Understanding Fuel Cell Technology and Broadband Properties

By Jennifer Gangi ■ *Fuel Cells 2000*

According to the press, government, industry and market analysts, fuel cells are on their way and the public had better get ready. In actuality, fuel cells are already here – commercially installed all over the world, and in numerous demonstration and test projects. In the next few years, consumers will see fuel cells in portable electronics, used as backup power sources, in stationary power products and buses, with passenger vehicles following suit soon after.

What is a Fuel Cell?

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

A fuel cell consists of two electrodes sandwiched around an electrolyte. Hydrogen is fed into the "anode" of the fuel cell. Oxygen (from the air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen 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, where they are reunited with the hydrogen and oxygen to form water molecules.

In principle, a fuel cell is similar to a battery, but a fuel cell does not run down, nor does it require recharging. What a fuel cell does require is a fuel. When a fuel cell system is equipped with a "fuel reformer," the fuel cell can utilize hydrogen from a number of hydrocarbon fuels including natural gas, methanol, propane, biomass, and gasoline. The emissions from reforming these various hydrocarbon fuels would still be cleaner than those from a combustion process. It is also possible to obtain hydrogen by separating water in an electrolyzer, or by extracting it from a compound that contains no carbon, such as ammonia or boron compounds.

The beauty of fuel cells is their versatility – since they are scalable, fuel cells can be stacked until the desired power output is reached. The voltage from a single cell is about 0.7 volts, just about enough for a light bulb. When the cells are stacked in a series, the operating voltage increases to 0.7 volts multiplied by the number of cells stacked. Fuel cells are being developed small enough for portable electronics such as cellular phones, laptop computers, and Personal Digital Assistants (PDAs), and large enough to provide quality stationary power to telecommunications relay towers, buildings, wastewater treatment plants, and the electric utility grid. Other applications include fuel cell powered bicycles, airplanes, locomotives, vacuum cleaners, boats – you name it. The possibilities are endless.

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Major Types of Fuel Cells

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

Phosphoric Acid – PAFC

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

Proton Exchange Membrane (or Polymer Electrolyte) – PEM

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

Solid Oxide – SOFC

This type of fuel cell could be used in big, high-power applications including industrial and large-scale central electricity generating stations. Some developers also see SOFC use in motor vehicles and are developing smaller fuel cell units for auxiliary power and even homes. A solid oxide system uses a hard ceramic material instead of a liquid electrolyte, allowing high operating temperatures.

Molten Carbonate – MCFC

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

Alkaline – AFC

Long used by NASA on space missions, these cells can achieve power generating efficiencies of up to 70 percent. They were used on the Apollo spacecraft to provide both electricity and drinking water.

Direct Methanol - DMFC

These cells are similar to the PEM cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. Many companies are testing miniature DMFCs for portable electronics.

Regenerative Fuel Cells – RFC

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

Zinc-Air Fuel Cells – ZAFC

In this fuel cell, zinc is consumed and releases electrons to drive a load, and oxygen from ambient air accepts electrons from the load. The overall chemical reaction produces zinc oxide. This is the same electrochemical process that occurs in primary zinc/air batteries such as the long-lasting alkaline batteries that consumers can purchase in local stores. However, in contrast to being discarded like a primary battery, the zinc fuel in a zinc/air fuel cell can be regenerated.

Fuel Cells Fit with Telecommunications

Fuel cells are an especially attractive energy source in the low power range, and the telecommunications industry is a perfect application to demonstrate their reliability and effectiveness. With the use of computers, the Internet, and communication networks steadily increasing, there comes a need for more reliable power than is available on the current electrical grid, and fuel cells have proven to be up to 99.999% (five nines) reliable. Fuel cells can replace batteries to provide power for 1kW to 5kW telecom sites without noise or emissions, and are durable, providing power in sites that are either hard to access or are subject to inclement weather. Such systems would be used to provide primary or backup power for telecom switch nodes, cell towers, and other electronic systems that would benefit from on-site, direct DC power supply. Many fuel cell companies are realizing this potential market and are teaming up with the major telecommunications players to test fuel cells in the field.

Verizon has teamed up with Nuvera Fuel Cells to successfully test a natural gas fuel cell powering a Verizon telecommunication system. This joint effort between Nuvera and Verizon, which will span a two-year period, includes the development, operation and evaluation of fuel cell powered demonstration units in the 5-kilowatt (kW)

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Fuel Cell Technology

With power outages, brownouts, and rising electricity and gas prices plaguing the country, distributed generation (DG) – power generation at the customer site that removes the primary reliance on the public grid – is on everyone's mind. This includes fuel cells as grid replacement/primary generation or for backup and remote power, so companies are working double time to produce a residential fuel cell system for homes and light commercial applications. According to Allied Business Intelligence Inc. (ABI), the current $40 million stationary fuel cell market will grow to more than $10 billion by 2010, and the overall fuel cell energy generating capacity will increase by a factor of 250, with global stationary fuel cell electricity generating capacity jumping to over 15,000 megawatts (MW) by 2011 from just 75 MW in 2001.

Fuel cells are ideal for power generation, either connected to the electric grid to provide supplemental power and backup assurance for critical areas, or installed as a grid-independent generator for on-site service in areas that are inaccessible by power lines. Since fuel cells operate silently, they reduce noise pollution as well as air pollution and the waste heat from a fuel cell can be used to provide hot water or space heating.

There are three main components in a residential fuel cell system - the hydrogen fuel reformer, the fuel cell stack and the power conditioner. Many of the prototypes being tested and demonstrated extract hydrogen from propane or natural gas. The fuel cell stack converts the hydrogen and oxygen from the air into electricity, water vapor and heat. The power conditioner then converts the electric DC current from the stack into AC current that many household appliances operate on. Fuel Cell Technologies Ltd. (FCT) estimates the expected pay back period on a residential fuel cell for a typical homeowner to be four years. The initial price per unit in low volume production will be approximately $1,500 per kW. Once high volume production begins, the price is expected to drop to $1,000 per kW, with the ultimate goal of getting costs below $500 per kW. Fuel cell developers are racing to reach these cost targets.

H Power is joining forces with energy companies all over the world, and has signed an $81 million contract with Energy Co-Opportunity (ECO), a consortium of rural electric cooperatives, to market its fuel cells exclusively through more than 900 cooperatives. ECO has agreed to buy 12,300 of H Power's 10kW fuel cells for $10,000 each, and installation began in the second half of 2001. The two companies are working to manufacture and ship units to power-starved California within the next several months, for about $8,000 per unit. Prices are expected to drop to between $3,000 and $4,000 in seven years.

Plug Power and GE MicroGen have joined to form GE Fuel Cell Systems, LLC, and are building a network of qualified regional distributors to market, install, and service their residential fuel cell. A public utility has already agreed to purchase 75 of Plug Power's first fuel cell systems, a $7 million agreement, commencing this summer. The HomeGen 7000 is capable of serving an entire household's energy needs. Several different commercial models are going to be introduced that can operate on natural gas, propane, or methanol and are expected to achieve 40% electrical efficiency. Excess heat generated by the fuel cell can be captured and used for hot water or heating, increasing overall efficiency to over 80%. GE has signed an exclusive distribution agreement with New Jersey Resources for deployment of the fuel cells in New Jersey and DTE Energy Technologies will distribute these units in Michigan, Illinois, Ohio and Indiana. KeySpan Technologies has signed on as well to purchase and test 30 fuel cells at selected locations in New York City and Long Island.

Global Thermoelectric Inc., a solid oxide fuel cell (SOFC) manufacturer, has developed a 2.3 kW residential fuel cell system that is designed to cover the base load of an average North American home. The first prototype, running on natural gas, has been delivered to Enbridge Inc., who will be testing the system to evaluate performance characteristics including heat recovery to meet residential hot water needs. The results of the testing will be incorporated into subsequent prototype designs.

Avista Labs has unveiled a prototype proton exchange membrane (PEM) fuel cell generator for residential and small commercial use. They are currently beta-testing their unit and plan on delivering a commercially viable product soon. Avista has eliminated many of the complex, expensive subsystem components-like pumps, compressors and purifiers of the traditional PEM fuel cell-and replaced them with one moving part: a high-efficiency fan. This scales down cost and repair, while

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range.

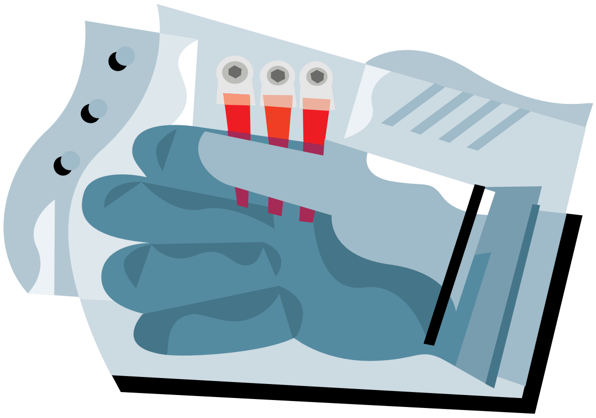
Hydrogenics Corporation has successfully tested a fuel cell at a cellular tower site provided by Nextel Communications. Hydrogenics installed the prototype HyUPS™ regenerative backup fuel cell power generator at the Nextel site in early July 2002, and subjected it to a rigorous test protocol over a two-month period. The test protocol was designed to simulate the profile of a full year's intermittent outages. The 25 kW, trailer-mounted, regenerative fuel cell was required to respond to simulated, as well as actual, power failures. During this testing period, the unit produced instantaneous power exceeding the quality characteristics of the local utility grid during each power outage.

Nextel Communications is also conducting extensive testing and evaluation of Metallic Power's zinc/air fuel cells as a backup power source for its cellular base stations. The fuel cells will offer 2.5 kW of backup power in a rack-mounted configuration that includes a 6-kW fuel tank to provide two to three hours of continuous backup under full load. The product can provide 24 to 72 hours of backup power for wireless and wireline communications infrastructure equipment. Metallic Power's zinc/air fuel cell automatically refuels (regenerates) itself with zinc fuel when utility power returns.

The Pennsylvania Department of Environmental Protection (DEP) purchased two 30-watt DCH Enable™ remote power systems to provide electricity to air quality sampling equipment, a data logger, and wireless communications equipment at two evaluation sites in the state. DEP will use the fuel cells to replace solar and battery-power systems currently used to power the equipment. The direct-hydrogen fuel cell systems are about the size of a large lunch box – small enough to remain out of view. They are inherently more robust than solar panels, and require significantly less maintenance than batteries. The fuel cells are designed to operate in an extended range of temperatures.

Other companies are working on fuel cells for telecommunications back up power as well. H Power has already sold fifteen 50-watt and one 100-watt evaluation fuel cell systems to a major Scandinavian energy company for remote telecommunications backup power applications.

Ballard Generation Systems is in the process of testing of its 10 kW natural gas fueled stationary fuel cell power generator. The unit is being designed for backup, light industrial and stand-



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increasing reliability.

IdaTech has demonstrated a 3 kW residential fuel cell system and has begun producing demo units for Bonneville Power. The methanol-powered system is about the size of a chest freezer and is expected to hit the commercial market in 2003.

UTC Fuel Cells (UTC) is developing PEM power plants running on propane and natural gas for homes and light commercial applications with a target date of 2003. UTC's stacks are modular and scalable, so when independent of the grid, multiple fuel cells can provide a high level of power reliability.

Many other companies are developing and testing fuel cells for residential applications, working together with utilities and distributors to bring them to market. Even automakers such as GM and Toyota are branching beyond vehicles and spending money on research and development for stationary applications.

To promote the commercialization of residential fuel cells, a bill proposing a stationary fuel cell tax credit has been introduced in both the House (H.R. 1275) and the Senate (S. 828), and referred to the Ways and Means Committee and the Finance Committees respectively. The bills would allow U.S. business and residential taxpayers that purchase fuel cell systems for stationary commercial and residential applications to be eligible for a $1000 per kW credit. It would be available for five years, until December 31, 2006, after which fuel cell manufacturers would be expected to produce a product at market entry cost. On top of that, many states have net metering laws in place today, which allow qualified customers to sell surplus electricity back to the grid, and heat produced from a fuel cell qualifies.

Fuel cells for residential applications are an appealing solution for all homeowners – suburbanites who need reliable, efficient and most importantly, inexpensive power; and rural dwellers who aren't connected to the utility grid. Within the next year or so, if the fuel cell companies have their way, fuel cells will not only become a household name, but part of the family.

by applications for telecom and other applications. Ballard has also joined with Coleman Powermate to develop portable and standby power products. As part of the collaboration, 50 prototype units will be developed.

Many technical and engineering challenges remain, and scientists and developers are hard at work on them. Fuel cells are still too expensive. One key reason is that not enough are being made to allow economies of scale. But once smaller fuel cells are introduced to consumers, it will help pave the way for fuel cell vehicles and residential/stationary applications. With more demonstrations, tests and partnerships between fuel cell and telecommunications companies, consumers will soon be dialing up to reliable and clean power all the time. ■

About the Author

Jennifer Gangi is Program Director with Fuel Cells 2000, a non-profit educational organization formed to promote the development and early commercialization of fuel cells and related pollution-free, efficient energy generation, storage and utilization technologies and fuels. The author may be reached with questions or comments via email at jennifer@fuelcells.org