

Much to gain from fuel cell research

What is a fuel cell?

Fuel cells generate chemical energy by combining hydrogen and oxygen. The chemical energy is captured and transformed into electrical energy.

A fuel cell is not a battery, nor is it a coal-fired electricity-generating “power” plant but it shares characteristics with both. Like a power plant, fuel cells generate electricity. Like batteries, fuel cells can be mobile and “fit” into the tools they power. Fuel cells that don’t need to be mobile can be much larger and installed near or inside a building.

Unlike batteries, most fuel cells are not independent, self-enclosed power supplies. But, they can run indefinitely as long as their fuel supply is maintained.

Unlike a coal-fired, natural gas or nuclear

molecule to another. Catalysts are used to encourage electrons to jump in a predictable direction and a predictable amount of energy is captured.

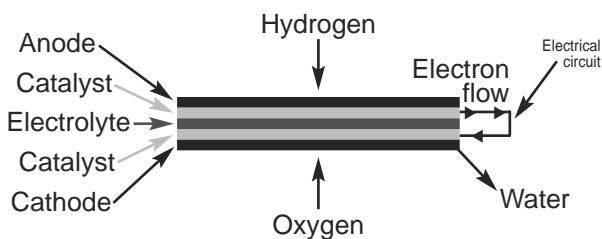
As evidenced in a magnet, electrons can bond atoms together or push them apart. In a fuel cell, the end of the generation process results in electrons binding two hydrogens and an oxygen atom, H_2O . That’s what is leftover from electricity production in a fuel cell: water.

The water is, of course, warm. It still contains energy in the form of heat. If the fuel cell operates at a high temperature, then the water isn’t liquid, it’s steam. This energy, too, can be captured and put to use if the fuel cell is powering a building. It can heat the building or provide warm showers.

Strictly speaking, there are no other byproducts, dangerous or otherwise, from fuel cell operation. There are, however, byproducts from fuel reforming.

Fuel Cells in general

Stacking multiple fuel cells increases the amount of electricity generated



power plant, a fuel cell doesn’t have to undergo a lengthy permitting/regulatory process to be installed. In some states, where air emissions are highly regulated and pollutants tightly restricted, fuel cells have been excused from continuing regulatory oversight. Many simply do not contribute in a significant way to pollution problems.

How it works

Fuel cells enable the energy of a moving electron to be captured as it jumps from one

Reforming for hydrogen

Reforming in this case means separating. A reformer is added to some fuel cells to separate hydrogen atoms from all other atoms in a substance. This process is only necessary when pure hydrogen is unavailable or inconvenient to use.

When pure hydrogen isn’t used, another substance, like propane, can be used instead.

Propane is made up of carbon and hydrogen atoms. In a propane fuel cell, the hydrogen atoms in each molecule are separated out (reformed) to fuel the fuel cell. The carbon atoms are discarded.

In some cell designs, the amount of carbon waste is so small, it’s just released into the air. In other designs, it’s combusted. Some designs capture it for later disposal. The substance from which hydrogen will be reformed (natural gas, gasoline, propane) determines how much carbon will be present and that, in turn, deter-

mines the design of the fuel cell and how the carbon is discarded.

Oxygen, the other fuel

Oxygen is also required to operate a fuel cell. It can be taken from the air surrounding the cell or it can be supplied in pure form via an oxygen tank. If it's taken from the surrounding air, impurities in the air become part of the fuel cell's exhaust. To a fuel cell, impurities in the air are any substances other than oxygen.

Transporting fuel

Pure hydrogen isn't as easy to buy or access in large quantities as the gasoline, coal, or water from which we derive most of our energy today. That's because demand for them has been much greater than demand for pure hydrogen. A high-capacity, national infrastructure for the other fuels already exists.

For fuel cells to become popular, some believe their fuel must be as easily accessible as gasoline or electricity. This is why fuel options other than pure hydrogen are being examined.

Habits

Some people may not be as eager to buy a fuel cell-powered car if they first have to learn about hydrogen. They won't hesitate to buy, however, if a new fuel cell-powered car can be "gassed up" just like the combustion engine in their old car.

Hydrogen is everywhere

There is so much hydrogen around, it might seem a little odd to have to pay for it. The reason hydrogen can be used in fuel cells, however, is because it readily "sticks" to other atoms. It's not naturally found in a pure form.

When buying fuel, a person is either buying the effort someone else made to strip hydrogen out of other substances, or buying convenience, so he neither strips it himself nor searches time-consumingly for a hydrogen filling station.

Fuel cell efficiency

To understand how fuel cells can contribute to the overall energy picture in the U.S., some comparison of efficiencies must be made. The efficiency of any electricity generator is determined by knowing how much fuel it takes to generate a given amount of electricity. Coal-fired generating plants typically operate at about 35% efficiency.

Solar panels (the fuel is sunlight) operated at about 5% efficiency when first developed. Today the best (and most expensive) solar panels use mirrors to "boost" fuel concentration. They operate at over 45% efficiency. State-of-the-art wind generators can achieve nearly 20% efficiency.

Types of fuel cells

The variety of fuel cell types listed below take advantage of different fuel sources and maximize the resulting benefits for different applications.

Alkaline fuel cells use alkaline potassium hydroxide as the electrolyte. They have been used by the National Aeronautics and Space Administration (NASA) on missions to space. They can achieve power generating efficiencies of 60 to 70 percent but are rather expensive for commercial applications. They are easily poisoned by carbon dioxide and can now operate as cool as between 74°F and 158°F.

Solid polymer fuel cells—also known as proton exchange membrane (PEM) fuel cells because the electrolyte is a proton exchange membrane—can operate at temperatures as low as 176°F. They can deliver lots of power from a small space and can accommodate sudden changes in electrical load. This makes them good for cars and trucks and, because they startup quickly, they also have the best potential for small applications such as video cameras.

Phosphoric acid fuel cells are on the market right now. They aren't cheap, but they are available and the Department of Defense has had many of them operating on bases and in associated research facilities since 1997. The most common type of acid electrolyte fuel cells, phosphoric acid fuel cells produce steam and operate at 37-42% efficiency. If the steam is captured for heating or hot water needs, efficiency can double. These are less powerful types of fuel cells than other of the same weight and volume.

Molten carbonate fuel cells operate at temperatures as high as 1200°F and can use coal-derived substances as fuel. The electrolyte is generally a carbonate salt mixture which, at these operating temperatures, is essentially liquid salt. Molten carbonate fuel cells are not mobile. They're appropriate when a lot of electricity is necessary most of the time. They may ultimately be most valuable to electric utility companies and large industrial plants, however, due to high operating temperatures, durability is a problem. Molten carbonate fuel cells should be smaller and less expensive than a fuel cell with comparable voltage. If the heat is captured and re-used, the efficiency of a molten carbonate fuel cell could theoretically reach 60 to 85 percent.

Solid oxide fuel cells are also for utility companies and large industrial plants although transportation applications are also being developed. The principal difference between molten carbonate and solid oxide fuel cells is the electrolyte used. In a molten carbonate fuel cell, the electrolyte can be derived from coal. Solid oxide fuel cells use a hard ceramic material. Temperatures in a solid oxide cell can reach 1800°F and, so far, such temperatures considerably erode their durability. Solid oxide fuel cells are not easily poisoned by impurities.

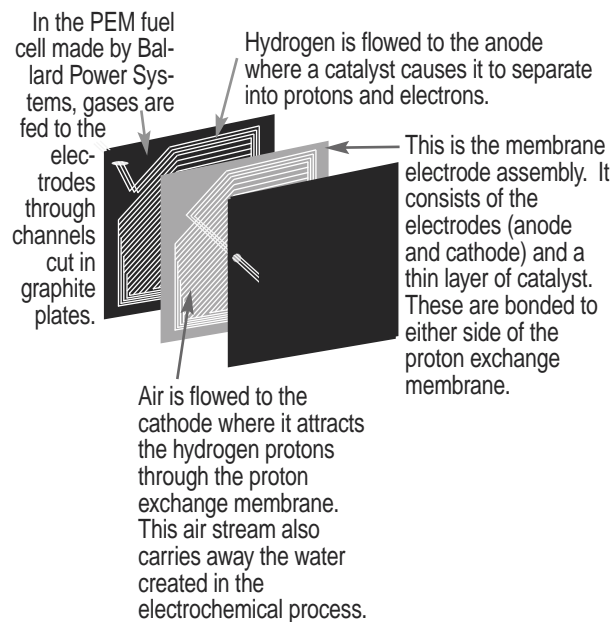
Direct methanol fuel cells are similar to the proton exchange membrane fuel cells. Both use a moist polymer membrane as the

electrolyte. Proton exchange membrane fuel cells all feature a reformer to draw the hydrogen out of any fuel they use. Direct methanol fuel cells, however, can use methanol without processing it through a reformer.

Separation in this case is achieved by the anode. It acts as a reformer by drawing hydrogen out of the methanol. Like the solid polymer/proton exchange membrane fuel cells, direct methanol fuel cells are currently available for certain applications.

Regenerative fuel cells are closed systems. Closed means they generate their own fuel. A solar-powered electrolyser separates water into hydrogen and oxygen. The fuel cell uses hydrogen and oxygen to generate electricity and the byproducts are heat and water. The water is fed back into the electrolyser which separates it into hydrogen and oxygen and the process begins again. This type of fuel cell most closely resembles a battery.

Regenerative systems will be necessary to establish manned outposts on the moon or other planets. Solar panels are ideal for generating electricity in space except when sunlight isn't available. On the moon, a night lasts two weeks, so a fairly hefty regenerative system would be required. Nights on Mars, however, are only twelve hours long. A regenerative system which can supply electricity through a mere twelve hours of darkness is more easily achievable. Development of these systems is underway.



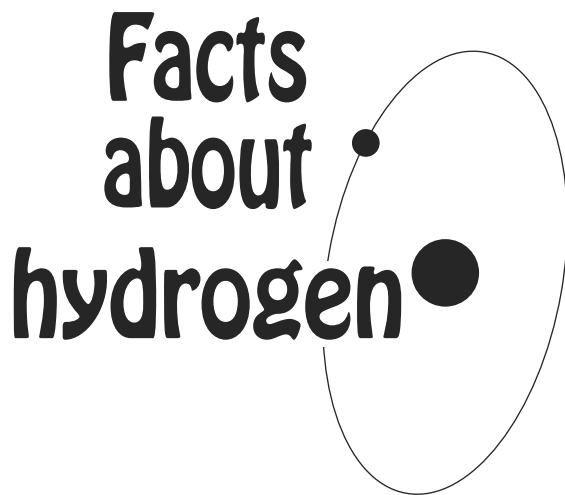
Who's who in fuel cell development?

The U.S. Department of Defense knows the most about fuel cells because they've been working on fuel cell projects since 1994 and actually using them since 1997. NASA, the Department of Energy, and the Environmental Protection Agency have also played key roles.

Private industry has done much of the research and funding for fuel cell development in partnership with the federal government and the Electric Power Research Institute, an entity

funded by private and public utilities. An incomplete list of companies offering fuel cells and related products includes:

- ▶ Cogeneration Technologies
- ▶ Renewable Energy Technologies
- ▶ Trigeneration Technologies
- ▶ EcoGeneration Solutions, LLC
- ▶ Biofuel Industries
- ▶ Solar Energy Systems



Hydrogen is a unique element in that it has only one electron, one proton and no neutrons. This makes it the simplest of elements.

Hydrogen, however, is combustible and since the Hindenburg disaster, people have been suspicious of using hydrogen as a transportation fuel.

The Hindenburg was a hydrogen-filled airship which crossed the Atlantic Ocean in 1936. In 1937, it tragically burned in Lakehurst, N.J., killing 36 people. At the time, it was assumed that the zeppelin burned because it was filled with hydrogen.

Studies of the accident have since revealed that the hydrogen gas was enclosed in bags made of cellulose acetate or cellulose nitrate, both of which are flammable. Additionally, the bags were coated with a material containing aluminum flakes so the flakes could reflect sunlight and keep the bags cool.

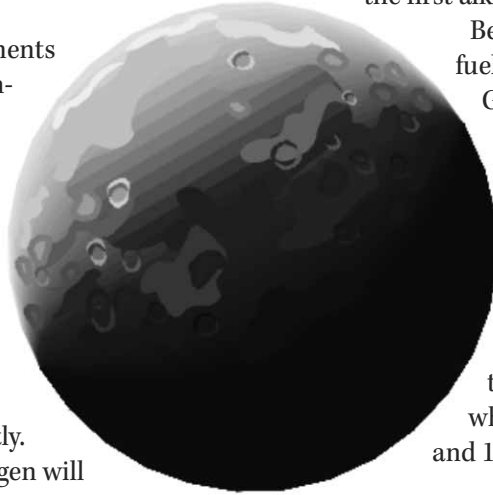
According to Addison Bain, a retired NASA safety expert, cellulose nitrate and metal chips are the ingredients of rocket fuel. Furthermore, accounts from witnesses describe a scene which could have resulted from a lightning strike (or many) to the dirigible.

In short, many elements of the Hindenburg's construction could have contributed to its destruction before hydrogen became a factor. Only one of those elements (the hydrogen itself) will be part of fuel cell operation and it will be safeguarded much differently.

In a fuel cell, hydrogen will be stored in a carbon fiber-wrapped composite material tank which can withstand greater impacts (without rupturing) than a vehicle.

In comparison with other fuels, hydrogen is more buoyant than gasoline and disperses more quickly than either natural gas or gasoline. In many circumstances, these two differences alone will make a fuel cell-powered vehicle safer than a gasoline-powered combustion engine.

Automatic hydrogen shut-offs are designed into fuel cell-powered vehicles so in case of an accident, dangers from the fuel are minimized. In terms of capacity, very little pure hydrogen is actually stored in or around a vehicle fuel cell. Obviously, fuel cells used in transportation are more at risk than stationary fuel cells but less hydrogen will be stored on a vehicle due to space considerations.



History of fuel cells

Sir William Grove in the 1800s discovered that hydrogen and oxygen could be combined to produce direct current electricity. In the 1950s, a British scientist built the first alkaline fuel cell system.

Between 1962 and 1965, fuel cells were used in the Gemini spacecrafts launched by NASA to orbit the earth. NASA used 1.5-kW alkali fuel cells in the Apollo missions between 1968 and 1972.

Current space shuttles use alkali fuel cells which supply between 7kW and 12kW of power.

Will a fuel cell will work for you?

Consider energy use.

To determine if a fuel cell is an appropriate solution for your building's energy needs, consider how much energy is needed and whether the thermal output (hot water) of a fuel cell can also be used. Efficiencies go up and payback time goes down as energy usage increases.

Consider space.

Fuel cells occupy space and must be surrounded by several feet of empty space.

Consider wiring and piping.

How possible will it be to wire connections from the fuel cell to the major electrical panel or panels? Where will the piping run for the water byproduct? A water presence requires attention to retaining walls, slopes and drainage paths and other elements of the environment. Is the location appropriate to answer these needs?

Consider central station power (the electricity grid).

How will the current electricity supply be affected by a fuel cell? The fuel cell can run:

- independently of the grid
- as a back up system to be used when storms interrupt the grid system
- as a peaking power source when excessive heat causes brownouts or blackouts across the grid.

Each scenario necessitates discussion with the current electricity provider and co-operation and planning between parties.

Consider thermal connections.

What will the hot water byproduct be used for? How will such use be implemented? According to the Department of Defense, thermal interfaces can be challenging to design.

Where can fuel cells be used?

The profit potential for fuel cell developers is tremendous depending on how inexpensively fuel cells can be manufactured and commercially sold. Also important is how easily an untrained public will find them to operate. The easier they are to operate and maintain, the faster they'll catch on, the better they'll sell, and the less expensive they'll be.

Fuel cells could potentially power cars, trucks, motorcycles, snowmobiles, boats, four-wheelers, bicycles, military vehicles, homes and office buildings (and all the equipment inside them), and every item that currently runs on batteries, i.e. video cameras, radios, computers, watches, calculators, flashlights, screwdrivers.

They may ultimately provide backup generation for facilities currently connected to central station power (the electricity grid). Although emergency services already have backup generators, fuel cells could en-

able non-emergency services to access backup power, too.

Fuel cells will allow mobility in tools not currently operated far from a central station outlet. Imagine refrigerators and microwaves in a tent or radial arm saws and lights at a new rural home site.

Predicting the future

Fuel cells are not expected to replace central station power as an electricity source for most homes and businesses. The reason is straightforward. When electricity is supplied via central station power, a small part of the electric bill reflects the cost of the electricity. The bulk of the bill, however, reflects the efforts of others to install, maintain, and service the system which transmits and distributes the electricity.

Fuel cells will also have to be installed, maintained, and serviced. These efforts won't be free and for many consumers, it will be easier, cheaper, and more convenient to stay hooked up to the grid.

In stormy areas or hurricane zones, however, or for people or companies with special needs, fuel cells could be a first step toward complete grid independence.

Collecting facts before you begin

Those interested in determining if a fuel cell would be appropriate for a given situation should track energy usage closely.

Recording the annual peak electricity demand for the site and the annual electricity usage are examples of numbers needed to properly assess the situation. Noting when electrical load is heaviest (day or night, weekday or weekend) is another recording necessity.

Demand charges on the current electricity bill, time-of-use charges and how these may or may not be offset by the addition of a fuel cell will require discussions with the current electricity distributor.

Research into their policies both current and anticipated is also recommended.

Where to go for specifics

Specific sizing and purchasing information can be obtained from individual fuel cell developers or manufacturers. Contact information is available on the internet.

The best place to start for all your fuel cell information needs is

Fuel Cells 2000
1100 H Street NW, Suite 800
Washington, D.C. 20005
Phone: 202-785-4222
Website: www.fuelcells.org

The information in this pamphlet was gathered from WAPA and ECO seminars attended by the 2002 WREN magazine staff, the websites for the companies listed above, the U.S. Departments of Defense and Energy, the Environmental Protection Agency, Electric Power Research Institute, and NASA, as well as information from WAPA publications, Fuel Cells 2000 and their website www.fuelcells.org, College Physics, fifth ed., a textbook published in 1974 by McGraw-Hill and Breakthrough Technologies published in 1998 by Mills McCarthy & Associates, Inc.