Fuel Cells: Technology, Status and Applications

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ABSTRACT

Fuel cells have been under development for terrestrial applications for over thirty years. Several manufacturers are offering products in different sizes for varying applications. While the current prices of most of the fuel cell offerings are uneconomically high, production increases will bring about a reduction in those prices. Therefore, now is the time to examine potential applications for fuel cells and begin the planning necessary to incorporate fuel cells into those applications.

The history of fuel cells, the several technologies involved and potential applications will be examined in this article. Estimates will also be made regarding price trends for the different types of fuel cells. Projections will be made as to the commercial availability of fuel cells from different developers.

HISTORY

Fuel cells have been around a long while—since 1839 when Sir William Grove discovered the concept in England. But the technology remained essentially a laboratory curiosity until NASA adopted fuel cells for use in space vehicles in the 1960s. Since then, many developers have been working on developing the technology for terrestrial application with the same operating characteristics as the space applications, but at more "down to earth" prices.

A fuel cell is an electrochemical electric generating device that converts the energy in a fuel directly into electric energy rather than requiring combustion of the fuel as in conventional electric generation. The fuel cell uses the same technology that your car battery uses, but it operates continuously as long as fuel is supplied and does not need to be recharged as the car battery does.

A fuel cell consists of three basic components, just like the car battery. Two electrodes—an anode and a cathode (positive and negative charged, just like the car battery)—and an electrolyte (a substance that causes the electrochemical reaction to take place) convert the hydrogen in a fuel and oxygen from the air into water vapor and an electric current. There are five basic types of fuel cells under development for earth bound use, each identified by its electrolyte. Each technology operates at a different temperature. Four of those technologies show economic promise for competitive terrestrial application.

FUEL CELL TYPES

The solid polymer fuel cell (or more commonly known as the PEM for Proton Exchange Membrane) uses a plastic material as an electrolyte and operates at around 200°F. This is the fuel cell that is being widely considered for automotive application. Vehicular applications will be economically available sometime after 2003 and stationary applications as residential sized fuel cells will be sold at competitive prices after 2004.

The phosphoric acid fuel cell (uses a blotter filled with phosphoric acid as an electrolyte) has been commercially available since 1992 and about 200 units have been sold. They have performed magnificently with very high reliability (over 90%), very quietly (many are installed at hospitals and hotels), with high efficiency (over 80% conversion efficiency as a cogeneration device) and with almost no emissions.

Carbonate fuel cells (using a carbonate salt impregnated ceramic matrix as electrolyte) were introduced into the market in 1999 with the first commercial design unit installed in 2000. These units operate at around 800°F and exhibit conversion efficiencies close to

50% for electric generation only and in the order of 85% as cogeneration devices. Early applications will also be special purpose uses, but with increased production volumes, the technology will become commercially price-competitive around 2004 or 2005. These units will be especially useful for industrial applications as well as hospitals, hotels, or any other place that requires electricity and heat (or cooling) around the clock.

Finally, the solid oxide fuel cell (a ceramic sandwich with an anode, electrolyte, and cathode all assembled together) will operate at temperatures exceeding 1000°F and provide efficiencies in the 45% to 50% range as electric generators. Because of the high operating temperatures, these fuel cells will make excellent cogeneration devices for industrial applications where high temperature steam is required. The solid oxide fuel cells will be commercially available, at competitive prices, in the 2005 to 2007 time frame.

A fifth type of fuel cell using an alkaline electrolyte has been widely used in the space program. This technology is very efficient and produces pure water as the only non-electrical discharge. However, pure hydrogen and oxygen are required and the CO_2 by-product of most fuel processing is poisonous to the electrolyte. Therefore, this type of fuel cell is not receiving much attention as a commercial device.

FUEL CELL ATTRIBUTES

First and foremost, fuel cells are the most efficient method for producing electric energy. Most conventional forms of electric generation operate with efficiencies less than 30% in the sized range of most fuel cells (smaller than 1000 kilowatts). On the other hand, fuel cell efficiencies begin at 35% for the least efficient, lowest temperature, smallest device and go up to 55% for the higher temperature, larger fuel cells. When fuel cells are combined with small combustion turbines in hybrid systems, efficiencies are expected to exceed 70%.

In addition to fuel cells being more efficient than other forms of generation, they maintain their high levels of efficiency over a wide operating range. Most fuel cells maintain their nominal efficiency (within about a 10% range) from about 50% of rated capacity to around 110% of capacity.

A second positive aspect of fuel cells is the absence of moving parts in the generation section of fuel cells. This lack of moving parts helps the device to achieve high efficiency and also reduces the number of components that require high levels of maintenance. And the absence of moving parts makes for much lower noise levels.

Finally, because fuel cells operate at temperatures below the NO_x formation temperature and therefore, discharge only water vapor and carbon dioxide, they are the most environmentally friendly electric generation devices. This environmental friendliness frequently reduces the complexity of the permitting process when siting fuel cell power plants and allow the unobtrusive siting of fuel cell power plants in industrial, commercial and residential locations. Several states have waived the environmental permitting process for fuel cell power plant installations.

These attributes make fuel cells the ideal generation device for dispersed applications. The remaining challenge is an economic one—production levels must be increased to reduce the unit cost so fuel cells can economically compete with other technologies.

TECHNOLOGICALLY SPECIFIC ATTRIBUTES

Solid Polymer (PEM) Fuel Cells

Solid polymer fuel cells operate in the 70° to 90°C range and are generally between 35% and 45% efficient. Because they require very pure hydrogen as a fuel, a high quality fuel processor is required to convert conventional fuels (natural gas, propane, methanol, or gasoline) into the necessary hydrogen for effective operation.

It is likely that PEM fuel cells will be commercially available for automotive application in late 2002 while stationary units for residential and commercial applications will be commercially available by 2003. Most developers have established mature commercial target prices for stationary fuel cells in the $1,500/kW range. PEM fuel cells are presently commercially available for very small-scale applications (>100 watts).

Phosphoric Acid Fuel Cells

The phosphoric acid fuel is the only one currently available in the kilowatt size range for commercial application. Since 1992, the

ONSI Corporation (now known as UTC Fuel Cells) has been marketing 200 kW fuel cells for niche applications and by the end of 2001, had sold over 200 units. The units have sold for $3,000 per kW, plus installation and have performed with very high reliability and availability.

The phosphoric acid fuel cell generally operates in the 40% to 45% range and at a temperature of 205°C. These units have all been sold as cogeneration units with the thermal energy used for laundry and other sanitary water purposes.

Carbonate Fuel Cells

Only one developer, Fuel Cell Energy Corporation, is currently developing this fuel cell type. This fuel cell was commercially available in 2001 and the target price at full production levels was $1,250 per kW installed.

Solid Oxide Fuel Cells

The solid oxide fuel cell is being developed by a number of developers and two configurations are being used. Siemens Westinghouse is developing a tubular form of fuel cell and this design has shown effectiveness and efficiency in long term tests. Other developers are developing a planar configuration with their cells being formed as circular disks with alternating cathodes, anodes and electrolytes interspersed with reactant distribution.

Solid oxide fuel cells are expected to become commercially available by about 2005 and are forecast to sell for approximately $1,500 per kW plus installation.

[In general, the various fuel cell technologies will be commercially available in the time frames mentioned above and at the costs referenced.]

APPLICATIONS

Fuel cells can almost be considered the universal dispersed generation technologies. Fuel cells are the cleanest, quietest, and most efficient form of generation available. However, they suffer one technological shortcoming that places a limit on their application—fuel cell power plants may not be as responsive to rapid, large magnitude loads changes as are rotating generation technologies. The fuel cell stack itself is capable of responding almost instantaneously to load changes, but fuel-processing equipment has an inertia inherent in its operation that frequently slows response.

Notwithstanding the above limitation, fuel cell applications are generally determined by:

- Electrical load size
- Electric load profile
- Thermal application

In summary, fuel cell applications can generally be considered as follows:

- **Residential**—PEM (alone or with battery storage)

- **Small Commercial with little thermal load** (storefront retail operations, professional offices, small dance studios) -PEM (alone or with battery storage)

- **Small Commercial with thermal requirement** (restaurants, small grocery stores and meat markets)—PEM with supplementary thermal production.

- **Large Commercial with limited hours of operation** (supermarkets, department stores, office structures, medical office buildings)—Phosphoric Acid or PEM, depending on size and thermal requirement.

- **Large Commercial with extended hours of operation**—(supermarkets, office structures, hotels, laboratories, health clubs/spas, health care facilities)—Phosphoric Acid or Carbonate, depending on size and thermal requirement.

- **Small Industrial with limited hours of operation**—Phosphoric Acid with supplementary thermal production or Carbonate, depending on size and thermal requirements.

- **Small Industrial with extended hours of operation**—Carbonate.

- **Large Industrial**—Carbonate or Solid Oxide, depending on size and thermal requirements.

- **Utility Applications**—Depending on application and size of load to be satisfied, most fuel cell technologies are applicable:
  - Power Quality Enhancement—Phosphoric Acid, Carbonate or Solid Oxide
  - Load Relief—Phosphoric Acid, Carbonate, or Solid Oxide if on the system lines. Any fuel cell technology if at a customer's site
  - Reliability Improvement—Carbonate or Solid Oxide

Proper fuel cell applications all require the standard economic and technical analysis. However, all of the benefits of fuel cells must be properly valued in any analysis conducted—environmental, efficiency, modularity, siteability, and ease of field construction.

SUMMARY AND CONCLUSIONS

All fuel cell technologies are on the threshold of commercial readiness. Fuel cells are available now for niche commercial and institutional applications. They will be available for larger commercial, institutional and small industrial applications within the next 12 to 18 months. Vehicular applications should arrive in the market within the next 18 to 24 months while residential size units will be economically available within the next 24 to 36 months.

All construction planning for projects to be completed within the next five years should include consideration of fuel cells for both primary and secondary energy supplies. All developers are now considering opportunities for early market opportunities.

References

Because the fuel cell industry is in such rapid transition, there are limited written references that are up to date. However, one basic reference that discusses all fuel cell technologies is:

Fuel Cells: A Handbook, 1994, US Department of Energy, Morgantown Energy Technology Center, Morgantown, West Virginia (an updated version is available on CD ROM from the Center)

A very effective and efficient on-line reference is Fuel Cells 2000. This non-profit educational activity seeks to promote the development, demonstration, and commercialization of fuel cells technologies and provides links to all significant fuel cell sites. It also provides regular news and technology updates.

ABOUT SES

Somerset Energy Services (SES) is a consulting firm dedicated to assisting with the commercialization of fuel cells and is available to provide assistance with fuel cell applications analysis and education. SES has over 20 years experience in the fuel cell industry, having been involved with developers of all major technologies. SES can be reached at 908-371-0987 for both voice and fax mail and e-mail at *SES371@aol.com*.

ABOUT THE AUTHOR

Arthur W. Quade completed a 35-year career with Public Service Electric and Gas Company (New Jersey) prior to starting his own consulting business. Some of his activities during that career involved a system-wide analysis on the impact of cogeneration/district heating in the cities served by PSE&G; managing two demonstrations of the IFC 40kW fuel cell; managing a demonstration of small engine-powered cogeneration machines for PSE&G; and conducting a business case related to possible investment by PSE&G of funds in fuel cell businesses.

In addition, Mr. Quade served as the utility's resident fuel cell expert based on over 20 years' experience on various EPRI and fuel cell developer advisory groups and internal corporate research efforts.

Following retirement in 1997, he formed Somerset Energy Services, a consultant firm devoted to aiding in the promotion and commercialization of fuel cells. Mr. Quade has been providing consulting services to several fuel cell developers as well as providing educational services relating to fuel cells to individual groups of potential users. In addition, Mr. Quade has been providing demand side management services to energy users in preparation for the future installation of fuel cell power plants.

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