Propane Fuel Cell

Business Planning Document

Summary and Conclusions

Breakthrough Technologies Institute, Inc.

For the Propane Education and Research Council

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Abbreviations

Common abbreviations used in the document include:

PAFC	Phosphoric Acid Fuel Cell
PEM(FC)	Proton Exchange Membrane Fuel Cell
SOFC	Solid Oxide Fuel Cell
MCFC	Molten Carbonate Fuel Cell
AFC	Alkaline Fuel Cell
W	Watt
kW	Kilowatt
MW	Megawatt
gW	Gigawatt
kWh	Kilowatt hour
ppm	Parts per million
ppmw	Parts per million by weight
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
NOx	Oxides of Nitrogen, usually expressed as ppmv of NO2

SOx	Oxides of Sulfur
NM	Not Measurable
CO	Carbon Monoxide
VOC	Volatile Organic Compounds
CO2	Carbon Dioxide
SECA	Solid State Energy Conversion Alliance (DOE Program)

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Executive Summary

At this time, the propane industry has the ability to compare numerous potential fuel cell technologies for propane-fueled applications while enjoying the strategic advantage of offering potential fuel cell company partners access to customers. Compared to several years ago, most fuel cell companies have an increased interest in propane at this time. Only one company has subsequently ruled out the use of propane in products in the range of 1 to 100 kW. Two companies (H Power and IdaTech) have publicly revealed fuel cell products specifically designed to operate on propane. To increase the fuel cell industry focus on propane, there are technical, marketing and financial issues to address.

This study, undertaken by the Breakthrough Technologies Institute in cooperation with the US Fuel Cell Council for PERC, provides a timely look at the state of the art in fuel cell commercialization. This study points out several key steps that the propane industry can undertake now to realize the advantages of timely partnerships, key market information, and propane industry strengths. With the advantage of time and existing customers, the propane industry companies can:

- Evaluate fuel cell market offerings to ensure that they suit their individual propane customer base.
- Provide customer information to fuel cell companies hungry for the data.
- Engage in competitive negotiations with fuel cell companies in order to obtain the best deal.
- Define and implement propane fuel specifications that will lower fuel cell energy costs and ensure fuel cell partnerships.
- Ultimately, participate in fuel cell commercialization; this will increase propane sales, expand markets and reduce seasonal fluctuations in demand.

Working with fuel cell companies now, in an atmosphere of measured progress and steady improvement, will allow the propane industry to avoid the pitfalls of missed deadlines and unmet expectations some have seen in the past. By forming strong partnerships now, built upon shared responsibilities and shared rewards, the propane industry can fully realize the benefits of this emerging energy technology.

With the earliest residential fuel cell products becoming available in 2004 (and likely not yet able to compete with grid electricity on average price at that time), the propane industry can define the narrow markets where its customers are willing to pay a premium for fuel cell power (something the fuel cell industry desperately needs). With fuel cell prices expected to fall late in the decade (~2010), the propane industry will have the advantage of early partnerships and, by comparing companies as they mature, choosing only the strongest partners when the time is right.

Some potential business planning methods include:

- ü Preparation of fuel cell product definitions based on propane customer needs -- to capture early adopters. This work would be cost-shared with the fuel cell companies.

  - ♦ The fuel cell companies desperately need this help.

- ü Requests for Proposals for collaboration agreements aimed at broad commercial deployment in 2010. Since activities now (e.g. demonstration projects, product specifications, and early adopter markets) will require near term work, the partnering agreements need to be in place soon.

  - ♦ Defined milestones and payments based on progress (and payments based on customer data provided by propane companies) can help to ensure effective partnerships for mutual benefit.

  - ♦ The Fuel Cell Commercialization Group has done similar partnering for the long-term commercialization of Molten Carbonate Fuel Cells in larger sizes. This might be a model for residential propane fuel cells.

- ü Preparation of special fuel cell fuel specifications, in cooperation with the fuel cell industry, to ensure fuel compatibility, to lower costs, and to address fuel switching.

  - ♦ The fuel cell industry has identified discussion areas including hydrocarbon content and odorant content.

  - ♦ Legacy products and current industry practice must be considered carefully while addressing this concern.

  - ♦ Dialogue with the fuel cell industry will be useful on these points.

- ü Work with the fuel cell industry to define a lower cost ~50 kW class product for propane customers where this makes the most sense.

  - ♦ Intellectual property developed in this way has value. The propane industry must be careful to capture this value through licensing agreements, rebates, or forward pricing agreements.

- ü Active pursuit of Federal and State incentives for propane fueled units – this may require State or Federal legislation.

- ü Active pursuit of “net metering” for propane fueled units -- this may require State or Federal legislation. While this may be difficult to accomplish, it provides tremendous financial benefits to users. This can translate into economic incentives for buyers and can increase sales. Similar tactics have been very successful for other clean power technologies and the clean nature of fuel cells makes them a likely choice for additional net metering legislation.

Introduction

In the past decade, fuel cell development efforts have increased dramatically. A number of technologies and applications have been demonstrated at and beyond the pre-commercial stage. Commercial versions of natural gas and hydrogen-powered fuel cell systems are available now with prices that are attracting customers in high-value applications like uninterruptable power supplies, remote users, and in areas where grid upgrades cost more than the fuel cell units. These commercial systems typically come with limited warrantees, but some units offer five-year warrantees in addition to maintenance contracts. In addition, pre-commercial versions of propane-powered fuel cells are also being used. Available fuel cell products range in size from less than one kilowatt to more than one megawatt. The challenge for propane fuel suppliers interested in participating in fuel cell commercialization is to identify technologies, applications and specific companies that will best utilize propane as a fuel cell fuel.

Driving Forces for Fuel Cells

Fuel cells are advancing for a broad set of applications because they address important business and societal issues.

Emissions

Because fuel cells are electrochemical devices, they produce power with only water as a byproduct. When a hydrocarbon fuel is used in a fuel cell power system, limited combustion may occur in the fuel processor, but it can be managed in a way that reduces total emissions of regulated pollutants (such as NOx, CO and SOx) to a very low level. United Technologies Corporation (UTC) estimated that its PC25 fuel cell emitted just 75 pounds of regulated emissions in a year of operation, compared to 41,427 pounds for the average U.S. fossil fuel generating station.

Fuel cells using hydrocarbon fuels also produce CO2, but the amount of CO2 produced by fuel cell power systems is lower than traditional power plants for several reasons:

1. Fuel cell power plants are very efficient. Efficiencies of commercial fuel cell power systems are approximately 40%, equal to or better than the best small and medium sized contemporary natural gas combined cycle power plants.

2. Fuel Cell Power Plants are located close to the load. Transmission and distribution line losses can be as high as 15%, and these losses increase CO2 production proportionately. Fuel Cell Power Systems avoid these increases entirely by putting the generation at the customer site.

3. Cogeneration -- fuel cell power plants can provide heat to the customer too. This use of cogeneration lowers CO2 emissions even further on a "per-customer" basis. Although some natural gas combined cycle turbine power plants do provide cogeneration, they are limited to large customers, with large electric loads (and their heat load must be large too in order to benefit from cogeneration with

these large turbine power plants). Fuel cell power plants can provide the benefits of cogeneration to small customers too. Even residential customers can have cogeneration using fuel cells.

Table 1. Emissions Characteristics of Selected Fuel Cells

Pollutant	MCFC	SOFC	PAFC
NOx	< 0.1 ppm	< 0.5 ppm	< 1 ppm
SOx	< 0.01 ppm	NM	NM
CO	< 10 ppm	NM	< 2 ppm
VOC	< 10 ppm	NM	NM
CO2	235 lb/hour	"lowest"	225 lb/hour

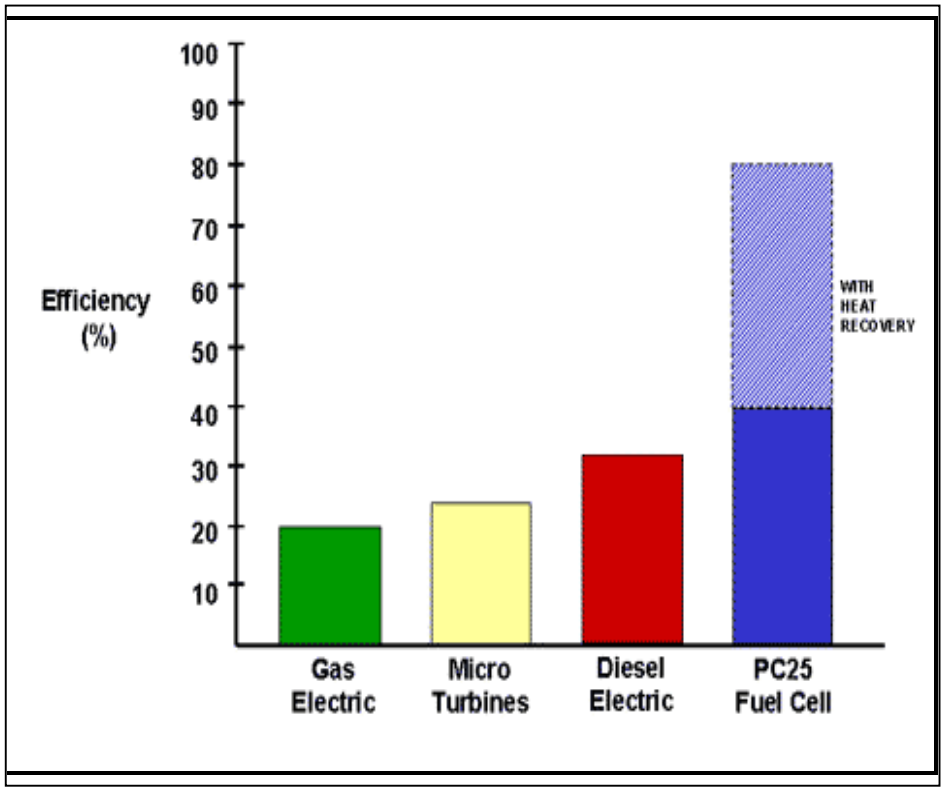
Source: BTI, from published company data. NM = Not Measurable

Because of this attribute, fuel cells have had a blanket exemption from air quality permits in California and other jurisdictions for approximately ten years, led by the South Coast Air Quality Management District, the agency responsible for cleaning up Los Angeles smog. Recent changes in California state law now require air quality permits for all distributed generation, including fuel cells, but fuel cells may be the only technology capable of meeting the strict requirements that come into use in 2007.

Efficiency

Because they do not use combustion as the primary means of generating electricity, fuel cells can also generate electricity very efficiently. This attribute helps lower the total cost of electric power generation and makes fuel cells an attractive solution for addressing carbon dioxide (CO_2) emissions from power production. Total power plant efficiency is also an important consideration for propane since higher efficiency can help offset propane's higher cost relative to natural gas.

Figure 1. UTC Fuel Cells Efficiency Comparison



Distributed Applications

Distributed generation is an important new concept in power generation that also creates market opportunity for fuel cells. Distributed generation encompasses a number of technologies, power ranges and applications. Broadly speaking, it involves replacing or supplementing grid power with power that is generated much nearer to the end user.

Drivers for distributed generation market growth include utility deregulation, concerns over grid reliability, dissatisfaction with electric utility service, corporate vertical integration to encompass electric service, and distributed generation supplier profit motives. Because they are quiet, efficient and have low emissions, fuel cells are seen as a promising generation technology for distributed applications.

Propane is one of several fuels that can be used in distributed generation units. Propane is a key fuel for remote distributed generation applications where natural gas is not an option.

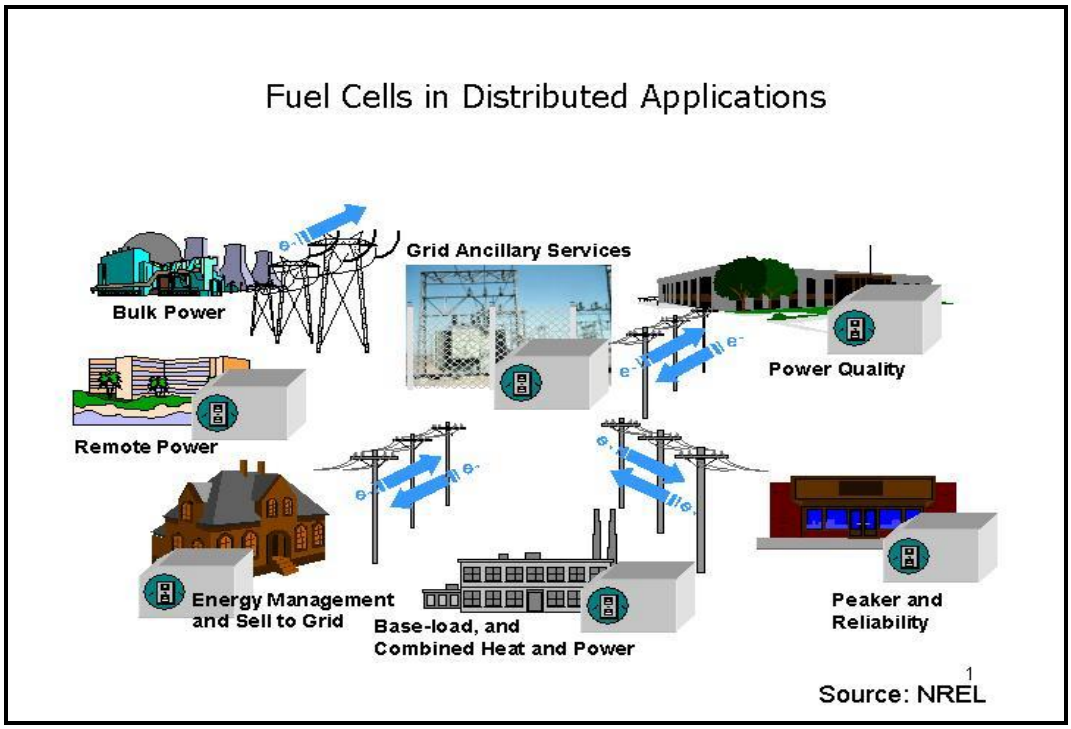


Figure 2. Distributed Applications for Fuel Cells

Vehicles

A key to a large base of fuel cell development work is the automotive industry's efforts to develop cleaner, more efficient vehicles. Every major automaker has a significant fuel cell development effort operating in internal teams and with externally funded efforts. These are long-range efforts involving teams of hundreds of engineers. Dozens of vehicles are being tested on city streets and highways, as well as on test tracks around the world.

The fuel for fuel cell vehicles is expected to be hydrogen or some sort of hydrocarbon delivered via the existing infrastructure. For a host of economic, technical, supply and infrastructure reasons the propane industry has concluded that on-road highway vehicle applications are not appropriate markets for industry investment at this time. The advent of the fuel cell vehicle will not alter this conclusion.

The major technology and cost reduction achievements that are already flowing from automotive fuel cell efforts, however, will have a dramatic impact on stationary applications that are much more aligned with the propane industry's strategic outlook.

Financial Support

Government funding, particularly from the Department of Energy, has been key to the development of fuel cells. On both the stationary and transportation fronts, the DOE has supported fuel cell technology development and prototype demonstrations. The 2002/2003 DOE budget for fuel cells is approximately $147 million, including hydrogen research. We estimate total 2003 federal government investment in fuel cells at $230 million.

Table 2. Bush Administration FY 2003 Request for Fuel Cells

Fuel Cell R&D Appropriations Bush Administration Request For the Department of Energy ($ millions)	
Program	**FY 03 Request**
Hydrogen	$39.88
Transportation FCs	$50.00
Distributed Generation Systems	$49.50
Fuel Cells in Buildings	$7.50
Total	$146.88

- President Bush proposed $22.5 million for the Solid State Energy Conversion Alliance, a Department of Energy program designed to develop a low-cost (<$400 kW) solid oxide fuel cell module for use in a wide variety of applications.

- The Congress in 2003 was expected to be even more enthusiastic than the Administration, with the House of Representatives proposing $31.5 million and the Senate $40.5 million.[1]

Private Investment

Arguably the most important component in the growth of fuel cell technology has been the significant increase in fuel cell investment by the public markets. In the late 1990's, the stock markets and, to a lesser extent, corporations in the energy business, made significant investments in fuel cell companies. These investors were attracted by the potential of fuel cells to play a significant role in transportation and stationary power markets. Well over a billion dollars was invested by the US stock markets, primarily the NASDAQ. A significant amount of this capital has been used to support the development and field trials of products for stationary power markets.

[redacted]

[1] The final appropriation awaits action by the Congress.

Achievements in Fuel Cell Development and Commercialization

Fuel cells are an exciting development with the potential to achieve the status of a disruptive technology, bringing about major changes in markets with financial significance. There has been substantial investment in fuel cell technology by government and from capital markets and corporate research budgets. It is estimated that $1 billion to $3 billion is being invested annually in fuel cell research, development, demonstration and testing.

Growth in the fuel cell industry can be measured in a variety of ways. For instance, since its founding in 1998, the U.S. Fuel Cell Council has grown from 14 members to a total membership of more than 100 companies. High-profile fuel cell development efforts are under way at established companies, such as Toyota, General Motors and Siemens-Westinghouse, and at entrepreneurial companies, such as Ballard and Plug Power. Employment in the industry may have reached 13,500 overall. General Motors reports a fuel cell staff of 500, while Toyota reports 400. Plug Power employs 380.

Below are some other very broad indicators of the achievements and status of the industry today, chosen from a growing list of successful demonstrations and pilot tests. More detail on products and demonstration units is provided in Appendix 7.

- ü Several fuel cell products are now "commercial" (a specific product, which is available on a purchase-order basis, at a list price, with a defined warranty).
    - ♦ Of particular interest are the 200 kW UTC PAFC natural gas power plant and the Ballard Nexus 1kW hydrogen fuel cell. The H Power EPAC 500-2 (120VAC 60HZ) hydrogen fueled 500-Watt power system was being sold up until the announcement that Plug Power will take over H Power. The future of this system is uncertain at this time, depending upon the merger of H Power and Plug Power and the resulting product line.
    - ♦ The Coleman Powermate unit has been offered for commercial sales to industrial users, running on hydrogen. (The launch was nearly a year behind schedule.)
- ü Several companies are offering small generators of 1 kW or less for emergency power and specialty applications.
- ü Natural Gas and propane-powered products from companies such as Fuel Cell Energy, Siemens-Westinghouse, Plug Power, and H Power are nearing "commercial" status as defined above. Fuel Cell Energy is actually competing on price with the UTC Fuel Cells units, and offering five-year warrantees.

Electricity Generation

- Plug Power's 5 kW PEM fuel cell systems have generated more than one million kilowatt-hours (kWh) of electricity.

- Approximately 230 United Technologies Fuel Cells PAFC units are in the field worldwide. The UTC fuel cells (and earlier models marketed by a UTC – Toshiba joint venture called ONSI) have operated more than 4.5 million hours.

- The worldwide fleet has demonstrated its reliability. Some ONSI units have operated well beyond 40,000 hours. The PC25 system requires only routine maintenance. Field experience indicates that units can operate well beyond five years before a major overhaul is required.

- H Power Corporation is now taking orders for its two commercial, direct hydrogen fueled product lines. The EPAC-500™ is a self-contained 500-Watt fuel cell power source. The Modular Power Solutions product line can be configured for indoor or outdoor use.

- An H Power unit operating on propane was installed at Yellowstone National Park in mid-2002. The 4.5 kW unit, installed at the busy West Gate, is powering ticket kiosks and an office, and provide heat for space heating.

- Hydrogenics Corporation announced the successful installation of its HyUPS™ regenerative back-up fuel cell power generator at a trial site provided by Nextel Communications in northern California. The next step of the trial will simulate grid power failure conditions in order to test the 25 kW HyUPS™ system under a variety of operating conditions.

- Fuel Cell Technologies (FCT), through Bonneville Power Administration, has sold two propane fueled solid oxide fuel cell systems to the U.S. National Park Service for use at Yosemite National Park in California. The FCT fuel cell systems will provide electricity, heat, and hot water service to the administration building within the park, running on propane.

- Sulzer AG's Sulzer Hexis business unit has finalized distribution contracts for the installation of 114 fuel cell systems in Germany. Three German power companies so far have ordered systems.

Vehicles

- There are more than 50 fuel cell vehicles (hydrogen and methanol) on the road in controlled demonstration fleets worldwide. In Sacramento, California, 16 vehicles are operating on city streets in a coordinated demonstration, with a total of 76,000 miles logged to date.

- Two-dozen fuel cell buses have been built and tested, and 30 buses are scheduled to enter revenue service in 10 European cities by the end of 2003.

- Japan has adopted a very aggressive posture toward fuel cell vehicles, and established a target of 50,000 FCV's in the Japanese passenger vehicle fleet by 2010.

- Japan's Ministry of Land, Infrastructure and Transport announced plans to exempt fuel cell vehicle (FCV) owners from taxes beginning in FY 03. The purpose of the tax waivers is to encourage consumers to buy the vehicles, which are expected to enter the market by the end of this year.

  - The purchase tax is significant in Japan, equal to five percent of the vehicle's purchase price.

  - There is also a 39,500-yen (about US$300) tax on vehicles with engines between 1.5 and 2.0 liters. Toyota and Honda plan to begin leasing fuel cell hybrid passenger cars to a limited number of users late in 2002, accelerating their timetables by about a year.

- The city of Los Angeles announced it would be Toyota's first customer. About 20 Toyota FCHV-4 fuel cell hybrid vehicles will be leased to government bodies, research institutes and energy-related companies in Japan and the United States.

Portable/Specialty Power

- A variety of sub-kilowatt products are available or coming onto the market, including units for backup power, battery recharging and portable generation.

- Companies marketing initial commercial products include Avista Laboratories, Ball Aerospace, Ballard, Greenvolt and others.

- Consumer power markets are being pursued aggressively by entrepreneurial firms such as DTI Inc. and by industry giants Panasonic, Motorola and Samsung, among others.

- MTI, Panasonic, and many other manufacturers are developing direct methanol fuel cell (DMFC) products.

Market Projections

Projections of fuel cell markets are speculative. Fuel cell development is proceeding rapidly, helping to lower costs. But high capital costs continue to be a problematic issue for the industry. Nevertheless, market projections are extremely favorable.

Distributed Generation

- RKS Research and Consulting found that American businesses - from financial institutions and sophisticated manufacturing plants to family farms - are increasingly interested in generating their own electricity. More than two-thirds of the businesses interviewed already own or lease some form of alternative electrical generation equipment, such as emergency or back-up generators and UPS systems.

  - Within the most interested customer groups, a substantial percentage - from 39% to 52% - are interested in purchasing distributed generation technologies for all of their electricity.

- Allied Business Intelligence (ABI) found the DG equipment market has become a global industry that could surpass $100 billion annually within a decade.

Fuel Cell Power Generation

- ABI projected the wide-scale adoption of commercial stationary fuel cell (FC) technology in the near future. The study, titled "Global Stationary Fuel Cell Markets - A Detailed Analysis of an Emerging Industry," indicates that fuel cell generation capacity will increase to nearly 16,000 megawatts (MW) by 2012, from its current level of about 45 MW.

- Business Communications Company, Inc. (BCC) projects that 130 gigawatts (gW) of new fuel cell power generation capacity will be installed in the U.S. by 2010. That figure is expected to reach 550 gW worldwide even sooner.

  - Overall, the report indicates the fuel cell market, valued at about $218 million in 2000, should increase to about $2.4 billion by 2005.

- The Freedonia Group projects the U.S. market for fuel cells and related products will rise better than fourfold through 2004 to $2.4 billion, of which $1.2 billion will be represented by fuel cell stacks and systems (i.e., the fuel cell unit itself). Explosive growth will continue thereafter, with the market reaching $7 billion by 2009.

  - The world market for fuel cell products and systems — including spending on research and product development, prototyping, test marketing, demonstration programs, etc., as well as commercial product sales — will more than triple through 2005 to $8.5 billion, and exceed $23 billion by 2010.

- Freedonia estimates the US market for uninterruptible power supplies (UPS) and other power protection systems may increase more than 7% per annum (including inflation) through 2005 to $9.2 billion.

International Relationships

- It has been estimated that more than 2,000 entities are involved in fuel cell research and development, demonstration and commercialization. The

industry is remarkably internationalized given its largely pre-commercial status.

- Every fuel cell company with significant commercial ambition has one or more relationships with companies in Europe and/or Japan, designed to provide technical support, capital, and/or access to markets.

- Significant relationships include Plug Power with Honda (for small generators), Plug Power with Valliant (for the European residential market), Fuel Cell Energy with MTU (for research and marketing), UTC Fuel Cells with Toshiba (for cogeneration), and many others.

- Many developers are international and are utilizing research facilities in more than one country. Examples include Nuvera, General Motors, and Siemens-Westinghouse.

Propane Strategic Vision

In July of 2000 the Propane Education and Research Council published its propane vision and technology roadmap. In that document, the following goals were presented:

- Develop new end-use technologies to draw new customers and increase sales.
- Develop propane reformers & other specific technologies
- Smooth out summer/winter peaks
- Review and analysis of fuel specifications.

BTI / PERC Propane Transfer Plan

Many fuel cell developers are considering the use of propane as a hydrogen-carrier fuel for rural and remote residential fuel cell applications. The early-adopter target market for propane fuel cells therefore consists of widely dispersed homes and small businesses that already use propane and are located away from power lines and natural gas distribution systems.

The near-term commercial potential of residential-scale fuel cells depends on propane customers' needs. Where their needs dictate more value for systems able to run apart from electrical distribution systems – quietly, efficiently, and cleanly – the higher costs of early fuel cell power systems will be accepted. Broader market forces in the energy services industry, particularly the move towards distributed power generation and the deregulation of the electric utility industry, also have an impact on the commercial success of propane fuel cells.

To promote propane's involvement in the commercialization phase of fuel cell electricity generation technology, Breakthrough Technologies Institute and the U.S. Fuel Cell Council, with the financial support of PERC, undertook a program of technology-transfer activities:

- Based on its experience and discussions with members of the propane industry, Breakthrough Technologies Institute (BTI) agreed to develop this technology transfer plan to facilitate propane industry readiness to meet the technical, regulatory, distribution and customer-service needs of early adopters of residential and small commercial fuel-cell technology.
- BTI developed a seminar format to be used to introduce, explain and distribute the information to propane firms across the United States.
- BTI, in partnership with the US Fuel Cell Council (USFCC), the trade association for the fuel cell industry, conducted three seminars in 2002.

Approach

Breakthrough Technologies Institute (BTI), in cooperation with the US Fuel Cell Council, developed this technology transfer plan to

- Ensure propane industry readiness to meet the technical, regulatory, distribution and customer-service needs of early adopters of residential and small commercial fuel-cell technology.
- Identify cost-effective options to meet the regulatory and technical requirements of fuel-cell installations.
- Provide a guide for propane marketers in their fuel cell business planning.

Presentations of This Planning Document

The plan has been delivered in a seminar format at four regional conferences in 2002.

- June 16, 2002, Tennessee Propane Association Conference, Memphis.
- June 25, 2002 - North Central Propane Conference, La Crosse, Wisconsin.
- July 16, 2002 - Propane Energy Expo, Branson, Missouri.
- November 18, 2002 - National Summary Event – In conjunction with The Fuel Cell Seminar, Palm Springs, California.

The Payoff For Propane

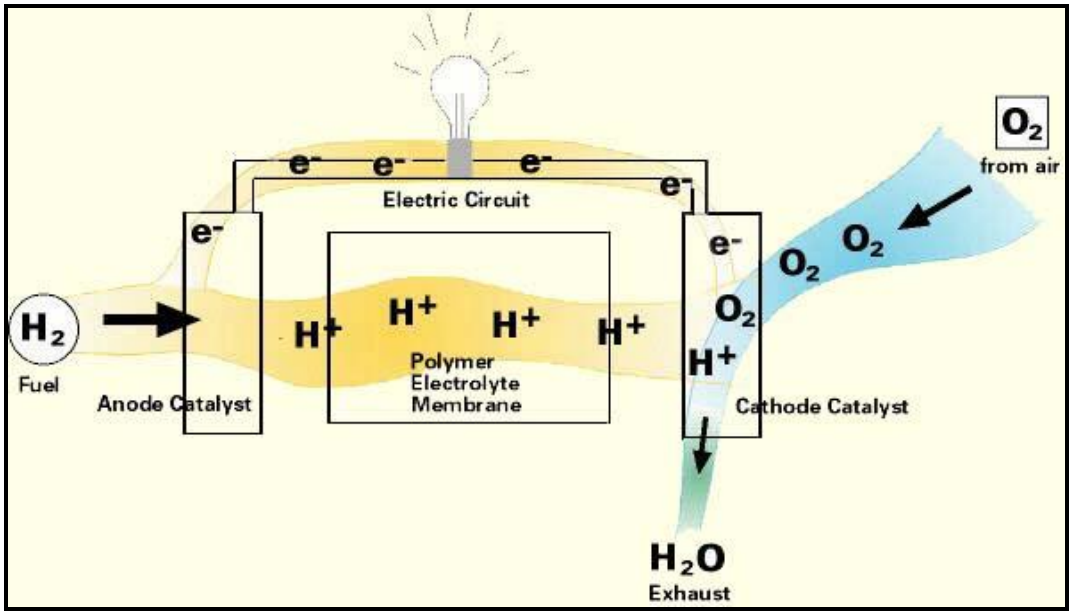
- The successful commercialization of a primary-power, residential fuel cell system operating on propane is expected to significantly increase annual U.S. use of propane.
- The propane market today is seasonal in nature, with high demand during the winter heating season and low demand during the summer.
- The use of propane in residential fuel cells will offer the propane industry an opportunity to level out fuel sales on an annualized basis independent of weather patterns.
- This also allows the propane company to add new customers that live in all-electric or nearly all-electric homes.

Fuel Cell Background

Fuel Cell Operation

A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water, heat and minimal pollutants as by-products. As long as fuel is supplied, the fuel cell will continue to generate power. Since the conversion of the fuel to energy takes place via an electrochemical process, not combustion, the process is clean, quiet and highly efficient – two to three times more efficient than fuel burning.

Fuel Cell Schematic



Source: DOE

Figure 2. Basic Operation of a Fuel Cell

A fuel cell consists of two electrodes separated by an electrolyte. Hydrogen is fed into the anode of the fuel cell. Oxygen (from the air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atoms split into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, where they are reunited with the hydrogen and oxygen to form water molecules.

In principle, a fuel cell is similar to a battery, but a fuel cell does not run down, nor does it require recharging. What a fuel cell does require is fuel. When a fuel cell

system is equipped with a “fuel reformer,” the fuel cell can utilize hydrogen from a number of hydrocarbon fuels including natural gas, methanol, propane, biomass, and gasoline. The emissions from reforming these various hydrocarbon fuels would still be less than those from a combustion process. It is also possible to obtain hydrogen by separating water in an electrolyzer, or by extracting it from a compound that contains no carbon, such as ammonia, hydrazine or boron compounds.

- The beauty of fuel cells is their versatility – since they are scalable, fuel cells can be stacked until the desired power output is reached. The voltage from a single cell is about 0.7 volts.

- When the cells are stacked in a series, the operating voltage increases by 0.7 volts each time a cell is added (stacked). (Thus the finished unit is called a “fuel cell stack.”)

Major Types of Fuel Cells

Fuel cells are a family of technologies. Fuel cell types are characterized by their electrolytes and their temperature of operation. The major types of fuel cells include:

Phosphoric Acid – PAFC

Phosphoric Acid Fuel Cells were the first fuel cell power systems offered for commercial sale to land-based civilian customers. They operated at a stack temperature of approximately 300 F and can produce steam needed for steam reforming of hydrocarbon fuels. They have operated for more than a year continuously in some applications and have reliabilities well above 90%.

There are currently more than 200 PAFC fuel cell systems installed all over the world, providing power and useful heat to hospitals, nursing homes, hotels, office buildings, schools, utility power plants, an airport terminal, landfills and waste water treatment plants.

Proton Exchange Membrane (or Polymer Electrolyte) – PEM

These cells operate at relatively low temperatures (about 175 degrees F or 80 degrees C), have high power density, can vary their output quickly to meet shifts in power demand, and are suited for applications like automobiles where quick startup is required. According to DOE, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries."

Solid Oxide – SOFC

A solid oxide system uses a hard ceramic material instead of a liquid electrolyte, allowing high operating temperatures. SOFC power plants run at high temperatures – approximately 1000 C – where their solid ceramic electrolytes conduct the ions needed to produce the cell reactions. This type of fuel cell could be used in big, high-power applications including industrial and large-scale central electricity generating

stations. Some developers also see SOFC use in motor vehicles and are developing smaller fuel cell units for auxiliary power and even homes. Fuel Cell Technologies has produced SOFC prototypes to run on propane.

SOFC power plants also have high potential efficiencies, realized by adding a turbine generator to their high temperature exhaust. This "micro-turbine" uses the clean high temperature exhaust gases to spin a generator, adding power output and increasing efficiencies. These "hybrid systems" are expected to have electrical efficiencies at or above 70%.

Molten Carbonate – MCFC

These fuel cells use a thick viscous liquid solution of lithium, sodium and/or potassium carbonates, soaked in a matrix, for an electrolyte. They promise high fuel-to-electricity efficiencies, about 60% normally or 85% with cogeneration, and operate at about 1,200 degrees F or 650 degrees C.

Regenerative Fuel Cells – RFC

Regenerative fuel cells are attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen, usually by an electrolyzer. The hydrogen and oxygen are fed into the fuel cell, which generates electricity, heat and water. The water is then re-circulated back to the hydrogen generator and the process begins again.

The characteristics of various types of fuel cell technologies are shown below.

FUEL CELL TECHNOLOGIES

Fuel Cell Technology	Electrolyte	Operating Temperature	Efficiency (%)	
			Electrical	Overall
PEMFC	Ion exchange membrane	50 C	30-35	50-60
AFC	KOH	80 C	Low	Low
PAFC	Phosphoric Acid	200 C	36	80
MCFC	Alkali carbonates	650 C	45-55	75-80
SOFC - High Temp.	Solid metal oxide	980 C	45-47	75-80
SOFC - Reduced Temp.	Solid metal oxide	660 C	42-45	60-70

Source: SFCCG, Inc. (Aug. 1997)

Table 3. Fuel Cell Types

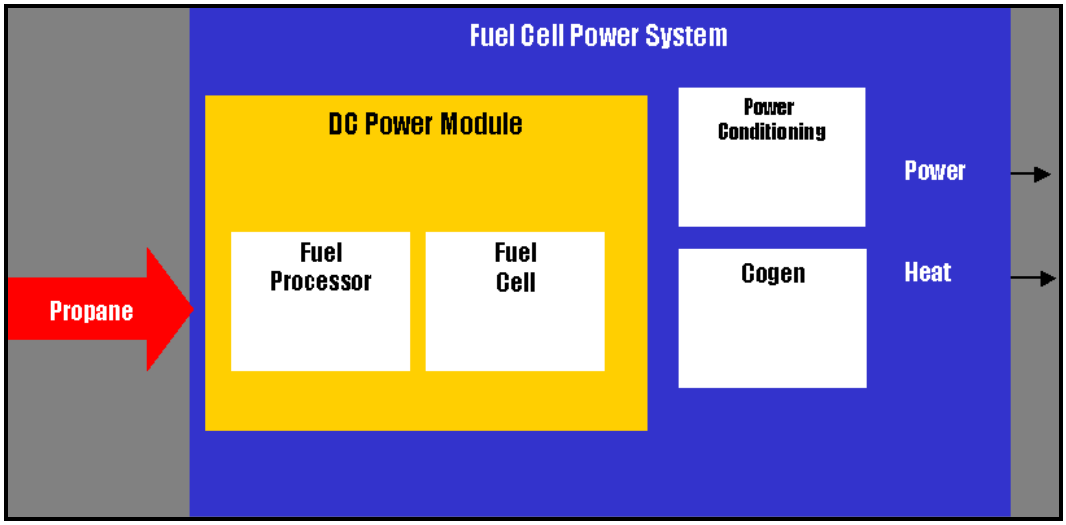
Fuel Cell Power System

A generalized schematic of a fuel cell power system is shown in Figure 3. Fuel such as propane (stored on site or delivered by pipeline) is introduced to a fuel processor, which removes impurities (including odorants) and converts the fuel to a hydrogen rich gas. The hydrogen rich gas enters the fuel cell where it reacts electrochemically with air (input air is not shown in the Figure 3 for simplicity) to produce DC power. Water and heat are also produced in the reaction.

The power-conditioning module converts the raw DC power to the form required for a particular application (generally 120/240V or 480V AC). The cogeneration module takes the waste heat from various points in the fuel cell system uses it to heat water or air. An external process (hot water heating, room heating, or process steam) can then use the hot water or air.

This particular schematic in Figure 3 most closely resembles a PEM (Proton Exchange Membrane) Fuel Cell Power System.

Figure 3. General Schematic of a Fuel Cell Power System



Source: BTI

For the reasons stated below (see p. 27), it was agreed at the outset of this project that this work would focus mainly on residential applications. Proton Exchange Membrane and Solid Oxide technologies are the only fuel cell technologies that can address power ranges at this scale (approximately 5 kW). MCFC is suited to larger generation units and DMFC systems are generally too small.

Table 4. PEM and SOFC Characteristics

	PEM (Proton Exchange Membrane)	SOFC (Solid Oxide)
Operating Temperature	80°C	+600°C
Start up*	Minutes	Hours
Efficiency 5 KW size	30-40%	35-45%
Efficiency +50 KW size	35-45%	40-60%
Estimated Cost Optimistic	~200 $/kW	~1000 $/kW
Major Challenges	Membrane Durability System Complexity	Stack Durability Heat management Startup

Source: BTI *From room temperature

Propane Opportunity

The most obvious fuel cell market opportunity for the propane industry is the sale of propane fuel. This is essentially an extension of the existing propane heating market. In a broader context, the propane industry could also

- ü market the power and heat that the fuel cell produces, and/or
- ü distribute, sell, service, and install the fuel cells.

It does not seem feasible that the propane industry would enter the manufacturing or technology development activities of fuel cells, unless the fuel expertise of the propane industry was applied to reformer technology.

Potential Synergies between Propane and Fuel Cells

Propane has a number of positive attributes for the stationary fuel cell market. It is an inherently portable and transportable fuel. Unlike natural gas and hydrogen, propane has good energy density at low storage pressure, meaning that it can be economically stored and delivered to the end user by tank truck or in cylinders. This means that propane can be made available where it is infeasible to pipe natural gas. This includes many markets such as rural and remote homes and businesses, and recreational areas, where propane is already used as a heating fuel.

Another propane attribute that provides an advantage over natural gas is its availability at pressure. Natural gas for residential use is typically provided at much less than 1 psi. With safety regulation changes, this might be increased slightly to perhaps 2 or 3 psi. This pressure is so low that many existing fuel cell system designs require a natural gas boost compressor to provide sufficient pressure to push the gas through the fuel processor and the fuel cell. This natural gas compressor adds significantly to the cost, noise and service requirements of the fuel cell system and its significant power consumption typically lowers net system efficiency.

By contrast, propane can be delivered without a pump at pressures greater than 50 psig. Besides eliminating the boost compressor, operating a fuel processor at higher fuel inlet pressures can bring several other benefits. For instance, the size and cost of fuel processor catalyst beds, control valves and other expensive components can be reduced.

Propane has many beneficial environmental characteristics. Since many fuel cell marketing strategies emphasize inherently positive environmental characteristics, it is important that the fuel not detract from those benefits.

- ü Propane's low carbon count (per BTU) provides an advantage to fuel cell systems, which are marketed as systems that produce low CO2 emissions.
- ü Unlike methanol and gasoline, propane has relatively benign human toxicity characteristics.

- Unlike some liquid fuels, propane is not a potential contributor to groundwater pollution.

In an era where energy security is becoming of greater concern, propane's position as a domestically produced fuel is another asset, which may create special opportunities.

The capital cost of fuel cells is likely to remain high during the early years of market development. Therefore, the points of synergy for propane's unique advantages should focus on high value fuel cell applications. Such applications should avoid direct competition with low cost grid electricity or natural gas. In addition, propane fuel cell efforts should address the growing trend toward distributed generation.

This study did not focus on potential markets for propane in the fuel cell vehicle market.

- Most automakers are concentrating their research efforts on reforming clean hydrocarbon fuels or using hydrogen produced off-board the vehicle.

- The one fuel cell vehicle market where propane is a potential competitor is the material handling equipment (i.e. lift truck) market. In this market area, propane used in internal combustion engines is already a strong incumbent fuel.

- Propane is a possible feedstock fuel for off-board production of hydrogen. Since Japan imports nearly all their hydrocarbon fuels, including liquid natural gas at costs above our domestic natural gas prices, propane is being used there as a low cost hydrogen carrier. For this reason, a hydrogen vehicle refueling station using propane is under construction in Japan.

- The propane industry should monitor developments in fuel cell powered material handling equipment to determine if a market opportunity exists.

Next Steps for the Propane Industry

As a tactical issue, several fuel cell and propane industry participants expressed the need for a propane fuel study that focused on how propane fuel variations influence fuel cell life and cost characteristics. Suggested tasks included:

- A testing program could determine the actual lifetime of various fuel cell system components (such as catalysts and sorbent beds) using different fuel constituents by varying the propane constituents and limiting or changing the contaminant and odorant levels used.

- The additional capital costs associated with different fuel constituent percentages, different fuel contaminant levels, and different fuel odorant levels could be explored by comparing sorbent and catalyst costs with upstream and local fuel cleanup costs.

Other industry-wide activities, which should be considered, include:

- Development of clearer guidelines for the addition of odorants over the complete chain of custody.

- Development of sulfur removal technologies to lower the costs of sulfur removal.

- Techniques for integrating fuel delivery and fuel cell servicing to reduce total O&M costs.

- Development of data regarding heating demands for premium power customers to evaluate the technical and economic value of using fuel cell cogeneration.

The commercial roles suggested by fuel cell companies (for either 5 kW or newer 50 kW designs) for the propane industry included:

- Profiling of “high value” end users in specific service territories.

  - A reasonable follow-on task would be a study to identify and quantify this grid-challenged market and engage propane companies in targeted data collection and targeted marketing efforts.

  - Development of data in these areas can by used as leverage by propane companies to attract fuel cell partners.

- Participation in fuel cell field trials.

- Targeting of existing off-grid customers and new housing developments.

- Propane reformer technology development via PERC or DOE.

Next Steps for Individual Companies

Individual propane companies should:

- ü Seek out partners among fuel cell companies and electricity suppliers.
- ü Identify grid challenged customers.
- ü Purchase units to test and demonstrate.
- ü Promote state-level financial support, electrical and fire code (NFPA code) modifications to facilitate the use of fuel cells in emergency and back-up applications, and fair interconnection standards.
- ü Accumulate market and technical data.

Development of strategies to tap the value of grid extensions without taxpayer subsidies by substituting propane fuel cells for uneconomic line extensions. Capturing the cost of grid extensions and grid upkeep avoided by using propane fuel cells can be an important factor in fuel cell economic competitiveness. Teaming of propane companies with electric utilities or regional electrical cooperatives to share benefits (such as deferred grid installation or upgrade costs) associated with the installation of fuel cells in remote or grid challenged applications is a key strategy that should be evaluated.