# Fuel Cells and CHP: An Industrial Market Status Report

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**ABSTRACT**

Fuel cells have been touted as one of the most reliable and environmentally sound methods of producing high-quality electricity for use in the industrial sector. Fuel cell developers are racing to produce larger quantities of fuel cells at lower prices. While the power densities of fuel cell stacks have been increasing, fuel cell technologies have unfortunately remained uneconomical for the majority of industrial customers. The growth of the fuel cell market has not increased at the rate at which developers and marketers would like us to believe. With stricter federal air regulations coming into effect in 2007 and more urban/industrial areas falling into non-attainment for pollutants such as nitrous oxides, operators of distributed generation systems may begin to consider fuel cells a more viable option.

In this paper we will explore the potential of various fuel cell technologies for providing onsite generation and heat at industrial facilities. Our analysis will include brief technical descriptions of the various fuel cell technologies as well as a description of appropriate end-use applications for the various technologies. We will determine which technologies hold the most potential for providing reliable power and heat for processes as well as estimates of technically and economically feasible industrial fuel cell capacity between now and 2020. The manufacturing service infrastructure; technical and market barriers to increased demand; and regulatory, permitting, and siting issues will be explored. We will outline the various factors that play in the technical and economic diffusion and offer sample diffusion estimates for the various fuel cell technologies.

## Introduction

Fuel cells have in recent years been hyped as the solution to most of the energy and environment challenges facing the United States. President Bush made a major commitment to fuel cell technology in his 2003 State of the Union address, and reflected this commitment in his FY2004 budget request (White House 2003). While the promise of fuel cells is great, the near-term market reality is somewhat more limited. Fuel cells represent an attractive distributed generation (DG) technology, but will have to compete with other technologies on performance and price.

According to the U.S. Department of Energy (DOE), distributed power is modular electric generation or storage located near the point of use. DG 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. Distributed energy technologies provide benefits that are not available from centralized electricity generation. DG 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.

Distributed resources can either be connected to the grid or operate independently. 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 requirements, as well as cooling and heating needs.

### General Advantages and Disadvantages of DG

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 percent, while electric efficiencies of greater than 40 percent 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 percent 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, 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. Transmission losses range from around 5 to nearly 20 percent in the United States depending upon location and time, with the national average hovering around 10 percent. DG facilities located near the source of demand 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 alleviates this problem by locating the generation near the demand.

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 range 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 then each 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 then 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 devise that is typically external to the fuel cell unit itself. A fuel cell system, which includes a fuel reformer, can utilize the hydrogen from any hydrocarbon fuel including natural gas, liquefied petroleum gas, 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 paper, we will be focusing on stationary applications that will serve the DG market. Four types of fuel cells (polymer electrolyte membrane, phosphoric acid, solid oxide, and molten carbonate) appear to have operational profiles that match well with the electrical needs of the primary stationary markets: residential, commercial, and industrial sectors. Fuel cells are most likely to supply these end-use markets rather than centralized power generation 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 start-up 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. Fuel cells do, however, offer highly reliable power with a minimal environmental footprint. In addition, these systems generate both power and heat, and achieve the high efficiencies needed to make use of the 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 paper 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 (PEM)
- phosphoric acid fuel cell (PAFC)
- solid oxide fuel cell (SOFC)
- molten carbonate fuel cell (MCFC)

In the technology descriptions that follow, these are matched to the various market segments where 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. However, due to resource, we selected what we believe will be the most successful technology type and size combinations in the United States (based on its residential, industrial, and commercial mix).

**Polymer Electrolyte Membrane Fuel Cell (PEM): 5–10 kW**

This technology will most likely arise as the dominant technology for the residential and small commercial sectors. The operating temperatures for PEM cells are low (under 200°F/93°C), and can be used with or without heat recovery. The low 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 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, Inc.) has been the leader in the development of residential PEM systems. Other developers have included H Power and Ballard.

**Table 1. Polymer Electrolyte Membrane Fuel Cell**

| 5–10 kW PEM | |
|---|---|
| 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% |

Note: HHV = Higher Heating Value

**Phosphoric Acid Fuel Cell (PAFC): 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 Central Park Police Station). This technology lends itself to commercial and small industrial applications, and is a good candidate for combined heat and power (CHP). 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 New York Central Park Police Station. The market will continue to grow in these niche areas before being adopted by a broader audience. PAFCs may begin to lose favor, however, when overall fuel cell costs begin to come down due to their lower comparative electrical efficiencies (30–40 percent compared to 40–50 percent for SOFCs and MCFCs). PAFCs also require a fuel reformer to extract hydrogen from a hydrocarbon fuel, whereas some of the higher temperature technologies such as SOFCs and MCFCs do not require this extra fuel treatment.

**Table 2. Phosphoric Acid Fuel Cell**

| 200 kW PAFC | |
|---|---|
| Operating Temperature (°F) | 400 |
| Package Cost ($/kW) | 3,500 |
| Installed Cost ($/kW) | 4,500 |
| O&M Costs ($/kW) | 0.03 |
| Electrical Efficiency (HHV) | 36% |
| CHP Efficiency (HHV) | 75% |

**Solid Oxide Fuel Cell (SOFC): 200–250 kW**

Solid oxide fuel cells in this size range will compete with the currently commercialized PAFCs in the commercial and small industrial market. SOFCs will initially only 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. That may eventually give this technology a competitive advantage over PAFCs. 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 percent) of this type of fuel cell will make it an attractive electricity and heat-generating option once initial manufacturing difficulties are overcome.

**Table 3. Solid Oxide Fuel Cell**

| 200–250 kW SOFC | |
|---|---|
| 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% |

**Molten Carbonate Fuel Cell (MCFC): 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. The industrial and large commercial building market will be where this technology will primarily take hold. This technology is currently in field trials. Fuel Cell Energy Corp. is the primary developer of MCFCs. This technology has 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 Cell**

| 200–250 kW SOFC | 250 kW MCFC | 2,000 kW MCFC |
|---|---|---|
| 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% |

## Pathway to Commercialization: Technical Potential

As an emerging technology, there are limits to how quickly fuel cells can take their place in the market. The eligible market base for the technical potential of fuel cells far exceeds the current manufacturing capacity. 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) DG market that can technically be served by fuel cells is close to 100 percent. 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 technology diffusion, 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- to 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 ability 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 market in the commercial and industrial sectors. We have employed an aggressive diffusion curve to describe the growth in the technical market between 2003 and 2022. 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 5. Technical Potential for Fuel Cells by Technology Type**

| Potential Capacity | PEM (kW) | PAFC (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 |

## 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 nitrous oxide and sulfur oxide emissions characteristics. To truly compete with other DG technologies, fuel cells will have to come closer in equipment life, cost, and supply and service infrastructure. The following table lists current characteristics for DG technologies in comparable size ranges.

**Table 6. Air Emissions Profiles of DG Technologies**

| | $NO_x$ (lb/MWh) | $SO_2$ (lb/MWh) | PM-10 (lb/MWh) | $CO_2$ (lb/MWh) |
|---|---|---|---|---|
| Gas-Fired, Lean-Burn Internal Combustion Engine | 2.2 | 0.006 | 0.03 | 1,108 |
| 3-Way Catalyst, Gas-Fired, Lean-Burn Internal Combustion Engine | 0.5 | 0.007 | 0.03 | 1,376 |
| Micro-Turbine | 0.44 | 0.008 | 0.09 | 1,596 |
| Small Turbine | 1.15 | 0.008 | 0.08 | 1,494 |
| Advanced Simple Cycle Turbine | 0.32 | 0.006 | 0.07 | 1,154 |

## 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 the following 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 percent. 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 fall below 40 percent (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.

### Other Technical Issues: Platinum and Hydrogen

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 U.S. Geological Survey, the world reserves of platinum group metals are estimated at 100 million kilograms (USGS 2003). 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. 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 may result, as well as unreasonably high prices

In order for fuel cells to truly move forward into the market, an improved system of hydrogen infrastructure will have to be implemented. Methods for hydrogen delivery, storage, and fueling are under development, and will remain so for the next several decades.

## Potential Environmental Impacts

Fuel cells have the potential to 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 are typically by-products of electric generating technologies are avoided. The types of air emissions are detailed below.

### Types of Air Emissions

The volumetric criteria air pollutants of fuel cell systems are typically as follows (UTC 2002).

- $NO_x$: <1 parts per million
- $SO_2$: < 1 parts per million
- $CO_2$: < 2 parts per million

These volumetric emissions rates do not reflect the various efficiency levels of the fuel cell technologies included in this paper. The table below takes the efficiencies of the various fuel cell technologies into account to estimate a real-world emissions.

**Table 7. 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 CHP 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.
- 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 systems is the complicated and lengthy plant siting and permitting process. In nitrous oxide 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. 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 fuel cell 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 lb/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 absolutely key to 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, the Massachusetts restructuring legislation directs its 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 (MDEP 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 (NESCAUM 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 a separate heat and power arrangement. 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 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 industrial and commercial 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 of lower quality (based on the difficulty of converting it 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 most CHP technologies because of their high relative costs. Fuel utilization helps to lower the overall costs of the fuel cell system.

## Markets: 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 uninterruptible power supply (UPS) systems. The high-security data market and the telecommunications sector are the areas 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 investment situation at fuel cell developers 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 in the advancement of fuel cell technologies. The overall investment retreat in the “tech” sector contributed to this phenomenon. However, the broader realization was 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 (Lenssen and Reuter 2001). Most fuel cell companies have also fallen behind on delivering fully commercial 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.

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 (Lensen and Reuter 2001). None of these companies has yet to deliver commercial-ready product as of this writing in late 2002. 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 one company has plans to release a limited-availability fuel cell vehicle for model year 2003, a far cry from the earlier pronouncements. Furthermore, the vehicle will require difficult-to-come-by hydrogen as a fuel.

### Various Proposals for 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 2003).

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. The proposal called for comprehensive assistance to remove technical, regulatory, and market barriers. The proposal recommended government intervention in the following six areas: research and development; demonstrations and pilots; government purchasing; financial and non-financial market incentives; fair interconnection and siting standards and requirements; and education and outreach.

## Conclusions

Fuel cells hold great promise for providing clean, reliable power for both stationary and mobile applications. There remain, however, several key challenges to the commercialization of this technology. For the next 20 years, the market for stationary fuel cells will remain constrained by such issues as the high costs of producing fuel cell membranes, the precarious financial situation of many fuel cell development companies, and the relatively short lives of fuel cells (compared to other DG technologies). The continued interest of U.S. government will help buoy the investment in fuel cell development, but even with this intervention, fuel cell markets will develop slowly. For the short- to medium-term future, other DG technologies in addition to fuel cells should continue to be improved and pursued. Fuel cells for stationary applications should not yet be viewed as a panacea for the barriers that face DG technologies.

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