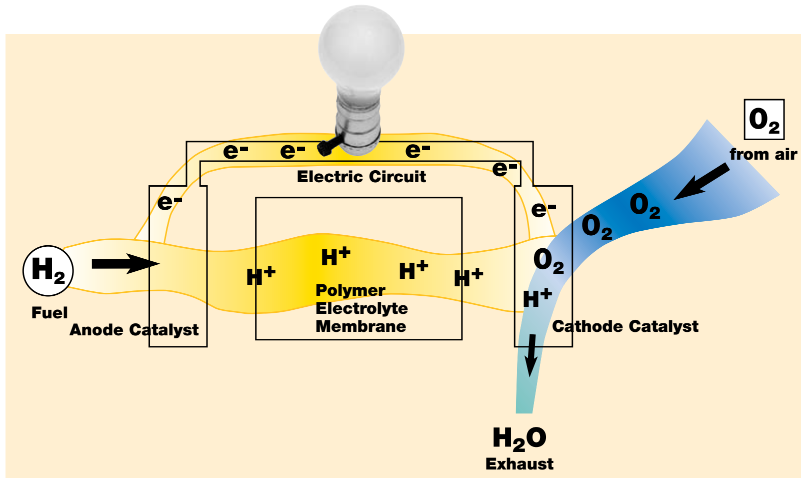
Energy Services FUEL CELL FACT SHEET

June 2006

Fuel cells promise clean, distributed generation

Versatile, energy-efficient and non-polluting, hydrogen fuel cells have the potential to revolutionize the way we power our nation. A fuel cell converts hydrogen, the most abundant element on earth, into electricity, and can be adapted to applications from powering laptop computers to vehicles to municipal power plants. And the only byproducts are heat and water, with practically no emissions.

A hydrogen fuel cell is a generator that produces electricity without combustion by combining hydrogen fuel with oxygen from air. It generates direct current like a battery but unlike a battery, it operates as long as it has fuel.



Converting the hydrogen "feedstock" directly into electricity without an intermediate combustion step makes fuel cells extremely efficient compared to internal combustion engines. The chemical process is also much cleaner than combustion, producing only water and heat. When the waste heat from a fuel cell is used to provide hot water or space heating, the efficiency of a unit increases to more than 80 percent.

Fuel cell modules can be installed as needed on sites without investing in large, remote powerplants or interconnecting to the grid. To increase the capacity of stationary sources, simply add more fuel cell modules. And, since there are few moving parts, fuel cells can be extremely quiet—an added benefit.

Fuel flexibility

The great thing about hydrogen is that it can be extracted from a wide variety of resources—water, methanol, ethanol, natural gas, gasoline or diesel fuel, ammonia or sodium borohydride—using a number of different technologies.

This fuel flexibility lends itself to energy diversity and the use of renewable energy. Solar, wind, hydro or geothermal energy can produce hydrogen from water. In fact, an electrolyzer/fuel cell system can function as a storage unit for intermittent sources, increasing their reliability and eliminating the need for extensive battery arrays. The electrolyzer uses energy from solar or wind units to split water into hydrogen and oxygen atoms. The hydrogen atoms can then be stored in tanks and used later in a fuel cell to produce clean, quiet power when the sun goes down or the wind stops blowing.

Hydrogen also can be extracted from gasoline, coal-based gas, natural gas, biomass, landfill gas, methanol or ethanol. More than 150 landfills and wastewater treatment plants across the country use methane-powered fuel cells as electricity generators, making the technology as valuable for reducing emissions as for producing power.

Since 1996, Connecticut's Groton Landfill has been producing 600,000 kWh of electricity a year, with a continuous net fuel cell output of 140 kW. The city of Portland, Ore., installed a fuel cell to produce power with anaerobic digester gas from a wastewater facility. It generates 1.5 million kWh per year, reducing the treatment plant's electricity bills by $102,000 annually.

Recently, the New York Power Authority launched a project to build eight fuel-cell power plants. Valued at $7.6 million, the project calls for the 200-kW units to be installed at wastewater treatment plants in Brooklyn, the Bronx, Queens and Staten Island. The powerplants will comprise one of the largest concentrations of fuel-cell power generators in the United States, while eliminating 170 tons of regulated emissions and 79,000 tons of carbon dioxide annually.

Fuel cell applications

Fuel cell technology is more than 150 years old but it remained in the laboratory until the U.S. space program used fuel cells to provide electricity on spacecraft in the 1960s. Today, the urgent need to develop cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels is rapidly propelling fuel cells into mainstream research and development.

Flexibility is one of the biggest advantages of fuel cell technology. Units can be manufactured in a broad range of sizes without affecting efficiency or environmental performance. Although not yet widely in commercial use, fuel cell demonstration projects throughout the country illustrate the technology's versatility.

Stationary power is the most mature fuel cell application. In large-scale building systems, fuel cells have been shown to reduce facility energy service costs by 20 to 40 percent over conventional energy service. Hospitals, municipal buildings, utility power plants and an airport terminal are among the facilities that have installed systems to provide primary or backup power. Phosphoric acid fuel cells are the usual choice for large-scale applications, but molten carbonate and solid oxide designs have begun to compete with PAFCs and may be commercialized in a few years.

Between 1994 and 1997, the Department of Defense Fuel Cell Demonstration Program installed PAFCs at 30 facilities and locations throughout the major armed services. The fuel cells provide primary electrical power, backup electrical power and heat. The program launched a residential demonstration in 2001, installing 22 proton-exchange membrane cells at 10 U.S. military bases.

Although only one stationary fuel cell for residential use is available in the United States, smaller systems—mostly PEM cells using propane or natural gas—supply electricity to homes around the world. Fuel cells show great promise for powering remote homes and as a backup power source. 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.

Transportation applications have received a great deal of attention recently, and with good reason. Highway vehicles account for a large share of petroleum use, greenhouse gas emissions and air pollution. According to the Environmental and Energy Studies Institute, if just 20 percent of cars used fuel cells, the United States could cut oil imports by 1.5 million barrels every day. All major automotive manufacturers—BMW, Honda, Nissan, Hyundai, Toyota, DaimlerChrysler, GM, Ford, Hyundai, Volkswagen—currently have a fuel cell vehicle either in development or in testing. However, fuel cell vehicles are not likely to be commercialized until at least 2010.

Portable fuel cells can be used to power a variety of devices, from handheld electronics like cell phones and radios to larger equipment such as emergency generators. Once available to the commercial market, miniature fuel cells will allow consumers to talk for up to a month on a cellular phone without recharging. Other applications for micro fuel cells include laptop computers, pagers, video recorders, portable power tools and low power remote devices such as hearing aids, smoke detectors, burglar alarms, hotel locks and meter readers. These miniature fuel cells generally run on methanol.

How fuel cells work

A fuel cell consists of a negative electrode, or anode, and a positive electrode, or cathode, sandwiched around an electrolyte membrane. Hydrogen is fed to the anode, and oxygen is fed to the cathode. A catalyst separates the hydrogen atom into a positively charged proton and a negatively charged electron, which take different paths to the cathode. The electron goes through an external circuit creating a flow of electricity. The proton migrates through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce only water and heat.

The equations for a proton exchange membrane fuel cell look like this:

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode: $4e^- + 4H^+ + O_2 \rightarrow 2H_2O$

Overall: $2H_2 + O_2 \rightarrow 2H_2O$

Most fuel cell systems are made up of three components—the hydrogen fuel reformer which extracts hydrogen from the fuel, the fuel cell stack and the power conditioner. Each cell produces only a small voltage, so individual fuel cells are "stacked" to generate a useful amount of electricity. The power conditioner converts the electric DC current from the stack into AC current that many household appliances operate on.

Safety

Like all fossil fuels, hydrogen is combustible and warrants the same caution any fuel should be given, as well as some cautions that are unique to the gas. When guidelines for proper handling and storage are observed, hydrogen is no more or less hazardous than any other fuel.

Hydrogen is flammable over a wider range of concentrations than either gasoline or natural gas. Since it is a very light gas, however, it offers some safety advantages over conventional fossil fuels. Due to its buoyancy, hydrogen dissipates more rapidly than other fuels in a spill. It tends to drift upward very quickly, even through tiny cracks in a roof, and disperse into the upper atmosphere where it is harmless.

Hydrogen is completely non-toxic, so it is impossible to contaminate anything with spilled hydrogen. In contrast, gasoline and oil puddle and seep into the ground if not cleaned up quickly.

The recommendations for handling hydrogen gas from the National Hydrogen Association's brochure, *Handling Hydrogen Safely*, are the same precautions that apply to all gases:

- Use hydrogen in areas that can be ventilated
- Prevent hydrogen leaks
- Take proper action if leaks occur
- Eliminate the opportunity for leaked hydrogen to accumulate
- Eliminate ignition sources

Types of fuel cells

The many types of fuel cells are distinguished by the kind of medium used to separate the hydrogen and oxygen. The different technologies lend themselves to specific applications. The primary technologies under development are:

- **Phosphoric acid fuel cells:** The PACF is the most commercially developed type of fuel cell and is being used in hotels, hospitals and office buildings. A 200-kW PAFC has powered the Yonkers, N.Y., Waste Treatment Plant since 1997. This plant turns sewage methane into fuel for the unit. PAFC can also power large vehicles such as buses, but their extended warm-up period limits their usefulness in private cars. The Georgetown University Fuel Cell Bus Program began running three PAFC-powered buses in 1994. Four years later, the program added two more buses, one using a PAFC and one using a PEM fuel cell.
- **Proton-exchange membrane fuel cells:** PEM cells operate at a relatively low temperature and can vary their output to meet shifting power demands, making them more suitable to power automobiles than the PAFC type of cell. These cells are the best candidates for light-duty vehicles, for buildings and many smaller applications. The energy technology company AeroVironment is testing a full-size PEM fuel cell and electrolyzer energy storage system on its Helios Prototype aircraft. Plug Power installed a PEM unit on an Albany, N.Y., home in 1998, launching what the company promoted as the "first permanent home installation in the United States." The 5-kW powerplant led to partnerships with both GE and Detroit Edison.
- **Solid oxide fuel cells:** Currently being used in small-scale demonstrations in Japan, SOFCs offer a promising option for high-powered applications such as industrial uses or central electricity generating stations. This type of fuel cell is also being looked at for use as small auxiliary power units on heavy duty vehicles to prevent idling diesel engines. The U.S. Department of Energy teamed with Siemens Westinghouse and Northern Research and Engineering Corporation in 2000 to build and study a SOFC-microturbine cogeneration unit. In a year of operation, the 220-kW SOFC ran on natural gas to achieve greater efficiency. DOE and Siemens Westinghouse hope to place a 1-MW fuel cell cogeneration plant in operation.
- **Direct-methanol fuel cells:** This new member of the fuel-cell family draws hydrogen from liquid methanol, eliminating the need for a fuel reformer. According to the U.S. Office of Transportation Technologies, the onboard reforming of liquid fuels eliminates concerns about hydrogen storage and a refueling infrastructure. The direct-methanol cell is a candidate for such applications as transportation, portable power sources for cellular phones and laptop computers, auxiliary power for instrumentation and vehicles and as a battery replacement for combat personnel and for battlefield applications.
- **Molten carbonate fuel cells:** The molten carbonate fuel cell has the potential to be fueled with coal-derived fuel gases or natural gas. Because of high operating temperatures, the applications are limited to large, stationary powerplants. The waste heat can be used for space heating, industrial processing or in a steam turbine to generate more electricity. During the 1990s, Mirimar Marine Corps Air Station in San Diego tested MCFCs to generate power and steam for use on the base.
- **Alkaline fuel cells:** Originally used by NASA on space missions, the alkaline fuel cell is now finding applications in hydrogen-powered vehicles. In July 1998, the Zero Emission Vehicle Company launched its first prototype taxi in London, England. The taxi uses a 5,000-watt alkali fuel cell that produces no noxious fumes and much less noise than taxis powered by traditional internal combustion. The company has also introduced a series of other commercial vehicles including delivery vans and airport tow-tugs. An associated company is demonstrating fuel-cell-powered boats.

Challenges to fuel cell commercialization

In spite of the many benefits fuel cells offer, the technology must overcome several barriers to succeed commercially. Cost is the greatest challenge to fuel cell development and adaptation. Current fuel cell cogeneration powerplants cost about $3,000 per kW. To compete in the broad power market, that price would have to come down to $1,500 per kW or less.

Also, the price of producing cells remains high. Several designs require expensive, precious metal catalysts, while others call for costly materials that are resistant to extremely high temperatures. Investments in mass production capabilities could help to bring down costs, but the demand for fuel cells has not yet reached the volume to stimulate such investments.

Technical issues must also be resolved for fuel cells to reach their commercial potential. New materials and improved designs are needed to make fuel cells more durable and dependable. Research into these areas is ongoing. The Department of Energy is sponsoring and participating in demonstration programs to test the durability of new components and designs.

The infrastructure for supplying hydrogen is still in a fledgling state. Cost is a factor in the fuel supply, too, since hydrogen is currently more expensive to produce than conventional fuels. Many of the more cost-effective production methods generate greenhouse gases. Fuel processor technology that can convert conventional and alternative fuels to hydrogen is under development.

Finally, consumers will have to learn more about the dependability and safety of fuel cell technology before they embrace fuel cell benefits. Utilities can play an important role in increasing public acceptance of fuel cells by becoming more familiar with the technology. Several organizations are dedicated to promoting fuel cell use in the United States. Below is a partial list of resources that provide up-to-date information on research and development, education programs, networking opportunities and technical assistance.

Additional resources

Publications:

A Fuel Cell Primer: The Promise and the Pitfalls
Tom Koppel and Jay Reynolds
Downloadable report providing the ins and outs on fuel cell technology and the emerging industry for investors.

The Fuel Cell Quarterly
Fuel Cells 2000
Quarterly newsletter carries updates on the most recent developments in the fuel cell industry.

Direct-Hydrogen-Fueled Proton-Exchange-Membrane Fuel Cell System for Transportation Applications: Hydrogen Vehicle Safety Report
C.E. Thomas, Directed Technologies, Inc., Arlington, Virginia, May 1997.
Order at **www.usfcc.com/resources/govreports.html (Order #DE98000309)**.

Hydrogen Safety fact sheet (215kb pdf)
National Hydrogen Association
Available at **www.hydrogenus.org/general/factSheet_safety.pdf**

Web sites:

Hydrogen, Fuel Cells & Infrastructure Technologies Program
USDOE Energy Efficiency and Renewable Energy
www1.eere.energy.gov/hydrogenandfuelcells/fuelcells

Department of Defense Fuel Cell Program
http://dodfuelcell.cecer.army.mil/

Fuel Cells 2000 Online Fuel Cell Information Center
www.fuelcells.org

US Fuel Cell Council
www.usfcc.com

International Clearinghouse for Hydrogen Based Commerce
www.hydrogencommerce.com

California Hydrogen Business Council
www.californiahydrogen.org

EnergyServices
Western Area Power Administration

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www.wapa.gov/es

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