SECTION 3 - FUELING THE FUTURE

Vocabulary

anode	**dissociated**	**fuel cell**	**positive terminal**
bipolar plate	**electrode**	**hydrogen**	**synthesis gas**
catalyst	**electrolysis**	**ion**	**synthesize**
cathode	**electrolyte**	**negative terminal**	

Hydrogen as an energy source

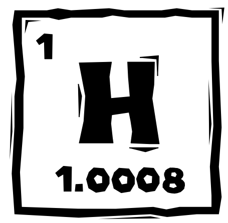


Figure 3-3-1
Hydrogen, the simplest and most abundant element in the universe, holds great promise as a fuel.

Hydrogen, the lightest element, may someday replace heavier compounds as a source of energy for transportation and many other applications. Although low-cost technology to allow this odorless, colorless, diffuse gas to be collected and used may be decades away, hydrogen's potential to be a clean energy source has some people hopeful about a future "hydrogen economy" that would not rely on fossil fuels.

Finding sources of hydrogen fuel is harder than you might think. Although hydrogen is the most abundant material in the universe, very little of it exists in free form in our atmosphere. It must be extracted from other compounds.

Natural gas and methanol provide much of the raw material for hydrogen today. Another source is water (H_2O). The hydrogen and oxygen in water can be **dissociated** with an electric current in a process called **electrolysis** *(see below)*.

FYI

'Making' Hydrogen

Two methods are generally used to produce hydrogen gas: electrolysis and **synthesis gas** production.

Electrolysis uses electrical energy to separate the hydrogen and oxygen atoms in water molecules. The electrical energy can come from any electricity source, including renewable fuels and solar energy. Some scientists envision a future in which large arrays of solar panels will provide this electric current. Other scientists and officials believe that electrolysis is unlikely to become the predominant method for producing large quantities of hydrogen. Non-electric ways of producing hydrogen, such as biomass gasification, may require less primary energy and will potentially cost less.

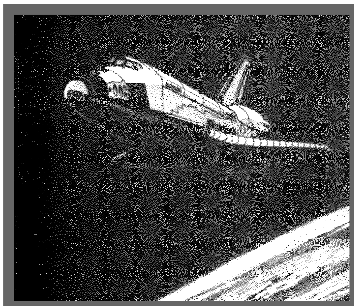
The predominant method of producing synthesis gas (a combination of carbon monoxide and hydrogen) is steam reforming of natural gas. In a steam reformer, methane or another hydrocarbon is passed over a **catalyst** along with steam. The process takes place under high temperatures and pressures using a special receptacle. The reaction converts the methane and water to CO and hydrogen.

Hydrogen can be burned in a modified internal combustion engine, producing extremely low emissions. A project in El Segundo, California, by the group Clean Air Now is researching the viability of vehicles fueled by hydrogen. The project includes an electrolysis station to generate hydrogen gas using electric power from solar panels. The other components are a fueling station and several vehicles modified to burn hydrogen.

Fuel cells

Another mechanism for producing energy using hydrogen gas is the **fuel cell**. A fuel cell uses hydrogen to produce an electric current. A fuel cell is like a battery—it has electrodes, electrolyte, and positive and negative terminals. But it produces electric current continuously rather than recharging and storing chemical energy.

Fuel cells require no recharging. As long as fuel and air are supplied, they can continue to produce energy indefinitely. The chemical process can be more efficient than combustion because it does not waste as much energy in creating heat. A fuel cell can be about twice as efficient as a gasoline-fueled internal combustion engine, and its primary by-product is water.



FYI

Space Power

The first fuel cell was developed in 1839 by Sir William Grove. While conducting an electrolysis experiment, Grove reasoned that he could reverse the process to generate electricity.

But it wasn't until the 1950s that a Cambridge University engineer, Francis Bacon, succeeded in building a fuel cell that could produce practical amounts of electricity over prolonged periods.

Later, at the beginning of the "Space Age," Pratt and Whitney Aircraft Corporation developed a fuel cell for the U.S. Apollo space program.

By 1965 fuel cells were routinely used in space flight, and today space shuttles use fuel cells to power such things as computers, life-support systems, and lighting. In addition, the cells do double duty, **synthesizing** pure water for the astronauts to drink and use.

When fueled with hydrogen and air or oxygen the cells provide power without chemical emissions. However, they tend to be heavy, and extracting and storing hydrogen as a fuel is still expensive. So fuel cells are primarily used where their characteristics are more important than their price tag—as in the self-sufficient, enclosed world inside a shuttlecraft or space station.

Fuel cells can be used wherever electricity is needed to power mobile phones, cars, houses, and laptops. Miniature models for a new "tiny" fuel cell are under design. Home-sized fuel cells are being tested in prototype homes across the country. More than 150 fuel cell power plants have been installed in Japan, North America and Europe.

Efficiency, cleanliness, quiet operation, and abundant fuel supply may promote widespread fuel cell use in the future, including use as power for personal transportation. However, the engineering work needed to make this practical is still at the research and development stage.

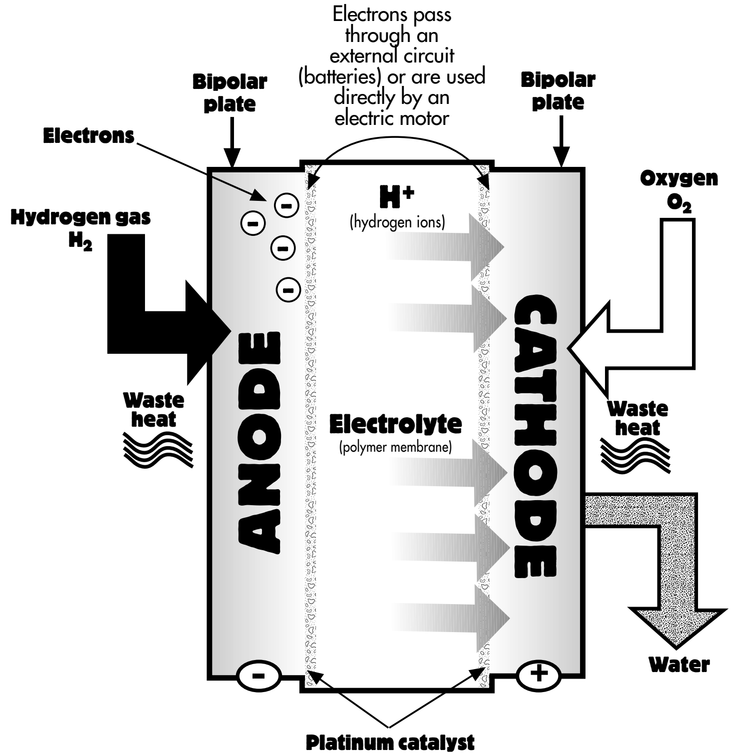


Figure 3-3-2 Proton exchange membrane fuel cell where $2H_2 + O_2 \rightarrow 2H_2O$

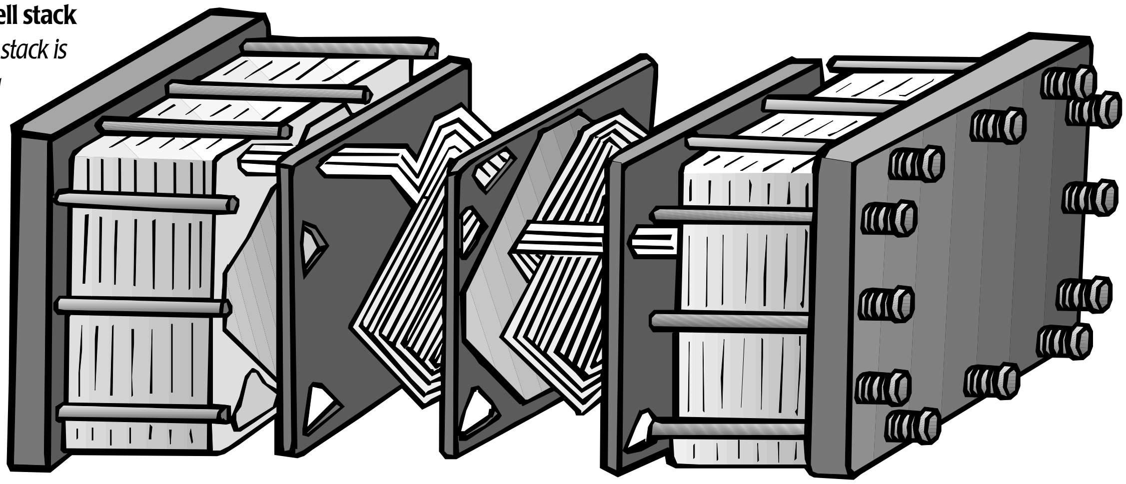
Fuel cell operation

In a proton exchange membrane (PEM) fuel cell, one of four types under development, hydrogen reacts with oxygen in the presence of a platinum catalyst to create voltage between two electrodes. A membrane serves as the solid electrolyte, instead of a liquid electrolyte as in a lead-acid car battery. Each fuel cell, which is actually very thin, is sandwiched between two **bipolar plates** (graphite sheets machined to create flow channels for hydrogen, air, and water). Each fuel cell produces just under one volt of electricity. To produce a higher voltage, many cells are sandwiched together in a stack (Figure 3-3-3).

Hydrogen is fed through channels in one bipolar plate. A platinum **catalyst** starts a reaction at the anode (negative electrode) that strips one electron from each hydrogen atom. The electrons flow through a circuit, providing power. The remaining positive hydrogen ions flow through the **polymer** membrane to the platinum-coated cathode. Oxygen is drawn from the air through the other bipolar plate, and here at the cathode, it combines with the hydrogen ions to form water.

Since 1984, research on proton exchange membrane fuel cells has reduced the amount of expensive platinum needed by more than 100 times. Less expensive materials for the bipolar plates, such as plastics and coated steel, are also being tested. By making the plates thinner, researchers have shrunk fuel cell size and weight as well.

Figure 3-3-3 Fuel cell stack
A portion of a fuel cell stack is highlighted, showing a single cell.



Fuel-cell vehicles

Several automobile manufacturers are working on fuel cells for vehicles. Daimler Chrysler, in alliance with Ford, has provided cars for the project in El Segundo as well as the NECAR 4, which is being developed in Europe. General Motors has also developed a fuel-cell car called the Precept.

Fuel-cell vehicles are electric vehicles that do not have to recharge. The vehicle operates on hydrogen or another hydrogen-bearing fuel such as gasoline or natural gas, in the same way that an internal-combustion vehicle does. The hydrogen is separated from these fuels in a reformer and is fed into the fuel-cell stack. The fuel cell then produces

Photo courtesy of Ballard

Bringing the Future Closer

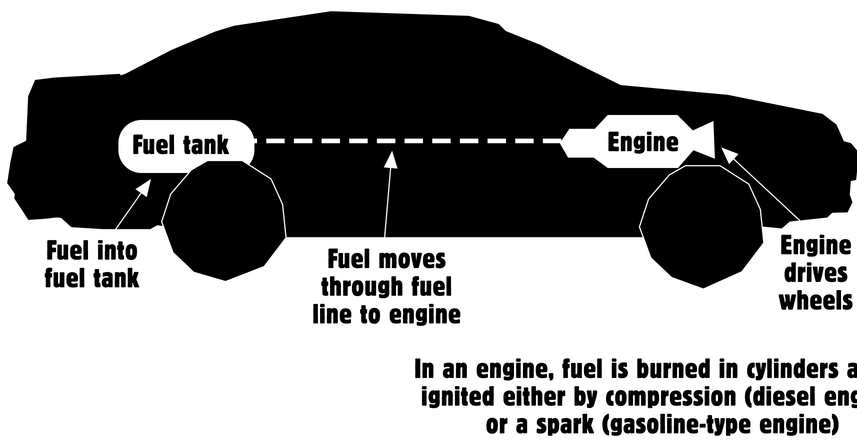
A Canadian company, Xcellsis, has been working to develop practical applications for its fuel-cell design. The design converts natural gas or methanol to hydrogen and then to electricity. The engine can also skip the reformation step and use pure hydrogen as fuel.

Xcellsis is field-testing prototypes of a full-size transit bus powered by its fuel-cell technology. The company is also working on a design for a fuel-cell locomotive to replace diesel ones putting out 3,800 horsepower. Motor-vehicle manufacturers such as Xcellsis' partners Daimler-Chrysler, Ford, General Motors and others are developing unique fuel cells for near-zero emission vehicles. Other fuel developers are evaluating the use of gasoline as a source of hydrogen on the vehicle.

Internal-combustion engine vehicles

Fuels

Alcohol fuels
Biodiesel
Gasoline
Hydrogen
Natural gas
Propane



Fuel-cell vehicles

Fuels

Alcohol fuels
Gasoline
Hydrogen
Natural gas
Other fuels are under development

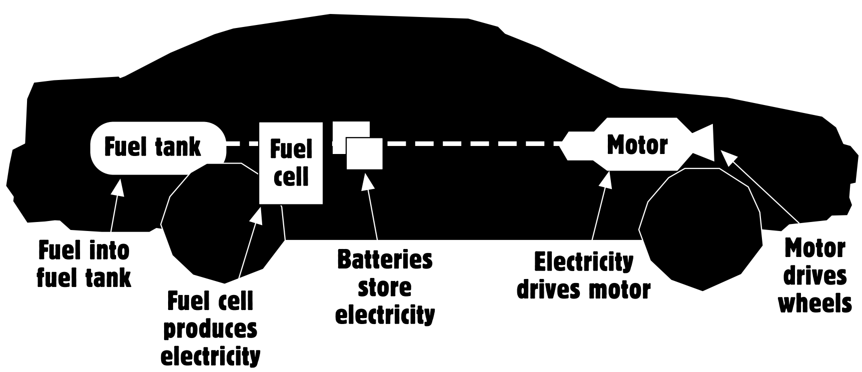


Figure 3-3-4a
Internal-combustion engine vehicles and fuel-cell vehicles

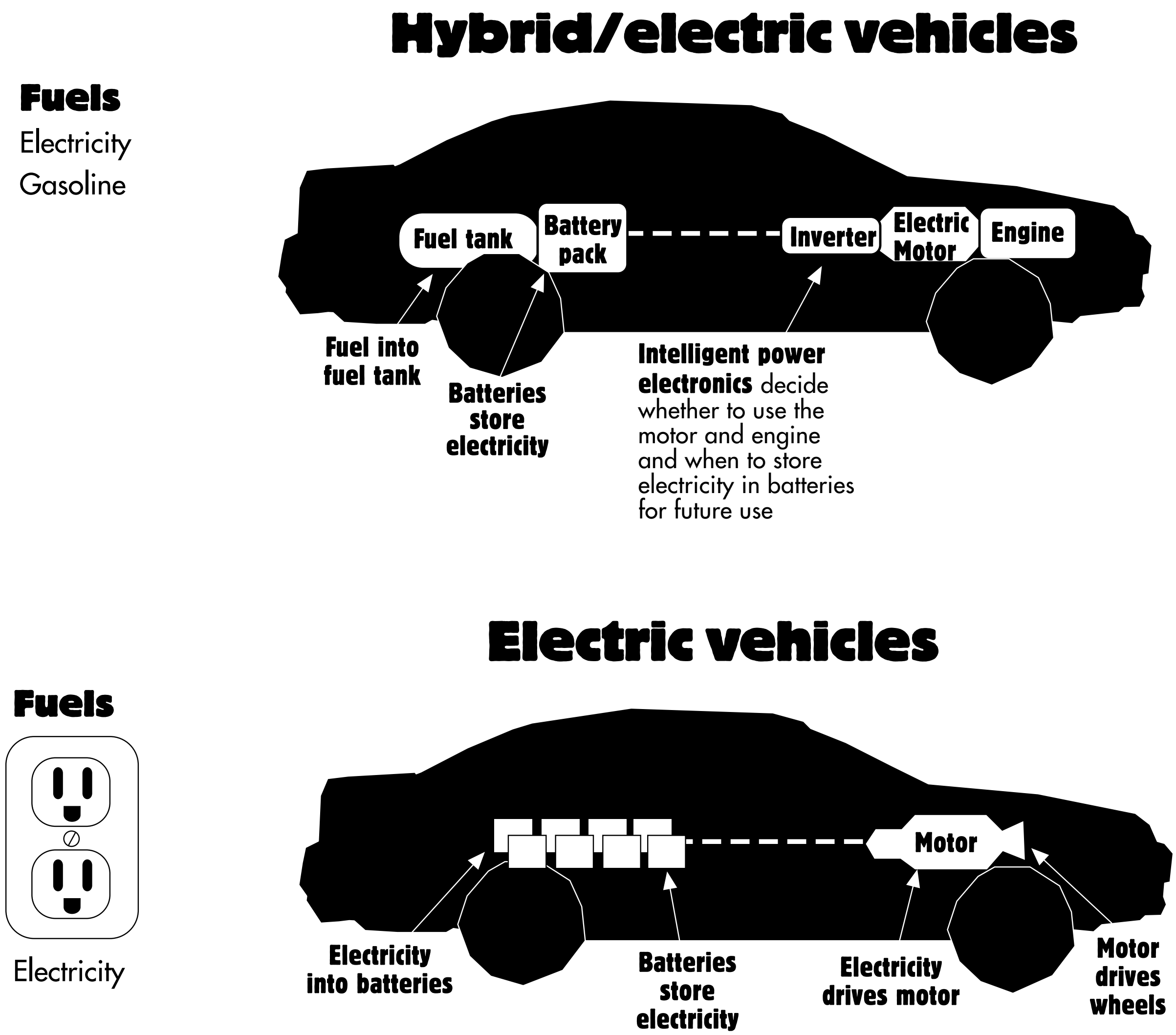


Figure 3-3-4b
Hybrid/electric and electric vehicles

electricity which is stored in batteries or used directly by an electric motor. For a comparison of fuel-cell, internal-combustion, hybrid/electric, and electric vehicles see figures 3-3-4a and 3-3-4b.

Transition to hydrogen power

Advocates of compressed natural gas (CNG) vehicles believe that natural gas technology and infrastructure may provide a bridge to the widespread use of fuel cells to power vehicles.

A reformation process that produces hydrogen from natural gas or other hydrocarbons can take place on board a vehicle. Reformation breaks the bonds between the source's hydrogen atoms and the rest of the molecule, releasing the hydrogen for use.

Alternatively, hydrogen for fuel-cell use can be stored in high-pressure tanks like those developed for CNG vehicles. The physical properties of hydrogen gas are similar to those of methane, the principal substance in natural gas. Uncompressed hydrogen gas occupies about 3,000 times more space than gasoline under normal conditions.

Compressors at CNG refueling stations could be modified to fill the hydrogen tanks of fuel-cell vehicles. Technologies that store greater volumes of natural gas onboard vehicles will also help move fuel-cell vehicles toward a practical environmental solution.

Fueling the Future Resource List

http://216.51.18.233/fct/goingon.html
Breakthrough Technologies Institute, Washington, D.C.
This "mini-site" summarizes activity on developing fuel-cell vehicles. The home site at http://216.51.18.233/index_e.html provides broader coverage of fuel cell types, operating principles and companies.

www.howstuffworks.com/fuel-cell.html
Howstuffworks.com, Inc.
Explains how fuel cells work, problems with fuel cells, efficiency and applications.

http://www.lanl.gov/worldview/science/features/fuelcell.html
Los Alamos National Laboratory, U.S. Department of Energy
Has a 36-page fuel-cell tutorial at
http://www.lanl.gov:80/energy/est/transportation/trans/pdfs/fuelcells/fc.pdf.