Project Number: 42-IB-0202

DISTRIBUTED RESIDENTIAL FUEL CELL SYSTEMS

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Paul R. Blanchard

Angela C. Rugg

Date: April 28, 2003

Approved:

Professor Isa Bar-On, Advisor

Abstract

Distributed Residential Fuel cell power is a potentially cleaner, more efficient, and more reliable power source than traditional grid power. This report analyzes the benefits and disadvantages of fuel cell power in homes to determine whether this is a valid replacement for grid power. The report also analyzes how legislation can affect the progress of the fuel cell market, and how fuel cells measure up to traditional power in cost, quality, and convenience.

Authorship

Table of Contents

Introduction

The U.S. relies heavily on inexpensive but non-renewable fossil fuels for power generation. The combustion of these fuels produces exhaust gases that are harmful to the environment. In addition to being dirty, production of energy via fossil fuels is also less efficient than renewable methods currently being tested. Fuel cells provide a renewable, more efficient source of power. They are already used as backup power generation in applications requiring a consistent, high quality source of power, such as banks, technical corporations and hospitals. However, fuel cells are very expensive to purchase, and require more attention than the traditional grid set-up. This required time and attention is traded for control, reduced environmental impact and a sense of security that unexpected power outages will not occur.

Not all types of fuel cells are appropriate for residential applications. Large institutions are using Phosphoric Acid Fuel Cells (PAFC), because a system composed of this type of fuel cell is mature and has been developed for use in industrial and commercial settings. In a residential setting, the most important types of fuel cells are those which have the potential to replace or supplement power produced by utilities and distributed via the power grid. All calculations and analysis will be based on Proton Exchange Membrane (PEM) fuel cells. This type of fuel cell is the most mature of the fuel cells with potential for home use, due to their operating conditions, including their low operating temperature, small unit volume, and short start-up time. Summaries of nine major types of fuel cells are included, each of which discusses the fuel cell's construction, characteristics, possible applications, and its benefits and shortcomings.

Fuel cells are expected to be cleaner than grid power, due to the fact that they are more efficient than traditional power generation methods, and when used with hydrogen fuel, they produce no harmful fumes or exhaust. Also, when a fuel such as gasoline or natural gas is reformed to hydrogen, it produces less CO2 than a combustion process [Natural Life Magazine, "Dirty" Hydrogen Could Foul Fuel Cell Potential]. Although an in-depth analysis will not be made in this paper, possible environmental impacts of the fuel cell lifecycle will be discussed.

Further integration of fuel cells into the power generation market would have many benefits. Fuel cells used continuously in cogeneration schemes, in which heat from the fuel cell is used to produce hot water have an efficiency of 85%. Although hydrogen must be separated from other materials, as it only exists naturally as part of a compound, it is a truly renewable source, more abundant than any other element on Earth. Another benefit is that the only waste product produced from hydrogen-powered fuel cells is water.

Distributed energy systems increase overall power grid distribution efficiency due to reduced transmission distances. Distributed energy systems also allow end users to take advantage of the heat generated by the cell in addition to power generated.

These systems, although environmentally beneficial, require a large initial investment. The high price tag is counter-acted by the low fuel cost over time, but the initial cost is still a road block to fuel cell adoption in the marketplace. The high price of fuel cells today reflects the fact that they are a technology in transition from experimental and developmental phases, to the commercial phase. As they become more widespread in usage, they should decrease in price. An analysis of initial costs, cost over time, and the payback period of the initial fuel cell investment, is included with current price estimates.

Convenience is an important factor in the consumer market for fuel cells. Despite unplanned outages that can cause inconvenience, using grid power requires no installation, setup, maintenance or fueling. If fuel cells are to be used, fuel must be continuously provided to the cell. An analysis of the possible fueling methods for fuel cells will be included in this paper.

How Fuel Cells work

In order to understand how fuel cells may eventually replace current industry standards, it is important to understand how they work. In principle, a fuel cell operates like a battery. However, unlike a battery, a fuel cell does not run down or require recharging. A fuel cell will produce energy in the form of electricity and heat as long as fuel is supplied.

A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat.

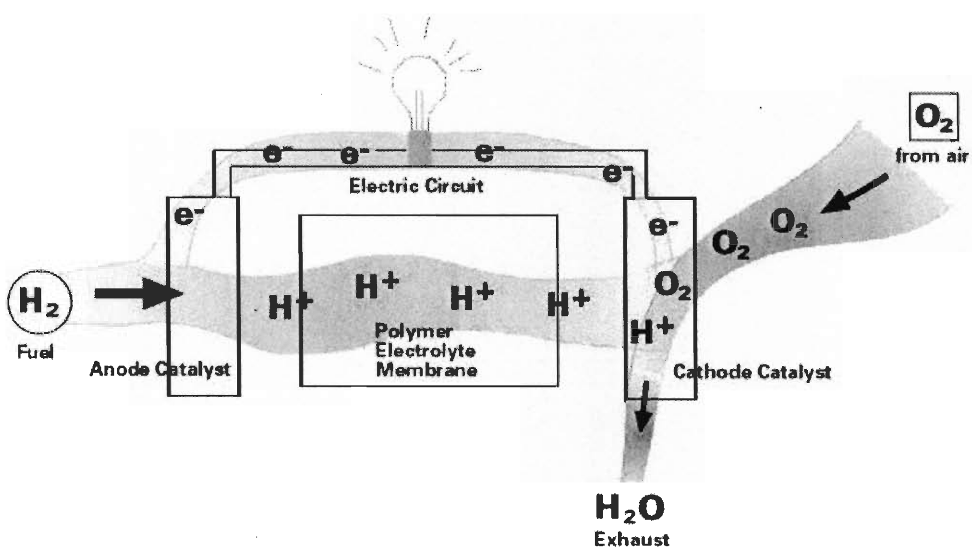

Figure 1 – Basic Fuel Cell Structure

Hydrogen fuel is fed into the anode (negatively charged electrode) of the fuel cell, and oxygen enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron; each taking a different path to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they reach the cathode, to be reunited with the dissociated proton and oxygen forming a molecule of water.

A fuel cell system which includes a "fuel reformer" can utilize the hydrogen from any hydrocarbon fuel: from natural gas to methanol, and even gasoline. Since the fuel cell relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes. [Breakthrough Technologies Institute/Fuel Cells 2000, *What is a fuel cell*]

Types of Fuel Cells

Some of the major fuel cell types being researched and put into use are discussed in the following sections. Fuel cells types differ in the material used for the electrolyte medium (fluid, solid, or membrane), the metal used as the catalyst, and other characteristics including temperatures of operation, size of the fuel cell, and appropriate applications. Different fuel cells can have different chemical reactions occurring at their anode and cathode, and run at a wide range of temperatures. Another difference is the characteristics of the fuel required by the different types of cells. Some fuel cells can directly extract hydrogen from a hydrogen rich substance while others require reformers and extremely pure forms of hydrogen.

Phosphoric Acid (PAFC)

PAFCs are commercially available today. More than 200 fuel cell systems have been installed all over the world - in hospitals, nursing homes, hotels, office buildings, schools, utility power plants, an airport terminal, landfills and waste water treatment plants. PAFCs generate electricity at more than 40% efficiency and nearly 85% if the heat this fuel cell produces is used for cogeneration. This compares to about 35% for the utility power grid in the United States. Operating temperatures are in the range of 300 to 400 degrees F (150 - 200 degrees C). At lower temperatures, phosphoric acid is a poor ionic conductor, and carbon monoxide (CO) poisoning of the Platinum (Pt) electro-catalyst in the anode becomes severe. The electrolyte is liquid phosphoric acid soaked in a matrix.

One of the main advantages to this type of fuel cell, besides the nearly 85% cogeneration efficiency, is that it can tolerate impurities in fuel. PAFCs can tolerate a CO concentration of about 1.5 percent, which broadens the choice of fuels they can use. If gasoline is used, the sulfur must be removed. Disadvantages of PAFCs include: it uses expensive platinum as a catalyst, it generates low current and power comparably to other types of fuel cells, and it generally has a large volume and mass. PAFCs, however, are the most mature fuel cell technology, and are available on the market. Through organizational linkages with Gas Research Institute (GRI), electronic utilities, energy service companies, and user groups, the Department of Energy (DOE) helped in bringing about the commercialization of a PAFC, produced by ONSI (now UTC Fuel Cells). Existing PAFCs have outputs up to 200 kW, and 1 MW units have been tested.

[Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Proton Exchange Membrane (PEM)

Proton exchange membrane (PEM) 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, such as in 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."

The proton exchange membrane is a thin plastic sheet that allows hydrogen ions to pass through it. The membrane is coated on both sides with highly dispersed metal alloy particles (mostly platinum) that are active catalysts. The electrolyte used is a solid organic polymer poly-perflourosulfonic acid. The solid electrolyte is an advantage because it reduces corrosion and management problems. Hydrogen is fed to the anode side of the fuel cell where the catalyst encourages the hydrogen atoms to release electrons and become hydrogen ions (protons). The electrons travel in the form of an electric current that can be utilized before it returns to the cathode side of the fuel cell where oxygen has been fed. At the same time, the protons diffuse through the membrane (electrolyte) to the cathode, where the hydrogen atom is recombined and reacted with oxygen to produce water, thus completing the overall process. This type of fuel cell is, however, sensitive to fuel impurities. Cell outputs generally range from 50 to 250 kW. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Molten Carbonate (MCFC)

These fuel cells use a 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. The high operating temperature is needed to achieve sufficient conductivity of the electrolyte. Because of this high temperature, noble metal catalysts are not required for the cell's electrochemical oxidation and reduction processes. To date, MCFCs have been operated on hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products. 10 kW to 2 MW MCFCs have been tested on a variety of fuels and are primarily targeted to electric utility applications. Carbonate fuel cells for stationary applications have been successfully demonstrated in Japan and Italy.

The high operating temperature serves as a big advantage because this implies higher efficiency and the flexibility to use more types of fuels and inexpensive catalysts as the reactions involving breaking of carbon bonds in larger hydrocarbon fuels occur much faster as the temperature is increased. A disadvantage to this, however, is that high temperatures enhance corrosion and the breakdown of cell components. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Solid Oxide (SOFC)

The solid oxide fuel cell is another highly promising fuel cell. This type of 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 fuel cell auxiliary power units (APUs) with SOFCs. A solid oxide system usually uses a hard ceramic material of solid zirconium oxide and a small amount of ytrria, instead of a liquid electrolyte, allowing operating temperatures to reach 1,800 degrees Fahrenheit or 1000 degrees Celsius. Power generating efficiencies could reach 60% and 85% with cogeneration and cell output is up to 100 kW. One type of SOFC uses an array of meter-long tubes, and other variations include a compressed disc that resembles the top of a soup can. Tubular SOFC designs are closer to commercialization and are being produced by several companies around the world. Demonstrations of tubular SOFC technology have produced as much as 220 kW. Japan has two 25 kW units online and a 100 kW plant being testing in Europe. [Technologies Institute/Fuel Cells

2000, *Types of Fuel Cells*]

Alkaline

Long used by NASA on space missions, these cells can achieve power generating efficiencies of up to 70 percent. They were used on the Apollo spacecraft to provide both electricity and drinking water. Their operating temperature is 150 to 200 degrees C (about 300 to 400 degrees F). They use an aqueous solution of alkaline potassium hydroxide soaked in a matrix as the electrolyte. This is advantageous because the cathode reaction is faster in the alkaline electrolyte, which means higher performance. Until recently they were too costly for commercial applications, but several companies are examining ways to reduce costs and improve operating flexibility. They typically have a cell output from 300 watts to 5 kW. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Direct Methanol Fuel Cells (DMFC)

These cells are similar to the PEM cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. Efficiencies of about 40% are expected with this type of fuel cell, which would typically operate at a temperature between 120-190 degrees F or 50 -100 degrees C. This is a relatively low range, making this fuel cell attractive for tiny to mid-sized applications, to power cellular phones and laptops. Higher efficiencies are achieved at higher temperatures. A major problem, however, is fuel crossing over from the anode to the cathode without producing electricity. Many companies have said they solved this problem, however. They are working on DMFC prototypes used by the military for powering electronic equipment in the field. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Regenerative Fuel Cells

Still a very young member of the fuel cell family, regenerative fuel cells would be attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solar-powered 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 solar-powered electrolyzer and the process begins again. These types of fuel cells are currently being researched by NASA and others worldwide. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Zinc-Air Fuel Cells (ZAFC)

In a typical zinc/air fuel cell, there is a gas diffusion electrode (GDE), a zinc anode separated by electrolyte, and some form of mechanical separators. The GDE is a permeable membrane that allows atmospheric oxygen to pass through. After the oxygen has converted into hydroxyl ions and water, the hydroxyl ions will travel through an electrolyte, and reaches the zinc anode. Here, it reacts with the zinc, and forms zinc oxide. This process creates an electrical potential; when a set of ZAFC cells are connected, the combined electrical potential of these cells can be used as a source of electric power. This electrochemical process is very similar to that of a PEM fuel cell, but the refueling is very different and shares characteristics with batteries. Metallic Power is working on ZAFCs containing a zinc "fuel tank" and a zinc refrigerator that automatically and silently regenerates the fuel. In this closed-loop system, electricity is created as zinc and oxygen are mixed in the presence of an electrolyte (like a PEMFC), creating zinc oxide. Once fuel is used up, the system is connected to the grid and the process is reversed, leaving once again pure zinc fuel pellets. The key is that this reversing process takes only about 5 minutes to complete, so the battery recharging time hang up is not an issue. The chief advantage zinc-air technology has over other battery technologies is its high specific energy, which is a key factor that determines the running duration of a battery relative to its weight. When ZAFCs are used to power EVs, they have proven to deliver longer driving distances between refuels than any other EV batteries of similar weight. Moreover, due to the abundance of zinc on earth, the material costs for ZAFCs and zinc-air batteries are low. Hence, zinc-air technology has a potential wide range of applications, ranging from EVs, consumer electronics to military. Powerzinc in southern California is currently commercializing their zinc/air technology for a number of different applications. [Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Protonic Ceramic Fuel Cell (PCFC)

This new type of fuel cell is based on a ceramic electrolyte material that exhibits high protonic conductivity at elevated temperatures. PCFCs share the thermal and kinetic advantages of high temperature operation at 700 degrees Celsius with molten carbonate and solid oxide fuel cells, while exhibiting all of the intrinsic benefits of proton conduction in polymer electrolyte and phosphoric acid fuel cells (PAFCs). The high operating temperature is necessary to achieve very high electrical fuel efficiency with hydrocarbon fuels. PCFCs can operate at high temperatures and electrochemically oxidize fossil fuels directly to the anode. This eliminates the intermediate step of producing hydrogen through the costly reforming process. Gaseous molecules of the hydrocarbon fuel are absorbed on the surface of the anode in the presence of water vapor, and hydrogen atoms are efficiently stripped off to be absorbed into the electrolyte, with carbon dioxide as the primary reaction product. Additionally, PCFCs have a solid electrolyte so the membrane cannot dry out as with PEM fuel cells, or liquid can't leak out as with PAFCs. Protonetics International Inc. is primarily researching this type of fuel cell. [Breakthrough Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells*]

Current Status of Fuel Cells

There are several key attributes that determine the applications in which fuel cells can be used. The main factors are size, power and cost. Other major factors are the fuel which the fuel cells use and the operating temperature of the cell. Fortunately, one of the major benefits of fuel cells is the fact that they are scalable over a wide power range. This means that they can be built to match almost any power requirement necessary.

Currently, fuel cells are an expensive method of producing power. One price for a larger scale fuel cell that is currently available was $750,000 for a 200kW cell. This particular cell was used to successfully power an entire office building for over a year. [Department of Defense, *Application Worksheet*]

In the near future, fuel cells are expected to become a more economically sound method of producing power. Tucson Electric Power Company (TEP), a regulated electric utility has a fuel cell about three to five years away from readiness. It's a thin film unit that doesn't need external reformation and runs at a cooler (600-700^{o}) temperature and has a higher power density than existing technology. The company expects a less than $1,000/kw cost versus $2,000-$3,000/kw for current technology. [Smithsonian Institution, Future Fuel Cell History]

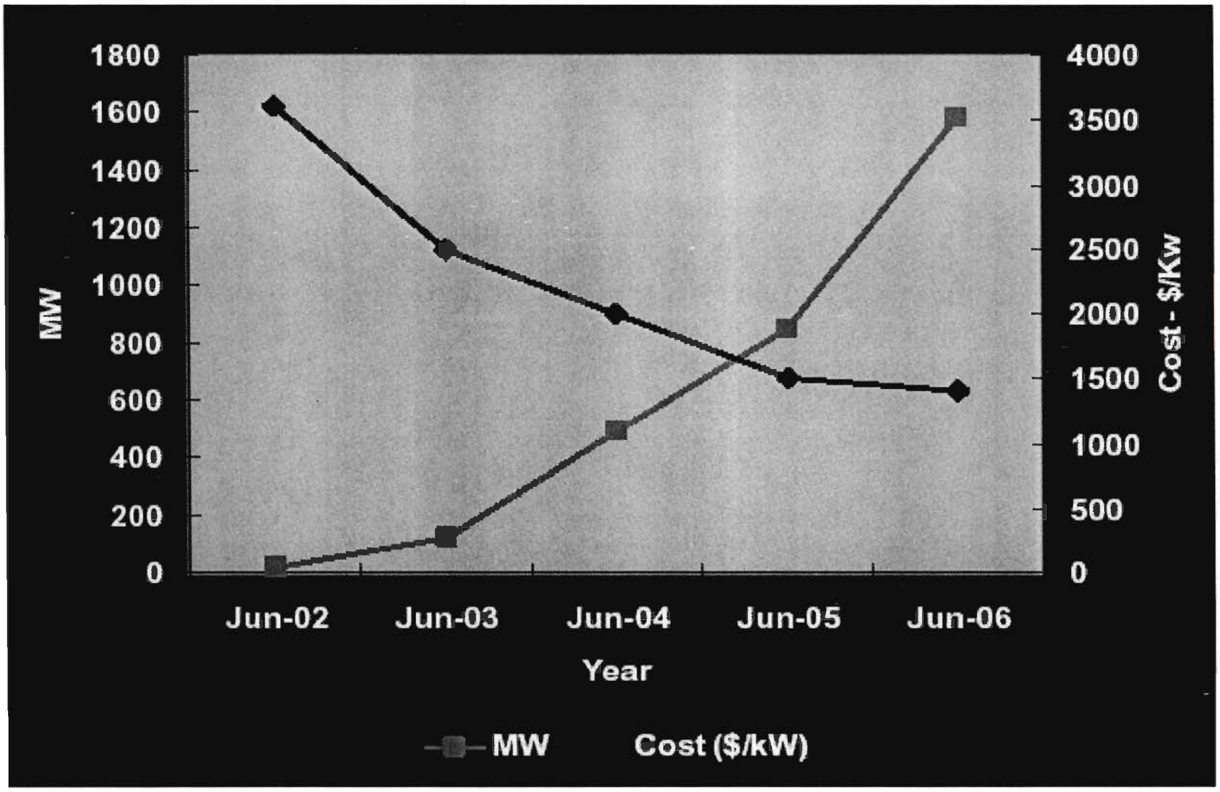

Figure 2 – Prediction of cost and scale of fuel cell use. [California Stationary Fuel Cell Collaborative, Strategic Plan]

Benefits of Fuel Cells

Fuel cell systems offer the potential for reliable, efficient, and cost-effective energy generation. Capable of operating on multiple fuels, such as natural gas, propane and hydrogen, fuel cell systems can be deployed to operate in parallel with the grid, as independent energy sources or to complement solar and wind generating systems. With a higher efficiency (approximately 40% without cogeneration, and up to 85% using the heat produced), than conventional power generation (approximately 35%), little or no exhaust and flexibility in installation and operation, they may offer commercially viable alternatives to existing power sources. [Plug Power, *Advantages of Fuel Cells*]

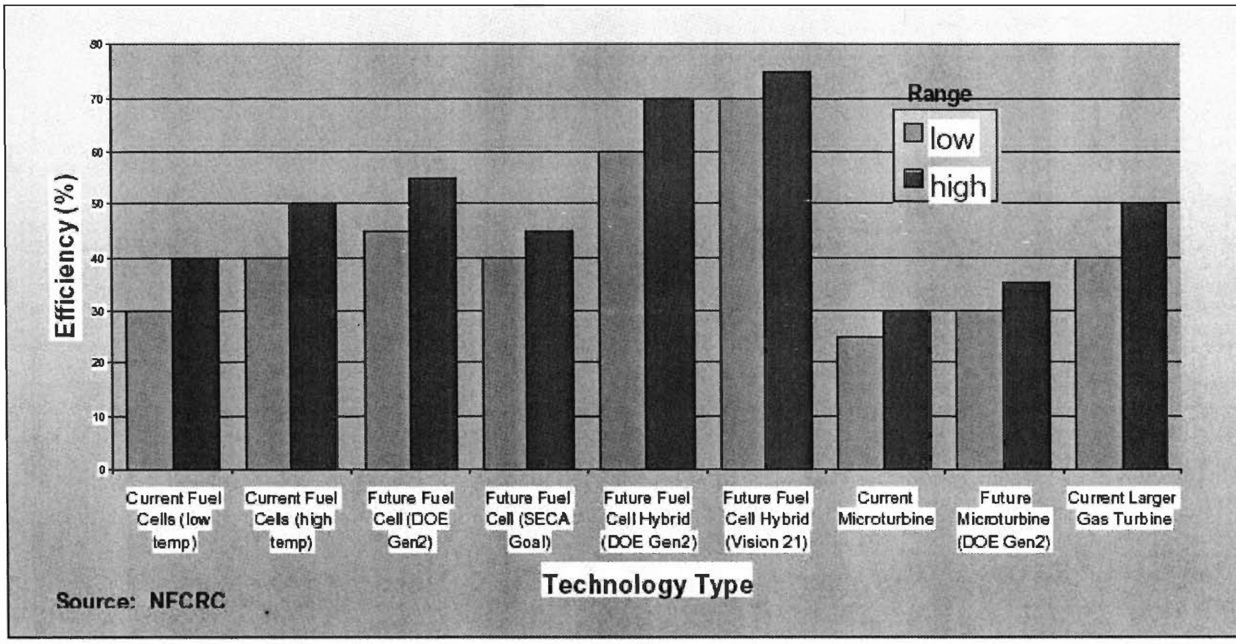

Figure 2 – Current and predicted fuel cell efficiencies

The key to the success of fuel cells is their high efficiency. The efficiencies of fuel cells are listed above (figure 2), comparing with microturbines and larger sized gas turbines, hybrid fuel cells, and the future projections. Because they are able to extract so much energy out of the fuel which they consume, it allows a significant reduction in the cost of fuel over the lifetime of the power generation device. Since the bulk of the cost of energy generation comes from the use of fuel, this reduction in fuel consumption leads to less expensive power.

Environmental Issues

One of the driving forces behind fuel cell power is that it has the potential for being cleaner and safer for the environment than existing technologies. Since hydrogen fed fuel cells produce no exhaust gases, a comparable amount of water to combustion, it is easy to assume that they are more environmentally beneficial than a coal or natural gas fired power plant. However, a deeper analysis must be made in order to see the whole picture. The origins of the hydrogen fuel must be analyzed, the process employed to construct the cell, as well as the disposal and recycle of a spent fuel cell must all be considered in order to make a decision on the environmental friendliness of fuel cell power.

Environmental issues are important to consider in the implementation of a new form of power generation. When deciding to incorporate any new system into the community, an in-depth analysis of the environmental impact of the system should be done, and taken into consideration. Discussion of the topic of fuel cell power production is usually laden with the suggestion of environmental benefits. Environmental issues are deeper than the exhaust fumes produced by a system, and require an in depth analysis. An in-depth analysis of these issues will not be done in this report; however, this section will discuss the pertinent factors of how fuel cell use may affect the environment.

One major issue being addressed is the shift that could come with fuel cells away from fossil fuels, and limited resources. Since fuel cells can run on many different hydrocarbon based fuels, the strain on limited resources can be alleviated, while the focus will shift to renewable energy. Hydrocarbons such as methanol and ethanol, wood and grain/fruit alcohols can be produced commercially, and methane gas, one of the main components of natural gas, can be produced from landfill site, and other biological resources. The process of turning waste into fuel is a promising concept, but may bring its own complications into the process.

The construction and disposal of fuel cells are environmental concerns as well. Fuel cells contain chemicals and metals which could be difficult to dispose of or recycle. In the manufacture of fuel cells, an intensive process occurs to construct a fuel cell.

On a continual basis, if pure hydrogen is chosen to be the main fuel for the fuel cell, hydrogen production will necessarily increase. The main production of hydrogen is presently by hydrocarbon cracking, or reform of natural gas or fossil fuels which may defeat the environmental benefits of using a hydrogen-fed fuel cell system. [California Hydrogen Business Council, Industrial Hydrogen Production] The cleanest way to obtain hydrogen on a large-scale level is to strip natural gas, which would cut CO_2 emissions by 70%, where gasoline stripping may reduce them by 20%. [Natural Life Magazine, "Dirty" Hydrogen Could Foul Fuel Cell Potential] Regenerative fuel cells show promise in this area, being designed to remove hydrogen and oxygen from the water they produce as waste. However, these fuel cells are still a new technology, so it will be up to other more mature types of fuel cells to bring the technology up to date.

Distributed Energy

How Distributed Energy Works

Distributed energy is characterized by the fact that power is generated by distributed sources along the power grid as opposed to one centralized source at the beginning of the grid. Distributed energy resources are parallel and stand-alone electric generation units located within the electric distribution system at or near the end user. Distributed energy resources can be beneficial to both electricity consumers and, if the integration is properly engineered, to the energy utility as well.

Benefits of Distributed Energy

Distributed energy resources can complement central power by providing incremental capacity to the utility grid or to an end user. Installing distributed energy resources at or near the end user can also benefit the electric utility by avoiding or reducing the cost of transmission and distribution system upgrades.

For the consumer the potential lower cost, higher service reliability, high power quality, increased energy efficiency, and energy independence are all reasons for interest in distributed energy resources. The use of renewable distributed energy generation and "green power" such as wind, photovoltaic, geothermal or hydroelectric power, and can also provide a significant environmental benefit.

Some of the primary applications for distributed energy resources include:

- Premium power - reduced frequency variations, voltage transients, surges, dips or other disruptions
- Standby power - used in the event of an outage, as a back-up to the electric grid
- Peak shaving - the use of distributed energy resources during times when electric use and demand charges are high
- Low-cost energy - the use of distributed energy resources as base load or primary power that is less expensive to produce locally than it is to purchase from the electric utility
- Combined heat and power (cogeneration) - increases the efficiency of on-site power generation by using the waste heat for existing thermal process

Most of the current distributed energy resource users use this type of energy generation because they have different power needs than most conventional users. Hospitals need high reliability (back-up power) and power quality (premium power) due to the sensitivity of the equipment used there. St. Vincent's Hospital on Staten Island, NY uses a 200 kW PC25 fuel cell, manufactured by UTC Fuel Cells, to supplement its grid power [UTC, New York Power Authority]. Industrial plants typically have high energy bills, long production hours, and thermal processes, and would therefore seek distributed energy applications that include low-cost energy and combined heat and power. Computer data centers require steady, high-quality, uninterrupted power (premium power). Distributed energy resource technologies are available to meet these individual, specific needs. [California Energy Commission, *California Distributed Energy Resources Guide*]

Grids and Utilities

Current State of Grid

The traditional grid is configured mainly in a way that allows only one-way power transmission. Two-way transmission is possible, but on a large scale, it causes power spikes, and failures. With restructuring, these problems can be avoided. Most problems occur because the reformers along the low voltage lines cannot handle the additional power over the lines, and will blow out if more power is added. [DE Report] Power surges can occur down the line from a residential generator because the power is not rerouted anywhere, it just continues down to the next customer in the chain. With a restructured grid, the power lines are arranged in a more web-like structure, avoiding some of the problems of the direct linear system. Restructuring not only includes a modification of the grid structure, but a modification of the grid technology as well. A modified power grid would have safety issues that need to be dealt with before it can be implemented.

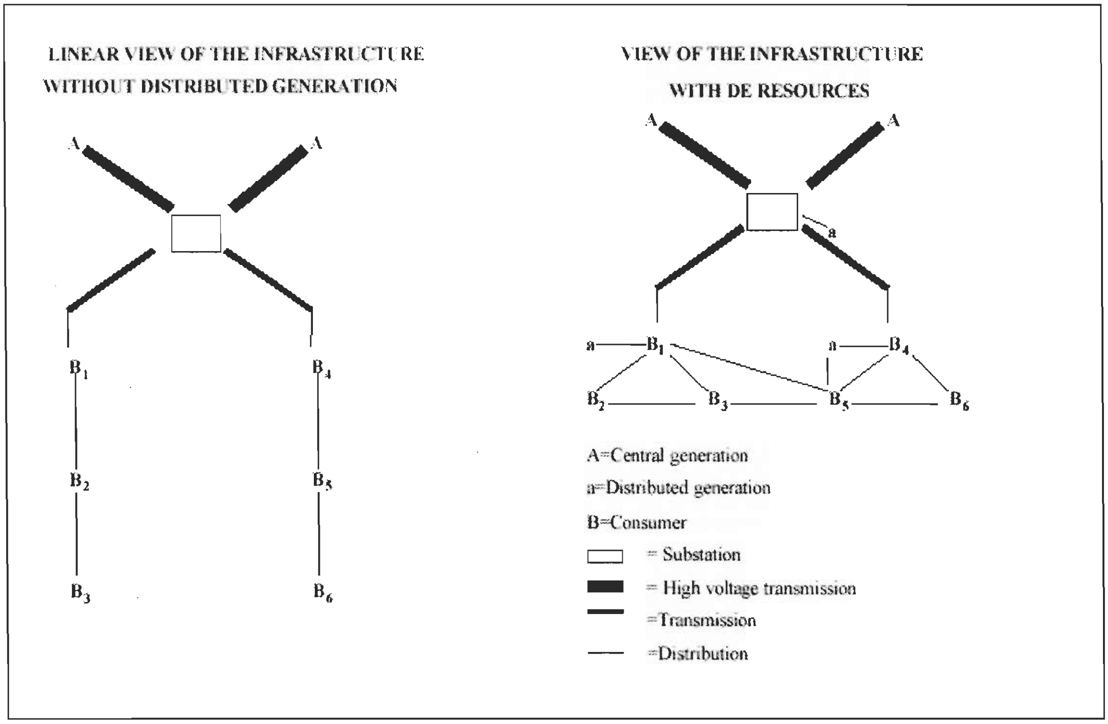

Figure A–Schematic of Traditional and Reformed Grid Source: DE Report Ch.4

In some places, such as parts of CA, MA, the grid has been restructured in a way that promotes consumer sell-back. Each municipality with a restructured grid has different specifications, meaning, some area grids can handle more power than others. In areas such as the Sacramento Municipal Utility District (SMUD), grid restructure has been successful. The renewable project in California is based on an experimental photo-voltaic project, which has been quite successful so far. The project is controlled and operated by the municipal utility. Other such projects also exist, although very few involve fuel cells of a significant number.

Just as projects like these become more popular in areas with the resources for photovoltaic, wind and solar thermal power, colder regions such as the Northeast can benefit from a fuel cell project which generates heat as well as power. Cogeneration, the process of using the heat generated during the fuel cell operation, may prove a useful way to exploit fuel cell power to its greatest potential.

Power Sell-back Procedures and Regulations

Most residents in the U.S are already connected to a grid and pay for the electricity as they use it. However, the price of electricity may not remain constant during all times of the day. During the "peak hours" of the day, utilities may charge a premium rate to account for the extra electricity they must produce at that time, and for the efficiency lost during off-peak hours.

One benefit of a grid connected residential source is the potential for peak-shaving. This occurs when a generator is run during hours that are considered "peak" by the utility. By generating residential power, the peak fees are avoided, and if the resident is in a state that supports net-metering payback at retail prices, peak sellback may prove profitable.

The Federal Energy Regulatory Commission (FERC) is pushing Congress to support a move to completely restructure power generation in the US, and deregulate the power industry. This would allow small generators to make more profit from their enterprise, and allow competition in the power market. Because of the way utilities are set up, it is difficult for small generators to break into the market. Almost all power generation is handled by a select few power utilities, and no utility is in competition with another for any specific area. New rules and standardized regulations would be controlled by regional transmission organizations. This would allow other sources of power to break into the market and would provide a venue for power price comparison. The move has support, but is going slowly, due to Enron collapse, CA blackouts, and a generally bad economy. [United Press International, Ferc Urges Requirement of Power Rtos]

Public utilities are not very likely to promote the selling back of power to the grid, since they often end up paying more than it would cost to produce the energy themselves. However, private sources add capacity to their generation power without requiring the major investment of adding to the current or building an additional facility. It is mostly due to legislation on the behalf of the resident that it is now possible to sell power back to the utilities. PURPA (the Public Utility Regulatory Policy Act) was the first big breakthrough, when it required, in 1978, that utilities buy power back at wholesale prices from any source which generates excess power.

At the time the act was passed, there was an energy crisis, in which public utilities were unable to meet their demand, and signed contracts with the government to buy power at the price it would have cost them to produce it. Many utilities are now able to produce cheap power again, but are still bound to purchase independent power at the previous prices. [Union of Concerned Scientists, Public Utility Regulatory Policy Act (PURPA)]

The practice of selling power back to the grid promotes consumer interest in purchasing power generation sources. It calls for the monitoring of the net usage of electricity. The electricity meter used to measure net usage can be spun backward when electricity is generated and forward when electricity is used. This way, consumers pay the premium price for only the net power used. If power is a net increase, they are paid the wholesale price of the electricity. Before net usage metering was supported, customers were required to run two meters, one that measured the power generated, and one that measured power consumed. The customer paid the high retail price for electricity used, and only earned the wholesale price for electricity generated. Minnesota, Wisconsin and SMUD pay their customers the retail price for the power generated. [New

Rules Project, Net Metering of Electricity]

Areas facing a shortage of power production will be more likely to encourage consumers to produce their own power. As distributed energy in general becomes more popular and accessible, more states will move to support this type of generation.

Tax Credits and Government Sponsored Benefits

The heavy initial financial burden of a fuel cell may prove daunting to homeowners, especially since the power they purchase from a utility requires no setup, installation, piping, rewiring or delivery of fuel. One place that consumers can get consumer help, and find actual financial benefits from owning and operating a fuel cell unit is from the government.

There are both state and federal tax breaks, and exclusions, as well as other legislation, such as PURPA and net-metering laws. Net-metering laws allow the homeowner to sell power back to the grid at better prices. While most of current legislation is aimed at other forms of distributed energy, they can be used as precedent laws that can eventually, if not already, apply to fuel cells as well. These are additional laws which encourage the decentralization of power production, to increase capacity for utilities, without incurring extra costs.

A tax credit exists for electricity generated by wind, closed loop biomass (plant material grown exclusively for power generation, yielding methane and methanol) and poultry waste. The companies receive a 1.8 cent benefit/kWh for the first ten years of operation. This credit was allowed to expire in December 2001, but was reinstated in March 2002 to last until December 2003 and made retroactive to cover the period of lapse. [Union of Concerned Scientists, Wind and Biomass Energy Tax Credit Saved – Again]

HPower Corp. and Energy Co-Opportunity are endorsing a potential tax credit of $1000 per kW purchased for stationary fuel systems to provide household energy [Business Wire, H Power and ECO Back Proposed Federal Tax Credit]. Oregon has a tax credit for distributed energy production. It supports a maximum credit of $1,500, based on kWh produced in the first year, by solar, stationary fuel cell, alternative fuel vehicle. [Oregon Department of Revenue, Residential Energy Tax Credit]

U.S. Congressman John B. Larson (CT-01) recently announced his support for an initiative that would create a tax credit for fuel cell technology meant to encourage the development and further use of fuel cells as an alternative energy source. Larson is a co-sponsor the legislation introduced by Representative Nancy Johnson, that would provide a $500 per kilowatt tax credit for stationary fuel cell systems of five kilowatts or more that have an electrical generation efficiency of 30% or higher. [Larson, John, B. Larson Announces Support of Fuel Cell Tax Credit]

The State of Washington has passed a bill adding fuel cells to net metering laws. Before this law, the only forms of energy eligible for net metering in the state were solar, wind and hydro energy. Other states that currently allow net metering of fuel cell energy are Colorado, Connecticut, Ohio, Oregon, Pennsylvania, Vermont, and Wisconsin. [XENERGY Inc., Washington Adds Fuel Cells to Net-Metering]

These credits and various others may help make it possible for fuel cell power to gain popularity by lowering the responsibility of the consumer to cover the entire initial price of the unit. This legislation, coupled with the fact that the prices of fuel cells should continue to decrease as the technology becomes more mature, makes distributed residential fuel cell systems a more attractive option for power generation.

Goal

The purpose of this report is to determine if fuel cells can effectively be used in distributed residential power systems. Quality, safety, power, size, cost and convenience are the requirements that a fuel cell system must meet. The current environmental impact of these systems must also be taken into account. A detailed analysis must be performed on current residential power technologies in order to determine this list of requirements that a fuel cell replacement would need to meet.

The requirements of distributed residential systems will be determined by analyzing the past statistics of these systems. This includes power statistics, current power costs, power quality analysis and overall environmental impact of current power systems. The ability of fuel cells to meet these requirements will be determined by analyzing several case studies involving distributed power systems and extracting valuable statistics.

After the requirements are determined, a cost analysis will be performed to determine if a distributed residential fuel cell system is economically feasible. This analysis includes initial costs, maintenance costs and fuel costs. It also must take into account the savings incurred when energy prices are compared to utility energy pricing and tax breaks and government regulations.

Physical numbers

Power requirements

The most important requirement of any power system is the quality and quantity of power that it must provide. Power requirements are some of the most critical requirements because if a replacement power source cannot meet power expectations, the system in which the replacement was made will fail, rather than just run poorly or inefficiently. The specifications needed to make a compatible fuel cell replacement can be determined through an analysis of average household power consumption.

The average household used 5kW of power at any one time, and 6,000-12,000 kWh per year (one kWh is equal to 3,413 BTUs [Smith; Van Ness; Abbott; *Chemical Engineering Thermodynamics*]), depending on the type of household [Energy Information Administration, Total Energy Consumption in US Households]. We can draw several conclusions from these facts. Since at any given time the average household uses 5kW, this should be the average power that a fuel cell in a distributed residential system should be capable of supplying. Also, the average consumer requires 6,000-12,000 kWh per year. Therefore, the fuel cell that is in the distributed residential system needs to be able to meet this kWh requirement as well.

Power quality is a very important factor to consider when deriving a set of requirements for a power system. The U.S. bulk power grid was designed to achieve a 10^{-3} reliability index, or 99.9 percent. This level is sometimes referred to as "3 nines" of reliability. In terms of outage expectation, "3 nines" means about 8.75 hours of outage per year. Reliability of greater than "4 nines" with low distortion is often referred to as premium power. Some DE technologies, including fuel cells and electric storage, are well suited to premium power markets [Consumer Energy Council of America, Distributed Energy, Chapter 4.].

Since fuel cell technology inherently provides superior power quality than the power grid, one does not need to worry about meeting this requirement when choosing a particular fuel cell for a distributed residential fuel cell. Furthermore, since fuel cells can provide superior power quality than the grid, this aspect makes a fuel cell system superior to a comparable grid based system that provided the same amount of power.

Fuel requirements

There are several methods available for supplying the required fuel for the existing types of energy generation devices. Heating furnaces need oil, and gas stoves and water heaters need natural gas or propane. Similar to these types of energy generation, fuel cells will require large amounts of fuel. If the fuel specifications of residential fuel cells are compatible with the specifications of existing technologies that are already in place for delivering fuel, it will reduce the initial investment required to install a fuel cell system. Also, by analyzing the amount of effort involved in maintaining the existing fuel supply systems we can develop a list of requirements to address the effort involved in fuel cell fuel supply systems.

The most common methods used for supplying fuel to power generation devices are either storage tanks or pipe lines. One example of storage tanks in use is the permanent storage tanks that are used for storing the heating oil used by furnaces. Oil storage tanks range in volume between 275 and 1000 gallons [Oil Tank Measurement Chart]. Heating oil costs approximately $1.41/ gallon [Department of Defense, *Application Worksheet*]. On average, a single-family residence with a heating oil furnace used about 750 gallons of fuel oil per year [American Petroleum Institute, Heating Oil in the United States]. Propane is stored in similar volume tanks ranging from 10 - 1000 gallons [Illinois Propane Gas Association, *BTU Content Comparison*].

Fuel pipes are another commonly used method for supplying fuel to residences. One example where fuel is supplied through pipes is natural gas. The average volume of natural gas consumed by a residential home in Maryland is 2500 m^3/year at approximately \$0.26/m^3 [Energy Shop, Natural Gas Buying Group].

With these facts in mind, several requirements for the fuel source of fuel cell systems can be established. There are two major inconveniences associated with using a storage tank to store fuel. First, the storage tank can be large, occupying space in the consumer's home or yard. Second, the tank must be refilled, requiring action on the consumer's part.

Existing fuel storage tanks are between 250 and 1000 gallons. The inconvenience caused by the amount of space that the tanks occupy is accepted by the consumers. If fuel cell storage tank volumes are kept within this range of 250 – 1000 gallons then the new tanks can not be considered more of an inconvenience than the existing tanks as far as size goes.

A sense of how often a tank must be refilled can be gained by analyzing the size of the tank and the annual consumption of fuel. If consumption of fuel is constant throughout the year then a 250 gallon oil tank must be refilled 3 times each year. However, if we assume that the bulk of the oil is consumed in the three months of winter then the 250 gallon tank must be refilled once a month during this period. Since it would be unsafe to allow the oil level in the tank to drop all the way to zero a consumer might have to refill one's tank every 3 – 4 weeks. This refueling rate can be used as a guide for the frequency of refilling a fuel cell tank because consumers are willing to tolerate this frequency of refueling.

Natural gas is piped into homes at approximately 2500 m^3/ year. The existing pipes would have to be modified if this rate were to substantially increase. Since replacing the existing pipes could prove to be a costly process, it would be financially beneficial if fuel cells consumed fuel at a rate of 2500 m^3/ year or less.

A third option for providing fuel for a fuel cell system would be to have portable fuel tanks. This method is completely dependent upon the existence of conveniently located fueling stations. One example where this method of fueling is used for is in systems where propane is used as the fuel source. A typical portable propane tank weighs 40 pounds and holds approximately 10 gallons of fuel. If a fuel cell supply tank had comparable statistics, this method of fueling could be a convenient method of providing fuel. If the weight and volume were to substantially increase, it would make it difficult for an individual to transport.

Comparing Fuel Cells to Residential Requirements

Listing the factors

In general, an individual will purchase a distributed energy system if they believe the time and effort required to purchase and maintain the system will yield sufficient benefits to offset the time and effort requirements. The main question that a potential buyer would have is "are the benefits gained worth the effort of switching?"

There are several factors that one must weigh when considering whether or not it is worth while to switch to distributed energy. Peace of mind is one of these factors. Some people will be driven to buy clean DE systems based on the fact that they are not as harmful to the environment. Others might purchase the system because they enjoy having cutting edge technology in their homes.

Independence from grid is another factor. One big advantage of distributed power is that it is not dependent on the grid. This fact opens up a large market for people who want to be grid independent. Some reasons for grid independence would be a location in a remote area, a demand for high power quality, or demand for high power reliability. [Consumer Energy Council of America, *Distributed Energy, Chapter 4*]

Saving money is always a factor when one is considering a new purchase. The main factor for switching to a distributed power system will be the promise of saving money. There are many cases where using a distributed energy solution for a power requirement is cheaper than a traditional grid based solution [Consumer Energy Council of America, *Distributed Energy, Chapter 4*].

Initial purchase and installation costs would be the greatest opposing factor to an individual investigating the purchase of a DE system. Since almost all houses are initially installed with grid power, DE systems competition requires no initial purchases, installation cost and no initial effort from the buyer.

One way to deal with this barrier would be for new houses to be initially set up for use with DE technology. Houses could be set up with an area designated for a power source, and custom wired to take advantage of such a system. In the case of fuel cell systems, the heating system of the house would also be designed around the use of a fuel cell.

Another way to defer the cost of a fuel cell would be for a utility company to purchase the system and pay for installation costs. The utility would then have the benefit of managing the installed system to help them manage peak power loads, which have showed the most extreme price volatility.

Maintenance of a DE system would also be an inconvenience. Once a DE system is installed it will require a certain amount of maintenance. Not only will it have to be refueled regularly, but it must be repaired if the system malfunctions. How the overall maintenance compares to existing power systems will make fuel cell systems more or less attractive to consumers.

Convenience

Power Quality

Power from distributed sources is generally more reliable and of better quality than the power purchased from the grid. With fuel cell systems, power quality is expected to increase from 99.9% reliability to 99.99999% [Consumer Energy Council of America, Distributed Energy, Chapter 4]. This translates into a decrease in outage time, from 8.76 hours per year to approximately 3 seconds per year. In addition to this, all outages for maintenance, etc, are controlled by the owner/operator of the cell, so if maintenance is necessary, the outage can be planned for a convenient time.

Installation

If a piped gas will be used, and the unit is to be attached to the grid, there will be installation involved. In addition to this, the power meter must be modified to handle net-metering if it is available. Installation of fuel cell units in households will generally handled by the company from which the unit was purchased. Since the companies must be paid for this service, the inconvenience of installation is converted into an increase in the initial cost of the system (see cost analysis).

As fuel cell units gain popularity, they may begin to be produced as small portable units, such as the Coleman Powermate, a PEM fuel cell designed for use as portable power for offices, homes, campsites, or anywhere else it is convenient to fit the unit. This unit is designed to be either stationary or movable, and required no installation. This unit is not designed to be connected to the grid, however it is not infeasible that grid connected devices should take this "convenient" form as fuel cells become more popular with consumers. This unit's off-the-shelf appeal may prove more attractive to consumers than a lengthy installation process.

The cost of the convenience of these units is shown in the high price tag, around $6,000 for a 1kW unit. Coleman sells its own specially fitted cylinders and tanks, which can be refilled by sending them back to the manufacturer for refill. [Coleman, Power Out of Thin Air]

Maintenance and Fueling

Maintenance of residential scale fuel cell units may be too inconvenient for homeowners if the maintenance involved exceeds the maintenance needs of existing power systems. Grid power sets a high standard for maintenance because it is owned and operated by the utility.

For a fuel cell unit to produce power efficiently, it must run constantly. Most units for sale and under development are designed to run constantly because it yields the greatest amount of power per unit of fuel. For this to be feasible, the owner must be able to either store a large amount of fuel, or to have the fuel piped in from an exterior source. This added inconvenience could lead potential buyers away from fuel cells.

Storing Fuel in a Storage Tank

If the type of fuel cell used in a distributed residential fuel cell system consumed fuel at a rate comparable to existing systems, a storage tank/delivery system would be a viable option for fueling the system. Existing technology uses tanks ranging from 250 - 1000 gallons. These tanks must be refueled at a frequency as high as once a month.

In order to determine how a fuel tank system would work with a fuel cell, some calculations must be made. There are 16,400 BTUs in one gallon of propane. A gallon of liquid hydrogen has 30,000 BTUs. We stated earlier that the average annual residential electricity consumption is between 6,000 and 12,000 kWh. Since there are 3413 BTUs in one kWh, approximately 1,250 – 2,500 gallons of propane would be consumed each year and 680 – 1360 gallons of hydrogen would be consumed. These numbers are assuming 100% efficiency, an ideal condition that will never be actualized. If the fuel cell ran at 50% efficiency, the volume required per year would be doubled.

At this rate of consumption, a user would have to have their fuel tank filled 2 – 8 times a year, depending on which extreme case one wants to consider. A good approximation would be assuming a 750 gallon tank, producing 10,000 kWh per year, using natural hydrogen fuel and a fuel cell running at 40% efficiency. The 10,000 kWh translates into 1138 gallons of hydrogen. When the 40% efficiency is factored in, the volume increases to 2844 gallons per year. This would translate into a tank being filled every 4 months, or 3 times a year [Newell, Mark; Potter, Amanda. Hydrogen Basics]. A gallon of gasoline contains about 115,000 BTUs, but fuel cells that use gasoline are generally less efficient [EV World, Advanced Electric Drive]. However, if the volume of the gas turned out to be a prohibitively high, gasoline could be substituted for hydrogen.

Piping Fuel to Residence

If natural gas can be used to run the desired power system there are many benefits. If the consumer has previously used natural gas for heating, the pipeline already exists for fuel delivery making the installation convenient. The question is how the consumption of gas in a fuel cell system compares to the consumption of the existing heating systems. Natural gas contains 1000 BTUs per cubic foot [Illinois Propane Gas Association, *BTU Content Comparison*]. An analysis can be performed on a fuel cell producing 10,000 kWh per year, using natural gas as fuel and a fuel cell running at 40% efficiency. The 10,000 kWh translates into 34,130 cubic feet of natural gas per year. When the 40% efficiency is factored in, the volume increases to 85,325 cubic feet per year. This translates into 2416 m^3/ year. This number is less than the average amount of natural gas being consumed per year (2500 m^3/ year). Since the volumes are comparable, fuel cells could be run on natural gas through fuel lines that already exist in many homes.

An added benefit of this is that if a fuel cell cogeneration unit is used, the natural gas used to run the fuel cell will also provide heat, which can be used as space heat, or to heat water. From a convenience point of view, this could eliminate the need for several appliances including a water heater and a furnace.

Even if the piping was not previously installed, it can still prove to be worth the effort of installing. Currently, natural gas providers have protocols in place for installing new lines in areas that meet certain criteria. [Progress Energy, Check List for Natural Gas Installation] An example of a qualifying area would be a residential neighborhood that had agreed to install natural gas systems in their homes if the natural gas company paid for the line installation.

Fueling Stations

If hydrogen is to be used, it can be hazardous to store in a large quantity, unsightly if stored in large tanks, and difficult and expensive to pipe to a residence. Hydrogen fueling stations are becoming available, however. At 16 sites in the U.S., mostly located in CA, hydrogen fuel is beginning to be sold, or in the planning stages for no later than a 2004 opening date. Most of these stations deliver liquid or compressed hydrogen [Breakthrough Technologies Institute/Fuel Cells 2000, Worldwide Hydrogen Fueling Stations]. Liquid Hydrogen weighs 70.8 kg (156 lbs.) per cubic meter. A one cubic meter fuel tank would hold 264 gallons. At previously calculated consumption rates, a one cubic meter tank would need to be refilled 11 times a year. A more portable

40 pound tank could hold approximately 10 gallons of fuel. This would require the consumer to refill a tank 286 times per year. This frequency is much too high, a larger tank is necessary. The limiting factor here is weight. If the weight is too high, the tank is no longer portable. An empty 50 gallon tank weighs 150 pounds [Sunshine Propane, *Tanks*]. This size tank is borderline portable. When full, the tank would weigh 550 pounds. At this volume, the tank would need to be refilled around 57 times per year or approximately once a week. Even if fueling stations are readily available, this process and frequency of refueling is borderline prohibitive when it is compared to existing fueling station standards like portable propane. Some suggestions to alleviate this problem are: the design of lighter fuel tanks, or the purchase of multiple tanks of smaller size.

If a consumer uses multiple tanks, it will allow them more time in between trips to the refueling station. If a consumer had three 50 gallon tanks, then they would have to make 20 visits to the refueling station each year. This frequency, again, as long as fueling stations are readily available, does not seem prohibitive when it is compared to existing fueling station standards like portable propane tanks.

Convenience Summary

Obviously, the maintenance and convenience of a fuel cell system directly depends on the method of fueling one has chosen for their system. The problem boils down to an issue of installation convenience versus maintenance and fueling convenience. The most convenient method would be to have the system preinstalled with an outside line feeding gas directly into the fuel cell. There would be no need for unsightly tanks and no worry of running out of fuel. This method can also be the most complex solution because, unless proper fuel lines already exist, it requires pipes to be placed between a fuel source and the customer.

The next most convenient method for fueling ones fuel cell would be the use of a storage tank and delivery system. This method would require the user to call a fueling service approximately twice a year to have their tank refueled. It also requires customers to have a fuel tank installed on their property.

The storage tank and delivery method can be further broken down into another problem: the size of the tank versus the inconvenience of refueling. Obviously, the larger the storage tank, the less frequent it needs to be refilled. If the tank it too large, it can take up excessive space in a consumers house or yard. A sufficiently large 500 gallon storage tank is a medium sized tank that will only require refueling every 3 months.

The convenience of this method of fueling is heavily dependent on the existence of fuel providers. If there were many fuel providers, it would be more convenient for a user to fill their tank, allowing them to do it more often with minimal effort. This would allow users to purchase a smaller tank. This situation would be epitomized by the realization of fueling stations, which would be similar to current gas stations, throughout the country.

If the fuel provider locations were sparse, users might need larger tanks because it may become inconvenient to have to call a company and schedule an appointment too often. An example of this would be a state regulated provider that required a months notice before they would give a refill, similar to today's cable companies. Overall, this method of fueling would be easy to install, and moderately easy to maintain. Requiring action by the user every 3 months to have it filled.

Finally, the least convenient solution would be for consumers to use portable fuel cell tanks. This method requires users to bring their tanks to fueling stations to have the refilled. This method requires dedication by the user because one would need to refill ones tanks every two weeks. This method is very convenient to install, very difficult to maintain.

Overall, the first two methods are comparable to the maintenance already performed by many energy customers. People already get heating oil delivered to their homes and have natural gas line installed in their yards. Modifying these actions to work with fuel cells would take a lot of effort to initially set up, but minimal effort to maintain, once the proper commercial support was laid out. The third method is inconvenient when compared to the first two. The only driving forces behind this method could have a lower cost and could be more readily available.

Money numbers

How much will this cost?

There are two cost associated with distributed residential fuel cell systems, the initial installation cost and maintenance and fueling costs. Initially, a consumer should expect to pay around $2,000 per kW of power that the fuel cell is expected to supply. The installation cost of a new power system will vary a great deal, depending on the residence in which it is installed. This variation is caused by different types of fuel cell systems that could be used in different types of residences.

The most cost effective solution is available to residences already using natural gas. Since the natural gas fuel line is already installed into the house, the only initial cost is the price of the fuel cell. For this type of system, the initial cost would be $10,000.

On average, natural gas will be consumed at 85,325 cubic feet per year (2416 m^3 per year). Natural gas is available at approximately $0.26 per cubic meter [Energy Shop, *Natural Gas Buying Group*]. This translates into a monthly fuel cost of approximately

$52.35 for natural gas use.

The method of using a storage tank to hold large amounts of fuel has some installation costs associated with it. This method of storage could be used store liquid hydrogen or propane. An above ground, 1000 gallon tank would cost approximately $1900 after installation. A 1000 gallon tank would cost $3000 to be installed underground [Sunshine Propane, *Tanks*]. This would bring the initial cost of a storage tank system up to $13,000.

On average, hydrogen will be consumed at around 2,844 gallons per year. The price of liquid hydrogen is estimated at $13 per million BTU [The Phoenix Project, Hydrogen Production]. This translates into about $0.26 per gallon, leading to a monthly cost of $61.62 for liquid hydrogen use. Propane would be consumed at approximately 5,202 gallons per year and costs approximately $0.72 per gallon, leading to a monthly cost of $312.12 for propane use [Energy Information Administration, Average Residential Propane Prices].

How much will one save?

The monetary cost of operating a fuel cell system can easily be compared to the monetary cost of using a traditional grid system. In order to properly compare the two methods, one must consider both the initial installation cost along with the monthly cost for power or fuel for each of the two power systems.

The homeowner does not incur any capital costs for power production when using existing grid power. Upon moving into a house, power is automatically provided by existing connection to the power grid infrastructure. All the capital costs of the power utility, as well as the cost of fuel and maintenance are included in the one bill the homeowner receives each month. A homeowner who wishes to switch to a distributed residential fuel cell system must cover the cost of purchasing a new fuel cell. The initial investment required for a residential fuel cell is $10,000. As far as initial cost goes, the grid cost far less money.

The cost of producing energy after purchase and installation should be less, due to the higher efficiency of the unit. The amount of money spent each month on grid power varies with location. Average electricity costs in Kentucky were 4.1 cents per kilowatt-hour during 2001, the lowest in the United States. This is less than half the cost of Massachusetts and California where costs were 10.8 cents per kWh and 9.6 cents per kWh respectively. Since the national average consumption of electricity was around 10,000 kWh per year, the price of a year's worth of power would be $410 in Kentucky, $1080 in Massachusetts and $960 in California. Using distributed natural gas powered fuel cell; the same amount of energy would have cost $628 to generate. In Massachusetts and California, the savings would be $452 and $332 respectively.

Further savings can be gained through the use of cogeneration. A homeowner will save money on power, as well as on hot water or space heat if cogeneration is employed. Cogeneration can reduce energy bills by 30% to 50% [Flexible Energy Inc, Why Cogeneration?]. This savings is achieved by extracting the energy out of the fuel at an extremely high, 85% efficiency. The extra 45% of energy that is extracted from the fuel is transformed into heat that can be used to heat water and air. In a residence generating 10,000 kWh per year, a cogeneration system will provide an extra 38,396,250 BTUs for heating water or air. This extra energy translates into approximately $600 in water heating savings [Union Gas, Residential Cost Comparisons].

The most cost effective approach for a distributed residential fuel cell system would be to have a system that takes advantage of cogeneration and is fueled by natural gas. After an initial investment of $10,000, over the course of a year, there will be a savings of up to $452 in electricity bills and a potential $600 savings in water heating bills. This annual savings of $1052 would allow a fuel cell to pay for itself after 9.5 years.

Time-Cost Analysis

In addition to monetary considerations, several other factors must be taken into account for a true evaluation of a power generation system. Some of these factors include: the life span of the generation device, maintenance and the fuel requirements of the system, the system's convenience and reliability, the peace of mind gained from using a particular system, the salvage value of a system and the existing legislation that affects the system. A thorough evaluation of this system, over time, must include all of these in order to be valid.

Life Span

The life-span of a fuel cell is important to consider in the analysis of continued maintenance and replacement costs. However, since proton exchange membrane fuel-cells are such a young technology, it is uncertain what the average life-span is. Several sources have offered widely disparate estimates for stationary continuous operation PEM fuel cells, from 40,000 hours (just over four and a half years) to twenty years. Natural gas turbines tend to have a lifespan ranging from 40,000 hours (4.5 years) to 60,000 hours (6.8 years). If an assumption of a six year life-span is made, we can compare a PEM fuel cell to a natural gas combustion generator with a similar life-span. Power from the utilities has no lifespan, as long as the structure of power remains the same as it is now.

Maintenance Cost

Fuel cell maintenance includes the cost of repairs when the cell malfunctions. Fuel cells should require much less maintenance than combustion engines and turbines because they have no moving parts, so all wear on the cell is chemical degradation. Over time this may wear out the membrane of a PEM fuel cell, and the electrolyte in some cells may need to be changed. Beyond this, the components of a fuel cell are durable, and will withstand more wear than a comparably sized engine or turbine. This factor leads to fewer repairs than on a car engine. However, when compared with grid power, which requires no consumer repairs, maintenance becomes an issue and an added expense. A reasonable estimate for fuel cell maintenance over the life of the fuel cell will be assumed to be $500 per year.

Salvage

If a fuel cell cannot be repaired, it may still have some salvage value, which could go to pay part of the cost of a replacement. Almost all fuel cells contain a noble metal catalyst, such as platinum or palladium, which should return as much value as it had before use in the fuel, minus the cost of extricating it from the interior of the fuel cell. This cost analysis will not include a salvage term, since the actual numbers cannot be estimated at this time.

Legislation

Legislation is available to many consumers who wish to generate power from renewable sources. Tax breaks exist to relieve the burden of large price tags on fuel cell units. For this cost analysis, the $1,000 tax refund per kW of fuel cell, and the 1.8 cent tax break per kWh will be considered for estimation purposes.

Peace of Mind Benefit

Fuel cell power provides the homeowner control over household power. The owner of a fuel cell is given the responsibility to fuel and maintain a fuel cell unit, and in return give a sense of peace of mind which can be attributed to knowing that the power will only go out if the cell needs maintenance, in which case, the homeowner can choose the time of outage, and prepare for it. When a fuel cell is a source of backup power in a grid connected system, the homeowner need never suffer a power loss because when the fuel cell goes down the grid can be tapped until the fuel cell is operational again. Another source of peace of mind is knowing that fuel cells are not harming the environment as much as traditional power generators.

Analysis

The table below (Table 1) illustrates the costs and benefits of a natural gas fuel cell, versus the current price of utility provided grid power. Figures are based on an assumption of the requirement for a 5kW power source, at a consumption rate of 10,000 kWh per year. The analysis assumes that the time value cost of maintenance is offset by the time value of the peace of mind gained from operating an environmentally friendly system.

	Natural Gas Fuel Cell w/ cogeneration	Grid Power KY	MA	CA
Initial Cost	$10,000	0	0	0
Yearly Maintenance Cost	$500	0	0	0
Monthly Fuel Cost	$52.53	0	0	0
Monthly Charge	0	$34	$90	$80
Peace of Mind Benefit	$500	0	0	0
Initial Legislation Benefits	$5,000	0	0	0
Yearly Legislation Benefits	$180	0	0	0
Cogeneration Savings	$600	0	0	0
Total Cost; first year	$4,850	$410	$1080	$960
Total Cost; subsequent years	$30.36	$410	$1080	$960

Table 1 – Power generation time – cost analysis

According to this analysis, a distributed residential fuel cell that is powered by natural gas and takes advantage of cogeneration will pay for itself in approximately 3.6 years (in MA.). If cogeneration is not used, the cost analysis yields drastically different results. Without cogeneration it will take 9.7 (in MA.) years for the fuel cell to pay for itself.

Conclusions

While fuel cells are not the immediate solution for the entire nation's power, there are many areas in which they would be useful. Fuel cell systems become increasingly attractive in areas where the cost of utility power is unusually high. In Massachusetts, a, installed fuel cell system using cogeneration would pay for itself in 3.6 years. Since the expected life of the fuel cell is longer than this period, it can be considered a good investment.

The main deterrent of fuel cell systems is the initial cost. Government tax breaks and lower monthly costs make this initial cost less deterring. In addition to these monetary compensations, there are several other benefits of fuel cells. Increased power quality and reliability will attract people to fuel cells. The environmental factor also plays a role in motivating people to switch to this clean source of energy.

Fuel cell power is not as convenient as grid power, but it is not overly inconvenient. Maintaining and fueling a fuel cell would require a similar amount of effort as many of the existing energy sources.

With existing technology, fuel cells are beneficial in many areas throughout the country. Since the technology is expected to steadily improve, it is only a matter of time before fuel cells are incorporated into all aspects of power generation throughout the country.

References

Consumer Energy Council of America, *Distributed Energy, Chapter 4.*July 2001

American Petroleum Institute, *Heating Oil in the United States*, August 1998, http://www.api.org/pasp/pa016.pdf

Breakthrough Technologies Institute/Fuel Cells 2000, *Stationary Fuel Cells - Market Info*, 12/02/2000 http://www.fuelcells.org/StationaryMarket.pdf

Breakthrough Technologies Institute/Fuel Cells 2000, *Types of Fuel Cells,* Retrieved 04/13/2003 from http://www.fuelcells.org/fctypes.htm

Breakthrough Technologies Institute/Fuel Cells 2000, *What is a fuel cell,* Retrieved 04/10/2003 from http://www.fuelcells.org/whatis.htm

Breakthrough Technologies Institute/Fuel Cells 2000, *Worldwide Hydrogen Fueling Stations,* http://www.fuelcells.org/charts.htm#H2Stations

Buchman, Isidor. *Type of Fuel Cell,* 2001. http://www.buchmann.ca/Article1-page3.asp

Business Wire, *H Power and ECO Back Proposed Federal Tax Credit,* 03/28/2001 http://www.njpcgreens.org/hpower.html

California Energy Commission, *California Distributed Energy Resources Guide*, January 18, 2002;http://www.energy.ca.gov/distgen/background/background.html

California Hydrogen Business Council, *Industrial Hydrogen Production*, 03/01/1999 http://www.ch2bc.org/industrial.htm

California Stationary Fuel Cell Collaborative, *Strategic Plan*, April 2002 http://stationaryfuelcells.org/DOCUMENTS/PDFd%20docs/strategicplanPresentation.pdf

Charlotte Regional Partnership, *Power Costs*, retrieved 04/28/2003 http://www.charlotteusa.com/crp/exploreourregion/regionaldata/stanly/41.htm

Coleman, *Power out of Thin Air*, 2003; http://www.airgen.com/

Department of Defense, *Application Worksheet* 02/11/2003 http://www.dodfuelcell.com/Application_Worksheet.xls

Energy Information Administration, *Average Household Energy Consumption Has Declined by 27 Percent since 1978,* November 18, 1999; http://www.eia.doe.gov/neic/press/press142.html \

Energy Information Administration, *Average Residential Propane Prices, Nebraska,* 04/07/2003 http://www.state.ne.us/home/NEO/statshtml/86.html

Energy Information Association, *Electricity Costs*, retrieved 04/28/2003 http://www.coaleducation.org/Ky_Coal_Facts/electricity/average_cost.htm

Energy Information Administration, *Heating Oil use in American Household*, 03/17/2003 http://www.eia.doe.gov/emeu/consumptionbriefs/recs/heating_oil/heating_oil.html

Energy Information Administration, *Total Energy Consumption in US Households*, 1997 http://www.eia.doe.gov/emeu/recs/recs97_ce/t1_4c.html

Energy Shop, *Natural Gas Buying Group,* 2003. http://www.energyshop.com/cgi-bin/quotes/auction/2a_vol.cfm

EV World, *Advanced Electric Drive*, http://www.evworld.com/databases/storybuilder.cfm?storyid=502

Fix it Right, *Oil Tank Measurement Chart* http://fixitright.freeyellow.com/tank.htm

Flexible Energy Inc, *Why Cogeneration?*, retrieved 04/28/2003 http://www.flexibleenergy.com/html/cogen.html

Goldstein, Lawrence H. *Gas Turbines and Fuel Supply Pressure Requirements*, May 1996 http://www.nrel.gov/analysis/emaa/natural_gas/#II

Institute of Environmental Research and Education, *Energy Profile of Vashon-Maury Island* http://www.iere.org/documents/VashonEnergyProfile.pdf

Illinois Propane Gas Association, *BTU Content Comparison, 04/27/2003* http://www.ilpga.org/cons_comps.asp

Larson, John, B. *Larson Announces Support of Fuel Cell Tax Credit,* 09/29/2000 http://www.house.gov/larson/pr_000929.htm

Natural Life Magazine, *"Dirty" Hydrogen Could Foul Fuel Cell Potential,* 2003 http://www.life.ca/nl/73/hydrogen.html

New Rules Project, *Net Metering of Electricity* http://www.newrules.org/electricity/nmeter.html

Newell, Mark; Potter, Amanda. *Hydrogen Basics,* December 1992.
http://www.homepower.com/files/Hp32p42.pdf

Oregon Department of Revenue, *Residential Energy Tax Credit,* 12/09/2002 http://www.dor.state.or.us/InfoC/101-641.html

Phoenix Project, *Hydrogen Production*, Retrieved 04/26/2003. www.phoenixproject.net/hydrogen.pdf

Plug Power, *Advantages of Fuel Cells,* Retrieved xx/xx/xxxx http://www.plugpower.com/technology/benefits.cfm?vid=54366&liak=86232565

Praxair, *Hydrogen Goes High-Purity for Fuel Cells*, 2003. http://www.praxair.com/praxair.nsf

Progress Energy, *Check List for Natural Gas Installation,* 2003. http://www.ncng.com/account/help/faq/service.html

SERC, *Frequently Asked Questions about Fuel Cells,* December 16, 1999. http://www.humboldt.edu/~serc/faq.html

Smith; Van Ness; Abbott; *Chemical Engineering Thermodynamics*, Boston, McGraw-Hill, 2001.

Smithsonian Institution, *Future Fuel Cell History*, 2001 http://fuelcells.si.edu/future/furmain.htm

Southern California Gas Company, *Equipment and Technology,* 2002, http://www.socalgas.com/business/useful_innovations/microturbines_more.shtml

Sweeney, Daniel, *Regenerative Fuel Cells: Eliminating the Infrastructure Requirement*, 09/11/2002. http://www.tmcnet.com/enews/content/v091102.htm

Sunshine Propane, *Tanks,* Retrieved 04/27/2003. http://www.sunshinepropane.com/product_tanks.htm

Union Gas, Residential Cost Comparisons, retrieved 04/28/2003 http://www.uniongas.com/Residential/ResCostComp/CstCmpIndex.asp#

Union of Concerned Scientists, *Public Utility Regulatory Policy Act (PURPA)* 10/26/2002 http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=119

Union of Concerned Scientists, *Wind and Biomass Energy Tax Credit Saved – Again,* 10/29/2002 http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=121

United Press International, *Ferc Urges Requirement of Power Rtos*
http://www.electricityforum.com/news/dec01/ferc_rtos.htm

University of California at Berkeley, *Hydrogen Fuel Cells Raise Efficiency*
02/17/2003
http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0,1471,2527,00.html

UTC, *New York Power Authority to Install Eight UTC Fuel Cells PC25TM Power Plants at New York City Locations,* 12/19/2001.
http://www.utcfuelcells.com/news/archive/121901.shtml

XENERGY Inc. *Washington Adds Fuel Cells to Net-Metering,*
04/21/2000 http://www.xenergy.com/dp/v4.htm#Washington