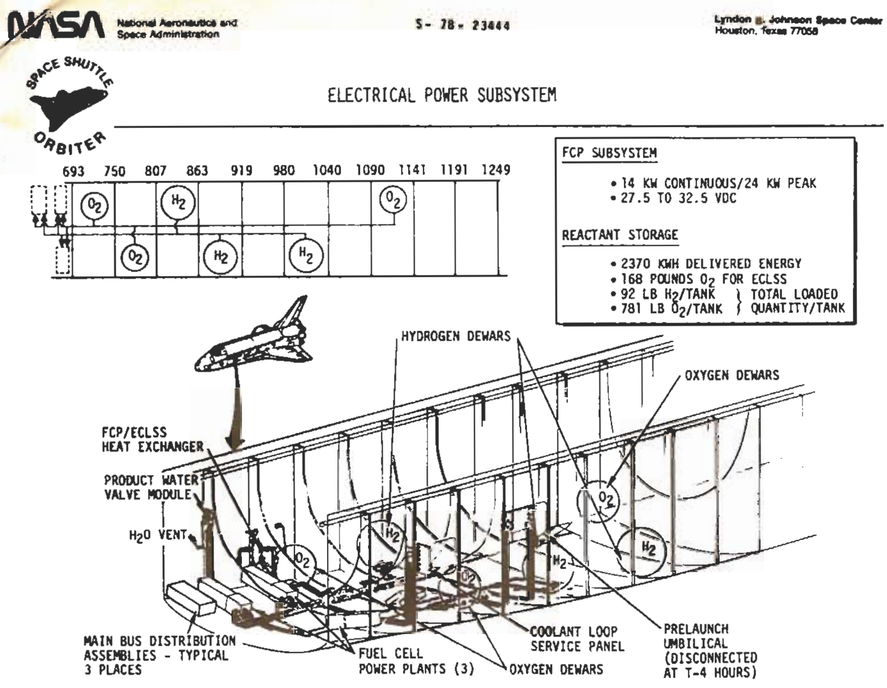


# FUEL CELLS

***Could fuel cells be the ideal energy source of tomorrow?***


**RALPH HUBSCHER**


**WARNING!!** This article deals with and involves subject matter and the use of materials and substances that may be hazardous to health and life. Do not attempt to implement or use the information contained in this article unless you are experienced and skilled with respect to such subject matter, materials and substances. Neither the publisher nor the author make any representations as to the accuracy of the information contained herein and disclaim any liability for damages or injuries, whether caused by or resulting from inaccuracies of the information, misinterpretations of the directions, misapplication of the information or otherwise.

FUEL CELLS COULD POTENTIALLY BE the most efficient and environmentally clean source of power ever developed. Fuel cells are an attractive alternative to conventional power generation because they are highly efficient, and produce drinking water as an added by-product. What more could you ask for in an energy source? The principle of fuel cell operation was discovered by Sir William Grove in 1839. He found that electricity could be generated by supplying hydrogen and oxygen to two separate electrodes immersed in sulfuric acid. For more than a century, however, fuel cells remained a mere curiosity.

The theory of fuel cell operation defied commercial applications for so long because of technical and financial obstacles. It wasn't until the 1960's, during the growth of the space program, that there was a renewed interest in developing fuel cell technology into a viable energy alternative to standard power generation.

There are two important concerns in conventional power generation: efficiency and pollution. Most of the power in the world is generated from heat engines using the heat from combustion of fossil fuels. Mechanical systems involve many energy conversion steps, and their efficiencies are limited by the laws of thermodynamics. That results in considerable power losses.

A fuel cell, on the other hand, converts potential chemical energy of fuel into electricity. It operates at a constant-temperature during the electrochemical process, therefore it's efficiency is not limited by thermodynamic laws governing heat engines.

Pollution is a result of combustion, industrial processing, and vehicle exhaust. Those pollutants consist of unburned fuel, partially burned fuel, carbon, carbon monoxide, carbon dioxide, dust, sulfur dioxide, nitrous oxides and so on. Waste heat from power plants warms up the rivers, causing havoc to the natural balance of fish and wildlife. And we all know of the devastating effects of acid rain, which results from man-made emissions of sulfur and nitrogen in the air. The by-product of a fuel-cell reaction, however, is water. Who would object to that?

## Fuel-cell chemistry

Fuel cells operate by converting the potential energy of certain chemical reactions directly into electrical current in a flameless, catalyzed reaction. Some types of fuel cells work very well at room temperature.

A basic fuel cell consists of an anode (+) and cathode (−) separated by a conducting electrolyte such as a solution of potassium hydroxide. A fuel, such as hydrogen gas, or hydrazine, is introduced to the negative electrode where it is oxidized, releasing electrons to the load. Oxidation is the process of removing one or more electrons from an ion or molecule. In fuel cells, hydrogen ions are formed at the electrode by electrochemical oxidation of the fuel. If the fuel is hydrogen, hydrogen ions are created by the following ionization reaction:

$$H_2 \rightarrow 2H^+ + 2e$$

Oxygen, air, or hydrogen peroxide (a source of oxygen) is fed to the cathode, where it is reduced, whereby the $O_2$ oxygen molecule splits apart. Ionic conduction completes the circuit through the electrolyte. Hydrogen and oxygen react to form water, as this chemical equation shows:

$$2H_2 + O_2 \rightarrow 2H_2O, \text{ or}$$

Hydrogen + Oxygen → water

If hydrazine is oxidized, additional nitrogen is formed which is a normal constituent of air, and also safe:

$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$, or
Hydrazine + Oxygen→Water + Nitrogen

You may be tempted to say that if hydrogen is such a "clean" fuel, we can just burn hydrogen in air and get pure water as the combustion product plus power. Burning hydrogen would indeed be a considerable improvement over burning coal, oil, or gasoline. However, when air is burned, a large amount of nitrogen is drawn into the combustion chamber and heated to roughly 1000°C. At that temperature, it partially reacts with oxygen and forms oxides of nitrogen. So, even though the reaction product of the main reaction is pure drinking water, the side reaction spoils it all by making the resulting water unsuitable to drink. If hydrogen and oxygen react in a fuel cell at room temperature, that problem is eliminated.

## Space-age power

The desirable characteristics of fuel cells led to the development of various systems ranging in size from 5-watt portable units, to the kilowatt (kW) power level for military applications, on up to large stationary plants delivering megawatts of power. The lower-power fuel cells were designed primarily for the space program and front-line military use where ease of operation, low maintenance, and low noise are important.

Fuel cells are used solely for power generation of space crafts because of one chief advantage: when power is required for more than a few hours, the battery weight per kilowatt-hour as a function of its operational life is far superior to that of conventional battery cells. A relatively light-weight fuel cell can have a lifespan of five to ten times that of a primary battery.

Fuel cells built between 1960 and 1970 for the Gemini and Apollo space missions and in 1980 for the Space Shuttle Orbiter are among the most successful fuel cells to date. They were needed because of their chief advantages over batteries—weight and lifespan. Those fuel cells used cryogenic reactants of hydrogen and oxygen.

Some space-craft power generation systems use solid polymer electrolyte (SPE) technology in the construction of their fuel cells. That type of fuel-cell assembly consists of an ion-exchange membrane-electrode system with gas distribution, current collection, heat removal, and water management. Many of those assemblies are bolted together between end plates to form an SPE stack assembly.

The Gemini system used three 1-kW SPE fuel-cell stacks. The Apollo system used a larger 1.5-kW fuel-cell stack based on a concentrated 45% potassium-hydroxide electrolyte. The Apollo power plant was designed to operate for over 400 hours. The fuel cell in Apollo 8 lasted for 440 hours, the system produced 292 kWh of power, and 100 liters of water.

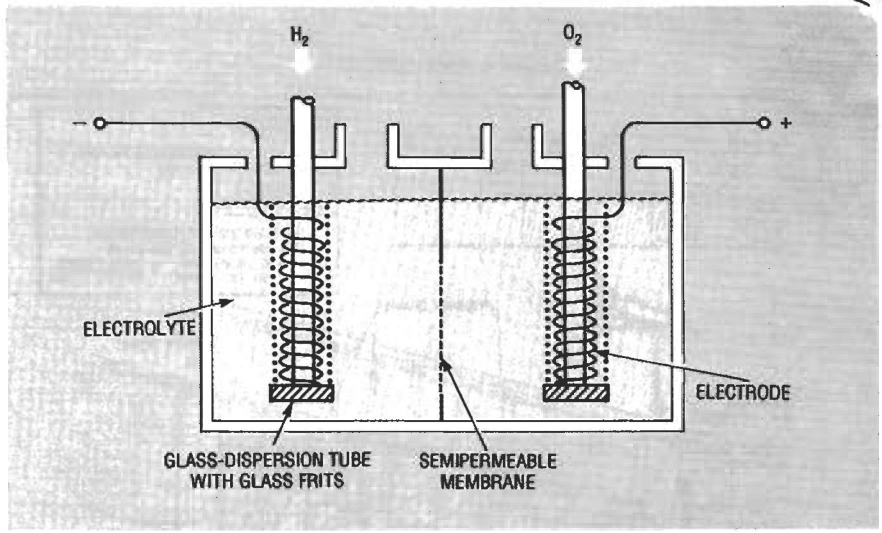


**FIG. 1—THE AUTHOR'S FUEL CELL uses two adjoining chambers separated by a semipermeable membrane. The chambers are filled with an electrolyte. Hydrogen is directed to one electrode, oxygen to the other.**

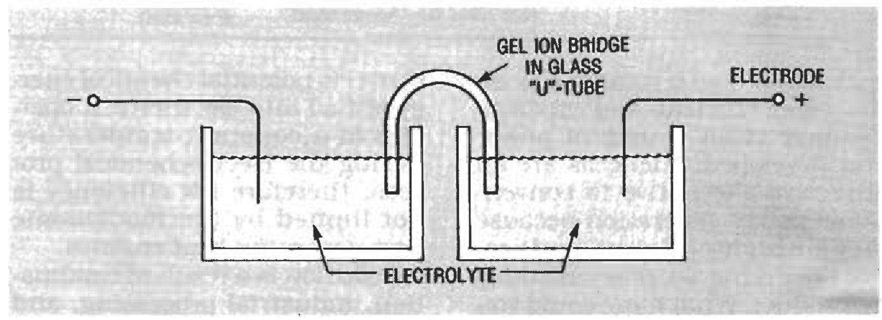


**FIG. 2—IONS TRAVEL ALONG a gel-on bridge in a glass tube placed in the electrolyte solution.**

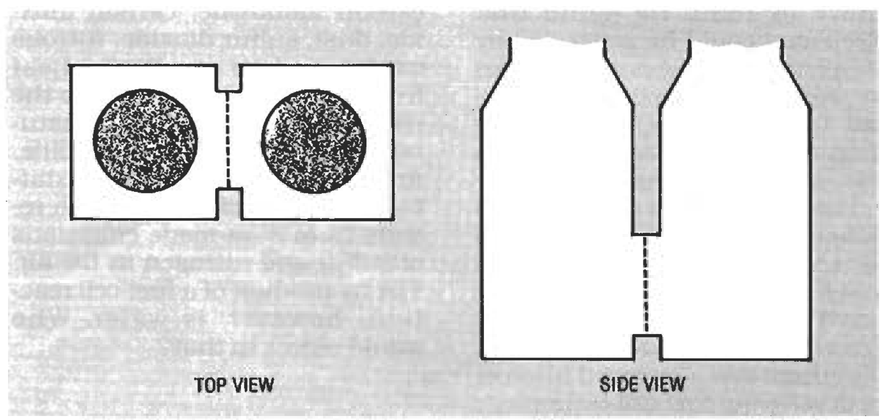


**FIG. 3—THE CONTAINER used for the fuel cell consists of square-based 250-ml polyethylene bottles with holes cut in their sides. A round piece of fine glass was cemented in with sealing wax and an additional layer of beeswax.**

The Space Shuttle system was more advanced in design than either the Gemini or Apollo fuel cells. The Space Shuttle fuel cells are 20 kilograms lighter and deliver six to eight times as much power. Each fuel cell power plant consists of a power section where the chemical reaction occurs, and a compact accessory section connected to the power section, which controls and monitors the power section's performance. The three fuel-cell power plants are coupled to the hydrogen and oxygen reactant subsystem and the power distribution subsystem. The fuel cells generate heat and water as by-products of electrical power generation. The excess heat is directed to Freon coolant loops, and the water to a potable water storage subsystem.

Some power specifications of each fuel-cell power plant are:

- 2 kilowatts at 32.5 VDC.
- 12 kilowatts at 27.5 VDC.
- 7 kilowatts continuous power.
- 12 kilowatts peak.
- All three fuel cell power plants are capable of supplying a maximum continuous output of 21,000 watts with 15 minute peaks of 36,000 watts.

Some experimental fuel cells have been considered for use with vehicles. The major prohibiting factor in their use is the difficulty in reliably containing hydrogen gas, and the possibility of an explosion. Also, special fuels such as hydrogen, methanol, and hydrazine are more expensive than hydrocarbon fuels.

Many advanced fuel-cell designs have been developed for power utility applications, but because of the typical problems of fuel storage and cost effectiveness, they have not been widely used.

**CHEMICALS USED IN FUEL CELLS**

- **Hydrogen—A colorless and odorless gas which is sold compressed in steel bottles. Small lab-size bottles are available together with simple low-priced reducing valves. Hydrogen is not poisonous, but extremely flammable and forms explosive mixtures with air.**
- **Oxygen—Also is sold in compressed form in lab-sized bottles. It is not toxic but must be kept from fire or flame since it will support combustion and can make a four alarm fire out of a glowing match.**
- **Hydrazine—Anyone not used to working with dangerous chemicals should not handle this compound. It is carcinogenic and should be dispensed in a hood only. Hydrazine should be handled with rubber gloves.**
- **Hydrogen peroxide 30%—Most everyone knows this chemical as a 3% solution for bleaching or wound treatment. The 30% concentration will bleach the skin and is dangerous when swallowed. Handle with rubber gloves.**
- **Sulfuric acid—It is poisonous when swallowed. It can blind you if splashed in the eye. It will burn holes in your clothes. A solution in water should be prepared by slowly pouring small amounts into plenty of cold water while stirring with a glass rod. Handle with rubber gloves.**
- **Potassium hydroxide solution 30%—Potassium hydroxide is a strong base and is poisonous. 300 grams are dissolved in 900 milliliters of cold water. Let it stand and cool off. Store in a plastic bottle with cap. Handle with gloves, it can damage the skin.**
- **Palladium dichloride—Dark brown crystals soluble in water. Moderately poisonous when swallowed. Dissolve 2 grams in 100 milliliters of water.**

## An experimental fuel cell

The author was able to build a successful experimental fuel cell by the technique described below. We must, however, issue this word of caution: This product should *NOT* be built or experimented with in any way except under the direct supervision of someone who is highly qualified in the fields of chemistry or chemical engineering. Some chemicals and gaseous by-products in a fuel cell could be toxic and/or explosive! All dangerous chemicals are listed in the sidebar. You must be familiar with proper handling and disposal of any chemicals used.

The author's experimental fuel cell uses two adjoining chambers separated by a membrane, as shown in Fig. 1. An electrode with catalytic properties is placed into each chamber. Both chambers are filled with a liquid electrolyte. One electrode is then purged with hydrogen gas, the other with oxygen or air, and a voltmeter is connected across the electrodes.

In order to be able to build a fuel cell you should be familiar with semipermeable membranes and catalysts. Semipermeable means that only some ions can pass through it but other matter is retained. In actual applications, separation of ions is not perfect, and some leakage usually occurs, and is permissible. Total blockage on the other hand would inhibit a reaction. The following materials could be used as semipermeable membranes:

- Unglazed discs of baked clay (an old clay flower pot).
- Fine glass frits (the partly fused mixture of sand and fluxes which glass is made of).
- Cellophane.
- Wet plaster.
- Moist, or hardened cement.
- Zinc oxide or zinc chloride cement.
- Certain types of plastic foam.
- Silicic acid gel, prepared by slowly acidifying sodium silicate solution.
- Gelatin saturated with salt.

Clay, cement or plaster discs should be as thin as possible. The gels should be used to build ion bridges according to Fig. 2. Glass frits can be bought at lab supply houses and are best for this use. If glass frits are used, the gases move upward, and stay in the proper place. Any fair separation will do. The author used two square polyethylene bottles and a large fine glass frit which was glued into holes cut in the sides of the bottles (Fig. 3).

In order to get hydrogen and oxygen to react at room temperature they must be coaxed a little. Without the proper catalyst, nothing at all happens.

A catalyst is a compound that hastens reactions without actually taking part in the reaction. If you set up a $H_2/O_2$ fuel cell with sulfuric acid and carbon electrodes for instance, there will be no electrical energy generated. If platinum- or palladium-coated carbon electrodes are used, the reaction gets going. Union Carbide has used this method and supply such electrodes.

The method the author used to plate carbon was to wrap platinum wire and a platinum net around the carbon rods, which works very well. An easy and low-priced way of producing a large surface of palladium is to coat nickel netting with palladium. That can be done by immersing a nickel net in a 2% solution of palladium dichloride over night. The coating looks black. Palladium coated nickel acts like pure palladium. The author had a supply of platinum on hand or he would have used the approach just mentioned.

The amount of palladium dichlorides you need costs about $20.00. Platinum, palladium, silver, nickel (especially Raney nickel) have been used as catalysts in different fuel cells. Platinum-group metals work so well because they have an affinity to hydrogen and will pick up considerable amounts of it for storage in their crystal lattices. A platinum electrode saturated with hydrogen, therefore, is practically an electrode of solidified hydrogen. The pure metal is too expensive, so palladinized nickel, platinized carbon or Raney nickel on a carrier matrix are the first choice.

Impinger-type glass tubes with frits or aquarium-type dispersion tubes are used as gas inlet tubes. The electrodes are wound around the tube in a coil. Copper wire leads are connected. The electrolyte is a 30% potassium hydroxide solution. Oxygen and hydrogen can be bought in small laboratory bottles with reasonably priced lab-reduction valves.

Hydrogen can also be produced from zinc and diluted hydrochloric acid. That leaves you with a solution of zinc chloride which is hazardous to the environment and must be disposed of in a manner prescribed by law.

The entire experiment was conducted in the open air in order to allow the flammable hydrogen to disperse. Rotameters were used to check gas flow. They can be replaced by bubble indicators if you prefer. Gas flow was 10-20 liters per hour (l/h) but can be varied. Oxygen flow should be about ½ that of hydrogen flow. The reaction is sluggish at the beginning as hydrogen has to saturate the platinum metal surface.

An indication of about 10 mV may occur for several minutes, which will then rise. There may be steps in this rise, therefore it may be necessary to put a little drain on the system by using a 100-ohm resistor connected across the 2 chambers. It can be removed again after a few minutes. That helps overcome polarization effects. The author measured 998 mV after about 10 minutes. To compensate for the slow start, the cell will generate a voltage for some time after the hydrogen is turned off.

After you finish, the potassium hydroxide solution should be poured into a well-capped plastic bottle. It can be used over again, but it will accumulate carbonate which makes it less effective. Some prefer diluted sulfuric acid for the same purpose because it keeps longer. Air can, in most cases, be substituted for oxygen. The amount must be raised, however, since only ⅕ of air is oxygen. Hydrogen peroxide can be used in place of oxygen but it dilutes the electrolyte.

Hydrogen can be replaced with hydrogen-containing gases such as "city gas" produced from coal, containing hydrogen, methane, and carbon monoxide. Several variations of fuel cell components that react at room temperature are shown in Table 1. The fuel cell can also be used as a one-shot unit for liquid fuel, namely hydrazine, and 30% hydrogen peroxide. Both compounds are rocket fuels but can be controlled very well. They are, however, highly toxic and poisonous. Because hydrazine is known to be a carcinogen, one should not work with it unless you are familiar with handling very poisonous substances. Hydrogen peroxide at 30% concentration will bleach your hands and should also be handled very carefully.

**TABLE 1**
**FUEL-CELL COMPONENTS THAT REACT AT ROOM TEMPERATURE**

| Fuel | Oxidant | Electrode Material | Electrolyte | Catalyst | Recorded Voltage (mV) |
|---|---|---|---|---|---|
| hydrogen 20 l/h | oxygen 10 l/h | carbon | 5% sulfuric acid | none | No reaction |
| hydrogen 20 l/h | oxygen 10 l/h | carbon/platinum | 5% sulfuric acid | platinum | 533 |
| hydrogen 20 l/h | air 40 l/h | carbon/platinum | 5% sulfuric acid | platinum | 469 |
| hydrogen 20 l/h | oxygen 10 l/h | platinum | 30% potassium hydroxide | platinum | 988 |
| hydrogen 20 l/h | oxygen 10 l/h | palladium on nickel | 30% potassium hydroxide | palladium | * |
| 2 ml 24% hydrazine hydrate | 10 drops 30% hydrogen peroxide | palladium on nickel | 30% potassium hydroxide | palladium | * |

*This reaction was not tried by the author, but works according to literature on the subject.

Fuel cells have been run with "steam reformed" methyl alcohol. At 200°C, methyl alcohol reacts with water to form hydrogen and carbon dioxide as shown in the following equation:

$$CH_3OH + H_2O \rightarrow 3H_2 + CO_2$$, or
methyl alcohol + water→hydrogen + carbon dioxide

At temperatures higher than room temperature many other reactions are possible. Some of them allow a separation and collection of the water formed.

You're probably wondering why fuel cells are not more widely used. The first big drawback is cost, which is always a primary consideration in power generation. Hydrogen is an expensive fuel compared to other types of fuels, and the storage of hydrogen is still a problem. Perhaps in the future, we'll use solar energy on a large scale to decompose water into hydrogen and oxygen which can then be stored. When energy is needed, the two gases can be recombined to water in a fuel cell. **R-E**