

# FUEL CELL

QUARTERLY

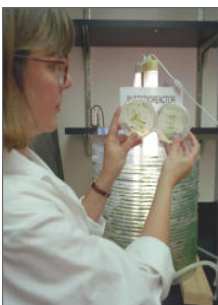
## Powering the Hydrogen Economy: Where Will the Hydrogen Come From?

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Hydrogen, the first element on the periodic table, is the most abundant, comprising about 90% of the visible universe and 75% of the universe's mass. It is also the lightest and simplest element, composed of only a single proton and electron. Yet when a catalyst is used to split hydrogen's electron and proton apart, it becomes quite an energy powerhouse. The electric energy derived from hydrogen can be used to power fuel cells for transportation, stationary or portable applications, running much longer and more efficiently than conventional energy sources. Hydrogen is also used in applications other than power, such as ammonia synthesis, hydrogenation of vegetable oil to make solid fat, oil refining, methanol and hydrochloric acid production, reduction of metallic ores and as rocket fuel.

The catch is that hydrogen does not naturally occur in its elemental form, but is chemically bound as a component in water, in hydrocarbon compounds and in organic matter. So how is liquid or gaseous hydrogen produced? The most common method is a thermal process, using high temperature steam reforming of natural gas to release gaseous hydrogen. Renewable liquid fuels can also be steam reformed. Another thermal process, gasification of coal or of biomass (such as agricultural or forest residues, organic municipal solid waste, farm animal waste, or novel sources like pecan and coconut shells, or pine wood), involves conversion of the feedstocks to a gaseous mixture and the subsequent separation of the hydrogen. Another method is electrolytic hydrogen production, which uses an electrolyzer to split water into hydrogen and oxygen. Other hydrogen production methods under development include photolytic water splitting using light; photoelectrochemical water splitting using semiconductors and sunlight; photobiological water splitting employing sunlight and specialized microbes, such as algae or bacteria, to metabolically produce hydrogen; and a thermalchemical process involving high-temperature water splitting.

Photobioreactor,  
source: DOE



Much of the hydrogen in commercial use today, produced by steam reforming or gasification, is produced and consumed onsite. Converting hydrogen to liquid form and transporting it (for use in hydrogen stations or to power stationary fuel cells) increases the cost. The U.S. Department of Energy has established a delivered, untaxed hydrogen cost goal of \$2.00-3.00 per gasoline gallon equivalent (gge) by 2015. According to the 2004 report, [The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs](#), the current estimated hydrogen production and delivery costs vary between \$2.10 and

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\$9.10/gge. However, successful R&D is anticipated to bring the cost down to \$1.75 to \$4.25/gge, making hydrogen cost competitive with gasoline. Some [National Hydrogen Association](#) member companies have already projected that they can produce and deliver hydrogen to fueling stations at a cost as low as \$1.20/gge (untaxed).

In addition to the hydrogen production methodologies discussed above, researchers are looking into alternative and innovative methods of producing low cost, renewable hydrogen, including methods of hydrogen generation on-site. Several recent news stories have chronicled a variety of hydrogen production methods, all in the early research phase:

[Researchers](#) at Virginia Tech, the University of Georgia and Oak Ridge National Laboratory have produced low-cost hydrogen using a combination of polysaccharides and 13 enzymes to make carbon dioxide and hydrogen. The researchers envision mixing the ingredients in a vehicle's fuel tank, where the reaction could yield enough energy to travel a distance of more than 300 miles.

[Microbiologists](#) at the University of Birmingham (UK) fed E. coli bacteria diluted chocolate waste from a Cadbury's factory, which reacts in the presence of the enzyme hydrogenase to produce hydrogen and organic acids.



R. sphaeroides was added to the reaction to increase yield and sufficient hydrogen was produced to power a small fan with a fuel cell.

An Oxford University [research group](#) has generated electricity using a biofuel cell placed inside a container of air with 3 percent added hydrogen. The fuel cell, comprised of two electrodes coated with hydrogenase enzymes, was able to generate electricity - the first to do so with such a small amount of hydrogen - without requiring an expensive platinum catalyst. The biofuel cell has successfully powered a wristwatch and other electronics. For more information on biofuel cells and microbial fuel cells, please see the article on page 3.

A [research team](#) from the University of Bielefeld (Germany) and the University of Queensland has developed a genetically altered turbo-alga that produces large quantities of hydrogen during photosynthesis. The alga, which can generate five times the volume hydrogen as wild algae, could eventually be used in a biological fuel cell. Additional research is aimed at increasing energy effi-

ciency, which currently stands at about 1.6 to 2 percent. This needs to be increased to a level of 7 to 10 percent to make the process economically feasible.

Since hydrogen has the potential to become a major energy carrier in the future, continued research will help overcome develop new production methods, overcome technology hurdles and achieve competitive cost targets. To learn more about hydrogen production methods, visit the U.S. Department of Energy's [hydrogen production web page](#) or view the National Hydrogen Association's [hydrogen production fact sheet](#). (SC)

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## Industry Watch

The moving and the shaking of the fuel cell industry.

ECotality has acquired Fuel Cell Store, an online retailer for the fuel cell industry based in Boulder, Colorado,

Proton Energy Systems and Northern Power Systems have combined and will now be known by the parent company name, **Distributed Energy Systems**.

Acumentrics has formed **Acumentrics Canada Ltd.** by acquiring the assets and hiring employees of Fuel Cell Technologies Ltd. of Kingston, Ontario.

Protonex Technology Corporation has entered into an agreement to acquire Mesoscopic Devices (Broomfield, Colorado) for \$12.4 million.

Rolls-Royce Fuel Cell Systems Inc. has acquired the assets of Ohio-based SOFCo-EFS Holdings LLC from McDermott International Inc.

## International Hydrogen and Fuel Cell Funding

Fuel Cells 2000 has published a draft report listing international funding for hydrogen and fuel cells. The analysis compiles websites, presentations and reports to show how much money countries around the world are spending on fuel cell and hydrogen research and demonstration programs

It is a work in progress and we welcome any edits, updates and suggestions.

<http://www.fuelcells.org/InternationalH2-FCpolicyfunding.pdf>

## Waste not, Want...More?

If someone told you that cow dung, raw sugar, peanut shells, yeast, rotten fruit, sewage and waste water and even human waste could power our buildings and produce fuel for our cars, you might think they were crazy. But with recent advances in research for biological and microbial fuel cells (MFCs), this might not be just a germophobe's nightmare.

MFCs use bacteria and carbohydrate-based biomass or organic material to produce electrons, which are then conducted into a circuit with the help of an inorganic mediator. Enclosed in oxygen-free anodes, the organic compounds are consumed, or oxidized, by the bacteria or other microbes. The electrons freed by this process are carried to an electrode, or anode, where they are then passed through a circuit, onto a cathode and finally transferred to an electron acceptor such as oxygen. When the electrons and oxygen form, water is created. As with all fuel cells, the byproducts of this process are all environmentally friendly: clean water, renewable carbon dioxide, and usable electricity.

So where the cow dung and sewage water come into play? When microorganisms like bacteria digest the compounds found in these substances, they produce carbon dioxide and water. However, when oxygen is prohibited from entering the equation, they produce carbon dioxide, electrons and protons. The electrons then kick-off the rest of the process.

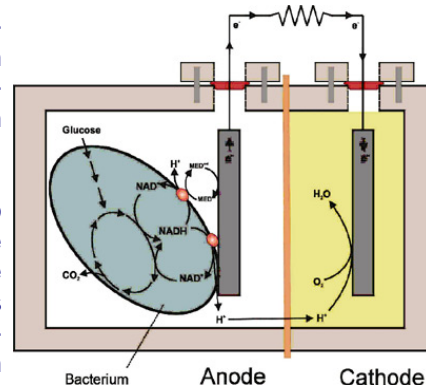


Diagram of MFC, courtesy of [www.microbialfuelcell.org](http://www.microbialfuelcell.org)

MFCs operate well in mild conditions relative to other types of fuel cells. Whereas most typical cells require temperatures of over 1000°F for large utility varieties and around 200-500°F for smaller cells, MFCs are efficient at very low comparative temperatures, such as 70-100°F.

One of the first arenas in which MFCs are being appreciated on a large scale is in plants that produce biodegradable wastewater, such as beer breweries. The MFCs used to clean this wastewater are BioElectrochemically-Assisted Microbial Reactors or BEAMRs. For example, Foster's brewery in Australia is planning to install their new MFC in September, powered by the discarded carbohydrates found in the wastewater. It will be capable of producing a little over 2 kilowatts of electrical power which is about the amount required to power an average home.

Two kilowatts may not seem like a lot, but breweries like Foster's that produce a large amount of waste compared to the energy spent are more interested in the water treatment benefits than the amount of sheer power. The fact that MFCs have the ability to purify water while still producing extra power is very exciting.

In fact, some of the newest advancements in the world of MFCs are very small indeed. For instance, researchers think that MFCs could be implanted into the body for use in pacemakers, microsensors or microactuators. Glucose and other carbohydrates in the blood would power the cell, eliminating the need to recharge batteries. More ideas include lawnmowers that convert cellulose in grass into energy, under-sea marine sensors, and other "Ecobots," or energy-autonomous machines and sensors.

Check out this great [website](#) dedicated to MFCs and the next time you turn up your nose as you pass a sewage treatment plant, just remember: with some bacteria and a little bit of help, that sewage and waste could be as good as gold. (BW)

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## Fuel Cells for Sale!

The U.S. Fuel Cell Council has compiled and published a comprehensive list of commercially available fuel cell products available for purchase from manufacturers headquartered in the U.S., Canada and Europe. The list includes stationary, portable, micro and transportation products and is available in EZ-Read or a Full Detail version on the USFCC website - [www.usfcc.com](http://www.usfcc.com).

The National Hydrogen Association (NHA) has also launched a new searchable [online listing](#) of 34 hydrogen and fuel cell products that are currently for sale or available for purchase within the next 12 months. Information for each product includes product dimensions, images, contact and purchase information.

## Hydrogen Stations are Springing up Everywhere!

Spring has been a busy period for hydrogen fueling stations, with five stations recently opening worldwide.

In April 2007, the second hydrogen station in Nevada opened at the Las Vegas Valley Water District's main campus. The station generates hydrogen onsite, using solar-generated energy to drive the electrolysis generators. The station will be used to fuel several Water District vehicles that have been retrofitted to operate on hydrogen.



GTI's hydrogen station

Also in April, Illinois' first hydrogen station opened at the Gas Technology Institute in Des Plaines. The station is publicly accessible by arrangement, with credit card access. The facility is capable of producing hydrogen from natural gas, ethanol, or electrolysis of water, and in the future, could produce hydrogen from the gasification of coal or biomass. The project was funded by U.S. Department of Energy (DOE) and Gas Technology Institute (GTI).

Chevron and Southern California Edison (SCE) opened a hydrogen station at SCE's headquarters in Rosemead, California in May 2007. An alkaline electrolyzer is used to produce the hydrogen onsite. The station serves a small demonstration fleet of Kia and Hyundai hydrogen fuel cell vehicles operated by SCE meter readers. The Chevron Hydrogen energy station is one of up to six stations that Chevron plans to build and operate under a DOE contract.

A mobile Linde hydrogen station was also placed in service in May at Hamburg, Germany's airport. The station will fuel two fuel cell tractors and a people-carrier at the airport. Since the vehicles operate at different pressures (the tractor at 350 bar and the people-carrier at 200 bar), two separate hydrogen tapping systems are provided.

Finally, Norsk Hydro opened its first hydrogen station - the second hydrogen station in Denmark - in June near the Norsk Hydro Research Center in the city of Porsgrunn. The station will be part of a planned 360-mile Hydrogen Road located between Oslo and Stavanger. Nine Toyota Priuses, modified by Quantum Technologies to operate on hydrogen fuel, have been delivered to the site. Hydrogen for the station is being delivered via an undersea gas pipeline from a nearby petrochemicals plant, connecting the station directly to the source of by-product hydrogen production.



Norsk's Porsgrunn station

This is definitely a great start to the year, but there are still 13 additional hydrogen stations anticipated to debut before the end of 2007! Ten of the planned stations will be located in California, where the state is establishing a network of hydrogen fueling stations along the state's freeways and urban centers. The new stations will be located at:

**Humboldt State University in Arcata.** Schatz Energy Research Center and Chevron Technology Ventures are teaming to develop this hydrogen station, which will produce hydrogen on-site by electrolysis. The station will support a hydrogen-powered Toyota Prius for a two-year demonstration. Future plans include development of a hydrogen power park using renewable gas from a local landfill.

**San Carlos.** Scheduled to open in December, the San Carlos mobile hydrogen station will be located at publicly accessible, 24-hr CNG fueling station. Steam methane reformatting will be used to generate 10 kg of hydrogen/day from natural gas. The station will also feature a solar PV cell component.

**San Diego.** Hydrogen will be produced on-site by electrolysis, powered by a 600 kW solar photovoltaic array installed at a middle school. The station will have a storage capacity of 100 kg and will dispense up to 39 kg of hydrogen per day. Future plans are to generate hydrogen from yard trimmings and food waste.

**California State University in Los Angeles.** Hydrogen will be produced on-site using wind power. The facility will be able to fuel five cars per day.

**UCLA in Westwood and Marine Corp Base Camp Pendleton.** Both stations will produce hydrogen on-site via steam methane reforming. The UCLA Station will support two demonstration DaimlerChrysler F-Cell vehicles and will have a fueling capability of 25 vehicles per day.

**Menlo Park.** San Mateo County and Distributed Energy Systems are teaming to deliver this station in 2007. The station will support California Fuel Cell Partnership vehicles

and a possible fleet of city-operated hydrogen cars.

**Westminster, Long Beach, and Los Angeles.** Mobile hydrogen stations will be located in these three cities. The Westminster and Long Beach stations will each have a hydrogen storage capacity of 150 kg. The Los Angeles station will be operated by the National Fuel Cell Research Center at the University of California, Irvine and will be able to fuel up to 10 cars per day.

Also in the U.S., the University of Texas, Austin, Texas Commission on Environmental Quality and Gas Technology Institute will debut a hydrogen station in summer 2007 that will support operation of a fuel cell-hybrid bus.

Outside the U.S., several international hydrogen stations are presently under development. São Paulo, Brazil will soon begin operating a small fleet of fuel cell-powered buses that will be fueled at a hydrogen station provided by Hydrogenics Corporation. Hydrogen will be produced on-site using an electrolyzer. In Munich, Germany, the first of three BMW Group/TOTAL hydrogen fueling stations will debut by the end of 2007 near the BMW Research and Innovation Center. The publicly-accessible station will feature Germany's first underground liquid hydrogen storage tank. The station will also offer both gas and diesel fuels.

At least 50 additional hydrogen stations are planned in the next few years in the U.S., Canada, China, Denmark, India, Italy, Norway, Spain and Sweden. If you would like to stay up-to-date with hydrogen station openings, or view the listing of currently operable stations, be sure to check out Fuel Cell 2000's frequently-updated *Worldwide Hydrogen Fueling Stations* chart at: <http://www.fuelcells.org/info/charts/h2fuelingstations.pdf>. (SC)

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## Help Fuel Cells 2000 Help the Fuel Cell Industry

Fuel Cells 2000 needs your help to make our programs as effective, and cost effective, as possible. We are conducting an informal review of the communications barriers fuel cell and hydrogen advocates are facing. We are hoping to launch some new communications tools and also provide a regular opportunity, if there is demand for it, for communications professionals to compare notes on strategies for overcoming these challenges. Please help us by taking a look at our survey - your answers will greatly improve our focus. In return, we will send you the survey results and a report. We are interested in the obstacles you and your organization face, in your strategies to overcome them, in success stories, in failures (and reasons why), and, finally, in your advice and wisdom on strategies for the future. Together, we hope the information and follow-up will help in some small way to shape the global message about fuel cells and hydrogen and help us all present a more unified front. You can send completed surveys to [Jennifer@fuelcells.org](mailto:Jennifer@fuelcells.org). The survey can be found at <http://www.fuelcells.org/surveyindustryfinal.doc>.

## Free Pass Into Grove Exhibits

For a free ticket to the Grove Fuel Cell Conference's exhibition, please go to [http://www1.elsevier.com/homepage/saf/emails/grove/grove\\_freeticket\\_fc2000.html](http://www1.elsevier.com/homepage/saf/emails/grove/grove_freeticket_fc2000.html).

The Grove will be held at the QCell Conference Center in London, England, September 25-27, 2007.

## Update on Hydrail

In our [last issue](#), we explored the increased interest in hydrail, or hydrogen-powered rail and talked about some of the projects around the world.

For those readers interested in following up with that article and staying on top of the most recent advancements, Bob Rose, executive director of Breakthrough Technologies Institute (Fuel Cells 2000's parent organization) recently gave a [keynote speech](#) at the third International Hydrail Conference. The conference was held at Catawba College in Salisbury, North Carolina, and had presentations by some of the world's leading experts in hydrogen and fuel cell-powered trains. The [conference website](#) has all the presentations from the past two conferences and lots of great resources on hydrail.

## Conference Presentations Available Online!

Fuel Cells 2000 posts every presentation that we give at various conferences and events around the world. These presentations contain lots of great information on hydrogen and fuel cells that we encourage readers to copy, cite and use in helping educate and inform others about the benefits of utilizing fuel cells and transitioning to a hydrogen economy. The documents contain useful data such as images, charts, statistics and technical information.

[http://www.fuelcells.org/info/conf\\_pres.html](http://www.fuelcells.org/info/conf_pres.html)

## Fuel Cells Breathe Easy in Great Outdoors

On weekends and vacations, city dwellers flock to the country in droves, ready to escape the smog and the noise caused by the hustle and bustle of daily life. Replacing loud and polluting generators with fuel cells can help keep people breathing easy at campgrounds, lakes and other recreation spots while providing long-lasting power no matter what time of year.

The great thing about fuel cells is that they can satisfy every power load, have low-to-zero emissions (depending on the fuel source), and they don't have to be attached to the electric grid which makes them ideal for the weekend warriors as well as environmentalists who want to leave as small a footprint as possible while having their outdoor fun. Fuel cells are also rugged, able to withstand harsh weather and cold temperatures. Another bonus for campers is that fuel cells are quiet, so besides eliminating the smoky emissions, they also greatly reduce noise pollution. Fuel cells are suited for auxiliary power to power electronics onboard recreational vehicles (RVs) or boats, or to provide power at a stationary location such as a campsite or ranger station. Since they are extremely reliable and provide a longer runtime than batteries, fuel cells are also ideal for emergency backup power.

Fuel cells for portable applications usually range in size from less than 1 kW to 3-5 kW, depending on its purpose. Portable fuel cells can run on various fuels, such as compressed hydrogen gas, low temperature metal hydrides, and methanol, making them extremely versatile for campers and travelers.

A few overseas companies are really making strides targeting the recreational market - in fact; you can now select an [SFC Smart Fuel Cell](#) (SFC) as an option in both Dethleffs Corporation and Niesmann+Bischoff motor homes. SFC offers three different models of their Energy for You (EFOY) line – EFOY 1600, EFOY 1200 and EFOY 600, each named for the power output they produce. The fuel cells run on methanol and fuel cartridges can be bought at over 500 sales points in Europe - one EFOY M10 cartridge can supply a motor home with independent power for up to four weeks.



SFC's EFOY

The EFOY fuel cells can be placed anywhere in the motor home, underneath the floor, or in a side or rear storage compartment. They weigh around 16 pounds and provide more power than solar systems, especially since they don't need the sun to produce energy. The fuel cells can also be used to recharge batteries for lanterns, cell phones and other equipment if needed.

Fuel cells as a whole are known to be rugged and durable and SFC has ensured that the EFOY fuel cell can operate under a wide range of temperatures and contains an antifreeze mode for activities in the winter or cold climates.

### Smooth Sailing

Shipboard power is extremely important, whether you are aboard a luxury yacht with top of the line appliances, or a small sailboat using radios, GPS and other equipment to navigate. SFC also manufactures the MFC 100, a fuel cell designed for boats and marine applications. It provides 100 ampere-hours (Ah) per day and can be mounted below the deck, or above the deck outside, since it has a seawater-resistant outer shell. Using a fuel cell eliminates the need for the cooling fixtures or exhaust pipes generators use, not to mention the engine noise and vibrations.

Another company focusing on boating market is [Voller Energy](#), based in the United Kingdom. Voller is currently developing a proton exchange membrane (PEM) fuel cell system that can run on a variety of fuels, including liquid petroleum gas (LPG), propane or butane. This product is designed for powering the 12V or 24V circuits onboard yachts, as well as in motor homes, and can even run on the cooking gas the stove uses. The system operates within a specified voltage range, switching itself on and off as the boat's power needs change.



Voller's ABC fuel cell charger

Voller already sells the Fuel Cell ABC portable fuel cell system which can be used to recharge the batteries in portable electronic that some campers might not want to leave behind.

## At the Campground

For those late night trips to the bathroom, [Angstrom Power](#) released its A2 micro hydrogen fuel cell flashlight in 2006. The 1 watt LED flashlight runs on hydrogen stored in the handle and can run for over 24 hours on a single charge. You can buy the fuel cell-powered flashlight now and if needed, a larger version of the system could be integrated into other portable devices such as a two-way radio. For mountain bikers, Angstrom also has the *micro hydrogen™* bike light. It can be affixed to a helmet or the handlebars and runs on a 21cc cartridge of hydrogen, equal to about 10 AA alkaline batteries. The light can last 20 hours between refueling, which can be done quickly, and you don't have to worry about recycling or disposing of numerous batteries on the trail.



Angstrom's A2 fuel cell flashlight

[Millennium Cell Inc.](#) has just entered into a joint development and licensing agreement with [Horizon Fuel Cell Technologies](#) to commercialize fuel cell products that provide over 20 watts of power. The first joint unit will be a 50W emergency power unit designed to provide recreational power in remote environments. The fuel cell could also support disaster relief professionals and park rangers, enabling communication during black-outs and out in the field.

So when leaving the hustle and bustle of the city behind, why surround yourself with more of the same when you finally get outdoors? Using fuel cells in recreational applications means no more smoky emissions and loud operating noises from standard generators, as well as longer lasting power and easier refueling than today's batteries. That should make everyone breathe a little easier. (JG)

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## Notable News & Notes

In the July/August issue of [Distributed Energy Magazine](#), FuelCell Energy's California State University Northridge installation has made the cover. Inside, there is an in-depth article on the university's commitment to energy efficiency and 1-MW fuel cell installation.



1-MW FuelCell Energy fuel cell

In the August 2007 issue of *Automotive Engineering International*, there is an article entitled, "[Honda Builds a Better FCX](#)" that claims the new version achieves 354 miles per gallon (gasoline equivalent). This is the highest range reported for Honda.

STOA, the European Parliament's Scientific Technology Options Assessment body, has published [Alternative Technology Options for Road and Air Transport](#), an inventory of 20 of the most promising transportation options, which are clustered in five technologies: hydrogen and fuel cells, battery electric vehicles, hybrid technology, biofuels and natural gas. The inventory provides a comparative overview of the pros and cons of each of these technologies.