyses collected from the project equipment are provided in Appendix C and summarized below in Table 1.

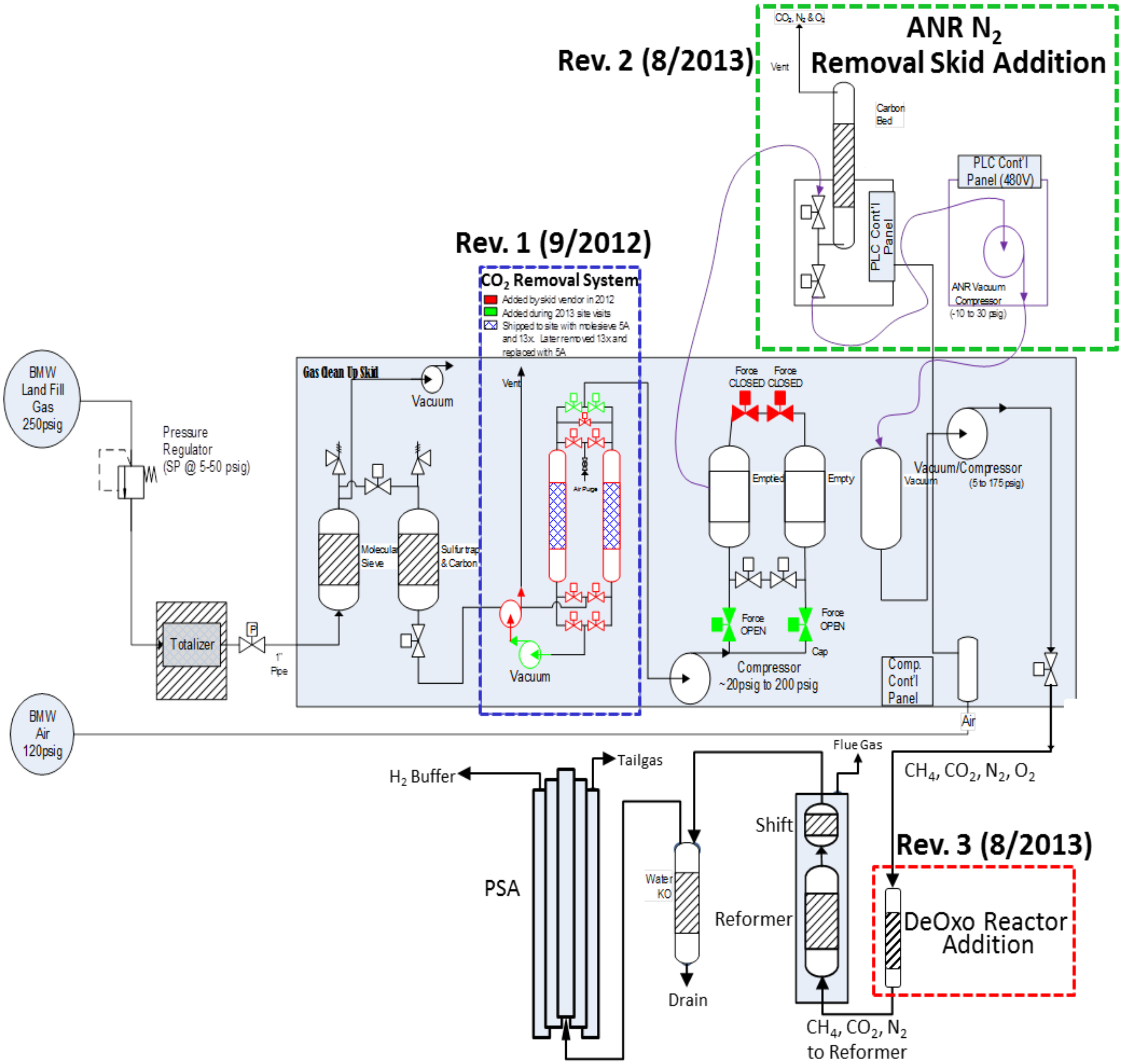

Figure 2: Gas Clean-up Componentry

Figure 3: Hydrogen Production Equipment

Constituent	Specification (umol/mol)	17 Oct 2013	14 Jan 2014
Total Hydrocarbons	2	1.4	1.2
Oxygen	5	<5	<5
Helium	300	<10	<10
Nitrogen	100	<5	<5
Argon	1	<1	<1
Carbon Dioxide	2	<0.4	<0.4
Carbon Monoxide	0.2	0.011	0.047
Total Sulfur	0.004	0.00072	0.0002
Hydrogen Fuel Index		99.99985%	99.99988%

Table 1: Project Gas Analysis Results

2.2.3 Phase 3. This phase provided for an operational trial using the host site's actual fuel cell-powered MHE units. The performance evaluation involved gathering data during an operational trial period in which several MHE units were fueled from the project equipment, and comparing that data with data drawn from pre- and post-trial data gathered from the same equipment when operating on delivered hydrogen. Post-trial assessments examined the impact, if any, of using LFG-sourced hydrogen on MHE fuel cell durability and maintenance requirements. Phase 3 began on 7 July 2014 and completed on 31 August 2014.

Prior to commencing the operational trial period the project team completed several pre-requisite actions. These tasks included:

- Installed a fueling post at the pilot facility site where fueling operations would take place;

- Started the clean-up and hydrogen production equipment, operated it at steady state, filled the 15 kilograms of on-site hydrogen storage, and then collected samples of the hydrogen to confirm the equipment was producing hydrogen consistent with the SAE J2719 hydrogen purity standards. The pilot scale equipment provided a capability to compress the hydrogen produced in the SMR to 5000 psi, store it in three storage cylinders and dispense it into the fuel cell equipment to fill the on board storage tanks to 2200 psi, which parallels the working pressures used by the host site's hydrogen infrastructure.

- Assessed the suitability of the LFG-sourced hydrogen for continued use in the host site's fuel cell-powered MHE units.

- Assured safe operations by conducting an orientation for the host site MHE operators who would be bringing their vehicles to the pilot equipment to be fueled. They paid particular attention to the unique safety and operational features of the project's fueling system compared with the safety and operational features of the existing fueling infrastructure deployed inside the host site's assembly facilities.

Once the preceding pre-requisites had been met, the team commenced the operational trial. Figures 4 through 6 below show the final pilot-scale equipment configuration and two of the MHE units that were fueled during the trial.

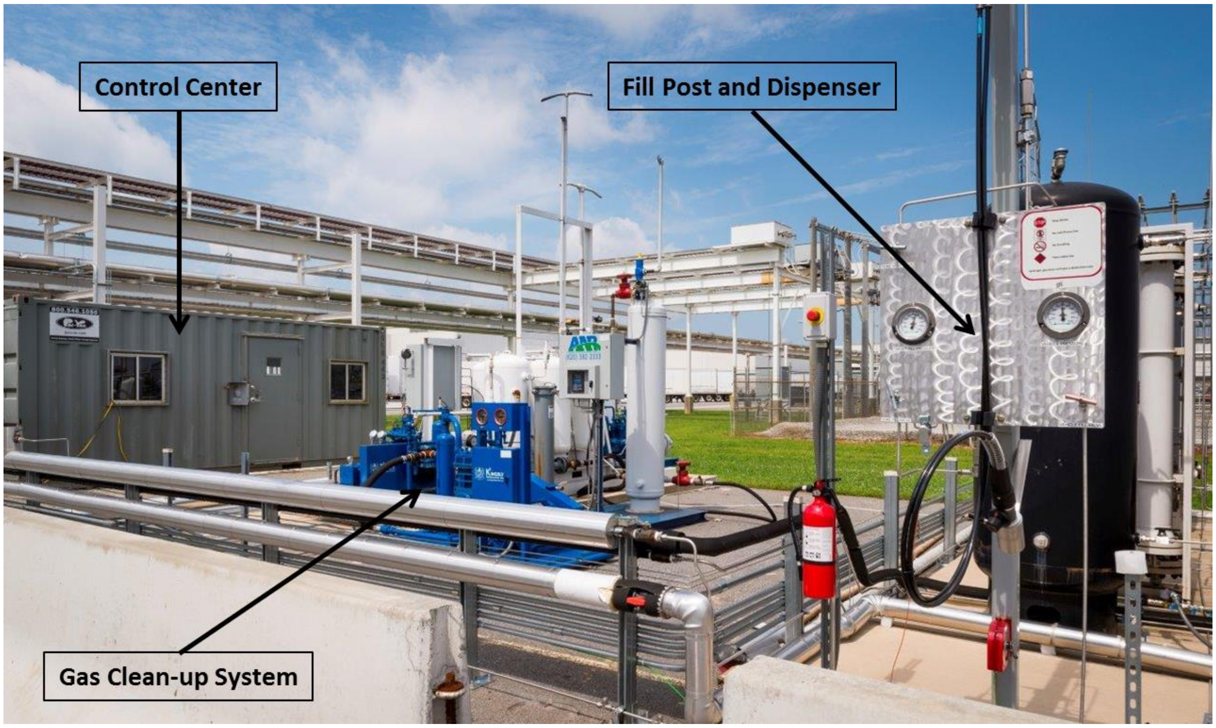

Figure 4: Pilot-Scale, On-Site, Renewably-Generated Hydrogen Production Equipment (SMR Equipment Shown on Figure 4)

Figure 5: Fueling a “Tugger”

Figure 6: Fueling a Fork Lift

Plug Power was contracted to monitor fuel cell performance prior to, during, and immediately following the trial period for each MHE unit fueled from the LFG-sourced hydrogen. The analysis conducted at the completion of the operational trial by Plug Power staff concluded that:

- The hydrogen used in the test did not damage the fuel cell and allowed for consistent stack efficiency;
- Performance of the fuel cell stacks was consistent with the beginning of life criteria; and
- The quality of hydrogen could be used effectively in the fuel cells.

A copy of the complete data analysis package prepared by Plug Power is provided in Appendix D to this report.

Upon completion of the operational trial, the project team restored the host site to its original (pre-project) condition. The only exception was that key connections / tap-ins to various services remained in place in the event the host site chooses to deploy a full-scale system in the future.

3.0 SUMMARY OF PROJECT ACTIVITIES

3.1 Project Context. The operating cycle at BMW involves two 10-hour shifts per day, six days per week, plus a single 10-hour shift on Sundays. When combined with the number of fuel cell-powered MHE units involved (>300 at the time of this report), there is potential for achieving a business case through economies of scale.

3.2 Original Premise. This project focused on leveraging the advantages of the host site's potential full-scale hydrogen demand requirements, and was governed by the premise that combining two proven technologies (i.e., gas clean-up and steam methane reformation equipment) lowers technical risk.

3.2 Approaches used:

3.2.1 Phase 1. The approach taken in project phase 1 is described in the final feasibility study (see Appendix B). In general, the project team focused on the following key strategic elements:

- For the purposes of the feasibility study, the comparative analysis began with two baseline assumptions:
    - The "start point" for LFG clean-up system analysis was set immediately after the post-siloxane removal compressor. This "start point" was chosen based upon the belief that opportunities for LFG-to-hydrogen conversion have the best economics when deployed as an add-on to an existing LFG-to-energy project, rather than as a stand-alone initiative.
    - The analysis assumed an input LFG cost from the source landfill at $4.50 per MMBtu. The output cost for a different input LFG cost using the same capital equipment configuration would be proportional to the $4.50 per MMBtu baseline analysis used in this feasibility study.

3.2.2 Phase 2. The approach taken in project phase 2 is described immediately below, and included the following key strategic elements:

- For the clean-up system:
    - Identify clean-up equipment requirements (volume of gas, inlet LFG composition, etc.);
    - Determine equipment pad sizes and locations; and

    - Design and fabricate clean-up equipment.

- For the reformer:
    - Refurbish the unit, which had been inactive for more than a year, and make its internal componentry ready for reuse on this project.

- Deploy the equipment at the host site:
    - Prepare the equipment laydown site;
    - Install the equipment; and
    - Connect the equipment to existing host site services (LFG, water supply, power, etc.).

- Operate the equipment to achieve required hydrogen purity
    - Commission and start-up the equipment;
    - Monitor and test hydrogen purity for variations over time (2 months minimum).

3.2.3 Phase 3. The approach included the following key strategic elements:

- Install a fueling post at the pilot facility site where fueling operations would take place;
- Start up the clean-up and hydrogen production equipment, operate it at steady state, fill the 15 kilograms of on-site hydrogen storage, and collect samples of the hydrogen to confirm the SAE J2719 hydrogen purity standards still are met following completion of project phase 2;
- Identify lift truck data that will be collected during the performance of the trial;
- Conduct training for personnel;
- Execute the operational trial and gather data; and
- Restore the host site to its pre-project configuration.

3.3 Problems encountered and steps taken to resolve those challenges. During the execution of the planned project activities the project team encountered several technical and non-technical challenges. These challenges, and the resolution for these challenges are summarized below by project phase.

3.3.1 Phase 1 Challenges:

- Challenge: The validity of the results since the study completed in October 2011 has been impacted by several significant “real world” events that occurred between October 2011 and January 2014 (close-out date for the first two phases of the project), including: new domestic natural gas discoveries drove down the price of natural gas, lowering the cost difference between natural gas and LFG; volatility in the SMR industry (e.g., new providers entering the market; capability improvements to products already in the market, potential economies of scale as demand increases, etc.) may have created a difference in cost data collected in the fall of 2011 versus market conditions existing in early 2014.
    - Resolution: Future adopters will need to re-examine the cost drivers of this technology solution on a case-by-case basis.

3.3.2 Phase 2 Challenges:

- Challenge: Clean-up system vendor “test gas” standard did not conform to the actual LFG composition, causing a faulty assumption that the original system design performed satisfactorily when first tested following fabrication. Subsequent performance validation testing against actual LFG composition revealed a failure of the clean-up system to meet specifications.
    - Resolution: re-blended vendor test gas to conform to the actual LFG composition.
- Challenge: Divergence between the actual LFG composition and “typical” other LFG sources. The actual LFG stream had unusually high levels of oxygen and nitrogen, making the typical adsorbent processes less effective for the unique host site LFG composition.
    - Resolution: Used an adsorbent process developed by American Nitrogen Rejection (http://www.n2rejection.com), a vendor whose product had demonstrated particular effectiveness in removing nitrogen; added an in-line oxygen absorbing unit downstream of the final pressure-swing adsorber (PSA) phase.
- Challenge: The original clean-up system vendor prescribed an operating environment for the PSA that used a differential pressure notably lower than prescribed for other PSA systems.
    - Resolution: The team consulted PSA subject matter experts in industry and at Argonne National Laboratory. Based upon those discussions, the team identified a new PSA vendor who leased a PSA system and associated adsorbents to the project team. The team also installed an additional compressor unit in line with the new vendor’s system to raise the differential pressure across the PSA.

The net result of all the technical solutions identified in this section enabled the modified gas clean-up system to meet all the performance requirements necessary for optimal SMR performance. The first time the end-to-end system (gas clean-up, SMR and downstream PSA) was operated, the results were as depicted previously in the 17 October column of Table 1.

4.0 Conclusions and Future Directions

Over the 42-month duration of this project, the project team successfully validated all the initial goals and premises for the effort, including:

- A capital equipment investment in LFG cleanup and steam-methane reformation, amortized over a 10 year or greater period of time, is cost-competitive versus delivered hydrogen for daily hydrogen demand of 500 kilograms or greater.

- SAE J2719 fuel cell-quality hydrogen can be produced reliably from a LFG source using commercially-available gas clean-up and hydrogen production equipment. A longer duration demonstration would have reduced the risk of potential long term contaminant breakthrough.

- Hydrogen produced from a LFG source that meets or exceeds all SAE J2719 purity standards has no detrimental performance or service life impacts when used in fuel cell-powered MHE.

On a national scale, the results of this project warrant further review and updating to account for several key variables that have a high likelihood of changing the baseline economics and business case analysis performed in the early stages of this project. These include:

- Volatility of natural gas prices since the recent discoveries of significant natural gas resources in North America. This volatility could cut in either a positive or a negative direction on the LFG-to-hydrogen production business case.

    - The drop in natural gas prices presents a challenge to the differential cost of creating biomethane, and could impair the business case for biogas-to-electricity projects. While the cost of LFG is locked in over the long term at the beginning of a new project, a subsequent drop in natural gas prices over a substantial period of time lowers the profit margins between reforming natural gas and reforming LFG accordingly.

    - Reduced natural gas prices can help trigger additional deployments of CNG and LNG trucks that displace diesel internal combustion engine trucks. The growth of

CNG and LNG trucks has helped to stimulate interest in converting biogas to a renewable transportation fuel and has resulted in biogas-to-energy projects.[8]

- Lower capital equipment cost for small distributed steam methane reformer systems technology and increased market volumes and competition for this technology could result in more competitive fuel cost.

In January 2015 Argonne National Laboratory completed an assessment of the overall LFG-to-Hydrogen project. Entitled "An Assessment of the Feasibility Study for Producing Hydrogen from Landfill Gas to Operate Fuel Cell Powered Materials Handling Equipment (MHE)," the full assessment can be found at Appendix E.

[8] http://www.epa.gov/lmop/documents/pdfs/conf/16th/03_Voell_presentation.pdf, http://www.siteselection.com/theEnergyReport/2009/december/landfill/, http://www.usdairy.com/~/media/usd/public/dairypowercasestudy_renewableenergy.pdf.pdf

Introduction
This project existed to develop and distribute educational material focusing on hydrogen and fuel cell technology to be presented to state and local government officials. The officials ranged from legislators at the state level to the planners at the local level. The activities associated with the project were based on a fundamental understanding of our diverse target audience and what issues and topics are of greatest interest to them.

The SCHFCA has built relationships with key government and industry groups to promote the creation of a hydrogen economy throughout South Carolina and the Southeast. Educational efforts have been key to the success of the SCHFCA in gaining acceptance of hydrogen energy technologies among government officials. Greenway Energy worked with Aiken Technical College, the Applied Research Center: Hydrogen and Savannah River National Laboratory on hydrogen workforce education and public outreach. Efforts on this project leveraged existing materials and expertise and create materials for government officials.

Hydrogen and fuel cell technologies are moving out of the laboratory and into economically competitive niche markets such as cell phone tower back-up power and forklift operations. As hydrogen technologies become competitive in these early markets, communities need to be educated about the opportunities afforded by hydrogen technologies and about safety concerns associated with them. The Hydrogen 101 program led by the South Carolina Hydrogen and Fuel Cell Alliance raised awareness about hydrogen and fuel cells to community leaders within South Carolina and the Southeast.

South Carolina is among a small, but growing, number of states that have a hydrogen implementation strategy and is on the leading edge of fuel cell research and adoption. The state has been recognized as one of the top five leaders in hydrogen and fuel cells, but a significant lack of information on hydrogen still exists among state and local leaders. In order to maximize the resources existing in the state and surrounding region, it is imperative to conduct an effective outreach and education program to inform the decision to accept hydrogen technologies in the local community.

Approach
The project team was composed of South Carolina based hydrogen experts with connections to technically accurate information and civic organizations and associations that have already established communication networks and events with our target audience. The entire team worked together to identify specific messaging that the local audience and sub audiences were interested in. Based on the feedback gathered from the civic organizations and other community opinion leaders, education materials and demonstrations were developed.

The marketing of the program was conducted through the existing websites, email distribution lists and communication networks. The distribution of the material was primarily conducted at events associated with each of the civic associations partnered on the project; however, several stand-alone events and webinars were planned.

<u>Task 1: State and Local Government Officials</u>

Earth Day events were a major part of April's education efforts in 2010. Approximately 1,000 people were reached during Earth Day events, of which an estimated 100 were decision makers.

One Hydrogen 101 presentation was made available to the Municipal Association of South Carolina through monthly webinars on April 14, with five decision makers participating. Contact with State legislators was elevated during the month of June as the Legislative Session in South Carolina wrapped up. The South Carolina Hydrogen Permitting Act was passing through the legislature at that time, so decision maker education efforts were in effect. These efforts reached 25 legislators and 130 total audience members.

Presentations were given at the Southern Legislative Council's Annual Conference to 129 attendees. Also at the Southern Legislative Council Annual Conference, a hydrogen powered truck was parked in front of the conference center for attendees to observe. The truck was also at the "Green is Good for Business" Conference September 14th and reached 100 attendees, as well as 300 businesspersons from across the state. A presentation was given to the SC Department of Health and Environmental Control consisting of air quality experts and senior department officials and reached approximately 300 people. Candidate and Decision Maker Briefings were held and included:

- Eddie McCain (I), SC 2nd Congressional District, on July 15th,
- Tim Scott (R), SC 1st Congressional District, on August 9th.
- J. McKeown, Charleston County Council on August 9th.
- Lori Lambert, Charleston County, on August 17th.
- Jeff Duncan (R), SC 6th Congressional District on August 25th.
- Trey Gowdy (R), SC 4th Congressional District on September 23rd.
- Paul Corden (D), SC 4th Congressional District on September 23rd.

The project team coordinated with the South Carolina Energy Office on a project called Odyssey Week, a series of events designed to showcase various different alternative fuel technologies during the week of October 11th to 15th. The H2 101 project participated in one of four events and reached 20 attendees.

Candidate and Decision Maker Briefings were held and included Senator Paul Campbell in December 15th and the new Columbia Mayor Steve Benjamin on December 16th.

An audit was scheduled under the direction of KPMG, set forth by SCHFCA in 2012. By the third quarter, SCHFCA had completed the audit. In-person presentations were made to over 45 groups of targeted South Carolina decision makers, including the National Congressional Candidates, staff of the National Presidential candidates, State House and Senate members and staff, Leaders at the SC Dept of Commerce and the Coastal Conservation League. In total, 21,672 targeted additional state and local government officials and decision makers were reached. SCHFCA hosted the US DOE Secretary Chu visit in South Carolina, which included briefing Congressman James Clyburn. Dr. Baxter presented on the updates of the BMW Landfill Gas-to-Hydrogen project and the Development of Hydrogen Education Programs for Government Officials project at the Annual Merit Review conference held in Washington, DC in May 2012.

The total number reached for this project was 23,635.

Task 2: Hydrogen Education for Codes Officials

Team members participated in the first application of newly adopted SC Hydrogen Permitting Act in 2010. The existing Sage Mill Hydrogen Fueling station, currently under expansion, was the first project to process through the new permitting system. The project team played a role in transitioning the Office of the State Fire Marshal into the new role as the statewide expert and Authority Having Jurisdiction (AHJ) in hydrogen and fuel cell facility permitting.

Meetings held in 2012 included David Blackwell, Bruce Kritz and Ed Roper of the Office of the State Fire Marshal, as well as Dr. Douglas P. Woodward, director of the Division of Research and professor of economics at the Darla Moore School of Business at the University of South Carolina, and U.S. Congressman John J. Duncan, Jr., Second Congressional District of Tennessee. Dr. Baxter delivered a presentation of keynote address given at the 5th annual winter meeting of the American Council of Engineering Companies of South Carolina/South Carolina Society of Professional Engineers. MHE case studies on early markets for hydrogen and fuel cell technologies were developed and Hydrogen 101 materials were utilized in wider public education efforts that reached additional non-decision makers.

Task 3: Southeastern States Education and Outreach:

The "Hydrogen 101" project was expanded to conduct outreach in neighboring southeastern US states, with an expected outcome to establish cooperative efforts among each state's stakeholders and, if possible, promote interstate cooperation among multiple states. The efforts that the project team conducted broadened the understanding of hydrogen and fuel cells among the stakeholders identified and encouraged those stakeholders to organize themselves to grow the industry in their states.

The states that were chosen to investigate were based on: level of current and past project activity; congressional support; and stakeholders/resources that benefit the hydrogen and fuel cell industry. The states were Florida, Tennessee and North Carolina.

There were several documents created under this task. The "Best Practices" document is a description of activities that have benefitted the SCHFCA Cluster and other leading hydrogen and fuel cell states. It was used in communicating potential activities that could be initiated. The "State Resources" provided a state-by-state listing and summary description of stakeholders, resources and champions. The "Stakeholder Survey" report provides results and findings of interviews conducted with economic developers and community leaders in selected states. The "Key Contacts" database provides a listing of contacts developed during the project for continued communication following the project.

A meeting with the U.S. Congressman John J. Duncan, Jr., Second Congressional District of Tennessee as held and the hydrogen and fuel cell economic cluster was discussed. It was noted that Congressman Duncan took interest in the lift truck Market Value Proposition publication.

Videos of educational information on hydrogen were made available on the SCHFCA YouTube channel and Greenway Energy YouTube channel, and Webinar presentations were made available to be viewed through a SlideShare channel. The "Hydrogen and Fuel Cells: Lift Trucks, A Practical Application" brochure was revised, printed and distributed at the 2011 Fuel Cell Seminar & Exposition to over 800 attendees and the 2012 Fuel Cell Seminar & Exposition to over 900 attendees and was also given out at every meeting held with Dr. Shannon Baxter. Dr. Baxter co-authored an article titled, "Staying the

Course with Hydrogen," which was published in the Columbia Regional Business Report in the September-October 2011 issue. Presentations made by Dr. Baxter included the Charleston Energy Conference,

- Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) in Washington, DC
- End-User Educational Program at the 2011 FCS&E in Orlando, FL
- 91st Transportation and Research Board Annual Meeting held in Washington, DC in January 2012
- Hydrogen and Fuel Cells Municipalities session at the World Hydrogen Energy Conference held in Toronto, Canada in June 2012
- Senate Fuel Cell and Hydrogen Caucus briefing in Washington, DC in July 2012

In 2013 and 2014, research on the case for fuel cells identified a number of relevant documents. The documents were bundled into categories that appealed to specific audiences depending on the stakeholders' priorities such as economic development, environmental protection or energy security. Several spreadsheet models were also identified that allow for stakeholders to estimate the benefit of hydrogen and fuels cells using parameters specific to their situation. The survey was revised and modified to be specific for the stakeholders contacted in each state and lists of relevant activity in each state including policies, projects, manufacturing and research were compiled.

Appendices:

Appendix A: Summary of Environmental, Safety and Energy Savings Considerations Associated with Fuel Cell – Powered Material Handling Equipment

Appendix B: Landfill Gas-to-Hydrogen Production: A Business Case Analysis for On-Site Production of Hydrogen Using Methane-rich Landfill Gas versus Hydrogen Sourced from Traditional Industrial Gas Vendors, dated 25 October 2011

Appendix C: Detailed analyses of hydrogen gas samples collected from the project equipment during Phase 2 of the project

Appendix D: Data Package from the operational trial

Appendix E: An Assessment of the Feasibility Study for Producing Hydrogen from Landfill Gas to Operate Fuel Cell Powered Materials Handling Equipment (MHE)

Appendix F: Summary of Educational Outreach Accomplishments