

Fuel Cells: Bringing the Future to the Present

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In recent decades, there has been an increasing concern about air pollution and the greenhouse effect. According to the Environmental Protection Agency (EPA), the United States alone attributed to 26 percent of the total greenhouse emissions in the past decade.¹ The Department of Energy estimates that the world emission rate of carbon dioxide will rise from 6.1 billion metric tons carbon equivalent in 1999 to 9.8 billion metric tons in 2020, and the world energy consumption rate will increase by 59 percent in the next twenty-one years.² The cloudy environmental outlook and energy shortage worries have galvanized tremendous effort to develop alternative power sources.

Fuel cells have the potential to become the predominant energy provider in the future. Some applications are already in the testing and marketing stages, but significant strides must be made before they can become mainstay. By examining some of the recent advances in automobiles and portable electronics, we can draw a picture the future of fuel cell technology closer to reality.

Fuel Cell Basics

First constructed by Sir William R. Grove in 1839, a fuel cell is an electrochemical device in which

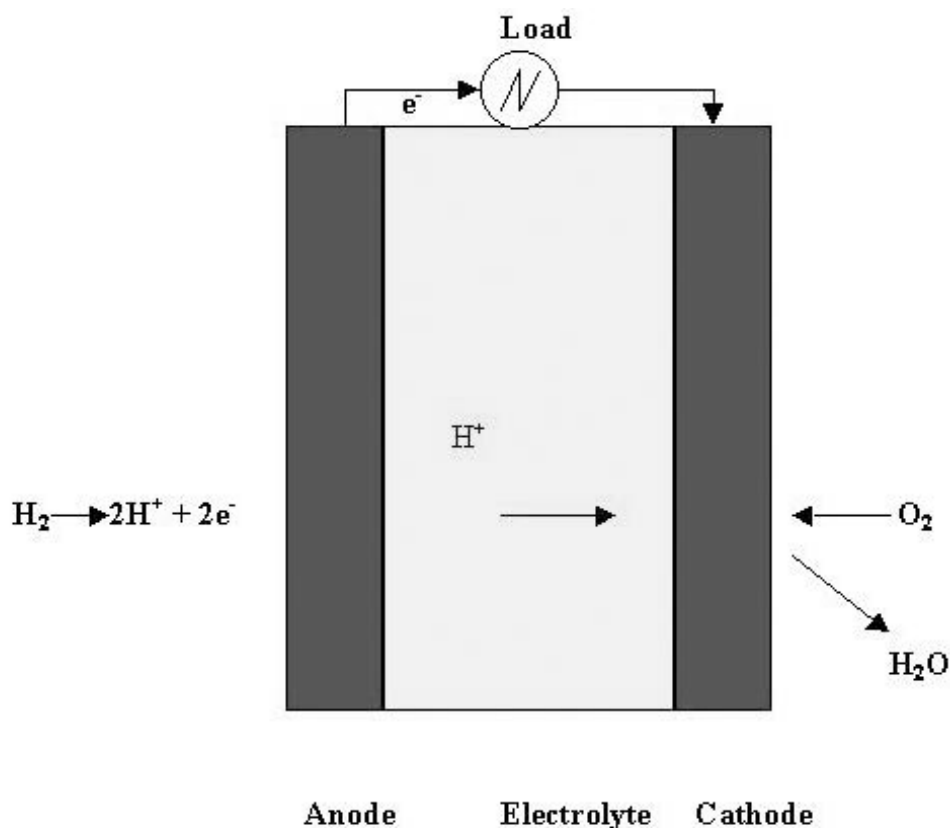


Diagram of a fuel cell.



Fuel cells help power the NASA Helios prototype

hydrogen and oxygen react to produce electricity, heat, and water. It consists of an electron-repelling anode, an electron-attracting cathode, and an electrolytic membrane that conducts ions to form a closed circuit. The anode first separates hydrogen into protons and electrons. The protons then pass through the electrolytic membrane to the cathode, while the electrons flow through an external circuit. Finally, the cathode combines the oxygen, protons, and electrons to form water and heat. Individual fuel cells can be stacked together to generate more power. Usually, catalysts such as platinum speed up the rate of the reaction.

Fuel cells have been preferred for many different applications because of certain attractive features. While internal combustion engines release high quantities of exhaust gases like carbon dioxide, carbon monoxide, methane, and nitrogen oxides, fuel cells release only water as a by-product. They can also achieve higher efficiencies than heat engines because they convert chemical energy directly to electrical energy, while internal combustion engines convert chemical to mechanical energy using heat as an intermediary. Other advantages of fuel cells include low noise output and the continual generation of power.

Nevertheless, fuel cells still operate below ideal efficiencies due to energy losses from equipment, power conversion, and fuel processing. Unlike oxygen that is supplied from the atmosphere, hydrogen is often obtained from a reformer that breaks down hydrogen-rich fuels such as ammonia, natural gas, ethanol, and methanol. Moreover, the direct current output of fuel cells requires conversion to alternating current through an inverter. The energy losses associated with the reformer and inverter, combined with

losses due to the equipment, reduce the efficiency to about 40 percent.³ This value is still higher than current internal combustion automobiles that might reach the ideal efficiency of 35 percent, but a realistic value of only 15 percent.⁴

While there are distinct advantages in using fuel cells, issues with fuel storage and operating costs hinder them from conventional use. Current means of hydrogen storage in li-

quid, compressed gas, and metal hydride forms all suffer from critical disadvantages: Liquefying hydrogen reduces a significant amount of stored energy, compressed hydrogen gas can be dangerous, and metal hydrides can be heavy.⁵ Hydrogen-rich fuels such as methanol require a reforming process that produces hydrogen as well some contaminants. In addition, high costs hold back commercial applications. For example, platinum averages \$180 per kilowatt of power produced and 50 kW is necessary to accelerate an automobile.⁴

The Power of Fuel Cells

Despite drawbacks, fuel cells have brought astronauts to space since the Gemini and Apollo missions. Now, from automobiles to portable electronics, fuel cells are finding useful applications on earth. Here are some recent developments.

Mobile Power Units

Automakers are optimistic about using fuel cells to produce a zero-emission vehicle (ZEV). Already, Ballard Power Systems released the world's first fuel cell-powered 32-foot transit bus in 1993. In 1997, DaimlerChrysler introduced the NEBUS (New Electric Bus) using Ballard fuel cells, and the cell efficiency was an impressive 55 percent. Not only was the NEBUS a ZEV, it was also able to reach 80 kilometers per hour with little noise. So far, the Chicago Transit Authority (CTA) and TransLink are collecting data from several prototype buses for public reactions to fuel cell-powered buses, needs of transit authorities and bus users, performance, and maintenance. Ballard projects commercial production of the NEBUS by the year 2002.⁶

An even greater interest is in the production of fuel cell-powered cars. DaimlerChrysler has also developed several generations of fuel cell-operated cars called the NECAR (New Electric Car). Most recently, the NECAR 5 was the first methanol-fueled vehicle with a reformer within the underbody of a Mercedes-Benz A-Class, making it comparable to normal A-Class vehicles in available space.⁷ The latest ZEV by General Motors, the HydroGen1, is powered by a 75-horsepower electric motor and run on hydrogen fuel.⁸ As production costs slowly decline, fuel cell-powered cars may eventually become big competitors in the car market.

Other applications are soaring. NASA's solar-powered Helios prototype is an uninhabited aerial vehicle developed for long periods of earth science imaging and atmospheric sampling missions. During the day it utilizes solar arrays to operate an electrolyzer that separates water into hydrogen and oxygen. By night, hydrogen and oxygen generate electricity from fuel cells.⁹

Portable Electronics

Aside from large vehicles, fuel cells have also found homes in smaller applications in which their main competitor is the battery. Fuel cells have the advantage of convenience over batteries because they do not need to be recharged or replaced. Moreover, fuel cells are more efficient. A methanol-powered fuel cell can run up to twenty times longer than traditional nickel-cadmium batteries while occupying less space. That means that one liter of methanol can operate a laptop continuously for over a week, while conventional lithium-ion batteries have less than a tenth of that energy.¹⁰

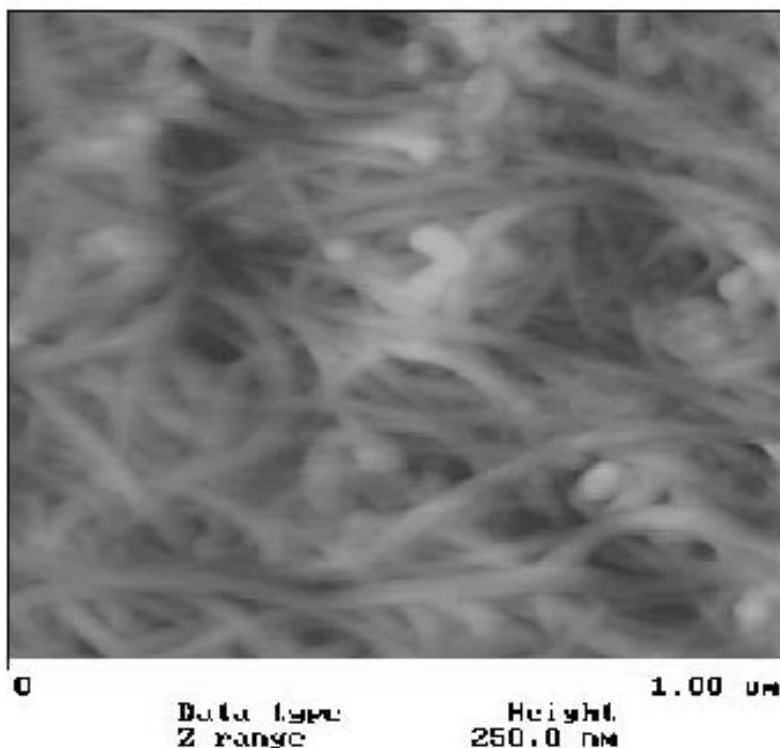
New technologies are on the way; the Fraunhofer Institute for Solar Energy Systems ISE in Germany is developing portable appliances in the 4Cs—computers, cellular phones, camcorders, and cordless tools. Additionally, the development of the banded-structure membrane has helped miniaturize fuel cells while still outputting suffi-

cient voltage. It consists of individual cell domains joined in a series to produce the necessary voltage and a separate hydride unit that stores hydrogen at high densities and low volumes.¹¹ H Power Corporation offers PowerPEM fuel cell systems that range from 35 W to 250 W of power, and they can be used in applications like traffic systems and consumer devices.¹²

Fuel Storage Dilemma

Currently, one of the major challenges in fuel cell technology is the development of lightweight, highly efficient methods of fuel storage. Hydrogen has been dubbed as the ideal energy carrier of the future, but significant improvements must be made before fuel cells become widely used. The solution to this dilemma may be carbon nanotubes (CNTs), which are descendants of the C₆₀ “buckyball.” They consist of sheets of carbon atoms packed in a regular hexagonal pattern and then rolled to form hollow tubes about 1.5 nanometers in diameter.¹³ Since their discovery, by Sumio Iijima in 1991, CNTs have caught the world's attention because of their many remarkable qualities, including super strength, low weight, high electrical conductivity, and temperature stability.¹⁴

Recently, CNTs have been reported to be effective material for hydrogen adsorption. The diameter of CNTs is about two to three times that of a hydrogen atom, so researchers believe that



Carbon nanotube bundles seen under an Atomic Force Microscope (AFM).
Courtesy of Ji Su, NASA Langley Research Center, VA

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hydrogen atoms can be tucked inside as well as between the tubes. The amount of hydrogen uptake is affected by pressure and temperature.¹³

The U.S. Department of Energy (DOE) Hydrogen Plan has established a commercially significant benchmark of 6.5-weight percent hydrogen adsorption and 62 kg H₂/m³ volumetric density. So far, various research groups have shown encouraging results. Dillon *et al.* reported a 5- to 10-weight percent hydrogen uptake at 133 K and 300 torr using single-walled nanotubes (SWNTs), and Ye *et al.* obtained 8.25-weight percent adsorption at 80 K and 100 atm using SWNTs.^{15,16} Lithium-doped CNTs have been

reported to absorb as much as 20-weight percent at 653 K. Ongoing investigations may eventually prove that CNTs are potential hydrogen carriers.

A Bridge to the Future

Since their discovery more than a century ago, fuel cells have proven to be a very efficient method of generating power in an ecologically friendly way. Applications in automobiles and portable electronics have revealed the potential of fuel cells, and current research strives to extend their capabilities. As more innovative technologies develop, the future of fuel cells may be closer to reality than once thought. ■