TEXAS LPG FUEL-PROCESSOR DEVELOPMENT AND FUEL-CELL DEMONSTRATION

Final Report

Pursuant to DOE Solicitation # DE-FC36-02GO12018

SOUTHWEST RESEARCH INSTITUTE®
SAN ANTONIO HOUSTON WASHINGTON, DC

Good Company
ASSOCIATES

Public Abstract

The first propane-powered fuel cell system in Texas is delivering electricity to the Texas Department of Transportation's TransGuide facility in San Antonio. This project was undertaken to develop a fuel processor running on commercially available propane, integrate that fuel processor with a PEM fuel cell, and demonstrate the operation of the system. The aim is to demonstrate the viability of propane as a hydrogen source, bringing non-polluting electricity and automotive power to areas served by propane. A study to assess potential markets has also been undertaken to provide insight into the future applications and direction for the technology.

The project team consists of HyRadix Inc. of Des Plaines, IL providing the propane-to-hydrogen fuel processor, Plug Power Inc. of Latham, NY providing the fuel cell, Southwest Research Institute (SwRI) of San Antonio, TX performing the independent testing of the system, Good Company Associates of Austin, TX conducting the market research, the Alternative Fuels Research and Education Division (AFRED) of the Railroad Commission of Texas acting as overall coordinator, the Texas Commission on Environmental Quality providing public information assistance, and the Texas Department of Transportation (TxDOT) providing the site for the demonstration. Funding for the project came from the U.S. Department of Energy through the Texas State Energy Conservation Office (SECO) and the Propane Education and Research Council (PERC).

HyRadix developed a cutting-edge fuel processor with an advanced sulfur removal system to enable the usage of commonly available propane as a fuel source for fuel cells. The fuel processor was integrated with a state-of-the-art PEM fuel cell from Plug Power. Independent performance testing by Southwest Research Institute prior to installation at the demonstration site testing showed that the integrated system efficiently produced electrical power, with no detectable NO_x or CO emissions. Good Company conducted a study investigating the size and scope of current and future markets for propane powered fuel cell systems. All of the project participants have an interest in exploring propane's potential contributions to energy conservation, pollution reduction and U.S. energy independence.

Data from the demonstration is being used by the manufacturers to improve the technical performance of the units and to develop the abilities of rural energy providers to support and service this technology. Integrated fuel cell systems in this power range of a nominal 5 kW are expected to find markets in a wide range of public- and private-sector applications, including continuous air-quality monitoring stations, district or county road-maintenance sections, rural residences and small businesses that use propane.

Table of Contents

1. Introduction.....	1
2. Technology Description	2
2.1. Fuel Processor Module	
2.2. Fuel Cell Module	
3. Contract Deliverables Discussion	4
3.1. Define Interface Requirements	
3.2. Develop LPG Fuel Processor	
3.3. Integrate Fuel Processor and Fuel Cell	
3.4. Testing at Southwest Research Institute	
3.5. Demonstrate One System	
3.6. Market Study	
4. Field Performance Summary	13
5. Lessons Learned.....	13
5.1. Shutdowns	
5.2. System Health	
5.3. Communication/Monitoring	
5.4. Service/Support	
6. Recommendations	14
6.1. Extended Run	
6.2. Proposal for Follow-up Demonstration	
6.3. Site Decommissioning	
6.4. Discussion about a production unit	
7. Summary and Conclusions.....	15

Appendix:

A	Interface Requirement Document.....	16
B	Southwest Research Institute Test Report	19
C	Good Company Market Study	38

1. Introduction

The Texas LPG Fuel Processor Development and Fuel Cell Demonstration Program is a broad-based public/private partnership led by the Texas State Energy Conservation Office (SECO), a state energy office. Partners include the Alternative Fuels Research and Education Division (AFRED) of the Railroad Commission of Texas; Plug Power Inc. Latham, NY; HyRadix, Inc. Des Plaines, IL; Southwest Research Institute (SwRI), San Antonio, TX; the Texas Commission on Environmental Quality (TCEQ); and the Texas Department of Transportation (TxDOT). The team proposed to mount a development and demonstration program to field-test and evaluate markets for HyRadix's LPG fuel processor system integrated into Plug Power's residential-scale GenSys™ 5C (5 kW) PEM fuel cell system in a variety of building types and conditions of service.

The program's primary goal was to develop, test, and install in Texas a prototype propane-fueled residential fuel cell power system. (In this document, the terms LPG, short for liquefied petroleum gas, and propane are used interchangeably to refer to commercial propane.) The propane industry is interested in the development of an optimized propane fuel processor, funded through its national check-off program, the Propane Education and Research Council. Lowering emissions of propane-based power generation will help meet increasingly strict environmental mandates. At the onset of this program, there was no propane fuel processor available for fuel-cell applications. The first major hurdle to the fuel processor was the removal of sulfur from the propane. Additionally, the processor needed to be able to handle the varying hydrocarbon content of commercial propane. Once the fuel processor was developed, it needed to be paired with a PEM fuel cell to provide electrical power. The diversified team consisting of state agencies, a fuel processor developer, a fuel-cell manufacturer, an independent nonprofit testing laboratory, and support from both the national and state LPG check-off programs, brought interdisciplinary knowledge, skill, experience and industry support to ensure the success of the project.

Phase 1 involved the development of an optimized LPG fuel processor by HyRadix. A \$500,000 cash match from the national Propane Education and Research Council (PERC) supported HyRadix's development.

Phase 2 integrated Plug Power's GenSys™ 5C PEM fuel cell system with HyRadix's fuel processor module. The resulting prototype was submitted to SwRI for efficiency and emissions testing.

Phase 3 called for the installation, monitoring, support and evaluation of the integrated system for three months. The electricity produced by the system was used to supplement the power demand of the Texas Department of Transportation's TransGuide headquarters in San Antonio, Texas. Installation was performed using standard plumbing, fuel-service and electrical-service practices, in compliance with applicable regulatory requirements. Use of the TransGuide site ensured ongoing technical and administrative support for data collection, maximum public visibility, and a location for site tours and educational/promotional events.

2. Technology Description

2.1. Fuel Processor Module: HyRadix, based in Des Plaines, Illinois, is dedicated to the development and commercialization of hydrogen generation technology for hydrogen vehicle

refueling, industrial applications and for fuel cells. Using an innovative combination of technology and equipment, HyRadix's hydrogen generating appliances produce hydrogen from the common infrastructure fuels natural gas and LPG.

The HyRadix Fuel Processor Program was initiated in UOP at the end of 1998. In 2002 UOP spun off the fuel processor effort into a separate company charged with commercializing the technology under development since 1998. The core team of scientists and engineers became the initial members of HyRadix Inc.

HyRadix follows UOP's well-established process for new technology development. HyRadix begins with Product Conceptualization, during which time HyRadix researches existing hydrogen generation chemistry and technology to develop a fundamental understanding of the issues, which lead to several proposed alternative technical solutions. From there Computer Modeling tools are applied to determine an optimal process solution. These computer-modeling tools are refined throughout the development program to continuously guide efforts. After developing an optimal computer-generated solution, Pilot Plants are constructed to complete proof-of-principle experiments to verify computer model predictions. After pilot plant testing, Prototype Units are fabricated which represent the actual fuel processor product HyRadix will deliver to the marketplace. Each successive prototype includes iterations on the design of the overall process as well as iterations on individual pieces of equipment.

The rigor of this development process has resulted in the development of a novel patented process technology with a unique heat integration scheme. This unique technology is superior to conventional auto-thermal type fuel processor technology in both hydrogen purity and system efficiency.

Building on the success of the natural gas processing, HyRadix looked to adapt the technology to LPG feedstock. The timing of HyRadix's development efforts matched the Texas Railroad Commission's program timeline, allowing HyRadix to significantly contribute to the development of propane-based fuel cell power systems in Texas. HyRadix believes that the Texas Railroad Commission's program is vitally important for the successful commercialization of fuel cell and fuel processing technology by extending the fuel base to propane.

Figure 2.1 – HyRadix Agilon Fuel Processor

2.2. Fuel Cell Module: Plug Power has gained extensive experience in the design and operation of PEM fuel cell systems since its inception in 1997. Plug Power's focus on natural gas powered fuel cell systems has resulted in the successful demonstration of systems with increasing functionality and reliability, decreasing cost, and has led to the development of the GenSys™ 5C system and other products including hydrogen fueled backup systems.

The GenSys™ 5C was manufactured and integrated with the HyRadix fuel processor module at Plug Power's Latham, New York, manufacturing facility. This facility, which opened in February 2000, is comprised of 50,000 square feet of dedicated production and production test facilities. Plug Power employs approximately 100 personnel in its production areas. The production processes are designed around the principles of Lean Manufacturing, and use the Toyota Production System as a model. As such, planning and production is via a "pull system" that is, systems are produced only as orders pull demand for product through the production system. Lead-time for delivery is between eight and twelve weeks for large orders, smaller orders can be fulfilled immediately. Current production capability allows for the manufacture of approximately five systems per week with the ability to significantly increase this rate.

The natural gas version of GenSys™ 5C is certified by CSA International for outdoor operation in accordance with the relevant codes and standards. The integrated system developed during this program did not retain the certifications because of the significant changes from the base design. Similarly, the power conditioning module of the GenSys™ 5C is UL Listed; however, this listing was not retained in the final, integrated system.

The GenSys™ 5C system provides cogeneration capability and is able to run in either a simple cycle electric or cogeneration mode, commonly referred to as CHP (Combined Heat & Power). Cogeneration heat is available when the system is producing electricity. If cogeneration heat is not required, the system will reject this heat to the environment. CHP was not utilized during this demonstration; see Section IV for more details. A typical GenSys™ 5C installation is shown in Figure 2.

Figure 2.2 – GenSys™ 5C Installation

3. Contract Deliverables Discussion

3.1. Define Interface Requirements: The primary challenge of this project was taking two stand-alone products with independent controls, safety systems and utility requirements and making them work together in a symbiotic relationship. The HyRadix and Plug Power teams started their analysis by developing an Interface Requirement Document. The intent of this document was to describe, in detail, the individual module requirements and to facilitate a gap analysis for integration of the systems. It also proved to be an effective tool for developing the high-level control strategy that was used for the integrated system. The Interface document is attached as Appendix A.

3.2. Develop LPG Fuel Processor: In developing an LPG fuel processor, HyRadix looked to build on the success of their technology for processing of natural gas. The greatest challenges related to commercial propane feedstock are the variability of the composition and the high levels of sulfur odorants. Sulfur is a poison to catalysts employed to produce hydrogen from hydrocarbon fuels, as well as to PEM fuel cell.

LPG desulfurization work began in October, 2002. Odorant concentrations can be much higher in LPG compared to natural gas. The most common odorants in LPG are ethyl and methyl mercaptan and ethyl and methyl disulfides (see Appendix C.) Smaller concentration components such as carbonyl sulfide will cause problems over time if not removed. Bench scale testing identified an effective adsorbent system for the removal of all sulfur from commercial propane. Long-term testing certified the adsorbent for use in the HyRadix Agilon fuel processor. Testing determined the sulfur break-through capacity to size the adsorbent bed and determine its life cycle.

With the sulfur removal system in place, bench scale testing of the ATR catalyst began in December, 2002. The catalyst selected proved reliable under the composition variance of the commercial propane feedstock. Following extensive process modeling and simulations, a process specification was issued for the LPG fuel processor.

The first four months of 2003 saw the construction and testing of two prototype units. With the lessons learned on the prototype units and the completion of component selection and testing, the demonstration unit to be integrated with the fuel cell was commissioned in April, 2003. Testing and optimization of the LPG fuel processor concluded with the shipment of the demonstration unit to Plug Power for integration with the fuel cell in July, 2003. At maximum LPG feed flow of 13.3 SLPM, the Agilon LPG reformer produces 90 SLPM hydrogen. Over a 30-hour test period, hydrogen purity averaged 43% (41%-46%) while carbon monoxide levels stayed below 1 vppm for the duration of the test.

3.3. Integrate Fuel Processor and Fuel Cell: The integrated fuel cell system is comprised of two major subunits: the fuel cell module (FCM) that includes the inverter/power electronics and the fuel processor module (FPM). Both the FCM and FPM are designed and manufactured to

be stand-alone solutions for their particular applications. The decision was made early on in the program to leave each system structurally intact and to concentrate on the interface between the two. The physical integration, therefore, became a basic exercise in sizing and installing hose/tubing to serve as transfer lines between systems. The main body of work focused on software, controls, safety systems, and to make the FCM and FPM work together.

Prior to arrival of the FPM at Plug Power, laboratory preparations were made. A bay within Plug Power's test farm was selected as the site for integration. This farm is an outdoor test area with a high-bay roof and pre-run utilities. LPG was not present at the farm and was installed before arrival of the FPM. Additionally, a support frame was built for the FPM and moved into place. The support frame was required in order to elevate the FPM above the water inlet to the FCM and allow proper drainage between systems. Computer terminals, communication links and network access were secured for HyRadix, and Plug Power personnel performed a preliminary safety review. During this time, a modified version of the standard Plug Power control and interface software was developed specifically for the integrated system.

The HyRadix FPM arrived at Plug Power during the week of July 28, 2003 and was immediately integrated with the GenSys™ 5CS fuel cell system. Connections were made for the water, fuel, and electrical systems, a final safety review was performed, software was loaded and initial start-up activities were performed.

Testing at Plug Power: The following tests were carried out by Plug Power and HyRadix at Plug Power's facility at 968 Albany Shaker Road in Latham, NY:

1. Integration, Debug, and Shakedown
2. System Capacity
3. FPM Auxiliary Power
4. System Efficiency
5. FPM Reformate Characterization
6. System De-ionized Water Usage
7. System Exhaust Temperature
8. Safety Shutdown Validation
9. Start-Up Time

The Integration, Debug, Shakedown, and Integrated System Testing that was performed at Plug Power from 07/28/03 – 09/28/03 demonstrated the feasibility of an LPG fueled Fuel Cell System. The resultant Integrated System is capable of operating at two (2) load points of nominal 2.5kWACnet and 3.5kWACnet power output to a customer, with a maximum average efficiency of 19.5%. The start-up time was reported to be 4 hours; however, controls modifications initiated after the test sequence designed to reduce start-up time were implemented, and the design team feels that a start-up time approaching 3 hours is achievable with this design.

The separate exhaust streams indicated maximum temperatures of 41°C and 101°C respectively for the FCM and FPM. Additional design integration to combine these two streams would reduce the overall system exhaust temperature. The maximum measured de-ionized water usage of 0.07L/hr equates to approximately 10L/day water consumption, assuming a standard 6:1 DI polishing cartridge.

TEST RESULTS

1. Integration, Debug, and Shakedown

The period from 08/06/03 – 09/14/03 was spent executing this portion of the test plan. By definition, this is a non-formal testing period spent identifying and executing solutions to problems. During this period the following problems were identified and solutions were implemented to correct:

- FCM – FPM communication protocol
- Plumbing integrity
- FCM – FPM water transfer robustness
- FCM air bleed design validation
- FPM controls development for FCM transient conditions
- Condensate transfer effectiveness
- Integrated system start-up controls development
- Operator cross-functional training
- Integrated System HIGH and LOW power set-point definition

2. System Capacity

System Capacity was measured using the following equation:

$$\text{NET POWER OUTPUT} = \text{FCM OUTPUT} - \text{FPM AUX POWER}$$

Where:

$$\text{FCM OUTPUT} = \text{FCMV} * \text{FCMI}$$

$$\text{FPM AUX POWER} = \eta \text{ CONVERTER} * \text{FPMI} * \text{FPMV}$$

FCMV and FPMV were measured using a handheld DMM.

FCMI and FPMI were measured using a handheld clamp-on ammeter.

The average Net Power Output reported during the HIGH power operation was 3511W, with a range of 3483W – 3538W and a sample size of 6.

The average Net Power Output reported during the LOW power operation was 2470W, with a range of 2312W – 2536W and a sample size of 6.

3. FPM Auxiliary Power

The FPM Auxiliary Power was calculated using the following equation:

$$\text{FPM AUX POWER} = \eta \text{ CONVERTER} * \text{FPMI} * \text{FPMV}$$

Where:

$$\eta_{\text{ CONVERTER}} = 0.95$$

FPMI was measured using a handheld clamp-on ammeter.

FPMV was measured using a handheld Digital Multi Meter (DMM)

The average FPM Auxiliary Power reported during the HIGH power operation was 655W, with a range of 633W – 670W and a sample size of 6.

The average FPM Auxiliary Power reported during the LOW power operation was 541W, with a range of 532W – 570W and a sample size of 6.

4. System Efficiency

The System Efficiency was calculated using the following equation:

$$\eta = \text{NET POWER OUTPUT} / \text{TOTAL POWER INPUT}$$

Where:

$$\text{NET POWER OUTPUT} = \text{FCM OUTPUT} - \text{FPM AUX POWER}$$

$$\text{TOTAL POWER INPUT} = \text{LHV}_{\text{fuel}} * \text{FLOW}_{\text{fuel}}$$

FCM OUTPUT was measured using a handheld Digital Multi Meter and clamp-on ammeter.

FPM AUX POWER was measured using a handheld Digital Multi Meter and clamp-on ammeter.

LHV_{fuel} was calculated using LPG fuel composition.

FLOW_{fuel} was measured using a Meriam LFE in conjunction with a manual pressure gauge, ambient pressure observations as reported at the Albany Airport, and a Type-K thermocouple.

The average efficiency reported during the HIGH power operation was 17.6%, with a range of 16.9% - 18.4% and a sample size of 6.

The average efficiency reported during the LOW power operation was 19.5%, with a range of 16.2% - 26.6% and a sample size of 6.

5. FPM Reformate Characterization

The FCM placed a requirement of a maximum concentration of CO in the reformate stream during steady-state operation of 10 ppm, and 50 ppm during load transients.

The system was operated at HIGH and LOW power for a minimum of 1 hour and transitioned from HIGH → LOW and from LOW → HIGH. CO was measured at the input to the FCM on-line using a Siemens NDIR Gas Analyzer with a CO sensitivity range 0-500ppm.

During all operating conditions, CO was non-detectable in the reformat stream.

6. System De-ionized Water Usage

System De-ionized Water Usage was measured using the following equation:

$$[\text{METER READING}_j - \text{METER READING}_i] / [j - i]$$

Where:

i & j represent the beginning and end of the specified test period respectively.

The average System De-ionized Water Usage reported during the HIGH power operation was 0.07L/hr as measured over a 10hr period.

The average System De-ionized Water Usage reported during the LOW power operation was 0.03L/hr as measured over a 12hr period.

7. System Exhaust Temperature

The System Exhaust Temperature was measured in 2 places using Type-K thermocouples installed in the FCM exhaust flow stream and the FPM exhaust flow stream accordingly.

The average System Exhaust Temperature in the FCM reported during the HIGH power operation was 41°C as measured over a 15 hour period.

The average System Exhaust Temperature in the FCM reported during the LOW power operation was 36°C as measured over a 16 hour period.

The average System Exhaust Temperature in the FPM reported during the HIGH power operation was 101°C as measured over a 15 hour period.

The average System Exhaust Temperature in the FPM reported during the LOW power operation was 97°C as measured over a 16 hour period.

8. Safety Shutdown Validation

The integration of the HyRadix FPM and the Plug Power FCM required the integration of two (2) independent Safety Shutdown systems. To ensure customer safety and the integrity of the integrated system, the combined Safety Shutdown system was validated during integrated system testing.

A fault was simulated in the FCM, and both the FCM and FPM were observed to execute the prescribed shutdown. Similarly, a fault was simulated in the FPM, and both the FCM and FPM were observed to execute the prescribed shutdown.

9. Start-Up Time

Start-Up Time is defined as the time it takes from initiating start to when the customer is receiving 90 percent of the desired load setting. This test sequence was performed from a Cold Start condition to HIGH power, with Cold Start being defined as all process temperatures <50°C.

The System Start-Up Time was measured as 4.0 hrs.

3.4. Testing at Southwest Research Institute (SwRI): On September 29, 2003, the System was shipped from Plug Power to SwRI for operational verification, emission and efficiency testing. SwRI used a duty cycle provided by Plug Power and HyRadix to test the system. The system was operated at two different power levels high, and low, which correspond to 3.2 kW and 2.3 kW respectively. These power levels were chosen to represent usage that would be common in home applications, although it is important to note that this system is not load-following at the present time. The total testing time was 54 hours of continuous running with 3 hours of startup and stabilization, 26 hours at the high power setting and 25 hours at the lower power setting. The data-acquisition system and fuel cell/reformer system were started and allowed to warm up until the high load setpoint was stable. Once the system was stable, the first 10-minute emission sample was taken as well as a fuel sample. The system ran for 26 hours at the high load level, at which time another 10-minute emission and fuel sample were taken. The efficiency average for the 26-hour period was 18.4%. The predominant gaseous emissions for the high load condition were hydrocarbons and carbon dioxide, at average values of 8.9 g/kWh and 1150 g/kWh, respectively. The same procedure was performed for the low load power level with an average efficiency of 18.6%. Predominant gaseous emissions for the low load condition were hydrocarbons and carbon dioxide, at average values of 7.7 g/kWh and 1150 g/kWh, respectively. For both load settings the total hydrocarbons were composed of more than 99.5% methane, resulting in a very small portion of regulated non-methane hydrocarbons. As for the other emissions, carbon dioxide is not regulated, but is comparable to propane internal combustion engines of equal power. Carbon monoxide and nitrous oxides emissions were below the sensor capabilities. The fuel analysis indicated the propane to be approximately 98 percent propane with an average energy content of 46.3 MJ/kg.

Power quality was another parameter quantified during these series of tests. Power quality is a function of the inverter rather than the actual fuel cell or reformer. Nonetheless, the reformer/fuel cell/inverter is a complete system that could be used in a stand-alone operation where power quality can be crucial. The power factor was very close to unity at 0.956, and the Voltage and Current Total Harmonic Distortion were 2.4 percent and 15.3 percent respectively. These values are acceptable for home and office sensitive power needs.

There are several opportunities for improvement in the current system. Some of these include: complete system integration, combined heat and power (CHP), and utilizing CO₂ enrichment in greenhouse applications. Combining the reformer into the fuel cell box and more closely integrating controls, heat balance and water balance will undoubtedly improve overall

system efficiency and yield a smaller, easier-to-install system. CHP has the potential to double or triple overall system efficiency by utilizing waste heat from the reformer and fuel cell to fulfill needed building heating load. Carefully choosing a food or building material crop that could be grown in a greenhouse heated and powered by a fuel cell system could be another way of increasing the overall system efficiency.

The SwRI final report is attached as Appendix B.

3.5. Demonstrate One System

Site Selection and Preparation. The demonstration site selected was the Texas Department of Transportation's TransGuide headquarters in San Antonio, Texas. This unique facility is the hub of the San Antonio intelligent highway system. Video feeds from over 130 cameras on the San Antonio highway system come into the facility and provide traffic managers and emergency responders with the ability to view traffic problems, reroute traffic, send messages via the message board, and alert emergency units of fire, police and EMS.

The site is at the southeast corner of the intersection of Loop 410W and Interstate 10, inside the entrance ramps of the highways. This facility was selected because of the interest of the Texas Department of Transportation in working with the partners, the highly visible facility location, the suitability of the electrical load and installation location, and the ability of on-site personnel to provide support to the program.

TransGuide installed two slabs for the site, one for the fuel tank and one for the fuel cell and fuel processor. In addition, TransGuide installed the required water supply and drain, two phone lines for data collection and telemetry, and dug the trench for the propane line. The installation site was behind the TransGuide building with a steep slope on one side. This made moving the fuel cell and fuel processor difficult, because a rough-service forklift was required to move the units to the slab. Even then, this proved to be a difficult task.

Qualified Railroad Commission staff installed the propane system with assistance from a local propane company, Gas Service Corporation of Helotes, Texas (GSC). Following refurbishing by AFRED staff, GSC moved AFRED's 1,600-gallon vertical propane tank from Austin to the TransGuide site and anchored it to the slab. Qualified Railroad Commission staff connected the gas lines, regulators and meters and tested the system for leaks.

The installation took about 2 weeks at the site: two days to install the slabs, one week to allow the concrete to cure, one day to install the propane system and two days to install the plumbing and phone lines for the fuel cell.

Design Electric of San Antonio performed the electrical connection under contract to Plug Power. An electric meter, a disconnect switch, a circuit breaker and a panel box were installed. The contractor required about two days to do the installation.

On January 15, 2004, the system was made operational by Plug Power and HyRadix technicians. However, problems were discovered, and it required an additional few days to get the fuel cell up and running. The unit was dedicated on January 21 with all the project partners and dozens of visitors at a media event organized and sponsored by the Texas Commission on Environmental Quality.

The front entrance to the TransGuide building in San Antonio, Texas.

The 24 hour operation of the TransGuide facility.

The back of the TransGuide building before installation of the fuel cell

1,600-gallon propane fuel tank installation

Fuel cell and fuel processor installed at the site

January 21, 2004, dedication of the fuel cell at the TransGuide site.

Training. On January 8, 2004, Plug Power, HyRadix and the Texas Railroad Commission conducted a training session for the employees of the Texas Department of Transportation at the TransGuide facility. This training included all employees who would routinely be in the proximity of the system. The employees of TransGuide were not trained to operate the fuel processor/fuel cell system. The session focused on safety, a high-level explanation of the system, and any action to be taken in the event of an emergency. A Texas Railroad Commission representative explained propane safety and the storage of propane at the facility. HyRadix representatives covered hydrogen safety, and response to any alarms from the FPM. A Plug Power representative discussed the electrical generation in the FCM and how to shut down the system.

Installation. The integrated system was installed at TransGuide on December 17, 2003. The system was situated on a concrete slab outside the north wall of the building. (See Figure 3.) The LPG tank that supplies the propane feed-stock to the fuel processor was installed about 50 meters from the system. The propane pipeline runs this distance under ground, surfacing at the edge of the concrete slab. Electrical lines run underground from the building to the system. These provide 120VAC power to the FPM and return the 120VAC electricity generated by the fuel cell. The project team decided not to use the cogeneration heat during this project. The final installation was a grid-parallel electrical installation. In this configuration, the integrated system exported the power it generated to the local electrical grid where it was consumed in the TransGuide building. A water deionization and filtration system was installed inside the building to supply water to the FCM, which in turn supplies water to the FPM. A phone line was connected to each unit for remote collection of process data. The FPM connects to its data collection server, located inside the building. The FCM also employed a data collection server periodically during the demonstration.

Figure 3.6.3 – System installation at TransGuide, facing east, with fuel processor module on the left and the fuel cell module on the right.

On February 23, 2004, a roof was installed over the concrete slab to help protect the FPM from inclement weather.

Operation: The original period of performance began on January 13, 2004, and ended on April 2, 2004. At the end of this period, the project team entered into an agreement for a no-cost extension of operation. The additional run-time was agreed to on a best-effort basis by HyRadix and Plug Power to accumulate more run hours on the machine. A secondary goal of the extension was to maintain visibility of the unit while the follow-up proposal (Section VII) was under consideration.

Throughout the demonstration, the majority of system shutdowns were software-related. These issues were attributed to the lack of robustness of the controls integration between systems. For example: the FCM has a periodic recovery sequence that it goes through when water builds up within the stack. The FCM will bump up the reactant flow rates and operate at an elevated power point in order to blow the water out of the stack and return performance to normal levels. The FPM was not designed to accommodate these types of sudden shifts in demand and at the levels that the FCM required. A series of modifications were made to reduce the frequency and magnitude of these recoveries within the fuel cell and ultimately reduce the shutdowns it caused.

Loss of communications was another problem throughout the demonstration. This refers to the communication between the FCM and Plug Power. The data used for notification and troubleshooting experienced a number of transmission failures. The root cause is unknown and the result was extended downtime as original failure modes were recreated to generate data.

In addition to the software issues described above, more expected sources of shutdowns occurred, such as low water and air supply because of dirty filters, component and instrumentation failure, etc. Overall performance figures can be found in Section 4.

3.6. Market Study

Good Company Associates, Inc., prepared a Market Study of Propane Fuel Cells. Based on the findings of the study, they made the following recommendations to prepare the propane industry for the commercialization of the propane PEM fuel cell:

- Develop propane fuel cell demonstration projects for the off-grid residential and telecommunications industry to show the viability and potential of fuel cell systems in these applications.
- Work with propane reformer manufacturers to ensure that the industry is taking all cost effective measures to address issues related to the varying sulfur content in propane.
- Continue to support propane fuel cell demonstration projects to provide valuable, real world performance data, identify product needs, and accelerate the development of commercial products.
- Promote the availability and uses of propane-powered fuel cells with residential and small commercial customers, co-ops and utilities.
- Promote the implementation of positive net metering programs in utilities and co-ops, so distributed generation users can sell excess power back to the grid for maximum return.
- Support the development of combined heat and power applications for fuel cells.

- Explore participation in, or support of, bulk propane fuel cell purchases, which could increase the economies of scale in propane fuel cell productions.
- Explore opportunities in the 100+ kW market.

The full report is located in Appendix C.

4. Field Performance Summary

The following data summarizes the overall performance of the integrated system for the period of performance from 1/13/04 – 6/16/04.

Commission Date	Data through	Total Hours in Period	Run Hours	Power Generated (kWh AC)	Average Output (kW AC)	Fuel Consumption (std. liters)	Fuel Consumption (BTUs)*	Electrical Efficiency (%)**	Availability (%)
1/13/2004	3/23/2004	1680	152	572	3.8	112,000	8.85E+06	18.2	9.0
3/24/2004	6/16/2004	2040	1052	3957	3.8	749,000	5.92E+07	18.9	51.6

Note 1: *Caloric value of gas = 19,900 Btu/lb*

Properties of commercial LPG were referenced from the LP Gas Association website - <http://www.lpga.co.uk/LPGA.htm> and verified by SwRI testing of 46.3 MJ/kg = 19,900 Btu/lb

Note 2: ***Power usage by FPM = 0.65kWh*

The reformat from the fuel processor was not analyzed for hydrogen content during the demonstration. Based on measurements made during the development stages of the program, the FPM performs at 74-79% Gross Hydrogen Efficiency (GHE.) Approximating the FPM GHE to be 77% for the demonstration period, the FCM efficiency for hydrogen to electrical power would have been about 24%.

5. Lessons Learned

5.1. Shutdowns: The unplanned shutdowns of the system can fall into four major categories: FPM hardware/software (9 instances), FPM process (8), FCM hardware/software (13), FCM process (1). The majority of these shutdowns occurred in the first part of the demonstration. The team addressed them to minimize reoccurrence. The availability of the system improved from 9.0% from January 13 through March 23 to 51.6% from March 24 through June 16.

5.2. System health: During integration and testing at Plug Power, both modules experienced unintended, extreme operating conditions as debug work was performed. Following the integration period, the testing performed at SwRI showed the system to be in good health. However, early into the demonstration period, the performance of both the FPM and the FCM began to deteriorate. Plug Power replaced the fuel cell stack. HyRadix replaced the ATR catalyst. The evaluation and replacement of these components caused a loss of run time during the initial demonstration period. Following these refurbishments, the system performance improved dramatically.

5.3. Communication/Monitoring: A couple of major issues arose during the demonstration of the system at TransGuide that hampered the performance of the system. The first was communication between the FPM and the FCM. The task of integration was very successful in its main objective of allowing the two units to operate as a symbiotic system. However, instances of miscommunication between the units caused component damage. Examples are unintended signal power surges in the shut-down sequence. In one case, an FPM signal damaged an FCM component, and in the other case an FCM signal damaged an FPM component. In each case, locating the problem, and shipping replacement parts caused

considerable down time. These types of issues reduced the operating time of the system, but have been addressed and are not a cause for concern looking to the future.

Another issue was the remote monitoring of the system. The FCM uses the standard data collection and reporting protocol that all GenSys 5C systems employ. This normally reliable system has had trouble during the demonstration period, perhaps due to the controls system changes made to accommodate a foreign fuel processor. This periodic loss of process data and error reports made troubleshooting difficult in the event of system problems. Plug Power sent a data collection server to address this midway through the demonstration period. On the FPM side, scheduled gas analysis could have been a part of the program to better monitor the performance. Because this was a prototype and the initial operation of the integrated system, these extra measures may have been helpful to provide a more reliable system. On fuel processors in the field, HyRadix now employs an internet based monitoring system from which they can make process adjustments to an operating system. This improves system efficiency and reduces shutdowns.

5.4. Service and Support: Service and support of a prototype unit is critical. HyRadix and Plug Power provided extensive on-site maintenance throughout the project. The total amount of service required was high but within the expected range for a unique prototype. SwRI supplemented HyRadix and Plug Power by providing the majority of first-response support. This was vital to the success of the demonstration because frequently, a simple push of the start button was all that was needed. If HyRadix or Plug Power personnel had to travel from their respective home offices for this type of activity, the budget would have been exceeded. SwRI was not committed to this support during the original 80-day demonstration but understood the situation and provided a tremendous service to the entire project team. SwRI has Plug Power-certified fuel cell technicians on their staff and were fully prepared to service the FCM. For the FPM, experience was gained with the system while under test at their facility and through on-site training directly with HyRadix. HyRadix and Plug Power retained SwRI under an official service agreement for the extended run period through June 2004. This agreement took some of the uncertainty out of the service structure and secured the involvement of SwRI for the remainder of the demonstration. This official agreement will allow a more timely response and reduce the downtime needed to restart the system.

6. Recommendations

6.1. Extended Run: The initial demonstration period of 80 days expired on April 2, 2004. At the end of this period, the project team entered into an agreement for a no-cost extension of the demonstration. The additional run-time was agreed to on a best-effort basis by HyRadix and Plug Power to accumulate more run hours on the machine. A secondary goal of the extension was to maintain visibility while the follow-up proposal was under consideration. As of June 17, 2004, the system was operating in this extended demonstration.

6.2. Proposal for Follow-up Demonstration: A proposal was submitted by the Alternative Fuels Research and Education Division (AFRED) of the Texas Railroad Commission to the Texas Commission on Environmental Quality for grant funding of a follow-up demonstration after completion of the original project. The proposal calls for the project teams to leverage the

existing system and installation in order to facilitate an additional six-month operation and performance evaluation of the integrated system.

SwRI personnel will perform the majority of on-site maintenance and will act as the primary service provider for integrated system. The proposal includes further training of SwRI staff and calls for return of the units to Plug Power and HyRadix respectively for post-mortem analyses.

Per the proposal, Plug Power and HyRadix will shut down their units at the end of the original demonstration period funded under contract No. DE-PS36-01GO90010. Each company will have the opportunity to perform any maintenance activities required prior to starting the follow-up demonstration.

6.3. Site Decommissioning: The fuel cell, reformer and propane system was left at the site after the demonstration period in anticipation of additional funding and another demonstration period of 6 months to a year. If the additional demonstration is not funded then the project partners will evaluate the alternatives.

6.4. Discussion about a Production Unit: Plug Power and HyRadix look ahead to the possibility of working toward a production unit of the LPG fuel processor module packaged together with the fuel cell module. Plug Power can manufacture their fuel cell system and HyRadix has the production capability for its propane fuel processor. By integrating both into a single unit, overall system efficiency will increase through better utilization of heat integration. As the market for such a system matures, production will be assessed.

7. Summary and Conclusions

Based on feedback from the Good Company market study, a propane based fuel cell power system has the potential to meet the needs of the developing market. The fuel processor successfully removes the sulfur odorants present in commercial propane and the variation in hydrocarbon content does not adversely effect the hydrogen purity of reformat sent to the fuel cell. The fuel cell system is capable of producing power of quality high enough for residential and industrial power applications. During the demonstration period, the system supplied power to The Texas Department of Transportation TransGuide Headquarters in San Antonio.

The emissions of carbon dioxide compare favorably with internal combustion generation of equivalent power, while the fuel cell system eliminates SO_x, NO_x, and carbon monoxide release. The overall propane to electrical efficiency was 18.5%, with much room for improvement as the design matures. In building, integrating, testing and demonstrating this system, the program team achieved all of the goals and deliverables for the project.

Appendix A

Interface Requirement Document

HyRadix/Plug Power

Fuel Processor (FPM) to Power Generation Module (PGM)

Interface Requirement Document

9/27/02

1. System Interface Schematic

The physical connections between the fuel processor module (FPM) and the fuel cell power generation module (PGM) are shown schematically below. It is assumed that the FPM will include its own control system to manage the fuel processor auxiliary equipment. The proposed system control strategy is described in section 3.

2. Interface Review

Intrfc. Tag	Parameter	HyRadix	Plug Power	Comments
F1	Port Size	1" tubing	2" sanitary flange	Either side can provide adaptor fitting.
	H ₂ Flow Max	80 SLM	125 SLM	80 OK, but will limit max power to < 5 kWac
	H ₂ Flow Min	13 SLM	25 SLM	OK
	H ₂ Flow Idle	20% = 16 SLM	No Spec	
	Pressure Max	2 psig	No Spec	OK
	Sulfur Max	No Spec	15 ppbv	
	CO Transient	No Spec	100 ppmv	
	O ₂ /H ₂	No Spec	0.007 to 0.017	Plug requirements to be reviewed based on ≤ 10 ppmv CO
F2	Port Size	1" tubing	2" sanitary flange	Either side can provide adaptor fitting.
	H ₂ Flow Max	24	42	OK consistent w/ F1 limit above

Intrfc. Tag	Parameter	HyRadix	Plug Power	Comments
	Dew Pt Temp	Non-Condensing	55-75C	Expect stream to be saturated, non-condensing. Requirement can't be met w/o stream conditioning.
W1	Port Size	½" PVC	0.375" compression fitting	Either side can provide adaptor fitting. Need to work out materials.
	Pressure	>10 psig	<1.5 psig	Hardware changes may be required.
W2	Interface	N/A	Expected	No water recovery from FPM.
C1, C2	Interface	N/A	Available	FPM doesn't need cooling.
A1	Interface	N/A	Expected	Need to route cathode exhaust to flue.
E1	Voltage	24 Vdc	42-60 Vdc	DC-DC converter req'd
E2	Protocol	Discreet&Analog	RS485	Must negotiate
	Weather Protection	No shielding provided (outdoor lab)	Enclosure designed for outdoor operation	Negotiate w/ Customer

3. System Control Strategy

The following summarizes the proposed system control strategy:

1. Fuel Processor Module (FPM) and Power-Gen Module (PGM) will each operate under its own control system supervision and E-Stop circuit. The E-stop circuits will be linked via dry-contacts, so that an E-Stop by either module will trip the other module's E-Stop circuit.
2. PGM and FPM will communicate over a RS422 link.
3. System startup will be initiated at the PGM, which will send a start command to the FPM.
4. During FPM startup (prior to reformat meeting the F1-node requirements given above), the PGM controls will bypass the fuel cell and return the F1 stream at F2 with minimal temperature and pressure loss.
5. FPM controls will signal to PGM when FPM is idling and ready to deliver reformat to the PGM. PGM controls will then switch reformat flow to the fuel cell.
6. PGM controls will command the FPM to deliver H₂ at a certain rate (% of full FPM capacity). FPM will communicate to the PGM the current operating point (% of full FPM capacity). PGM controls will set the fuel cell stack load current based on the H₂ delivery rate.
7. Load changes will proceed based on ask-confirm H₂ delivery communications between PGM and FPM.
8. In the event of an FPM E-Stop, the pre-determined dry contact in the FPM will open and initiate an E-STOP in the PGM.

In the event of a PGM E-Stop, the pre-determined dry contact in the PGM will open and initiate an E-STOP in the FPM.

Appendix B

Southwest Research Institute Test Report

Efficiency and Emissions Testing of a LPG Fuel Cell

FINAL REPORT

SwRI® Project No. 03-10206

Prepared for

**Texas State Energy Conservation Office
LBJ State Office Building
111 East 17th Street, Room 1114
Austin, Texas 78701**

April 2, 2004

SOUTHWEST RESEARCH INSTITUTE®
SAN ANTONIO HOUSTON WASHINGTON, DC

Appendix C

Market Potential Study of Propane Fuel Cells June 1, 2004

Prepared by:

Good Company
ASSOCIATES

Table of Contents

Page

Executive Summary	3
Introduction	6
Project Strategy	7
Technology Background	8
Alkaline Fuel Cells	
Phosphoric Acid Fuel Cells	
Molten Carbonate Fuel Cells	
Solid Oxide Fuel Cells	
Proton Exchange Membrane Fuel Cells	
Proton Exchange Membrane Fuel Cell	
Extended Technology Forecast	11
Fuel Cell Technical Barriers – Transient Loads	12
Opportunities for Combined Heat and Power	13
External Reformer Technologies	14
External Reformer Technology Forecast	
Notable Fuel Cell Demonstrations	15
Texas Distributed Generation Market	16
Comparison: Operating Characteristics of Distributed Generation	
Selection of Propane	
Fuel Pricing	
Fuel Cells as Prime Power	
Market Opportunities	20
Telecommunications	
Control Office Facilities	
Relay Stations	
Backup Power	
Battery Replacement	
APU	
Forklift	
Residential Market	
Off-grid Homes	

- Recreational Vehicles
- Small Commercial Opportunities
- Reliable Power Market
- Quality Power Market
- Boat Market
- Emergency Backup Generators
- Rural Electric Market
 - Power Quality
 - Grid Support

Market Summary	31
Market Strengths	32
Market Weaknesses	33
Market Threats	34
Recommendations	35

Executive Summary

Propane fuel cell systems offer a promising alternative energy source in many niche applications and remote parts of the country, particularly in the off-grid residential market and the telecommunications industry. The fuel cell industry projects that once the price of fuel cells reaches \$1,500 per kW, that 5 – 10%, fuel cells will be competitive in many of these markets. Advancements in the last several years indicate that fuel cells can reach this price in the not too distant future. These cost reduction efforts and the continuing demonstration of the technology are paving the way for these new markets to directly impact propane sales.

In this study, we explore the current and near term market potential for small (5-25 kW) propane fuel cells and recommend areas toward which the propane industry may direct its research efforts. We analyze potential market segments, and based on this analysis, we then estimate the potential market size. We created a summary market projection for the U.S. market in Table 2, and more detailed market projections for Texas in the body of the report.

For a variety of reasons including cost, size, and long-term reliability, we do not foresee propane fuel cells driving significant propane sales in the short-term (1-5 years). The industry expects that within 8-10 years, they will achieve appropriate cost and performance targets. The propane industry can play a crucial role in ensuring that the development efforts include propane-fueled systems to shape the market and set the stage for future success of the industry.

Five types of fuel cells are currently leading the race toward commercialization. These technologies are the proton exchange membrane fuel cell, the alkaline fuel cell, the phosphoric acid fuel cell, the molten carbonate fuel cell and the solid oxide fuel cell. Given this study's focus on the small-scale, near-term market we believe that the proton exchange membrane (PEM) fuel cell will be the leading technology. The PEM fuel cell's operational characteristics seem to provide a better fit for the demands of the small-scale market. While the other competing fuel cell technologies do offer promise to drive the sale of propane, these manufacturers' current products, which are near commercialization, are focused on large applications of at least 100 kW and up.

In this study we analyze the residential backup, off-grid residential, stand-by power, recreational vehicle, boating, forklifts, truck auxiliary power units, telecommunications, small commercial, premium, and reliable power markets. Given the current state of the technology, we have forecasted the demand for propane fuel cells and the resulting demand for propane.

As you will see from Table 1, the early fuel cell opportunities will come in markets that receive benefits which outweigh the high first cost of fuel cells. However, as more markets adopt this technology, the price will be reduced, making it cost competitive in further market areas.

Table 1.

Fuel Cell Distributed Generation Business Opportunities

While the exact price points and timeline required for the introduction of fuel cells is difficult to project with any accuracy, the above graph illustrates a possible sequence of market adoption. For “early adopters” to make the shift to fuel cells, the value of the non-grid electricity must outweigh the cost of batteries and/or extending the electric grid to that site. For example, adopting fuel cell technology could enable companies such as chip fabricators and financial transaction centers to avoid large financial losses from power outages or spikes and sags. Others may avoid less tangible but equally valuable losses from power outages, such as hospitals and other life supporting facilities.

Forklifts

The forklift market, which places a premium on increased productivity and emission-free operation, offers a market niche that may accelerate commercialization of fuel cells. For instance, California’s proposed forklift fleet average regulations and the high cost of powering electric forklifts (which includes battery cost and recharging time), indicate that hybrid propane/fuel cells may be very competitive in this market. With a 10 percent penetration of the U.S. forklift fleet of roughly 1,000,000 trucks, this market would generate 126,731,429 gallons of propane annually.

Auxiliary Power in Trucks

Another opportunity for the propane industry would be truck auxiliary power units (APU). Typical Class 8 sleeper trucks idle an average of 1,800 hours per year, which leads to significant fuel cost, wear on the engine, and harmful emissions. These factors have created an immediate demand for cost effective, emission free APU alternatives. A 10 percent penetration the 500,000 long haul trucks in the U.S. would generate sales of an additional 60,928,571 gallons annually.

Recreational Vehicles

Recreational vehicles (RV) represent one of the largest markets for small scale distributed generation. By 2010, the Recreational Vehicle Industry Association estimates that there will be 8 million RV owning households in

America.¹ RVs are typically equipped with 5-20 kW systems to provide air conditioning, electric ranges and power lights, etc. The units are typically fueled by diesel or gas, from the same fuel source as the engine. Propane is often used for heating and cooking and could be used to power a fuel cell generator. Additionally, propane is available for sale at most of the larger RV rest stops and camping areas. If 10 percent of these units were replaced with fuel cells, the market would generate 54,158,730 gallons.

Residential

The exact number of off-grid homes is difficult to ascertain, however the editor of Home Power magazine, Richard Perez estimates it at roughly 180,000 to 200,000.² The market is currently growing at 30% per year. According to Perez, 82% of these homes use photovoltaic (PV) systems with batteries and backup generators as their primary source of power. If 10 percent of these off-grid homes chose fuel cells for primary power, they would represent a potential new market of 33,573,000 propane gallons.

Telecommunications

A very interesting market for propane fuel cells is the telecommunications industry. Two of the industry's potential use for propane fuel cells includes relay stations and wireless communications control office facilities. These markets require 25-200 KW fuel cells, and several fuel cell manufacturers are already making commercial inroads in this market. A 10 percent penetration of the 3,500 relay towers in the U.S. would generate 10,378,167 new propane gallons annually.

Telecommunications at control office facilities offer another very interesting opportunity to stimulate propane sales through the introduction of propane fuel cells to provide facility power. This study does not provide an in-depth analysis of the industry segment, however, as the type and size of fuel cells expected to be used in this industry are larger than those investigated in this study. However, given the potential of this market, we have provided some basic analysis.

Given the market segments explored in this study, the best opportunities, based on the time to commercial market and the total potential propane sales, are identified in the chart below.

Table 2.
U.S. Near-term Propane Fuel Cell Opportunities

Application	Market Share	Fuel Cell Size (kW)	US Annual Propane Sales (gal)*
Forklifts	10%	3	126,731,429
Truck Auxiliary Power Units	10%	5	60,928,571
Recreational Vehicle	10%	5	54,158,730
Residential Off-grid (Prime Power)	10%	5	33,573,000
Telecommunication- Relay Stations	10%	30	10,378,167

* Assume 30% fuel cell efficiency

Based on the findings of this study, we recommend the following actions for the propane industry:

- Promote propane fuel cell forklift and propane fuel cell APU development.
- Develop propane fuel cell demonstration projects for the off-grid residential and telecommunications industry to show the viability and potential of fuel cell systems in these applications.
- Work with reformer manufacturers to ensure that the reformers are developed to use propane.
- Continue to support propane fuel cell demonstration projects which provide valuable, real world performance data, and accelerate the development of commercial products.
- Promote the implementation the of positive net metering programs in utilities and coops, so distributed generation users can sell excess power back to the grid for maximum return.

¹ RVIA, <http://www.rvia.org/Media/fastfacts.htm>

² Richard Perez, Home Power Magazine, February 1 telephone interview.

- Support the development of combined heat and power applications for fuel cells.
- Explore participation in, or support of, bulk propane fuel cell purchases, which could increase the economies of scale in propane fuel cell production.
- Explore additional propane fuel cell opportunities in the 100+ kW market.

Introduction

Propane fuel cells hold a great deal of market potential, as they offer a ready source of power for remote facilities, installations, and residences that do not have access to natural gas utilities and have a need for more reliable or higher quality electric service. Currently many of these potential customers generate onsite power using reciprocating engine generators or underwrite line extensions, which can be very costly. Propane fuel cells offer these rural customers an efficient and environmentally friendly alternative source of power. Propane fuel cells also have additional properties as a distributed generation source which can offer value to rural utilities as a mitigation technique for congestion problems and an alternative to the costly build out of the electric distribution system. Finally, propane powered fuel cells' quiet, emission free, vibration free operation may offer added value to users such as boat and RV owners willing to pay a premium for such properties. As evidenced by the huge investments in the fuel cell technology development, by the federal and state government as well as private industry, the market potential is huge.

The Propane Education and Research Council (PERC), the U.S. Department of Energy and the Texas Railroad Commission's Alternative Fuels Research and Education Division (AFRED) see the potential of the fuel cell market to drive the sale of propane. They have taken a leadership role by working with Plug Power, HyRadix, the Texas Department of Transportation (TxDOT), the Texas Commission on Environmental Quality (TCEQ), the Texas State Energy Conservation Office (SECO), City Public Service of San Antonio (CPS), Good Company Associates, and Southwest Research Institute, in the demonstration of a 4 kW propane powered fuel cell at the Texas Department of Transportation Transguide facility in San Antonio, Texas.

For this demonstration, Hyradix created a propane fuel reformer to convert retail propane into hydrogen to run the fuel cell. The 5 kW fuel cell created by Plug Power, has been operating in a grid parallel mode, interconnected with CPS's transmission and distribution system at the TxDOT Transguide facility. While the unit primarily supplies baseload power to the utility grid, it is capable of supplying enough electricity to power a portion of Transguide's transportation monitoring equipment.

As part of the project, Good Company Associates conducted a market assessment of the short term (1-5 year) market potential of small scale (5-25kW) propane fuel cell systems. Good Company was tasked with determining the gallons of propane that could be sold to power the emerging market for fuel cells.

Project Strategy

Good Company conducted this study of the market potential for propane powered fuel cells through the following steps:

1. Identifying the near-term (five-year) technology potential. Working with information from HyRadix, Plug Power, and the Southwest Research Institute, we documented the existing propane fuel cell capabilities and developed a reasonable projection of the near-term future of the technology in order to present scenarios to potential customers and to establish certain necessary details on market size. Our projections will enable fuel cell and reformer manufacturers to better evaluate the market and the scenarios include references to such factors as:
 - a. Unit size (5-25 kW).
 - b. Propane fuel consumption.
 - c. Water consumption/requirements.
 - d. Temperature/weather limitations.
 - e. Fuel quality concerns.
 - f. Technical applications including ability to serve transient loads vs. base loads (i.e., backup vs. base vs. peak power).

2. Quantifying the size of the potential market for propane fuel cells by acquiring reasonable estimates of the numbers in various prospective customer groups:
 - a. Commercial customers with critical operations having a demonstrated demand for more reliability or higher quality in their power supply. These facilities include medical institutions, technology and telecommunications centers, financial/banking facilities, and light industrial facilities.
 - b. Niche markets which may become early adopters who may have smaller power needs, but with long hours of use and ready supplies of propane.
 - c. Existing residential customers. The likely prospects in this group would have a less reliable power supply, perhaps due to being located at the edges of the electrical grid, necessitating a need for local supplemental or backup generation.
 - d. Remote new construction. In this case, a propane fuel cell could serve as an alternative to extending the power grid to meet remote customers needs, and could potentially serve a number of facilities, such as a neighborhood or a farm operation. This scenario could create a market for larger capacity fuel cells and thus has the potential for greater economies of scale.
3. Examining the most promising markets for propane fuel cells, based on such factors as lack of access to the natural gas grid, reliability of current power systems, utility cost-avoidance, and air quality concerns. We pay particular attention to identifying customers currently using reciprocating diesel generators as power supply. We conducted original research and analyzed numerous sources of existing data.
4. Projecting, in gallons, the near-term market for propane as a fuel cell source supply.
5. Identifying obvious market strengths, weaknesses, opportunities and threats such as regulatory factors, permitting requirements, costs, infrastructure requirements and competing products.

Our study assumes that any prospective customers or customer groups have relatively easy access to a supply of propane. Good Company's scope was to assess the market potential for propane fuel cells in the state of Texas, and to extrapolate the results to reflect the potential market nationally. Given the current state of development of the technology, the projections of possible market penetration of fuel cells in the future assume that prices continue to decline and products continue to improve.

Technology Background

This section of the report examines the major types of fuel cells and explores fuel reformer technology. Additionally, we look at how the competing technologies lend themselves to the primary goal of this study: increasing the short term demand for propane through the distribution of small scale (5-25 kW) fuel cell systems.

A fuel cell generates electricity (illustrated below) by using two electrodes, a cathode and an anode to pass charged ions through an electrolyte. The electrolyte conducts ions but not electricity. The electricity resulting from this process is thus freed and conducted to the electric load via an external circuit. There are five primary fuel cell types differentiated by the type of electrolyte material they use: proton exchange membrane fuel cells (PEM), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and alkaline fuel cells (AFC).

Illustration from Fuel Cells 2000, <http://www.uwec.edu/grossmzc/macombbd.html>

Alkaline Fuel Cells (AFC)

Alkaline fuel cells have been demonstrated as early as the 1940's and were used on the Apollo spacecraft. These fuel cells can be produced relatively inexpensively as they do not use precious metals in their electrodes. However, unlike other fuel cells, carbon dioxide can create serious performance degradation. Consequently, the perceived attractiveness of the technology is diminishing and very few manufactures are actively developing the technology in the U.S.

Phosphoric Acid Fuel Cells (PAFC)

Phosphoric acid fuel cells are the only commercially established fuel cell in the market. UTC Fuel Cells has sold a 200 kW product since 1992 and there are more than 250 units operating worldwide. These products have proven very reliable with demonstrated useful lives as high as 70,000 hours and 90-95% availability.

However, much of the development of these fuel cells is mostly appropriate for larger scale applications and, due to raw material costs, extensive cost reductions seem unlikely in the near term. For this reason we have not focused our study on this technology.

Molten Carbonate Fuel Cells (MCFC)

The MCFC has many of the same operating characteristics as the SOFC. Like SOFC's, MCFC's are a high temperature technology, operating at 1100 to 1400 degrees Fahrenheit. This high operating temperature makes the internal reformation of fuels possible but decreases the load following capabilities and increases unit startup time. MCFC's are expected to operate at up to a 50% electrical efficiency and this high efficiency offers fuel cost advantages in prime power applications.

The high temperature operation is ideal for industrial combined heat and power applications, but this high temperature also leads to a decrease in the durability of the fuel cell components in today's products. The high temperature also requires significant thermal shielding to retain heat and protect personnel. Scientists are currently exploring new materials and designs, which will increase the cell life without decreasing performance.

Fuel Cell Energy is leading the development of MCFC in the US and currently has 200 kW, 1 and 2 MW units commercially available. However, there seems to be limited focus on small-scale MCFC units.

While the MCFC internal reformation is capable of handling propane, doing so requires different operating conditions than those for natural gas. These large applications generally have large fuel needs and have natural gas readily available making natural gas an obvious fuel choice. To enter this market, it would be up to the propane industry to encourage MCFC manufacturers to develop the systems and specifications to operate at maximum efficiency using propane.

Solid Oxide Fuel Cells (SOFC)

The SOFC holds the second largest market share of the competing fuel cell technologies at roughly 20%.³ The SOFC is a high temperature fuel cell, operating at temperatures from 1300 to 1900 degrees Fahrenheit. This operation temperature also makes the internal reformation of fuels possible. Additionally, high temperature operation removes the need for precious metal catalysts, which offers cost benefits. The SOFC is anticipated to have electrical efficiencies of 50% to 60% in distributed generation (DG) applications, which will provide lifecycle cost advantages in prime power uses. It should also be noted that SOFC's are the most sulfur resistant FC technology. While the SOFC internal reformation should be capable of handling propane, the same issue of fuel choice applies here, as with MCFC applications.

The SOFC is generally considered to be at a less advanced stage of development than many of the competing technologies. The earliest products in this technology class are in the 150 kW range, larger than the scope of this study. Development is underway on the 1-10kW systems, though the time for development will delay the market for these systems. Additionally, the units have a relatively high capital cost and do not offer the same short-term production cost reductions of PEM fuel cells. The high temperature internal reformation process increases startup times and makes load following more difficult. Consequently, the units are more suited to supplying base load power. The high temperature operation is ideal for industrial combined heat and power applications, but this high temperature also leads to a decrease in the durability of the fuel cell components. The high temperature also requires significant thermal shielding to retain heat and protect personnel.

SOFC developers are currently working on developing units with lower operating temperatures, which would have fewer durability problems and cost less. However, this reduction will likely lead to a loss in operating efficiency, at least in the near term.

Proton Exchange Membrane (PEM) Fuel Cells

Based on the rural market penetration of the propane industry, the stage of development of the PEM technology, and its operating characteristics, the PEM fuel cell offers the best short-term opportunity to increase propane sales. However, it should be noted that this does not limit the potential for other technologies to drive additional sales of propane.

Proton exchange membrane fuel cells are the most common type of fuel cell being developed today, representing roughly 75% of the units produced today.⁴ PEM fuel cells offer a variety of advantages to the market. The PEM fuel cell operates below 200 degrees Fahrenheit, which makes it ideal for mobile applications. This low operating temperature facilitates fast unit startup times. This quick start capability should help PEM fuel cells enter the standby power market. PEM fuel cells currently demonstrate approximately a 30% electrical efficiency and are

³ Fuel Cell Today, Fuel Cell Market Survey, Stefan Geiger, Mark Cropper, July 30, 2003.

⁴ Fuel Cell Today, Fuel Cell Market Survey, Stefan Geiger, Mark Cropper, July 30, 2003.

projected to reach as high as 40% electrical efficiency. While this electrical efficiency is the lowest of the competing technologies, it is equivalent to or higher than the competing fossil fueled internal combustion engines.

Perhaps one of the most attractive characteristics of the PEM fuel cell is its ability to handle transient or fluctuating loads. The PEM fuel cell provides high quality partial load operation, meaning its efficiency improves at lower load levels, and is relatively constant down to ¼ of the unit's rated capacity. This translates to good power quality in load following conditions. These qualities will make the PEM fuel cell desirable in stand-alone applications, high quality power applications, and applications serving transient loads.

PEM fuel cells are relatively simple to manufacture, which should facilitate dramatic cost reductions when they reach mass production. Mass production will be necessary to enter the mainstream market. Additionally, because the major automotive manufacturers are investing primarily in the development of the PEM fuel cell, research on this technology has seen the largest infusion of capital. This infusion of funding should facilitate the technology advancements necessary to reach cost competitive production.

The PEM fuel cell has three primary weaknesses. First, the lower electrical efficiencies compared to other fuel cells could translate into higher lifecycle operating costs as this translates into more fuel usage. Second, the low temperature operation limits, but does not eliminate, combined heat and power (CHP) applications. The low temperature is only useful for low quality heat applications such as water heating, which is the main need for base load heat for the rural residential market. (It should be noted that PEM fuel cell manufacturers are developing higher temperature PEM fuel cells to allow for CHP application.) An increase of operating temperatures to 300 degrees Fahrenheit will increase the CHP applications of the technology.

While extended-life testing has yet to be completed on PEM fuel cell products, the technology is now being sold commercially. Additional product development, enhancement, and improvement will expand the commercial viability of the technology beyond the current niche markets, such as backup battery replacement, which are being successfully introduced today.

Proton Exchange Membrane Fuel Cell 5 Year Extended Technology Forecast

Given that PEM fuel cells appear to offer the most promise for the short-term, small-scale sales, we have focused our research on the near term potential developments in this industry. That said, anticipated development is a large function of sales, government investment and private sector investment.

Perhaps one of the most critical elements driving the cost of fuel cells is the lack of economies of scale. The current volume of market demand for fuel cells prohibits large investments in manufacturing facilities. Ironically, one of the major factors holding the price at current levels around \$4000/kW is the limited scale. This problem represents the classic chicken and egg conundrum; sales will not increase until prices drop and prices cannot drop until sales increase. Currently, several groups are exploring concepts to create the bulk purchasing power necessary to drive fuel cell prices down. The Clean Energy Group out of Vermont has organized twelve states actively pursuing the commercialization of fuel cells into a coalition. The volume of sales generated by such a group could be large enough for fuel cell manufacturers to achieve significant economies of scale and drive the price of fuel cells down to competitive levels. Additionally, other organizations such as Fuel Cells Texas, the Texas Energy Center, and the California Stationary Fuel Cell Collaborative are working to develop bulk purchases of fuel cells.

The scale necessary to achieve dramatic price reductions varies depending on which manufacturer you speak with. Estimates range from sales of 25 MWs to 100 MWs. While this number dwarfs current sales, it is a mere fraction of the entire electric capacity in the country. Texas alone has roughly 70,000 MWs of generating capacity.

The timeline for developing a truly commercially competitive product varies depending on whom you speak with. Plug Power representatives believe that in the next five years a commercial propane fuel cell system, complete with a fuel reformer will be available for about \$1,200/kW. Plug believes that these units will soon be commensurate in

size and weight with current internal combustion generators and demonstrations will continue to reduce cost, while increasing reliability and durability.

Table 3.
Plug Power's GenSys Development Progress

2001-2002 "SU1" over Beta Unit	2002-2003 GenSys 5C	2004 - Next Generation Prototype
40% decrease in size	60% decrease in material cost	40% decrease in material cost
55% decrease in weight	7X decrease in service call rate	45% increase in efficiency
65% decrease in mfg. Labor	5X increases in stack life	60% decrease in size
57% decrease in material cost	Multi fuel capacity (LPG or NG)	60% decrease in weight

The propane industry could play a crucial role in reaching the future development milestones by helping to demonstrate technological advancements and new applications to hasten market acceptance.

Fuel Cell Technical Barriers - Transient Loads

A transient load is one that has notable swings in demand. For instance the load of a typical residence changes dramatically during the day. The constant load may be as low as a few hundred watts; however when an energy intensive appliance such as the water heater or air conditioner comes on, the load jumps to as high as 20+ kW, depending on the size and number of the appliances in use at that time. The ability of an energy source to meet this changing electricity need, or load follow, is referred to as its "dynamic response". The dynamic response varies among fuel cell types. The ability to load follow is determined in three major component areas of a fuel cell, the fuel reformation process, the energy generation process, and the energy conversion process, where the energy is converted into useable electricity. With all fuel cell systems, inserting batteries or an equivalent technology into the electricity conversion process can address this load following requirement, however batteries are expensive and not practical solutions for large transient loads. While adding cost, they are a practical solution for residential applications or other small transient loads.

High heat fuel cells (SOFC and MCFC) have limited demand response capabilities in the reformation and energy generation processes. These fuel cells require a relatively constant high temperature to internally reform fuel and generate electricity. Consequently they do not have good dynamic response to changing loads. As they are designed today, MCFC and SOFC are more suitable to provide base load power, unless they are combined with some form of energy storage. This option may be appropriate in smaller applications but probably not in larger applications. In larger applications, such as an office building, it is possible to use the fuel cell for base load power which has some load variability, and rely on the grid for peaking power needs.

The low temperature PEM fuel cell energy generation component, or stack, is relatively responsive to changing loads, given a sufficient stream of hydrogen. Currently, however, the reformation of propane or natural gas to hydrogen creates the bottleneck. This type of fuel reformation is essentially a steady state process which does not handle change in demands well. As the reformation technology improves the ability to handle demand fluctuations may increase as well. In addition to using energy storage technologies to handle load fluctuations, PEM fuel cells have the option of utilizing hydrogen storage systems to create a buffer in the reformers required response time.

Opportunities for Combined Heat and Power

Due to the different operating temperatures of fuel cells, they offer varying opportunities for combined heat and power (CHP) applications. While PEM fuel cells operate at lower temperatures, they can provide sufficient waste heat for use in operations which are coincident with hot water demand, such as hot water heating. As cited before, research is under way to develop PEM fuel cells with higher operating temperatures to expand CHP options. Such utilization of CHP opportunities can increase the total efficiency of fuel cell systems, decrease the peak load requirements, and decrease the cost effectiveness of fuel cells. As detailed in Table 4, however, it will take significant increases in efficiency and reductions in fuel cell capital costs before any fuel cell system is competitive

with grid supplied power. However, research into the effectiveness of such systems is relevant, particularly in the off-grid residential market where fuel cells will be competing with more expensive forms of energy such as photovoltaic (PV) systems.

Because of the extremely high operating temperatures of SOFC's and MCFC's, these fuel cells offer more opportunities for CHP applications. The high quality waste heat to energy generated by these fuel cells can be used for heat exchange systems for cooling and refrigeration as well as industrial applications. Additionally, because large industrial customers can negotiate time of use rates, DG CHP can be used to offset electricity demand during high priced peak load hours. This potential opens vast markets such as restaurants, warehouses, supermarkets, and schools. States such as New York and California are currently supporting demonstration of such applications. The New York State Energy Research and Development Authority (NYSERDA) currently will reimburse up to 50 – 60% of the cost of a fuel cell CHP system.⁵ Similarly, California's Self Generation (SELFGEN) program will reimburse up to \$4.50/Watt of the cost.⁶ According to Paul Eichenberger⁷, by using this buy down program and possible emission credits, 200 kW baseload CHP systems are very close to cost competitive in areas with the highest utility rates in California. While these utility electricity rates are 2-3 times of those in Texas and Texas does not offer a similar buy down program, the concept demonstrates an interesting longer-term market niche for high temperature fuel cells.

External Reformer Technologies

Because fuel cells require pure hydrogen to operate, low temperature fuel cells, which cannot internally reform conventional fuel sources to hydrogen, require an external fuel reformer to create it. Numerous companies are quickly working to develop reformation technologies.

Current reformers face several technical challenges. First, the units are expensive; currently the reformer represents roughly 40% of the cost of an integrated fuel cell/external reformer system. Reformers are large. The Hyradix system currently being demonstrated at the Transguide facility in San Antonio, Texas, is 4.25' x 1.65' x 3.9' in size.

Reformers also require de-ionized water to operate, which can be produced from regular tap water. While this may not be a barrier in some applications, it would be a factor in dry climates, remote applications and mobile applications where availability of water is limited. However, since fuel cells produce water as a byproduct, it is expected that future systems will be developed with zero net water use.

Particularly relevant to the propane industry, reformers require technology to handle the sulfur in the gas. While the technology is reliable, it must be understood that the greater the concentrations of sulfur, the more frequent the need for maintenance. At this time, it is difficult to determine the cost implications of unregulated levels of sulfur or recommend if it is a problem that needs to be addressed by the propane industry.

Other elements found in propane such as propylene, ethane and butane also present technical challenges in the reformation process. Currently reformers can be designed to handle up to 5-10% propylene. Varying levels of ethane and butane can be accommodated as well, though they may lower the throughput of the reformer. As development progresses, the ability to handle these elements will only improve.

External Reformer Technology Forecast

In the next five years, advances in absorbent and catalytic technologies will lead to a more compact design of reformers that will be roughly 1/3 of the current size. Units will have higher thermal efficiencies, reduced

⁵ <http://www.nyserda.org/rddopps.html>

⁶ <http://www.nyserda.org/rddopps.html>

⁷ Paul Eichenberger, Emergent Energy Group, February 11 phone interview.

maintenance requirements, and an order of magnitude increase in reliability. Given that fuel cells are net producers of water, it is highly likely that in the near future, reformers will have a net zero usage of water. While recovering this water may come at some additional cost, the benefits in terms of market acceptance probably make this cost acceptable. Units will be designed to work in all temperature conditions.

Assuming these improvements advance according to projections, reformers are expected to cost roughly \$3,000-\$4,000 to supply a 5 kW unit.⁸ This cost could come down even further but it is largely dependent on the size of the market. While a fraction of the current cost, this expense will still prove a significant impediment to market adoption for consumers, such as residential off grid users looking for cost effective energy production. However, consumers concerned with power quality may be able to overlook this expense.

Notable Fuel Cell Demonstrations

There are numerous programs and demonstration projects currently under way which will better define the future fuel cell markets.

- Long Island Power Authority's (LIPA) residential fuel cell demonstration. The LIPA has recently funded a program to purchase 75 Plug Power 5 kW PEM fuel cells. This program was to developed to explore the potential of fuel cells to reduce system electricity demand, limit transmission system congestion, and demonstrate the viability of numerous small fuel cells to provide clean reliable power to the LIPA electric grid. As this program has just been launched, results are not currently available.⁹
- The Bonneville Power Authority (BPA) has agreed to purchase 110 prototype PEM fuel cells from IdaTech to test on various applications.¹⁰
- Sulzer Hexis has agreed to a two-year pilot program with the Swiss utility group, Axpo Holdings, to test 1 kW SOFC CHP units.¹¹
- IdaTech has received a grant from the Department of Energy to develop a 50 kW PEM grid independent fuel cell for demonstration in several hotels across the country. Prototypes are expected to be installed in late 2005.¹²

Texas Distributed Generation Market

Fuel cells are classified as a distributed generation (DG) source of electricity. To begin to understand the ability of fuel cells to drive the sales of propane, it is valuable to understand the size of the DG market in Texas. The size of DG units typically ranges from 1 kW up to 7 MWs. As smaller units have no state or federal level registration requirement and are completely portable, it is difficult to provide an exact figure on the size of the market. However, several recent studies examining emissions sources in Texas provide us with a decent estimate.

A 2003 study completed by Environ International Corporation estimated that Texas has 35,000 diesel DG units in the state, ranging from 5 kW- 7 MW.¹³ While this figure does not include DG units powered by natural gas or propane, this study quoted the Renewable Energy Policy Project stating that at least 90 percent of back-up onsite

⁸ Michele Davies, Hyradix, Interview, February 6, 2004.

⁹ http://www.plugpower.com/is/studies_lipa.cfm

¹⁰ <http://www.idatech.com/media/news.html?article=7>

¹¹ http://www.hexis.com/map/SulzerDocuments/DocumentsImages/Documents/Hexis/News/Medienmitteilung_Engl.pdf

¹² <http://www.idatech.com/media/news.html?article=54>

¹³ *Estimates of Emissions for Small-Scale Diesel Engines*, Environ International Corporation, Environ Study, December 22, 2003.

generation units are internal combustion engines that run on diesel fuel, according to a 1997 Renewable Energy Policy Project report released in 1997.

Given the scope of this study, we have focused our research on small scale DG sources such as portable generators and standby generators. In its 2002 study *Micropower at the Crossroads*, TexPirg estimated that portable generators comprised roughly 24,000 of this 35,000.¹⁴ These units are compact freestanding units, kept in private residences and at small business for emergency power in case of power outages, or for recreation activities such as camping. Given the reliability, compact size and portability, availability of fuel supply and low price, it is highly unlikely that fuel cells will be able to capture any significant market share in the short- to mid-term future. Additionally, these units are only used in emergencies or for occasional outings. Therefore penetration of this market will do little to drive propane sales.

Comparison of Operating Characteristics of Distributed Generation

Consumers choosing distributed generation have a wide variety of choices. Because of the wide variety of sizes, technologies, and fuel choices it is difficult to list them all. The following table, however, provides some general observations:

¹⁴ *Micropower at the Crossroads*, TexPirg, Public Citizen, Environmental Defense, 2002.

Table 4.
Comparison of DG Technologies¹⁵

	Reciprocating Engine	Micro-turbine	Fuel Cell
Size (MW)	0.01	.03-.25	.005-2
Electric Efficiency (HHV)	30	23-26%	30-46%
Total CHP Efficiency (HHV)	69	61-67%	65-72%
Power Only Installed Cost (\$/kW)			
Grid Interconnection	700-1,000	1,500-2,300	2,800-4,700
CHP Installed Cost (\$/kW)	900-1,400	1,700-2,600	3,200-5,500
O&M Cost (\$/kWh)	0.018	.013-.02	.02-.04
Availability	>96%	95%	90%
Equipment Life (Yrs)	20	10	10*
NOx Emissions (lb/MWh)	.2-6	.5-1.25	<.1

* Fuel cell life is expected to be 10 years.

It is important to note that, particularly with fuel cells, the operational characteristics vary greatly depending on the source. However, given the current characteristics, reciprocating engines are, far and away, the selection of choice.

Selection of Propane

Current DG sources typically use diesel, gas, natural gas or propane as the fuel source. Because fuel cells are powered by hydrogen, liquid or compressed hydrogen must be considered another alternative fuel source. However, current sources of hydrogen are limited, and unless created as a byproduct of another process, hydrogen is expensive to produce. There is currently no hydrogen distribution system and onsite storage of hydrogen is problematic at best. Additionally, the codes and regulations for any mass hydrogen storage are onerous. Consequently, in the short-term, hydrogen is not a realistic threat to the current primary fuel sources. Fuel cells are typically fueled by reformed natural gas or propane. (In some cases gas from wastewater treatment plants or from landfills can be a source.) Additionally, fuel cell manufacturers are exploring ways to utilize diesel as a feedstock.

Determining whether propane will be chosen to supply fuel cells or other internal combustion DG systems is complex and can depend on many factors. However, the primary determinants are fuel availability and cost. The rule of thumb for availability in Texas is that natural gas is available east of Interstate-35 however; even in the Western corridor of Texas natural gas is readily available in many town centers.

Fuel Pricing

To correctly calculate the energy costs of these fuel choices it is necessary to track not only prices, but the energy content associated with these prices. The tables below track fuel prices for 2003 and then convert these prices into energy content or British Thermal Units (BTU) per dollar.

Table 5.

¹⁵ *Gas-Fired Distributed Energy Resource Technology Characterizations*, Gas Research Institute and NREL, November 2003.

2003 Residential Retail Price (\$/Gallon Excluding Taxes)

Fuel	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Propane	1.224	1.297	1.399	1.304	1.296	1.25	N/A	1.161	1.16	1.167	N/A	N/A
Gas	1.473	1.641	1.748	1.659	1.542	1.514	1.524	1.628	1.728	1.603	N/A	N/A
Diesel *	1.032	1.209	1.241	1.07	0.977	0.962	0.976	1.03	0.996	1.017	1.018	N/A
Natural Gas (\$/Mcf)	8.07	8.43	9.71	10.04	10.56	11.78	12.54	12.76	N/A	N/A	N/A	N/A

* EIA Jan 2004

2003 Residential Retail Price (BTU's/dollar Excluding Taxes)

Fuel	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Propane	68,627	64,765	60,043	64,417	64,815	67,200	N/A	78,898	78,966	78,492	N/A	N/A
Gas	79,566	71,420	67,048	70,645	76,005	77,411	76,903	71,990	67,824	73,113	N/A	N/A
Diesel *	124,128	105,955	103,223	119,720	131,116	133,160	131,250	124,369	128,614	125,959	125,835	N/A
Natural Gas	127,261	121,827	105,767	102,291	97,254	87,182	81,898	80,486	N/A	N/A	N/A	N/A

* DOE, http://www.afdc.doe.gov/pdfs/afv_info.pdf

As these tables demonstrate, on an energy content basis, propane is an expensive fuel option. Therefore, given identical performance characteristics, convenience and availability, consumers will choose natural gas over propane. This fact effectively limits the selection of propane to areas where natural gas is not available.

In examining these tables, the seasonality of price swings for propane is also readily apparent. If fuel cells can be deployed and drive a more consistent demand for propane, it may reduce some of this seasonality.

Fuel Cells as Prime Power

In the current market distributed generation, as a prime power source, is rarely cost competitive with electricity supplied by the electric grid. However, numerous factors in today's market could change this generalization. Table 6 below looks at the cost of electricity generated by fuel cells given a fixed price of propane at \$1.25/gallon and varying capital costs, efficiencies, and O&M costs. As the table clearly indicates, it will take dramatic efficiency and reliability improvements and capital cost reductions before the typical consumer will choose to use a fuel cell if they have access to the grid.

Table 6.
Fuel Cell Prime Power Electricity Cost Evaluation

Scenarios	Current Costs *	Mid O&M, Mid Eff., Low Cap. Cost	Low O&M, High Eff., Low cap. Cost
Fixed Cost (1 kW)			
Installed	\$ 5,500	\$ 1,000	\$ 1,000
O&M (\$/kWh * kWh)	\$ 1,320	\$ 520	\$ 200
Total	\$ 6,820	\$ 1,520	\$ 1,200
Fixed Cost per kWh	\$ 0.17	\$ 0.04	\$ 0.03
Variable Cost (Propane)			
Unit size (kW)	1.00	1.00	1.00
Electrical Efficiency	30%	45%	65%
Propane Price (\$/gal)	\$ 1.25	\$ 1.25	\$ 1.25
Electric Heat Rate (Btu/kWh)	11,373	7,582	5,249
Propane Btu's/gal	84,000	84,000	84,000
Gallons/kWh	0.1354	0.0903	0.0625
Variable Cost (Propane) per \$/kWh	\$ 0.17	\$ 0.11	\$ 0.08
Total Fuel Cell Cost/ kWh (FC+VC)	\$ 0.34	\$ 0.15	\$ 0.11

*GRI, NREL Study, November 2003, p5-32

** Estimated fuel cell life (hrs): 40,000

Using a straight cost of power formula such as the table above, a residential fuel cell would have to achieve 65% total efficiency, a \$1,000/kW capital cost, an Operation and Maintenance cost of \$0.005/kWh with propane prices at \$1.25/ gallon to be competitive with residential electric grid power at today's rates.

It is important to note, however, that this simple calculation fails to address several other potential economics benefits of a DG power source. First, DG can replace the need for major transmission and distribution (T&D) upgrades. In rural areas, DG can provide grid reliability and load support on the fringes of the T&D system. This option can eliminate the need for alternative transmission fixes. Consequently, utilities and electric cooperatives may consider spending money on DG to save money on transmission and distribution. (This application is discussed more in the Utility Interview Section.) Alternatively, cooperative or utility customers can eliminate the cost of the tying into the distribution system by staying off grid and supplying all their power from a DG source. In rural areas, the cost of building a feeder line to tie into the system is often borne entirely by the customer and typically costs \$15,000 - \$20,000 but can run much higher depending on the terrain. (These costs can be substantially higher in other more densely populated areas of the country.) For particularly remote locations DG can be a cost effective alternative.

Distributed generation is frequently discussed as a cost effective alternative to expanding the transmission system in highly congested areas. This sort of congestion frequently occurs in metropolitan centers such as Dallas and Houston. Given the air quality issues in these areas, however, installing traditional fossil fueled internal combustion engines can be difficult, if not impossible to obtain permitting. Consequently, the clean energy produced by fuel cells is the most viable alternative. While this market opportunity is very promising for fuel cells, these areas are typically served by natural gas and the size of the DG units required by a utility are typically several hundred kW's and larger. Consequently, this market appears to offer limited short-term opportunity to drive propane sales.

Market Opportunities

As the cost of fuel cells comes down and reliability increases, market opportunities for propane powered fuel cells will continue to grow. The use of fuel cells in CHP applications promises to further increase the cost effectiveness

of fuel cells and broaden their adoption. For instance, the exploration of using SOFC's in the trucking industry to power the refrigeration elements could prove to be an attractive opportunity to drive the sale of propane. The development of residential fuel cell parks, which supply whole neighborhoods with power and reduce congestion on the transmission system, may be another opportunity. The following sections however, detail markets outlined in our scope of work and others considered the most immediate opportunities for the propane fuel cell industry.

Telecommunications- Control Office Facilities

Telecommunication control office facilities are a very interesting market for propane fuel cells. A 2002 Cellular Telephone Industry Association estimated there were 127,000 US sites, with the population growing at a 22% a year. The major wireless communications companies are already exploring the potential of fuel cells to meet the power needs of these towers, especially in remote areas. According to Verizon Wireless, the typical facility requires 100 – 300 kW. Fuel cells that effectively employ CHP systems could be a cost effective source of prime power for many of these remote facilities. Phosphoric acid, molten carbonate, and solid oxide fuel cells seem to be the leading candidates to fill this market niche. Before fuel cells systems will be implemented, however, the reliability will have to be improved. Consequently, this market seems to be several years away, at best, before we will see any commercial adoption. Table 7 explores the potential propane demand created by this market.

Table 7.
Wireless Facilities Propane Fuel Cell Demand

Number of Stations	FC Market Share	FC Size (kW)	Annual Energy Consumption (kWh)	Propane Sales (Gal/Year)*
127,000	10%	200	18,542,000,000	1,075,940,544
127,000	20%	200	37,084,000,000	2,151,881,088
127,000	30%	200	55,626,000,000	3,227,821,633

* Assuming 70% system efficiency

Telecommunications- Relay Stations

According to ABI Research there is a minimum of 3,500 relay towers in the U.S. These towers require about 25-40 kW of power.¹⁶ Additionally, according to this ABI study, because of the FCC's move to an all-digital system, many of these require new, larger power supplies to accommodate the equipment necessary to transition to an all-digital system. As many of these towers are in remote locations, it may be practical to use propane powered fuel cells rather than pay the cost to build feeder lines to interconnect with the electric grid. The following chart estimates potential propane sales related to this market.

Table 8.
Relay Stations Propane Fuel Cell Demand

Number of Stations	FC Market Share	FC Size (kW)	Annual Energy Consumption (kWh)	Propane Sales (Gal/Year)*
3,500	10%	30	76,650,000	10,378,167
3,500	20%	30	153,300,000	20,756,333
3,500	30%	30	229,950,000	31,134,500

* Assuming 30% system efficiency

¹⁶ *Stationary Fuel Cells, US and Global Early Market Opportunities*, Allied Business Intelligence, 2001.

Telecommunications- Backup Power

According to the manager of the backup power systems for the LCRA's network of two-way communication towers (300+ towers), most of the back-up generators are 35 kW to 60 kW. While this seems like excessive capacity, the hot climate in Texas requires that the equipment rooms have air conditioning, which increases the capacity requirements. Given the limited use of backup generators, initial capital cost of backup equipment is a key consideration, which makes fuel cells an unlikely candidate. Due to the large size requirements of these backup systems and the desire for low cost backup systems we do not believe this will be a market to drive propane sales.

Telecommunications- Battery Replacement

The FCC requires telecommunications towers to have at least four hours of emergency backup power, typically batteries, in case of power loss. Fuel cell manufacturers such as Plug Power are already marketing small fuel cell units (Approximately 5 kW) as a cost effective and reliable replacement for these emergency backup battery systems. As these systems are only required to have the capacity to operate four hours per year, fuel cell manufacturers can use hydrogen to power the fuel cell more cost effectively than propane. Consequently this does not appear to be a market that is relevant to the propane industry.

Truck Auxiliary Power Units (APUs)

The truck APU market represents a very interesting market opportunity for propane fuel cells. According to the DOE, a typical class 8 truck idles approximately 1,800 hours per year. This excessive idling occurs when truckers leave their engines running to power their sleeper cab conveniences such as air conditioning and television, or to provide power to the large refrigerator units for trucks carrying temperature sensitive loads. This idling has tremendous financial impact on the trucking industry. According to the EPA, idling trucks will consume \$1.5 billion in diesel fuel and produce 11 million tons of CO₂ and approximately 150,000 tons of NO_x per year.¹⁷ As fuel cells provide better electrical efficiency than an idling truck engine, propane costs to power a fuel cell APU could be lower than the diesel fuel costs required to keep the engine running. Use of an APU also eliminates significant wear and tear caused during idling, and therefore, provides another financial incentive to use an APU. Additionally, many states are now offering grants or rebates for NO_x emission reduction technologies. Texas is currently paying roughly \$5,000/ton of NO_x reduced. Given that each truck produces approximately one-half ton of NO_x per year while idling, over a ten-year life, a truck that installs an emission free fuel cell APU could earn, roughly, a \$25,000 rebate toward the purchase price of the fuel cell APU. Consequently, potential fuel cost and engine wear and tear savings, and emission reductions make this a good market for fuel cell APUs.

As with most applications, the cost of fuel cells must come down and the reliability of fuel cells must increase before there is wide market adoption of fuel cell APUs. If the cost of the APUs can be offset by rebates or grants for the fuel cells' emission benefits, however, the cost hurdle may be overcome soon. Another challenge in this market is fuel choice. While diesel fuel reformers are less advanced than propane reformers, several companies are working on the technology. If the technology is perfected and diesel can be converted with the same or better efficiency than propane, the industry will likely choose diesel fuel for the fuel cells as the trucks already carry diesel.

Table 9 provides an estimate for the potential annual propane sales for APUs in the Heavy-Duty Truck Industry:

Table: 9.

¹⁷ NETL- Media Backgrounder., www.netl.doe.gov/newsroom/backgrounder/mb-0007.html

Texas APU Market Propane Sales

Truck APU Market Size	Texas Market Share	Fuel Cell Market Share	Generator size (kW)	Annual Operation (Hrs)	FC Efficiency	Annual Propane Sales (Gal.)
500,000	5%	5%	5	1800	30%	1,523,214
500,000	5%	10%	5	1800	30%	3,046,429
500,000	5%	5%	5	1800	40%	1,142,411
500,000	5%	10%	5	1800	40%	2,284,821

Forklifts

Forklifts represent a very exciting opportunity for propane fuel cells for a variety of reasons. First, forklifts must have low to zero emissions if they operate indoors. Consequently, the majority of indoor forklifts are electric, which require expensive batteries and extensive down time for recharging. If a fuel cell power unit can be priced at roughly \$1,500/kW, they can compete directly with the electric batteries on a straight operational cost basis, when factoring in the associated down time savings. Second, propane internal combustion engines currently power a majority of the non-electric forklifts so propane fuel cells are a logical choice once they are price competitive.

The forklift market makes up the largest market for electric vehicles worldwide. Many of these trucks operate 24 hours a day, seven days a week, making this a potentially lucrative niche market for propane fuel cells. According to industry expert Ray Gwin, the US forklift fleet is roughly 1,000,000 trucks. To effectively enter this market, fuel cells face two hurdles: price and reliability. However the fuel cell industry is rapidly addressing both of these factors. Numerous recent press releases¹⁸ cite the fuel cell forklift market as, possibly, the first truly commercial opportunity for fuel cells because they offer emission free operation and compete against high cost alternatives.

Table 10 estimates the propane sales potential in Texas alone:

Table 10.
Texas Forklift Market Propane Sales

Forklift Market Size	Texas Market Share	Fuel Cell Market Share	Average Power Demand (kW)	Annual Operation (Hrs)	FC Efficiency	Annual Propane Sales (Gal.)
1,000,000	5%	5%	3	3120	30%	3,168,286
1,000,000	5%	10%	3	3120	30%	6,336,571
1,000,000	5%	5%	3	8760	30%	8,895,571
1,000,000	5%	10%	3	8760	30%	17,791,143
1,000,000	5%	5%	3	3120	40%	2,376,214
1,000,000	5%	10%	3	3120	40%	4,752,429
1,000,000	5%	5%	3	8760	40%	6,671,679
1,000,000	5%	10%	3	8760	40%	13,343,357

Residential Market

¹⁸ <http://www.canadait.com/cfm/index.cfm?It=106&Id=19647&Sv=VC&Lo=2>

While the rural residential market offers an intriguing market opportunity, a 2002 Fuel Cell Today market¹⁹ survey found a continued shift of focus away from this sector. Most companies seem to acknowledge that the market cannot support the fuel cell systems they can produce today, not only as prices are too high but also because the lifetime of the systems is still too short. It is generally agreed that fuel cell systems in households will need to operate for around 40,000 hours or five years without a major rebuild, which might include changing the stack. However, few companies have demonstrated individual systems for more than 10,000 hours.²⁰ Additionally, the average household has a very transient load, ranging in demand from only a few hundred watts to as much as 20+ kW during peak moments such as when air conditioners and hot water heaters are running. Current systems cannot handle these transient loads without the use of expensive battery banks.

Plug Power believes that in the coming years they will have a 5 kW residential unit which includes internal batteries to handle the transient loads for most off-grid homes for \$1,200/ kW. If a reliable system with these operational capabilities could be built at this price point, it could open the off-grid residential market.

Given the current state of technology development, fuel cells are unlikely to be considered by homeowners in the near term. Consequently we have focused on attempting to estimate the size of the potential markets and the product requirements such as size and reliability to access this market.

Residential Market: Off-grid Homes

The exact number of off-grid homes is difficult to ascertain, however the editor of Home Power magazine, Richard Perez estimates it at roughly 180,000 to 200,000.²¹ Perez, considered an expert in the field who is often used as a resource by the federal government for off-grid market data, calculated this figure by extrapolating the total market size from his database of 54,000 inventoried off-grid homes. Perez estimates that this inventory represents roughly one-third of the total market. According to his most recent survey, completed in January of 2003, Texas has about 5% of the off-grid homes in the U.S. This percentage equates to about 9,000 to 10,000 homes. The market is currently growing at 30% per year. If Perez's estimates are correct, this would mean the addition of about 3,000 new off-grid homes per year in Texas.

According to Perez, 82% of these homes use photovoltaic (PV) systems with batteries and backup generators as their primary source of power. The typical PV system averages about 2.5 kW. The typical backup generator is 4-12 kW. Battery size varies greatly with the power demands of the home. Given a nationwide cost estimate \$35,000/mile to build a feeder line to tie into an electric grid, Perez estimates that, if a consumer is more than a quarter (1/4) mile from the electric grid and has to bear the total cost of line construction, it is cost effective to buy a PV/battery/generator system.

Determining the potential propane demand for this market segment depends on whether the system is intended to replace the PV system or just the generator. (Given the peak load requirement of a household, fuel cells will likely be combined with battery storage to meet peak loads. The total storage required will, however, be less than what is required for a PV system.)

Assuming the fuel cell is the primary source of power the following table represents possible propane demand:

Table 11.

¹⁹ Fuel Cell Today Fuel Cell Market Survey, Stefan Geiger, Mark Cropper, July 30, 2003

²⁰ Fuel Cell Today Fuel Cell Market Survey, Stefan Geiger, Mark Cropper, July 30, 2003

²¹ Richard Perez, Home Power Magazine, February 1 telephone interview.

5 kW Fuel Cell Off-Grid Res. Annual Propane Demand- Primary Power Source

Texas Off Grid Houses	% of Market	TX Propane FC Houses	FC Efficiency	Propane Sales per House* (Gal)	Total Sales (Gallons)
9,500	5%	475	30%	1,767	839,325
9,500	10%	950	30%	1,767	1,678,650
9,500	5%	475	35%	1,514	719,150
9,500	10%	950	35%	1,514	1,438,300
9,500	5%	475	40%	1,325	629,375
9,500	10%	950	40%	1,325	1,258,750

* PERC Propane Fuel Cell Study

It is impossible to determine exactly what will drive the choice between using a PV system or a fuel cell system. According to BP Solar, the lifecycle cost of PV- generated electricity ranges from \$0.20 to \$1.00/kWh²² depending on the size of the system and the amount of energy storage required. For fuel cells to replace these systems, one would have to assume that they would have to provide energy at least this cheaply. Additionally, PV- systems are extremely reliable. Therefore, fuel cell reliability will have to be very robust to compete.

Alternatively, assuming the fuel cell replaces just the generator, propane demand will be greatly reduced. According to Perez, the typical user will run the generator 2-3 hours per day to serve heavy loads and charge batteries. This usage pattern generates the following demand:

Table 12.

5 kW Fuel Cell Off-Grid Annual Propane Demand- Backup Generator (2.5 hrs/day)

Texas Off Grid Houses	% of Market	TX Propane FC Houses	FC Efficiency	Propane Sales per House* (Gal)	Total Sales (Gallons)
9,500	5%	475	30%	618	293,430
9,500	10%	950	30%	618	586,861
9,500	5%	475	35%	529	251,512
9,500	10%	950	35%	529	503,023
9,500	5%	475	40%	463	220,073
9,500	10%	950	40%	463	440,145

* However, it should be noted that many of these generators currently run on propane, therefore replacing them with a propane fuel cell will not create additional fuel sales.

Given the low capital cost of internal combustion generators, roughly \$400/kW, it seems unlikely fuel cells will replace these generators in the near future. However, because of the quiet operation and emission free operation of fuel cells, it is possible that some customers will be willing to pay a premium for a fuel cell generator.

Recreational Vehicles

Recreational vehicles (RV) represent one of the largest markets for small scale distributed generation. In 2002²³ alone, there were 19, 519 RV's and motor homes sold in Texas. By 2010, the Recreational Vehicle Industry Association estimates that there will be 8 million RV owning households in America.²⁴ RVs are typically equipped with 5-20 kW systems to provide air conditioning, electric ranges and power lights, etc. The DG units are typically fueled by diesel or gas, from the same fuel source as the engine. Propane is often used for heating and cooking and could conceivably be used to power a fuel cell generator. Additionally, propane is available for sale at most of the larger RV rest stops and camping areas.

²² BP Solar webpage, <http://www.bpsolar.com/contentdetails.cfm?page=51>.

²³ Emily Crawford, Texas Recreational Vehicle Association, Emailed Interview, January 2004.

²⁴ RVIA, <http://www.rvia.org/Media/fastfacts.htm>

The sale of propane-powered fuel cells to the RV market faces several immediate hurdles. First and foremost, the current size of the fuel cell and reformer is significantly larger and heavier than would be practical in an RV. Second, the reliability and serviceability of the fuel cell systems will need to be improved before customers are willing to consider fuel cells. Third, related to propane sales, it may be difficult to convince manufacturers that it is wise or beneficial to switch the generator fuel to something other than the engine fuel. Fourth, the electric load in RVs can be very transient as users turn on and off the Air conditioner, range and other appliances. To adequately serve this function will require some form of battery system. Finally, the cost of a fuel cell system is a large impediment to adoption. However, the quiet, emission free operation of a fuel cell could fetch a premium.

Another factor limiting the attractiveness of this market to the propane industry is that most RV stops and camps currently provide electric hookups for their campers. Consequently, generators have very limited use. According to Onan, the largest manufacturer of RV generators, a generator would rarely be used more than 400 hours in a year and often are used significantly less.

Table 13 provides an estimate for the potential annual propane sales for the RV Industry:

Table 13.
RV Market Propane Sales

RV Market Size in 2010	Texas Market Share	Fuel Cell Market Share	Generator size	Annual Operation (Hrs)	FC Efficiency	Annual Propane Sales (Gal.)
8,000,000	5%	5%	5	100	30%	1,353,968
8,000,000	5%	10%	5	100	30%	2,707,937
8,000,000	5%	5%	5	200	30%	2,707,937
8,000,000	5%	10%	5	200	30%	5,415,873
8,000,000	5%	5%	5	400	30%	5,415,873
8,000,000	5%	10%	5	400	30%	10,831,746
8,000,000	5%	5%	5	100	35%	1,160,544
8,000,000	5%	10%	5	100	35%	2,321,088

Small Commercial Opportunities

Opportunities in the typical small commercial sector appear fairly limited, as distributed generation cannot compete on a cost basis with utility supplied power. As discussed earlier, distributed generation can provide economic benefits to the system such as congestion mitigation and as an alternative to transmission and distribution build outs, however, the current regulations and pricing structure do not enable customers to capture these benefits of distributed generation.

Additionally, the electric loads of most businesses are greater than the target market envisioned in this study. A small data processing center requires 50 kW at peak load and a fast food restaurant requires about 75 kW at peak load.²⁵

Reliable Power Market

The “reliable power market” describes customers who need constant reliable power because loss of power can cause significant financial losses. These industries include brokerage operations, financial transaction centers such as credit card sales authorization centers, airline reservation operations, etc. According to ABI research, however, most of the operations require over 1 megawatt capacity.²⁶ Given these power requirements, this market does not present an opportunity for the type of small-scale systems being explored in this study. These businesses offer an intriguing market for future study, however, because consistent reliable power is more valuable to these customers because the loss of power causes greater financial harm to businesses than any increased cost in electricity. For example, according to this study, a brokerage operation can lose almost \$6.5 million per hour of downtime. To address this problem, the First National Bank of Omaha installed four UTC PAFC 200 kW fuel cells to provide reliable power. Because of the power reliability of PAFC’s, the higher cost of electricity per kWh made sense. According to the Texas Workforce Commission, there are 164 financial transaction/processing businesses in Texas.²⁷

Quality Power Market

The “quality power market” is comprised of industries such as internet service providers, chip fabricators and stock exchanges that need quality power that does not have the voltage spikes and sags common in typical utility power.

²⁵ Patricia Hoffman, U.S. Dept. of Energy, Phone Interview, December 2, 2003

²⁶ *Stationary Fuel Cells, US and Global Early Market Opportunities*, Allied Business Intelligence, 2001.

²⁷ Texas Workforce Commission, Tracer Search ES202, Financial transaction/processing center search).

As with the reliable power market, this sector will likely be served by fuel cells with capacities of 200 kW and above, and are consequently not in the focus of this study but are a market worthy of further study.²⁸

Boat Market

Propane powered fuel cells in the boating industry offer many of the same attractive characteristics and challenges as the RV industry, or any other mobile application. The quiet, reliable, emission free operation is a huge potential draw for consumers. However, before this market takes off, fuel cells' capital costs and size and weight will need to be reduced dramatically. Additionally, fuel cell system reliability will need to be further demonstrated before consumers are willing to depend on them. Additionally, as with RV's these generators are typically fueled by the same fuel that powers the engine. It may be challenging to switch this practice.

Texas has the 6th largest number of boats registered, tallying a fleet of 624,390 boats.²⁹ There were 19,335 new boats sold in 2002 alone. Of these boats, only those over 30 feet are typical candidates for generators. These generators range between 5-30 kW in size. It is estimated that 3-4% of the boats registered are over 26 feet and may have an onboard generator.³⁰ (Boating statistics do not capture the 30+ foot market size therefore we suggest a conservative estimate of 2 %.) These statistics yield an approximate fleet of approximately 12,500 boats which have generators and something less than 400 boats sold per year, which may consider a propane fuel cell as the generator of choice.

Boats frequently utilize propane for heating and cooking applications so adding generation to this list is feasible. It is worthwhile to note that some boats from Europe and Australia are now using propane propulsion systems. If this trend spreads to the U.S., it could be beneficial to switch to using propane fuel cell systems. Boats in this sector of the market have a transient load, which depends on what appliances are running off of the generator, however, as discussed in the Fuel Cells Technical Barriers: Transient Loads section, fuel cells with internal batteries are expected to handle these load following requirements.

The boating industry has begun to look at industry standards for fuel cell use on boats however they have not adopted any guidelines or regulations yet.³¹ It will be critical to ensure this happens in a timely fashion for propane fuel cell market adoption.

Table 14 estimates potential propane sales driven by the use of fuel cells in the boating industry.

Table 14.

²⁸ *Stationary Fuel Cells, US and Global Early Market Opportunities*, Allied Business Intelligence, 2001.

²⁹ *2002 U.S. Recreation Boat Statistics*, National Marine Manufacturers Association.

³⁰ *2002 U.S. Recreation Boat Statistics*, National Marine Manufacturers Association.

³¹ Tom Marhevko, National Marine Manufacturers Association, Phone interview, January 22.

Boating Market Propane Sales

Texas Market Size	FC Market Share	Generator Size (kW)	Annual Operation (Hrs)	FC Efficiency	Annual Propane Sales
12,488	5%	5	50	30%	21,135
12,488	10%	5	50	30%	42,270
12,488	5%	5	100	30%	42,270
12,488	10%	5	100	30%	84,540
12,488	5%	5	200	30%	84,540
12,488	10%	5	200	30%	169,081
12,488	5%	5	400	30%	169,081
12,488	10%	5	400	30%	338,162

Emergency Backup Generators: For Hospitals, Fire Stations, Water Treatment Plants, etc.

Emergency standby generators are required by fire and safety codes at numerous public facilities such as hospitals, fire stations, and wastewater treatment plants. There are approximately 6,984 emergency standby generators³² in Texas. These units are installed to provide service when power is out or when there are fluctuations in voltage or frequency. Typical backup units are 40-80 kW and generally used exclusively for backup generation. According to a sales manager of Clifford Power Systems, a dealer for a leading generator manufacturer (Koehler), 70% percent of the units sold are diesel and the remaining 30% are propane or natural gas. Units are generally tested once per week for ½ hour run time.³³ According to a 2003 CARB report³⁴, these units typically only run 30 hours per year. Given this limited usage but vital importance of these units, important characteristics for emergency backup generator are:

- Low capital costs
- Black start capability (Ability to start generating electricity without power from the electric grid)
- High reliability
- Low fixed maintenance costs

Because of the low operating hours, efficiency, emissions and variable maintenance costs are not usually major factors in unit selection. While PEM fuel cells offer the potential for high reliability, black start capability, and low maintenance costs, the current state of the technology does not make fuel cells a viable option at this juncture. Additionally, the high capital costs further reduce the attractiveness of fuel cells in these applications. Even in the event the capital costs could be reduced, the number of gallons of propane used in these applications would be very insignificant.

Electric Utility Market Opportunities

The electric utilities provide a mixed market opportunity for propane fuel cells. The most obvious connection is that the primary markets for propane have significant overlap with the electric utility markets. The electric utilities do not generally promote distributed generation for their customers as they are in the business of selling their own electricity. Logically, they are also typically not in support of net metering programs which can make distributed

³² *Micropower at the Crossroads*, TexPirg, Public Citizen, Environmental Defense, 2002.

³³ Jay Herrin, Clifford Power Systems (Generator Sales), Phone interview, February 6.

³⁴ *Diesel Risk Reduction Plan*, California Air Resources Board, October 2000.

generation more economically attractive to customers. There are, however, numerous applications where customer or utility use of distributed generation can be in the economic interest of the utility.

The electric utility perception of fuel cells seems to vary widely. Discussions with the Texas Electric Coop Association, the National Rural Electric Cooperative Association, and many of the Generation and Transmission Cooperatives and Distribution Cooperatives yielded a wide array of perspectives.

While many of those interviewed acknowledged that distributed generation could provide value to their systems by reducing congestion and the need to build out the T&D system, there was virtually no work or studies available about the actual value, the market potential, or where and how these strategies could be applied. According to Buff Whitten of Southwest Electric Coop, the analysis of when to use DG incorporates cost, reliability, and fuel availability.³⁵ As with most applications we have discussed, fuel cells are not competitive on cost and reliability today, but may be an attractive alternative in the next 5 years.

One strategy to consider is having utilities become dealers of DG products. Responses on this concept were mixed. Many of those interviewed suggested that this strategy did not make sense because it is outside the realm of the expertise of the utilities and would do little to help profits, and could hurt profits by limiting power sales. On the opposite spectrum, the San Bernard Electric Cooperative has already looked at being a distributor. The most common response, however, was that a competitive fuel cell system is not available today and would not be for some time.

If a cost effective application can be demonstrated, some utilities have shown a willingness to embrace it. The Southwest Electric Coop started a solar pump program in which they promoted and sold solar water pumps. The motivation behind this program was the fact that Coops actually lost money on the operation and maintenance of the small distribution lines required to power remote water pumps, even if the customer paid for the line construction. This suggests that it may be beneficial for the fuel cell or propane industry to further study the cost effectiveness of DG applications in an electric utility system.

Rural Electric Power Quality

Utilities and cooperatives are responsible for providing stable useable power to their current loads. Unless customers dramatically expand their power demands the utilities and coops have to pay for any upgrades required for regular use power quality, consequently they are potentially a market for cost effective solutions. That said, few of those interviewed saw power quality, especially in the residential market, as a major issue.

Rural Electric Grid Support Market

Grid support is the strategic placement of small generators in local areas where demand is high but it is not economically feasible to increase the power of grid to meet this demand. Utilities and coops typically use large diesel or natural gas engines to meet these peaking, voltage support, or load service needs. Jeff Murski of the MidSouth Coop, a large proponent of the potential of distributed generation, thought that the immediate market for DG in grid support applications was in the 100+ kW size. Murski felt that there might be a handful of eligible sites in his service area which could find a real economic value through such DG applications. While this market seems to offer some promise, the applications seem to be on a larger scale than that which is in the scope of this study.

Market Summary

The best opportunities for the propane industry have been summarized in Table 15 below, based on the length of time it will take for the application to be available in a commercial market, the size of the units, and the total

³⁵ Buff Whitten, Southwest Electric Coop, Phone interview, January 13.

potential propane sales in gallons. We have extrapolated the national numbers, based on our findings in the Texas market and the Texas market share. We recommend that these will be the most favorable markets.

As you can see from our findings, the telecommunication wireless facility prime power will produce the largest annual propane sales numbers, and this market warrants further evaluation. Since this size (200 kW) application is outside the scope of this study and will not be a PEM fuel cell, it would also require entirely different evaluation, development, and marketing.

Table 15.
Most Immediate Propane Fuel Cell Opportunities

Application	Market Share	Fuel Cell Size (kW)	US Annual Propane Sales (gal)*
Telecommunication- Wireless Facility Prime Power**	10%	200	1,075,940,544
Forklifts	10%	3	126,731,429
Truck Auxiliary Power Units	10%	5	60,928,571
Recreational Vehicle	10%	5	54,158,730
Residential Off-grid (Prime Power)	10%	5	33,573,000
Telecommunication- Relay Stations	10%	30	10,378,167

* Assume 30% fuel cell efficiency

** Fuel cell size is larger than the scope of this study and fuel cell type is not a PEM fuel cell

Market Strengths

The ability to sell propane fuel cells depends on two factors, fuel cells attractiveness and the selection of propane as the fuel choice. Propane has a distinct market advantage due to its broad distribution infrastructure. Despite natural gas' price to energy content advantage, highlighted in Table 5, the infrastructure costs required to extend the distribution system make it unlikely that natural gas lines will be extended far into the rural areas.

Fuel cells have numerous competitive advantages which should enable the technology to expand its market. Most commonly discussed, fuel cells are virtually emission free. This characteristic is a huge market advantage in areas of Texas with air quality problems, as competing technologies may have difficulty acquiring permits or otherwise meeting air quality standards imposed by the state or federal government. Further, states such as California are considering strict emission requirements on all diesel generators including small-scale systems. If Texas adopts such standards, it could dramatically increase the marketability and cost competitiveness of fuel cells in all applications. Additionally, many small scale DG customers, such as RV owners or off-grid home owners, may be willing to pay a premium for the silent, emission free operation of fuel cells.

While most fuel cells have not demonstrated the level of reliability required for market acceptance at this stage, they offer the potential to be dramatically more reliable and provide higher quality power than the typical distributed generation system. Fuel cells do not utilize moving parts which frequently wear out or break down. As the commercial PAFCs have demonstrated, fuel cells have the potential for operation of 40,000 hours, and up to even 70,000 hours. Additionally, because they can perform well at partial loads, they can provide higher quality power. Another notable advantage of PEM fuel cells is that they can come online quicker than internal combustion engines.

Finally, distributed generation as a whole offers many advantages when combined with the current T&D system. Distributed generation can provide grid support and congestion relief without the need for expensive T&D system upgrades. Furthermore, small DG systems have a major aesthetic advantage over new, aboveground transmission lines. Consequently, emission free DG systems like fuel cells will not have public approval challenges associated with the citing and construction of new transmission lines.

Fuel cells offer the opportunity for tremendous total system efficiency when they can harness thermal heat. This ability can lead to efficiencies upwards of 80%. The ability to harness this waste heat can make fuel cells tremendously cost efficient to operate. High heat fuel cells, such as the MCFC and SOFC, offer tremendous potential in industrial CHP applications because the thermal energy recovered through a CHP system is high enough quality to power industrial applications. Additionally, industrial applications can maximize the use of this thermal energy.

Market Weaknesses

Many of the market weaknesses of fuel cells represent the stage of development of propane powered fuel cells rather than inherent weaknesses of the technology. Currently the capital cost of a propane fuel cell system cannot

compete with the available alternatives. Assuming the capital costs come down as expected, fuel cells will still be more expensive than traditional internal combustion alternatives. In applications such as backup or stand-by power where the generator is used infrequently, low initial capital cost is a critical selection factor.

Current reliability and serviceability of fuel cells is another major weakness of fuel cells. Customers of any class or size are reluctant to employ untested or unproven technologies. With the exception of PAFCs, none of the competing technologies have had long-term demonstrations of commercial products. Exacerbating this problem is the widespread recognition that there is limited support in place to maintain and service fuel cells, particularly in rural areas.

The size and operation of small commercial and residential fuel cells present a major impediment to their adoption in many markets. Current products are way too large for use in the RV and boat markets. Additionally, citing and interconnection requirements need to be more fully addressed to enable customers to easily integrate fuel cells. Finally, the current water requirements for the reformation of propane make propane fuel cell use impractical in applications where water is scarce such as remote telecommunications towers and even RVs and boats. While all of these problems may well be addressed in the near future, they are virtual roadblocks to market adoption currently.

The cost of electricity generated from fuel cells dramatically exceeds the cost of grid power. Consequently, most consumers with access to the grid will choose grid power unless there are mitigating circumstances.

While many experts acknowledge that distributed generation such as fuel cells has additional value in the form of emission free energy production and the offset of peak generation and T&D costs, the current utility system makes it very difficult for smaller individual DG users to capture this value. For instance, while industrial customers can negotiate time of use pricing and reduce their purchases of expensive peak power through the use of distributed generation, small commercial and residential consumers can not, therefore the incentive to buy small DG systems is reduced. Furthermore, since Texas' T&D system costs are pooled across the entire system, individual customers who reduce congestion or the need to upgrade the transmission system cannot be compensated for this value.

A further market hindrance in the adoption of propane-powered fuel cells is propane's cost relative to natural gas. As highlighted in Table 5, based on energy content, propane is the most expensive fuel source among those compared. Consequently, capital costs and electric efficiency aside, it is the most expensive fuel source to utilize.

Another major weakness stems from the fact that propane fuel cell systems have some difficulty load following in transient load applications. Currently, to overcome this weakness requires the utilization of alternatives such as battery banks, which add cost.

Finally, the unregulated presence of sulfur in propane places added demands on reformers for low temperature (PEM) fuel cells, as the system has to be over engineered to handle varying levels of the sulfur. While this is not technically a problem, it does make the reformers more expensive and potentially increases the frequency of maintenance.

Market Threats

The primary threats to the propane fuel cell market fall into two categories: the selection of alternative fuels to power fuel cells and the selection of alternative technologies competing in the distributed generation market.

As we have discussed, propane is an easily transferable, storable and useable fuel with a vast distribution network. Additionally, depending on the application, propane is a clean fuel source. However, propane is an expensive fuel based on energy content.

The major threat to the selection of propane is the availability of lower priced fuels. Natural gas is likely to be the selected wherever it is available. In the future, availability of a cost effective and user-friendly hydrogen fuel source is similarly threatening, however this may be a many years in development.

Fuel cells which run off of reformed diesel could pose another major threat to the propane fuel cell market. While such a reformer technology is not currently commercially available it is a possibility being researched. If a cost effective method can be developed to reform diesel, it could be a future threat.

The fuel cell market faces threats from numerous distributed generation alternatives depending on the application. Some commercially available alternatives include solar, wind, geothermal, internal combustion engines and microturbines. While the applicability and attractiveness of these technologies varies depending on the application they do represent alternatives that are available to the consumer.

Another threat, or rather concern, is the possibility that the development of the fuel cell technology may not meet its current goals.

Recommendations

While the propane fuel cell market growth looks to be slow in the near future, continued research and the rapid pace of development will create a vibrant market for fuel cells if current expectations are met. While the propane industry is not involved in the actual research, they can play a pivotal role in accelerating the development of the market, by creating and broadening its scope. We recommend the following actions:

- Develop propane fuel cell demonstration projects for the telecommunications, forklift, truck APU, RV, and off-grid residential markets to show the viability and potential of fuel cell systems in these applications.
- Work with propane reformer manufacturers to ensure that the industry is taking all cost effective measures to address issues related to the varying sulfur content in propane.
- Continue to support propane fuel cell demonstration projects to provide valuable real world performance data, identify product needs, and accelerate the development of commercial products.
- Promote the availability and uses of propane-powered fuel cells with residential and small commercial customers, coops and utilities.
- Promote the implementation of positive net metering programs in utilities and coops so DG users can sell excess power to the grid for maximum returns.
- Support the development of CHP applications for fuel cells.
- Explore participation in or support of bulk propane fuel cell purchases which could increase the economies of scale in propane fuel cell production.
- Explore opportunities in the 100+ kW market