STATIONARY FUEL CELLS: FUTURE PROMISE, CURRENT HYPE

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EXECUTIVE SUMMARY

Fuel cells have been promoted as the next technological leap in the area of power production. This technology offers the potential to replace traditional combustion-based electric-generating technologies in both mobile and stationary applications. Fuel cells can operate on any hydrogen-rich fuel, whether renewable or fossil. The emissions profile of the technology is very attractive. There are negligible sulfur and nitrogen emissions produced during operation. Fuel cells can offer reliable power for high-tech and high-security facilities. Fuel-cell-powered vehicles will eliminate many of the mobile-sourced air emissions problems that plague urban regions.

While fuel cells do hold much promise for providing clean and reliable power, the fact remains that they are still a developing technology with much room for improvement in both technical performance and cost. Furthermore, fuel cells are not an emissions-free technology. When the hydrogen to fuel them is obtained from fossil fuels, there are still significant carbon emissions. While the United States does not currently impose limits on carbon dioxide emissions (a significant contributor to global climate change), future limits on this pollutant may in fact make other electricity-generating technologies either as attractive or more attractive than fuel cells. In this report, our purpose is to fairly characterize fuel cell technologies. We present the benefits and disadvantages of this technology, the current and future market situation for fuel cells, and sample diffusion curves. We believe that fuel cells will play a significant part in the future distributed generation (DG) portfolio in the United States and worldwide, but will most likely be only one of many technologies that are employed in the generation of clean, efficient electricity and thermal energy.

A fuel cell is an electrochemical device in which a fuel reacts with an oxidant to directly produce electricity. A fuel cell consists of an electrolyte surrounded by two electrodes. Hydrogen is fed into the anode of the fuel cell. Oxygen or air enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits 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 to be reunited with the hydrogen and oxygen in a molecule of water. Individual fuel cells can be combined into a fuel cell stack.

A variety of fuels can be used for fuel cells. Pure hydrogen is the fuel of choice for nearly all designs currently under commercial development. For such fuel cell systems, another fuel can be used as a hydrogen carrier by reforming it in a device that is typically external to the fuel cell unit itself. A fuel cell system that includes a fuel reformer can utilize the hydrogen from any hydrocarbon fuel including natural gas, liquefied petroleum gas, gasoline, methane and landfill gas, and methanol. Since the fuel cells employ a chemical process instead of a combustion process, air emissions from this type of a system are typically much lower than those from various combustion technologies.

In this study, we focus on stationary applications that will serve the distributed generation market. In this market, there are four types of fuel cells that appear to have operational

profiles that match well with the electrical needs of the residential, commercial, and industrial sectors. Fuel cells will most likely supply end-use markets for several reasons. The small overall size and high cost of the systems make them a less suitable technology choice for supplying wholesale power. Stationary fuel cells also have a relatively long startup time and cannot be shut down easily once they have reached proper operating temperatures. This characteristic makes the technology most suitable for providing base-load power. An advantage of fuel cells is that they offer highly reliable power with minimal environmental footprint. In addition, the systems can be utilized for the generation of both power and process heat.

Fuel cell technologies are typically classified according to their electrolyte type. The following technologies have been selected for detailed analysis in this study based on several factors including their attractiveness to their particular customer segment, the amount of resources that have been devoted and will continue to be devoted to research and development (R&D) in their class, and their degree of commercialization.

- Polymer Electrolyte Membrane (PEM), also frequently referred to as "Proton Exchange Membrane" cells
- Phosphoric Acid Fuel Cell (PAFC)
- Solid Oxide Fuel Cell (SOFC)
- Molten Carbonate Fuel Cell (MCFC)

PEM fuel cells were chosen to be included in this study due to the high degree of research and investment in both the stationary and mobile markets by companies such as Ballard, GM, and Plug Power. PAFCs were the only commercially available fuel cells, and have the most logged operating hours of any type of fuel cell. The systems have been successfully used for several years. Unfortunately, PAFCs are no longer being sold. Their manufacturer, UTC, has decided to concentrate on similarly sized PEM cells for this market. SOFCs have been demonstrated by Siemens Power Technologies and Fuel Cell Technologies, Ltd. MCFCs are perhaps in the earliest stages of development of all the technologies described in this study, but because of their great potential for offering high-quality power and heat in the over 1 megawatt (MW) size range, they were included in the study. We have chosen to not include alkaline fuel cells for analysis. While this technology has been utilized successfully in aerospace applications, it does not seem to have great potential for stationary applications. Few manufacturers are exploring alkaline fuel cells for this market.

An assortment of technical problems and costs issues related to market entry and expansion remain for fuel cell manufacturers. The problems can be mainly attributed to three areas:

- *Stack Life:* Typical stack lives of 7 years have been reported by several fuel cell stack developers (Kreutz and Ogden 2000). This issue is particularly problematic for PEM cells whose reported stack lives do not exceed 10,000 hours (and no more than 5 years in typical residential applications). For stationary residential applications, the stack life should be guaranteed for 50,000 hours in order to gain a significant market share (Lenssen and Reuter 2001).

- *Fuel Reformers*: The cost of fuel reformers continues to be a barrier to creating economically attractive fuel cell systems. The efficiency of a fuel reformer is generally around 75%. This in and of itself is not particularly distressing, but when combined with the efficiency of the fuel cell stack, the overall system efficiency can sometimes falls below 40% (a level much below what many engines and especially engine cogenerating systems can reach).
- *Power Electronics and Overall System Integration*: Overall integration of the reformer, fuel cell stack, and backend power electronics has not been optimized. Also, estimated lifetimes for overall systems have yet to be proven. Furthermore, inverters and other power electronic components remain significant costs in the overall fuel cell system, and must still be reduced in order to gain market acceptance.
- *Broader Market Barriers*: These include market awareness, infrastructure, market/regulatory treatment for low emission systems, interconnection or other hassle costs, etc.

In order for fuel cells to become widely adopted, they will have to be competitive with other DG technologies in their same size range. Fuel cells already have attractive nitrous oxide (NO_x) and sulfur dioxide (SO_x) emissions characteristics. In order to truly compete with other DG technologies, they will have to come closer in equipment life, cost, and supply and service infrastructure. Table ES-1 lists current cost characteristics for fuel cells.

Table ES-1: Fuel Cell Costs

Technology	2003 Installation Cost ($/kW)	Operating and Maintenance Costs ($/kW/yr)
5–10 kW PEM	$5,500	$71
200 kW PAFC	$4,500	$81
200 kW PEM (estimated)	$4,500	$81
200–250 kW SOFC	$3,500	$84
250–2,000 kW MCFC	$2,800	$96

Fuel cells are not currently cost-effective when compared with other generation technologies, both renewable and fossil based. Equity research from CIBC World Markets indicates that manufacturers need to at least triple or quadruple their production capacity by year-end 2004 in order to bring the selling price of units down to the $1,500–2,000/kW range. This would be a steep ramp-up in production, but not one that is impossible. Market penetration in the near future will be heavily dependent on programmatic intervention from federal and state agencies.

The eligible market base for technical potential far exceeds the current manufacturing capacity of fuel cells. The production of the membrane cells remains both expensive and technically difficult, as the membranes foul easily. Because of this, the early year projections (2003–2007) typically reflect the rate at which manufacturers can produce the product. Later year projections follow a typical technology diffusion curve. Strictly speaking, close to 100% of the small-scale (under 1 MW) DG market could technically be served by fuel cells. There is not nearly enough manufacturing capacity (nor will there be for at least 10 years) to serve this market. The authors determined that the technical potential, in the early years of this study, will be limited by manufacturers' ability to bring products to market. This limitation is evident in all of the technology potential descriptions presented in the following section.

The technical potential in the 10–20 year timeframe will most likely not be constrained by this limitation. We believe that fuel cells will compete technically with primarily non-renewable technologies such as natural-gas engines and turbines. Because fuel cells offer the added advantage of being able to provide hot water and steam as well as electricity, we have determined that this technology will be able to meet a portion of the combined heat and power (CHP) market in the commercial and industrial (C&I) sectors. We have employed an aggressive diffusion curve to describe the growth in the technical market between 2003 and 2022 (Table ES-2). We predict that the growth in the beginning years will be fast (in many cases doubling or tripling each year), but that since the current manufacturing capacity is still low, the total technical potential remains rather small until 2012. We assume that the production barriers will begin to disappear within 10 years and that technical potential will be able to mirror that of the overall CHP market in the various size ranges from 2012 to 2022.

Table ES-2: Technical Potential for Fuel Cells by Technology Type

Potential Capacity	5–10 kW PEM (kW)	200 kW PEM (kW)	200–250 kW SOFC (kW)	250–2,000 kW MCFC (kW)
2003	6,891	80,120	20,000	51,875
2007	11,518	166,138	117,644	192,801
2012	87,464	1,261,608	892,951	1,464,108
2022	847,693	4,896,875	5,594,602	15,028,614

We believe that fuel cells will play a significant part in the future DG portfolio in the United States and worldwide, but will most likely be one of many technologies that is employed in the generation of clean, efficient electricity and thermal energy. It is evident that several things must occur in order for fuel cells to really take hold in the market:

1. Government-supported R&D
2. Government-supported near-term markets
3. Continued decline in the cost of fuel cells
4. Market conditions continuing to drive DG demand

Assuming that all of these events continue to take place within the next 10–15 year timeframe, it is reasonable to expect commercially viable fuel cells for each fuel cell technology type at that point.

INTRODUCTION

According to the U.S. Department of Energy (DOE), distributed power is modular electric generation or storage located near the point of use. Distributed generation systems include fuel cells, biomass-based generators, combustion turbines, solar power and photovoltaic systems, wind turbines, microturbines, engines/generator sets, and storage and control technologies. Fuel cells and other distributed energy technologies provide benefits that are not available from centralized electricity generation. Fuel cell technologies can be located close to the point of electricity use, thus avoiding transmission and distribution (T&D) losses and constraints of the electrical grid. While most DG typically relies on natural gas, diesel, or renewable resources, the technologies can offer a greater deal of fuel flexibility. The generators can also be quieter, more efficient, and less polluting than traditional central-station electricity generators.

Fuel cells and other distributed resources can either be grid connected or operate independently of the grid. Those connected to the grid are typically interfaced at the distribution system. In contrast to large, central-station power plants, distributed power systems typically range from less than a kilowatt to tens of megawatts in size (DOE 2002). Distributed energy resources are playing an increasingly important role in the nation's energy portfolio. They can be used to meet base-load power, peaking power, backup power, remote power, and power quality, as well as cooling and heating needs.

Fuel cells have been promoted as the next technological leap in the area of power production. This technology offers the potential to replace traditional combustion-based electric-generating technologies in both mobile and stationary applications. Fuel cells can operate on any hydrogen-rich fuel, whether renewable or fossil. The emissions profile of the technology is very attractive. There are negligible sulfur and nitrogen emissions produced during operation. Fuel cells can offer reliable power for high-tech and high-security facilities. Fuel-cell-powered vehicles will eliminate many of the mobile-sourced air emissions problems that plague urban regions.

While fuel cells do hold much promise for providing clean and reliable power, the fact remains that they are still a developing technology with much room for improvement in both technical performance and cost. Furthermore, fuel cells are not an emissions-free technology. When the hydrogen to fuel them is obtained from fossil fuels, there are still significant carbon emissions. While the United States does not currently impose limits on carbon dioxide emissions (a significant contributor to global climate change), future limits on this pollutant may in fact make other electricity-generating technologies either as attractive or more attractive than fuel cells. In this report, our purpose is to fairly characterize fuel cell technologies. We present the benefits and disadvantages of this technology, the current and future market situation for fuel cells, and sample diffusion curves. We believe that fuel cells will play a significant part in the future DG portfolio in the United States and worldwide, but will most likely be one of many technologies that are employed in the generation of clean, efficient electricity and thermal energy.

Fuel Cells in a Distributed Generation Context

There are many advantages to employing DG technologies such as fuel cells. The average efficiency of U.S. electric generation has been stagnant since the 1960s at about 32%, while electric efficiencies of greater than 40% are being achieved today by fuel cells and other DG technologies (Shipley et al. 2001). When these technologies are operated with heat recovery, their efficiencies can approach 80% or more. By utilizing high-efficiency heat systems, we can extract a greater amount of the available energy from our natural resources. Increased fuel efficiency translates directly into reduced emissions of greenhouse gases (GHG) and other pollutants. By generating power at or near the site (which is why it's called distributed generation), DG helps avoid the construction of new central station power plants. DG capacity can be constructed more quickly than large central facilities, and additionally, thermal energy can be recovered to meet local demand.

Our current electricity supply infrastructure relies upon power plants located remotely from the centers of electricity load growth. U.S. transmission losses range from around 5% to near 20%, with the national average hovering near 10%. DG facilities are located near the source of demand and can eliminate this additional loss. It is becoming more difficult and costly to site new supply infrastructure due to congestion and opposition from neighbors to T&D lines and substations. Many people consider these facilities unsightly and potentially dangerous. The process to gain approval for the construction of these facilities can take years. In some areas, the T&D system is becoming overtaxed, leading to increased concerns about the reliability of electricity service, particularly during periods of peak demand. DG also alleviates this problem by locating the generation near the demand.

While DG technologies offer many advantages to conventional central-station generation, there are several significant disadvantages as well. While DG can be significantly more efficient than the national average for electricity generation, the proximity of the generation to workplaces and communities can result in increased air emissions closer to population centers. There have been many studies analyzing the health effects of exposure to pollutants from fossil fuels. While the health risk for clean and efficient technologies is small, it still must be taken into account when siting a DG facility. Noise is another disadvantage of DG. While the noise from a small generator may be relatively insignificant in an industrial facility, a similarly sized generator could be unbearably loud in a small commercial or residential setting.

Fuel cells hold particular promise for providing highly reliable electricity with very low air emissions in both stationary and mobile applications. Fuel cell systems currently under development have ranged in size from just a few Watts (suitable for providing power for portable electronic devices) to about 3 Megawatts (suitable for providing electrical power and thermal energy to an industrial manufacturing facility or large commercial building).

WHAT IS A FUEL CELL AND WHY DOES IT HOLD PROMISE FOR THE STATIONARY MARKET?

A fuel cell is an electrochemical device in which a fuel reacts with an oxidant to directly produce electricity. A fuel cell consists of an electrolyte surrounded by two electrodes. Hydrogen is fed into the anode of the fuel cell. Oxygen or air enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits 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 to be reunited with the hydrogen and oxygen in a molecule of water. Individual fuel cells can be combined into a fuel cell stack. The number of fuel cells in the stack determines the total voltage, and the surface area of each cell determines the total current. Multiplying the voltage by the current yields the total electrical power generated.

A variety of fuels can be used for fuel cells. Pure hydrogen is the fuel of choice for nearly all designs currently under commercial development. For such fuel cell systems, another fuel can be used as a hydrogen carrier by reforming it in a device that is typically external to the fuel cell unit itself. A fuel cell system that includes a fuel reformer can utilize the hydrogen from any hydrocarbon fuel including natural gas, liquefied petroleum gas, gasoline, methane and landfill gas, and methanol. Since the fuel cells employ a chemical process instead of a combustion process, air emissions from this type of a system are typically much lower than those from various combustion technologies.

In this study, we will be focusing on stationary applications that will serve the DG market. In this market, there are four types of fuel cells that appear to have operational profiles that match well with the electrical needs of the residential, commercial, and industrial sectors. Fuel cells will most likely supply end-use markets for several reasons. The small overall size and high cost of the systems make them a less suitable technology choice for supplying wholesale power. Stationary fuel cells also have a relatively long startup time and cannot be shut down easily once they have reached proper operating temperatures. This characteristic makes the technology most suitable for providing base-load power. An advantage of fuel cells is that they offer highly reliable power with minimal environmental footprint. In addition, the systems can be utilized for the generation of both power and process heat.

FUEL CELL TECHNOLOGY DESCRIPTION AND MARKET APPLICABILITY

Fuel cell technologies are typically classified according to their electrolyte type. The following technologies have been selected for detailed analysis in this study based on several factors, including their attractiveness to their particular customer segment, the amount of resources that have been devoted and will continue to be devoted to research and development in their class, and their degree of commercialization.

- Polymer Electrolyte Membrane, also frequently referred to as “Proton Exchange Membrane” cells
- Phosphoric Acid Fuel Cell

- Solid Oxide Fuel Cell
- Molten Carbonate Fuel Cell

PEM fuel cells were chosen to be included in this study due to the high degree of research and investment in both the stationary and mobile markets by companies such as Ballard, GM, and Plug Power. PAFCs were the only commercially available fuel cells, and have the most logged operating hours of any type of fuel cell. The systems have been successfully used for several years. Unfortunately, PAFCs are no longer being sold. Their manufacturer, UTC, has decided to concentrate on similarly sized PEM cells for this market. SOFCs have been demonstrated by Siemens Power Technologies and Fuel Cell Technologies, Ltd. MCFCs are perhaps in the earliest stages of development of all the technologies described below, but because of their great potential to offer high-quality power and heat in the over 1 MW size range, they were included in this study. We have chosen to not include alkaline fuel cells for analysis. While this technology has been utilized successfully in aerospace applications, it does not seem to have great potential for stationary applications. Few manufacturers are exploring alkaline fuel cells.

In the technology descriptions that follow, we match the types to various market segments where we believe they will be most attractive, based on their operating and performance characteristics. Other fuel cell technology and scale combinations that are not included in this section may very will succeed in the marketplace, but due to resource restrictions in the study, we have chosen to select what we believe will be the most successful technology scale combinations in the United States (based on its residential, industrial, and commercial mix).

Polymer Electrolyte Membrane Fuel Cell: 5–10 kW

This technology will most likely arise as the dominant technology for the residential and small commercial sectors. As shown in Table 1, the operating temperatures for PEM cells are low (under 200°F/93°C) and they can be used with or without heat recovery. The temperatures would allow for residential-grade water heating, but are too low for producing high-quality steam. Several manufacturers have introduced demonstration and field trial units with this technology in this size. The primary fuel for residential PEM fuel cells will be natural gas. The technical market will therefore be constrained by the location and availability of natural gas service. Early market reports indicate that the adopters of residential fuel cells will be high-end new construction single-family residences. Most of these types of residences are built in areas with natural gas service. GE Fuel Cell Systems (a joint venture between General Electric Distributed Power and Plug Power) has been the leader in the development of residential PEM systems. Other developers have included H Power and Ballard.

Table 1: PEM Fuel Cells, 5–10 kW

Operating Temperature (°F)	150
Package Cost ($/kW)	4,700
Installed Cost ($/kW)	5,500
O&M Costs ($/kW)	0.03
Electrical Efficiency (HHV)	30%
CHP Efficiency (HHV)	68%
Commercialization Status	Pre-commercial/demonstration

Phosphoric Acid Fuel Cell and Polymer Electrolyte Fuel Cell: 200 kW

This technology has been utilized in the only commercialized fuel cell product to date. The technology was first introduced into the commercial market by International Fuel Cells/ONSI (now called UTC Fuel Cells), and has over 200 installed units worldwide (including Times Square and the Central Park Police Station). This technology lends itself to commercial and small industrial applications, and is a good candidate for CHP (see Table 2). The technology remains expensive relative to other DG technologies, but running the units with heat recovery makes the economics more favorable. The initial market for PAFCs has typically been in high-value niche industries. Early adopters have included high-reliability and high-value applications such as the Bank of Omaha central credit card processing center. The technology is also attractive in situations were a minimal environmental footprint is desired, as was the case with the Central Park Police Station. The market will continue to grow in these niche areas before the technology is adopted by a broader audience.

United Technologies Corporation (UTC), the developer of the PAFC, has stopped taking orders for this technology. The company has decided to pursue the development of PEM fuel cells in this size range. Operating and cost characteristics for these units are not yet available. It is expected that the 200 kW PEM units will have similar efficiencies and operating characteristics to the smaller PEM cells and will initially cost approximately the same as the PAFC units for this size class.

PEMs of this size may begin to lose favor, however, when overall fuel cell costs begin to come down due to their lower overall electrical efficiencies (30–40% compared to 40–50% for SOFCs and MCFCs). PEMs and PAFCs also require a fuel reformer to extract hydrogen from a hydrocarbon fuel, whereas some of the higher temperature technologies such as SOFC and MCFC do not require this extra fuel treatment.

Table 2: Phosphoric Acid Fuel Cells and Polymer Electrolyte Fuel Cells, 200 kW

	PAFC	PEM (estimated)
Operating Temperature (°F)	400	150
Package Cost ($/kW)	3,500	3,500
Installed Cost ($/kW)	4,500	4,500
O&M Costs ($/kW)	0.03	0.03
Electrical Efficiency (HHV)	36%	30%
CHP Efficiency (HHV)	75%	68%
Commercialization Status	Commercially available	Pre-commercial/ demonstration

Solid Oxide Fuel Cell: 200-250 kW

SOFCs in this size range will compete with the formerly commercialized PAFCs and pre-commercial PEMs in the commercial and small industrial market. SOFCs will be used in facilities with high heating loads such as Internet data centers and industrial manufacturing facilities. This technology can be operated at high enough temperatures (~1,750°F) to eliminate the use of a fuel reformer (see Table 3). This may eventually give SOFCs a competitive advantage over PEMs of similar size. Developers of this technology include

Siemens Power Generation and Fuel Cell Technologies, Ltd. Mass manufacturing of SOFC technology remains difficult due to the susceptibility of the fuel cell membranes to fouling by sulfur and other contaminants. The higher operating temperatures and higher electrical efficiency (40–50%) of SOFCs will make them an attractive electricity- and heat-generating option once initial manufacturing difficulties are overcome.

Table 3: Solid Oxide Fuel Cells, 200–250 kW

Operating Temperature (°F)	1,750
Package Cost ($/kW)	2,850
Installed Cost ($/kW)	3,500
O&M Costs ($/kW)	0.10
Electrical Efficiency (HHV)	45%
CHP Efficiency (HHV)	70%
Commercialization Status	Pre-commercial/demonstration

Molten Carbonate Fuel Cell: 250–2,000 kW

This technology is attractive because it does not require a fuel reformer. Direct fuel cells can be operated on many types of hydrogen-rich fuel. The direct fuel cell systems operate at higher temperatures than many technologies—this makes the technology an excellent candidate for heat recovery and steam generation in industrial applications (see Table 4). MCFCs will primarily take hold in the industrial and large commercial building. This technology is currently in field trials. Fuel Cell Energy Corp. is the primary developer. MCFCs have been plagued with similar manufacturing difficulties as SOFCs. The larger proposed unit size, however, makes this fuel cell attractive to industrial customers in high-value markets. Initial markets for MCFCs include the biotechnology and pharmaceutical industries.

Table 4: Molten Carbonate Fuel Cells, 250–2,000 kW

	250 kW	2,000 kW
Operating Temperature (°F)	1,200	1200
Package Cost ($/kW)	4,350	2,400
Installed Cost ($/kW)	5,000	2,800
O&M Costs ($/kW)	0.04	0.03
Electrical Efficiency (HHV)	43%	46%
CHP Efficiency (HHV)	65%	70%
Commercialization Status	Pre-commercial/demonstration	

Technologies and Size Ranges Not Selected for Full Analysis in this Study

Technologies in addition to those described above may very will succeed in the marketplace, but due to the study's resource restrictions, we have chosen to concentrate on what we believe will be the most successful technology scale combinations in most applications. A brief summary of some alternative technologies is included below, including sample technical potential diffusion curves based on several market factors.

Alkaline: 10–100 kW

While this technology has been utilized successfully in aerospace applications, it does not seem to have great potential for stationary applications. Few manufacturers are exploring alkaline fuel cells.

Proton Exchange Membrane: 0.025–0.5 kW

This size range is most applicable to residential backup applications. This market is very small, and the high costs of these systems would prohibit their penetration into all but the smallest high-end residential customer segment.

Solid Oxide: 5–10 kW

This size class is most suited to residential and small commercial customers. The high operating temperatures of these cells would require heat recovery to be viable. The majority of residential and small commercial customers do not have appropriate heat requirements to allow this technology to be operated optimally.

Manufacturing Service Infrastructure

In the past, the demand for fuel cells had been greater than national manufacturing capacity. This is beginning to change as capacity increases while installation costs remain high (Satyapal 2002). The production of the membrane cells remains both expensive and technically difficult, as the membranes foul easily. Because of this, the early year projections (2003–2007) typically reflect the rate at which manufacturers can produce the product. Equity research from CIBC World Markets indicates that manufacturers need to at least triple or quadruple their production capacity by year-end 2004 in order to bring the selling price of units down to the $1,500–2,000/kW range (Mogil 2002). This would be a steep ramp-up in production, but not one that is impossible.

Sales, Service, and Installation Infrastructure

Expertise and working relationships between the developers, industrial energy managers, environmental permitting offices, and construction staff have already started to be developed. The United States is likely to rely on existing engineering and C&I electrical heating, ventilating, and air conditioning (HVAC) firms for expertise in the short term.

Many fuel cell companies have forged strategic alliances with automotive and DG technology companies. The fuel cell developers hope to capitalize on the relationships that these more established companies have with their customers in order to introduce them to fuel cell technology.

PATHWAY TO COMMERCIALIZATION

Fuel cells, like many revolutionary technologies will likely follow an S-shaped market diffusion curve. The growth in the market will be slow for a period of years until the point where the technology becomes more cost effective, or other market forces propel it forward. In the paragraphs below, we describe sample technical potentials for the various fuel cell technologies on which we've concentrated.

HOW DO FUEL CELLS COMPARE WITH OTHER DG TECHNOLOGIES?

In order for fuel cells to become widely adopted, they will have to be competitive with other DG technologies in their same size range. Fuel cells already have attractive NO_x and SO_x emissions characteristics. In order to truly compete with other DG technologies, they will have to come closer in equipment life, cost, and supply and service infrastructure. Table 5 lists current characteristics for DG technologies in comparable size ranges. Fuel cells are approximately four times as expensive to install as the most commonly installed DG technology, the internal combustion engine. Fuel cells are also nearly twice the installed cost of microturbines, a technology to which they are frequently compared. A more detailed discussion of fuel cell costs and how they affect the commercialization of systems is included in "Cost and Related Information."

Table 5: Air Emissions and Cost Profiles of DG Technologies

	NO_x (lb/MWh)	SO_2 (lb/MWh)	PM-10 (lb/MWh)	CO_2 (lb/MWh)	Total Installation Cost ($/kW)
Gas-Fired Lean Burn IC Engine	2.2	0.006	0.03	1,108	~$800
3-Way Catalyst Gas-Fired Lean Burn IC Engine	0.5	0.007	0.03	1,376	~$1,000
Micro-Turbine	0.44	0.008	0.09	1,596	~$1,900
Small Turbine	1.15	0.008	0.08	1,494	~$1,600
Advanced Simple Cycle Turbine	0.32	0.006	0.07	1,154	TBD

Technical Market Barriers to Increased Demand

An assortment of technical problems and costs issues related to market entry and expansion remain for fuel cell manufacturers. The problems can be mainly attributed to three areas:

- *Stack Life:* Typical stack lives of 7 years have been reported by several fuel cell stack developers (Kreutz and Ogden 2000). This issue is particularly problematic for PEM cells whose reported stack lives do not exceed 10,000 hours (and no more than 5 years in typical residential applications). For stationary residential applications, the stack life should be guaranteed for 50,000 hours in order to gain a significant market share (Lenssen and Reuter 2001).
- *Fuel Reformers*: The cost of fuel reformers continues to be a barrier to creating economically attractive fuel cell systems. The efficiency of a fuel reformer is generally around 75%. This in and of itself is not particularly distressing, but when combined with the efficiency of the fuel cell stack, the overall system efficiency can sometimes falls

below 40% (a level much below what many engines and especially engine cogenerating systems can reach).

- *Power Electronics and Overall System Integration*: Overall integration of the reformer, fuel cell stack, and back-end power electronics has not been optimized. Also, estimated lifetimes for overall systems have yet to be proven. Furthermore, inverters and other power electronic components remain significant costs in the overall fuel cell system and must still be reduced in order to gain market acceptance.
- *Broader Market Barriers*: These include market awareness, infrastructure, market/regulatory treatment for low emission systems, interconnection or other hassle costs, etc. These barriers will be discussed further below.

REGULATORY, PERMITTING, AND SITING ISSUES

Potential Environmental Impacts

Fuel cells potentially could have the lowest level of air emissions of any fossil fuel-based electricity-generating technology. Because fuel cells do not involve the combustion of a fuel, the NO_x and SO_x emissions that typically are byproducts of electric-generating technologies are avoided. The types of air emissions are detailed in Table 6.

Types of Air Emissions

The volumetric criteria air pollutants of fuel cell systems are typically as follows (United Technologies Corporation, 2002):

$$NO_x = <1 \text{ ppm}$$
$$SO_2 = < 1 \text{ ppm}$$
$$CO_2 = < 2 \text{ ppm}$$

These volumetric emissions rates do not reflect the various efficiency levels of the fuel cell technologies included in this study. The table below takes the efficiencies of the various fuel cell technologies into account to estimate a real-world emissions rate on a lb/MWh output scale.

Table 6: Air Emissions Profiles of Fuel Cells by Type

	PEM	PAFC	SOFC	MCFC
NO_x (lb/MWh)	0.06	0.03	0.01	0.05
SO_2 (lb/MWh)	TBD	0.006	0.005	TBD
PM-10 (lb/MWh)	TBD	0	0	TBD
CO_2 (lb/MWh)	1,360	1,078	950	~900

Source: Bluestein 2002

Regulatory Barriers to Installation of Fuel Cell Systems

Fuel cell systems are highly efficient and reliable, and offer some flexibility in fuel selection. Most stationary fuel cell systems will be installed with heat recovery for the creation of hot water or steam. A combined heat and power fuel cell system offers the inherent environmental benefits of fuel cells along with much higher overall efficiencies by utilizing more of the useable output of the system. Modeling analysis has demonstrated that clean CHP technologies such as fuel cells have significant air emissions, transmission, and price benefits (Morris 2001). Despite these benefits, fuel cell CHP remains an underutilized technology hindered by a number of disincentives. These barriers can be summarized as:

- complicated permitting systems that are complex, time consuming, and varied;
- regulations that do not account accurately for the overall system efficiency of fuel cell CHP or credit displaced emissions and grid losses;
- difficult and frequently prohibitive interconnection arrangements with utilities; and
- depreciation schedules that do not reflect the true life of fuel cells and other CHP assets (Elliott and Spurr 1999).

One of the greatest barriers to the installation of fuel cell and other DG systems is the complicated and lengthy plant siting and permitting process. In NO_x and ozone environmental quality non-attainment areas, major new emission sources are required to meet New Source Review (NSR) requirements to obtain operating and construction permits. The NSR sets stringent emission rates for criteria pollutants and requires the installation of the best available control technology. New sources are also required to offset existing emissions in non-attainment areas. However, current emissions standards are generally based on fuel input, an approach that does not recognize the fuel efficiency of CHP. Moreover, non-uniform interconnection standards and unfair utility tariffs inhibit the installation of fuel cells and other DG resources. The following paragraphs outline some of the strategies that can be employed on the state level to help make CHP an attractive option.

Output–Based Regulations

Current air regulations do not take into account the increased efficiency benefits that occur when heat is recovered in a generation system. Creating output-based standards for pollutants (in pounds per megawatt-hour [lbs/MWh] output or equivalent unit) for emissions would allow fuel cells and fuel cell CHP to take credit for this increased fuel utilization (and subsequently lower carbon emissions). The creation of output-based standards is key in encouraging the adoption of the cleanest and most efficient electricity generation technologies. Several states have prepared rules for the adoption of output-based standards. For example, Massachusetts restructuring legislation directs the Department of Environmental Protection (DEP) to develop an output-based standard for any pollutant determined to be of concern to public health and also to implement at least one standard by May 2003 (Massachusetts Department of Environmental Protection 1999). In a related effort, the Northeast States for Coordinated Air Use Management (NESCAUM) has devised a model Emission Performance Standard rule, on an output basis, for its member states (Northeast States for Coordinated Air Use Management 1999).

When devising output-based standards, it is important to understand the importance of system efficiency and the value of thermal energy. There have been many debates over the value of recovered heat in a fuel cell CHP system. It is difficult to imagine process steam or heated water output as being of the same value as electricity. However, one must consider how process heat is obtained in separate heat and power arrangements. In typical industrial settings, boilers fueled by natural gas, fuel oil, or coal are required to provide steam and hot water needs. The combustion of a fuel to produce this heat has its own set of thermal losses and emissions. These losses are in addition to the losses and emissions inherent to the grid-supplied electricity that must be purchased from the local utility. The value of heat must be considered in comparison to how it is obtained in a standard situation.

While many regulators and energy experts consider fuel cell CHP to be primarily an electricity-generating technology, it is important to understand that C&I operators frequently think of CHP as a heat-generating technology with the added benefit of onsite power production. Therefore, while thermal energy may be considered to be lower quality (based on its difficulty in being converted to other forms of energy) than electricity, it is nonetheless highly valued in both industrial and commercial settings. In fuel cell systems, the increased fuel utilization is of even higher importance than in most CHP technologies. Fuel utilization helps to lower the overall costs of the fuel cell system.

COST AND RELATED INFORMATION

Table 7 below lists current cost characteristics for fuel cells.

Table 7: Fuel Cell Costs

Technology	2003 Installation Cost ($/kW)	Operating and Maintenance Costs ($/kW/yr)
5–10 kW PEM	$5,500	$71
200 kW PAFC	$4,500	$81
200 kW PEM (estimated)	$4,500	$81
200–250 kW SOFC	$3,500	$84
250–2,000 kW MCFC	$2,800	$96

Fuel cells are not currently cost-effective when compared with other generation technologies, both renewable and fossil-based. As was stated earlier, manufacturers need to at least triple or quadruple their production capacity by year-end 2004 in order to bring the selling price of units down to the $1,500–2,000/kW range. Market penetration in the near future will be heavily dependent on programmatic intervention from federal and state agencies. These initiatives are discussed in the sections "Various Proposals for Federal Government Intervention" and "State Initiatives."

Most manufacturers agree that as the number of fuel cell systems installed increases, the cost of the systems will decline. If a progress ratio of 85% is assumed, then it would require a six-fold increase in installed capacity in order to bring fuel cell technologies to the $1,500–2,000/kW level. (The progress ratio is the rate of cost decline with each doubling of cumulative capacity.) An 85% progress ratio is very aggressive and may not hold true for fuel cells, especially considering the very early stages of commercialization for most fuel cell technologies. However, if this progress ratio does hold true, Table 8 shows the estimated price per kW that would result with a six-fold increase in installed capacity.

Table 8: Possible Costs after Capacity Increases

Technology	Cost after Six-Fold Increase in Capacity
5–10 kW PEM	$2,074
200 kW PEM (estimated)	$1,697
200–250 kW SOFC	$1,320
250–2,000 kW MCFC	$1,056

It should be noted, however, that the Solid State Energy Conversion Alliance (SECA) has established a goal of creating a reliable fuel cell unit suitable for stationary or transportation applications by 2010 for $400/kW.

ESTIMATED TECHNICAL POTENTIAL

The eligible market base for technical potential far exceeds the current manufacturing capacity of fuel cells. The production of the membrane cells remains both expensive and technically difficult, as the membranes foul easily. Because of this, the early year projections (2003–2007) typically reflect the rate at which manufacturers can produce the product. Later year projections follow a typical technology diffusion curve.

The analysis described below is for a bounded technical potential. Strictly speaking, the potential of the small-scale (under 1 MW) distributed generation market that can technically be served by fuel cells is close to 100%. There is not nearly enough manufacturing capacity (nor will there be for at least 10 years) to serve this market. It was determined that the technical potential in the early years of this study will be limited by manufacturers' ability to bring products to market. This limitation is evident in all of the technology potential descriptions presented in the following section.

The technical potential in the 10–20 year timeframe will most likely not be constrained by this limitation. We believe that the fuel cells will compete technically with primarily non-renewable technologies such as natural gas engines and turbines. Because fuel cells offer the added advantage of being able to provide hot water and steam as well as electricity, we have determined that this technology will be able to meet a portion of the CHP market in the C&I sectors. We have employed an aggressive diffusion curve to describe the growth in the technical market between 2003 and 2022 (see Table 9). We predict that the growth in the beginning years will be fast (in many cases, doubling or tripling each year), but that since the manufacturing capacity is still low, the total technical potential remains rather small until 2012. We assume that the production barriers will begin to disappear within 10 years and that technical potential will be able to mirror that of the overall CHP market in the various size ranges from 2012 to 2022.

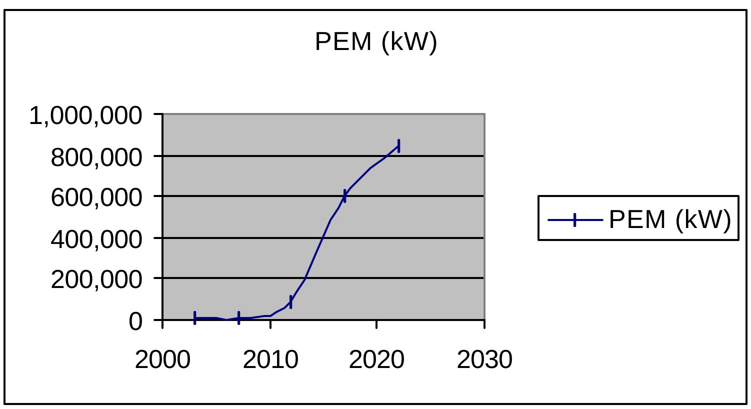
Table 9: Technical Potential for Fuel Cells by Technology Type

Potential Capacity	5-10 kW PEM (kW)	200 kW PEM (kW)	SOFC (kW)	MCFC (kW)
2003	6,891	80,120	20,000	51,875
2007	11,518	166,138	117,644	192,801
2012	87,464	1,261,608	892,951	1,464,108
2022	847,693	4,896,875	5,594,602	15,028,614

Polymer Electrolyte Membrane Fuel Cell: 5 –10 kW

The 2003 technical potential is based on an estimate of the 400 total reported North American installations as a share of the total annual production of 300 PEM fuel cells annually, as reported by Plug Power and Ballard (Mogil 2002). We estimated the 2007 technical potential by assuming a 100% annual increase in production of PEM fuel cells between 2003 and 2007; We estimated that the annual production would increase by 50% between 2007 and 2012 and 50% again between 2012 and 2017, and then slow down to a 5% increase from 2017 to 2022. The total electricity consumption estimates for PEM fuel cells are based on the residential kWh/kW ratio.

Technical Potential for Technology Type and Scale 5–10 kW PEM	Energy Generation 2003 (kW)	Energy Generation 2007 (kW)	Energy Generation 2012 (kW)	Energy Generation 2022 (kW)
USA	6,891	11,518	87,464	847,693

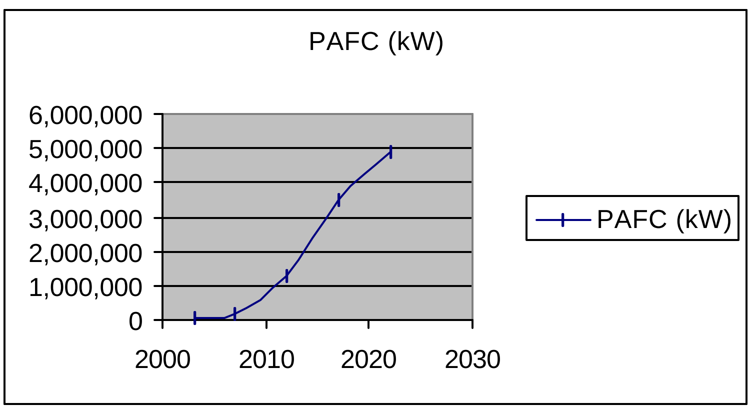


Polymer Electrolyte Membrane Fuel Cells: 200 kW

Annual production capacity of PAFCs in this size was approximately 200 units/yr. We assumed that because the PEM cells of this size will be serving the same market, the technical potential will be the same. Thus, the 2003 technical potential is 80,120 kW. We estimated the 2022 technical potential based on the 2002 commercial/institutional and industrial CHP potential increased by 12%[1] total to 2022 from the current technical market for units between 100–500 kW. We estimated a 20% market share by 2022. (This market share was based on the fact that PEM electrical efficiencies average from 30–40%, and can be under 30% when losses attributed to fuel reformer losses are taken into account. There are existing technologies with higher efficiencies and operating temperatures whose technical specifications make them more attractive to CHP applications than PEMs.) We estimated the annual growth rate to be 20% from 2003 to 2007 and 50% from 2007 to 2012. We estimated the kWh potential by assuming that units operate for 85% of the time (7,446 hours annually). This is a reasonable assumption for this type of DG unit operating in commercial or small industrial settings. The load profile is based on the national commercial buildings load profile. The capacity coincidence factors are estimates. PEMs will fulfill primarily base load electricity needs; however, we have assumed that the systems will sustain some unplanned outages.

While it is true that the relatively low temperature output of PEM fuel cells does not make them as favorable a candidate for CHP applications as the higher temperature fuel cell technologies, lower temperature heat recovery technologies are continuing to develop. We believe that these technologies will mature at a similar (if not faster) pace than fuel cells and will make the CHP market for PEM fuel cells more appealing.

Technical Potential for Technology Type and Scale 200 kW PEM	Energy Generation 2003 (kW)	Energy Generation 2007 (kW)	Energy Generation 2012 (kW)	Energy Generation 2022 (kW)
USA	80,120	166,138	1,261,608	4,896,875



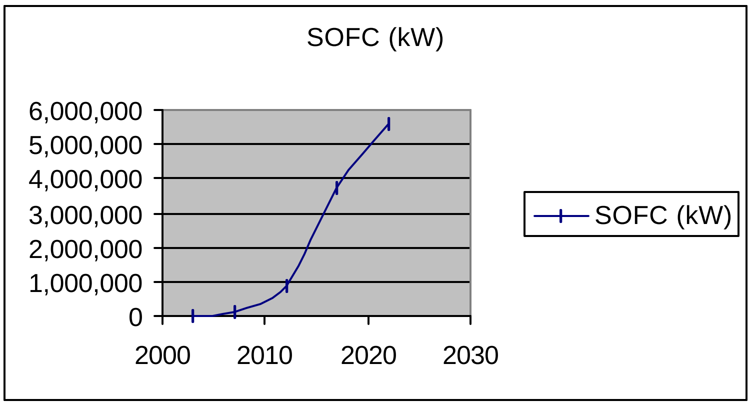
Solid Oxide Fuel Cells: 200–250 kW

The technical potential for 2003 is based on Siemens' estimate (Mogil 2002) of current manufacturing capacity at 20 MW/yr (Mogil 2002). We estimated the 2022 technical potential based on the 2002 commercial/institutional and industrial CHP potential increased by 12%[2] total to 2022 from the current technical market for units between 100–500 kW. We

[1] This is an estimate of the growth in buildings with operating hours >4,000 hrs/yr.
[2] This is an estimate of the growth in buildings with operating hours >4,000 hrs/yr.

estimated a 50% market share for 2022, and the annual growth rate for new capacity manufacture to be 50% from the current level for 2003 to 2007, and 50% again from 2007 to 2012. We estimated the kWh potential by assuming that units operate for 85% of the time (7,446 hours annually). This is a reasonable assumption for this type of DG unit operating in commercial or small industrial settings. The load profile is based on the national commercial buildings load profile. The capacity coincidence factors are estimates. SOFCs will fulfill primarily base load electricity needs; however, we have assumed that the systems will sustain some unplanned outages.

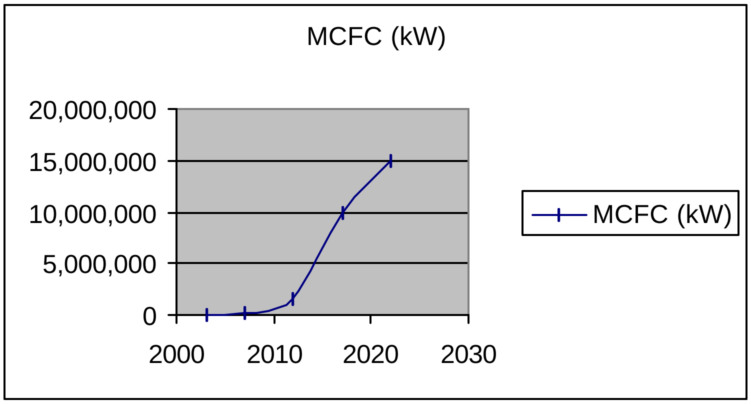
Technical Potential for Technology Type and Scale 200–250 kW SOFC	Energy Generation 2003 (kW)	Energy Generation 2007 (kW)	Energy Generation 2012 (kW)	Energy Generation 2022 (kW)
Statewide	20,000	117,644	892,951	5,594,602



Molten Carbonate Fuel Cells: 250-2,000 kW

The 2003 technical potential is based on a 100% share of Fuel Cell Energy's current annual capacity of 50 MW/yr. We estimated that this capacity will increase by 30%/yr until 2007 and that the market diffusion will increase 50%/yr between 2007 and 2012. Total industrial and commercial technological potential in the United States in 2022 is just over 15 GW (for units under 2 MW). We estimated that 40% of these sites will be amenable to MCFCs. We estimated the kWh potential by assuming that units operate for 85% of the time (7,446 hours annually). This is a reasonable assumption for this type of DG unit operating in industrial settings. The MCFC load profile is based on the load shape of the glass industry. This industry was chosen because it has a mix of continuous and batch processes that best describes industry as a whole. The capacity coincidence factors are estimates. MCFCs will fulfill primarily base load electricity needs; however, we have assumed that the systems will sustain some unplanned outages.

Technical Potential for Technology Type and Scale 250–2,000 kW MCFC	Energy Generation 2003 (kW)	Energy Generation 2007 (kW)	Energy Generation 2012 (kW)	Energy Generation 2022 (kW)
Statewide	51,875	192,801	1,464,108	15,028,614



MARKET DEVELOPMENT

In this section, we will discuss fuel cell markets and the pathway to fuel cell commercialization including technology diffusion, government initiatives, and other market issues.

Adoption into the Marketplace

Fuel cells have the potential to revolutionize the nation's energy and transportation infrastructure. Many "leap-frog" technologies have in the past been developed with intervention outside the private sector. An example of this type of intervention occurred with the commercialization of jet engines. Jet engines also contributed a major improvement in the generation of electricity in the form of stationary combustion turbines. The prevailing technologies had previously been mostly coal- and wood-fired boilers and internal combustion engines. The jet engine was first developed in the United States during World War II, but did not saturate the commercial airline industry until the late 1960s and early 1970s. The relatively rapid diffusion of the jet engine into the commercial airline industry can be attributed to three major factors (Mowery and Rosenberg 1981).

First, technological spillover allowed commercial producers to adapt the expensive jet technologies that were developed primarily for military purposes. Without having to heavily invest in the initial engine development, private producers could more easily create a profitable jet airbus for the commercial sector. Producers also received spillover technologies from the chemical, electronic, and materials industries. In many cases, these are the same industries that benefit from CHP applications.

Second, the government also affected the diffusion of the jet engine from the demand side. Not only did the military support the R&D of the jet program, its contracts with plane producers allowed companies to develop the capital equipment and production hardware needed for the production of military aircraft lines. These tools were then used again in the production of commercial aircraft.

Finally, the economics of the commercial airline industry dictated the rapid diffusion process. Economically, commercial jet planes flew at higher load factors than propeller models. In the regulated, fixed price environment of the time, it was far more profitable to fly jets. There were considerable demand-side advantages that drove the incorporation of jet engines. From a competitive standpoint, jet planes were more appealing to passengers. Jets proved to be not only much faster than props, but they produced a far more comfortable flying environment. These advantages were demanded by consumers. The airlines responded by ordering new jet fleets.

In many ways, this experience maps reasonably well into the experience associated with CHP systems and fuel cell technologies. For the diffusion of this technology to become more rapid, several things need to take place. First, government intervention in the form of R&D and commercialization assistance must be sustained. The technology itself must also continue to improve. The electrical output densities must increase such that the installation costs become more in line with current generation technologies.

Also, market conditions should drive the demand for fuel cells. In certain states such as Texas, there is an ever-increasing constraint on the T&D capacity of the electric grid. This creates an attractive market for DG and CHP technologies. As the cost of fuel cells decrease and their power output increases, constrained markets such as these will be attractive for further fuel cell commercialization. Moreover, the environmental cost of operating other fossil-based generation technologies must increase in order to create a more attractive market for fuel cells. This may begin to become more of a factor in parts of the country where NO_x emissions trading begins and in severe NO_x non-attainment areas such as the Houston-Galveston region.

Using the example of jet engine commercialization, it becomes evident that several things must occur in order for fuel cells to really take hold in the market.

1. Government-supported R&D
2. Government-supported near-term market
3. Continued decline in the cost of fuel cells
4. Market conditions continuing to drive DG demand

Various Proposals for Federal Government Intervention

The U.S. government has played a major role in the development of viable commercial fuel cells. The NASA space program was the initial commercial use of fuel cells. A number of other federal agencies have funded initiatives consistent with their mission, including the Departments of Defense, Transportation, Commerce, and Energy, and the Environmental Protection Agency. The Department of Defense has been the single largest purchaser of fuel cell cogeneration units, and has supported private purchases most years since 1994. The tax code includes incentives for the purchase of fuel cell vehicles and infrastructure, and significant new tax incentives are pending in Congress (Rose 2002).

In September 2002, a coalition of fuel cell and fuel cell infrastructure developers created a proposal for federal government intervention to broaden fuel cell markets (Rose 2002). The proposal called for comprehensive assistance to remove technical, regulatory, and market barriers. The proposal recommended government intervention in the following six areas: R&D, demonstrations and pilots, government purchasing, financial and non-financial market incentives, fair interconnection and siting standards and requirements, and education and outreach.

In 2003, DOE announced its "Climate Change Fuel Cell Buy-Down Program." The agency will issue grants to buy-down the cost of stationary fuel cell demonstrations. The aim is to buy-down the lesser of $1,000 per installed kW or one-third of the total project cost.

State Initiatives

Over twenty states offer additional financial incentives for fuel cells. The states are Arkansas, California, Connecticut, Hawaii, Illinois, Indiana, Kansas, Maryland, Massachusetts, Michigan, Montana, Nevada, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington (DSIRE 2003). A brief description of a few of the most aggressive programs is included below.

Connecticut has a Clean Energy Fund that is designed to promote the adoption of renewable energy and ultra-clean generation technologies. The Fuel Cell Initiative within this program includes educational, research, installation, and demonstration funding for fuel cells in industrial and building applications. In 2001, the fund provided $5 million for commercial demonstration and R&D projects. In 2002, the funding levels were increased to $8 million (Connecticut Clean Energy Fund 2003).

California operates a Self Generation Program that includes fuel cells in its portfolio. The program offers financial incentives to customers that install new, qualifying self-generation equipment installed to meet all or a portion of the electric energy needs of a facility. The program has an annual budget allocation of $125 million. For fuel cells operating on non-renewable fuel (such as natural gas) and utilizing heat recovery, a rebate of the lesser of $2.50/W or 40% of project cost is offered (CPUC 2002).

New Jersey (DSIRE 2003) has included fuel cells in its Renewable Portfolio Standard program. The standard mandates that by 2012, 4% of the kWhs sold in the state by each electric power supplier and each basic generation service provider shall be from Class I renewable energy sources (which includes fuel cells).

New York (DSIRE 2003) as one of the most favorable environments in the country for fuel cell adoption and has several initiatives underway that have resulted in the installation of fuel cells at various facilities in the state. The New York Energy $mart Distributed Generation and Combined Heat and Power Program has allocated $67 million to support the DG/CHP public benefits program between 2001 and 2006. The New York State Energy Research and Development Authority (NYSERDA) is administering a $6 million project (funded by the Clean Air/Clean Water Bond Act and Plug Power) to demonstrate fifty 7 kW PEM fuel cells at ten New York State-owned sites. Other anticipated NYSERDA projects include: installation and demonstration of a 250 kW fuel cell at Brookhaven National Laboratory on Long Island; implementation of test fuel cells at a remote telecommunications site with a 5 kW load; and a project by NYPA to install eight more 200 kW fuel cells at wastewater facilities in New York City at a cost of $14 million. Governor Pataki's Executive Order No. 111, issued in 2001, directs state agencies and other affected entities to seek to increase their purchase of energy generated from specific renewable technologies to meet 10% of their energy requirements by 2005, and to increase that share to 20% by 2010. The Green Buildings Tax Credit Law, enacted in May 2000, contains provision for fuel cells—the fuel cell component provides a 30% credit (6%/yr over 5 years) for the capitalized cost of each fuel cell. The fuel cell must be serving green space and must use a qualifying alternative energy source. There is a cap of $1,000/kW multiplied by the direct current (DC) rated capacity.

Current Investment Situation at Fuel Cell Companies

Companies who manufacture and develop stationary fuel cells are focusing on 2 main markets for the short term: premium power and residential. Most viable markets in the premium power sector are still developing. Fuel cells in this market are competing with more established technologies such as batteries and advanced uninteruptable power supply (UPS) systems. The high-security data market as well as the telecommunications sector is the area in which some progress has been made.

In the residential market, the 5–10 kW PEM fuel cell has seen the most promise. Several demonstration projects in the high-end residential market have proven to be technologically viable. PEM cells, however, have had difficulty reaching the level of 40,000 continuous operating hours that are deemed necessary for achieving success in the stationary market. Furthermore, the continued high costs of the systems will limit the technology to all but a few high-end residential segments.

The amount of investment into fuel cell development will contribute to the ultimate success or failure of this technology. The softening of technology stock prices in 2001 through 2002 has had a dampening influence on the advancement of fuel cell technologies. The overall investment retreat in the "tech" sector contributed to this phenomenon; however, it was also the broader realization that enterprises valued at 5 billion dollars or more (such as many fuel cell companies) should be generating higher revenues and profits than had been the case in the fuel cell companies (Primen 2001). Most fuel cell companies have also fallen behind on delivering fully commercialized products to market, with International Fuel Cell being the only company as of this date to succeed in this regard. Developers are still in the development phase, and this overall trend has remained unchanged for the past 2 years.

According to Primen, the revised commercialization schedules of many fuel cell developers still remain too optimistic. A historical perspective on how predictions made by fuel cell companies compare with reality helps justify this conclusion. For example, in early 1999 at least five PEM fuel cell companies (including Dais-Analytic, Energy Partners, H Power, IdaTech, and Plug Power) had plans to ship market-ready residential fuel cells in 2000 or early 2001 (Primen 2001). None of these companies has yet to deliver commercial-ready product as of this writing. Even mobile fuel cell developers and partners such as Daimler-Chrysler had made tentative commitments such as 100,000 fuel cell vehicles on the road by 2004. Currently, only Honda has released a limited-availability fuel cell vehicle for model year 2003–2004 in California (Kliesch 2003). Ford also released 15 vehicles for limited demonstration in 2002, a far cry from the earlier pronouncements (Ford Motor Company 2003). Furthermore, the vehicle will require difficult-to-come-by hydrogen as fuel.

Platinum

Back-end emissions control technologies for generators such as selective catalytic reduction employ platinum and/or palladium catalysts for reduction of various harmful oxides. EPA Tier II emissions standards will essentially make the use of this type of control mandatory for all fossil-fuel burning technologies. Gasoline vehicles already require platinum catalytic converters for control of tailpipe emissions as well. There has been a good deal of research and discussion on whether or not the continual increasing demand for precious metal catalysts will become a limiting factor in the commercialization of fuel cells.

According to the United States Geological Survey, the world reserves of platinum group metals are estimated to be 100 million kilograms (Tonn and Das 2001). The amount of platinum in fuel cells is steadily decreasing. According to DOE, current 50 kW fuel cell designs use approximately 100 grams of platinum as a catalyst, down from over 200 grams just a couple of years ago. DOE's long-term goal is 10 grams of platinum per 50 kW fuel cell (DOE 2000). Under favorable conditions for platinum and palladium supplies, including low catalyst requirements, low population growth, low market penetration rates of both stationary and mobile fuel cells, and low growth in demand of developing nations, there will be no shortage of these metals before 2030. If, however, the demand for fuel cells is higher than anticipated, a shortage of metal catalysts as well as unreasonable high prices may result (Tonn and Das 2001).

Hydrogen Availability and Infrastructure

PEM fuel cells and PAFCs require pure hydrogen as a fuel. SOFCs and MCFCs can use an unreformed hydrocarbon fuel. In either case, availability of a hydrogen-rich fuel source such as natural gas at a site is required. For stationary fuel cells, the issue of pure hydrogen availability is not as pressing as it is for the mobile market. Stationary fuel cell systems that require reformed fuel are sold and packaged with a reformer. These stationary systems do not have the size constraints inherent to mobile fuel cells and therefore can afford the space penalty of an onsite reformer. A hydrogen infrastructure is therefore not as pressing for the development of the stationary market.

There are inherent synergies between the mobile and stationary markets, however. Automotive companies have vast expertise in brining production costs down for new products as well as mass-producing products at minimal costs. It has been argued that a true expansion of the stationary fuel cell market will be closely tied to the commercialization of viable mobile technologies. Obviously, the availability of hydrogen for vehicular applications will become necessary for the expansion of the mobile market. The resulting hydrogen infrastructure would assist in the development of the stationary fuel cell market.

Natural Gas Constraints and Price Volatility

Over the last 3 years, a persistent pattern of volatile natural gas prices has emerged in U.S. markets. From wholesale price levels that were reliably in the $2–3 per thousand cubic feet (MCF) range, we now have prices that are running in the $5/MCF range and higher. These prices seem to stem from fundamental supply and market factors that do not show signs of abating:

- Natural gas is the fuel of choice for electricity generation (including fuel cells), home heating, commercial food service, and a growing number of industrial boilers and processes. This creates continuing demand pressure on the market.
- Domestic production has been limited by diminishing production from established fields, and technical and cost challenges in developing new fields. Most new capacity requires deeper wells or deeper ocean drilling, both of which drive up production costs.
- Limits on pipeline capacities and routings also constrain the availability of gas in some regional markets.
- Imports, such as liquefied natural gas (LNG), are expensive, and terminal facilities and tankers are limited. So we can't as easily turn to gas imports the way we have with oil, where foreign producers are often less expensive than domestic supplies, and shipping systems are better established.
- Price volatility has become a persistent problem in all the unregulated energy markets: oil, gas, and electricity. Because prices fluctuate so much, it is more difficult to justify capital investments in new drilling equipment, exploration, new power plants, and other supply projects.

Energy price volatility discourages investment in DG and efficiency projects, because price uncertainty makes it difficult to predict the economic return on the investment. In the late 1970s and early 1980s, energy prices were high and rising, and forecasts showed prices rising steadily into the future. Several energy service companies, who then financed projects on long-term cash flow based on rising energy prices, went out of business. Some CHP projects have recently shut down because they are no longer cost effective as a result of the increases in natural gas prices. While the cost of the fuel is a rather small part of the installation and maintenance cost of operating a fuel cell, the issue of price volatility may discourage interest in operating DG systems in general.

CONCLUSIONS

Fuel cells have been promoted as the next technological leap in the area of power production. This technology offers the potential to replace traditional combustion-based electric-generating technologies in both mobile and stationary applications. Fuel cells can operate on any hydrogen-rich fuel, whether renewable or fossil. The emissions profile of the technology is very attractive. There are negligible sulfur and nitrogen emissions produced during operation. Fuel cells can offer reliable power for high-tech and high-security facilities. Fuel-cell-powered vehicles will eliminate many of the mobile-sourced air emissions problems that plague urban regions.

While fuel cells do hold much promise for providing clean and reliable power, the fact remains that they are still a developing technology with much room for improvement in both technical performance and cost. Furthermore, fuel cells are not an emissions-free technology. When the hydrogen to fuel them is obtained from fossil fuels, there are still significant carbon emissions. While the United States does not currently impose limits on carbon dioxide emissions (a significant contributor to global climate change), future limits on this pollutant may in fact make other electricity-generating technologies either as attractive or more attractive than fuel cells.

In this report, we sought to fairly characterize fuel cell technologies. We presented the benefits and disadvantages, the current and future market situation, and sample diffusion curves. We believe that fuel cells will play a significant part in the future DG portfolio in the United States and worldwide, but will most likely be one of many technologies that is employed in the generation of clean, efficient electricity and thermal energy. It is evident that the following things must occur in order for fuel cells to really take hold in the market.

1. Government-supported R&D
2. Government-supported near-term markets
3. Continued decline in the cost of fuel cells
4. Market conditions continuing to drive DG demand

Assuming that all of these events continue to take place within the next 10–15 years, it is reasonable to expect commercially viable fuel cells for each fuel cell technology type discussed.

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