Fuel cells

Generating clean energy

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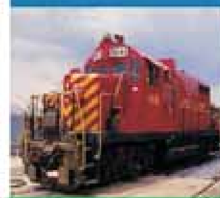
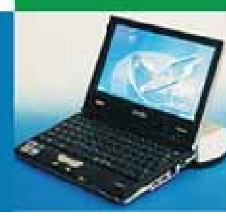




Introduction

A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes, one positive and one negative, called, respectively, the cathode and anode. The reactions that produce electricity take place at the electrodes. Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.

Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution—much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, which is water.

A single fuel cell generates a tiny amount of DC (direct current) electricity. In practice, many fuel cells are usually assembled into a stack or cell to generate more power.

Operation of fuel cells

The purpose of a fuel cell is to produce an electrical current that can be directed outside the cell to do work, such as powering an electric motor or illuminating a light bulb or a city. Because of the way electricity behaves this current returns to the fuel cell, completing an electrical circuit. The chemical reactions that produce this current are the key to how a fuel cell works.

In general terms, hydrogen atoms enter a fuel cell at the anode

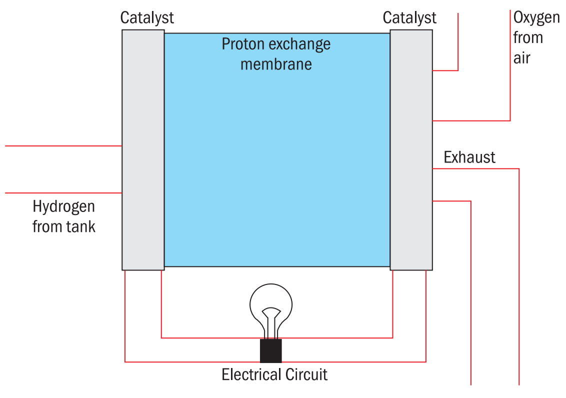


Figure 1 Operation of a fuel cell

where a chemical reaction strips them of their electrons. The hydrogen atoms are now 'ionized', and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work. If AC (alternating current) is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter.

Oxygen enters the fuel cell at the cathode where it combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions. The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction. Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.

The type of fuel also depends on the electrolyte. Some cells need pure hydrogen, and therefore demand extra equipment such as a 'reformer' to purify the fuel. Other cells can tolerate some impurities, but might need higher temperatures to run efficiently. The type of electrolyte also dictates a cell's operating temperature.

Important types of fuel cells

Alkali fuel cells operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide (chemically KOH) in water as their electrolyte. Cell output ranges from 300 W (watt) to 5 kW (kilowatt). Alkali cells were used in Apollo spacecraft to provide both electricity and drinking water. Efficiency is about 70% and operating temperature is 150 to 200 °C.

MCFCs (molten carbonate fuel cells) use high-temperature compounds of salt (like sodium or magnesium) carbonates (chemically, CO_3) as the electrolyte. Efficiency ranges from 60% to 80%, and operating temperature is about 650 °C (1200 degrees F). Units with output up to 2 MW have been constructed, and designs exist for units up to 100 MW. The high temperature limits damage from carbon monoxide 'poisoning' of the cell and waste heat can be recycled to make additional electricity.

PAFCs (phosphoric acid fuel cells) use phosphoric acid as the electrolyte. Efficiency ranges from 40% to 80%, and the operating temperature is between 150 to 200 °C (about 300 to 400 degrees F). Existing PAFCs have outputs up to 200 kW, and 11 MW units have been tested. PAFCs tolerate a carbon monoxide concentration of about 1.5%, which broadens the choice of fuels they can use. If gasoline is used, the sulphur must be removed. Platinum electrode-catalysts are needed, and internal parts must be able to withstand the corrosive acid.

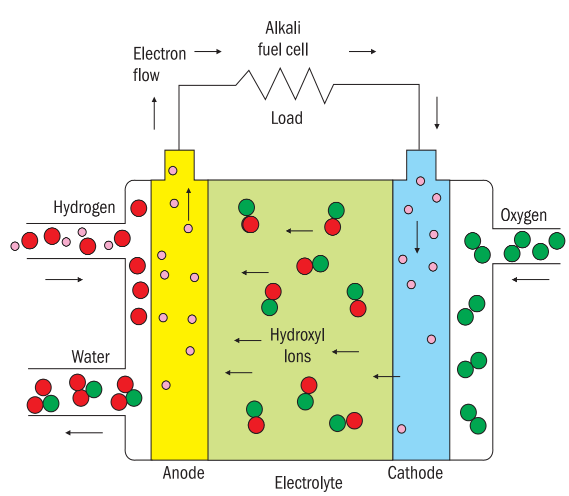


Figure 2 An alkali fuel cell

There are numerous types of fuel cells that have been made. The most common are shown in Table 1. Each type uses different materials and operates at a different temperature.

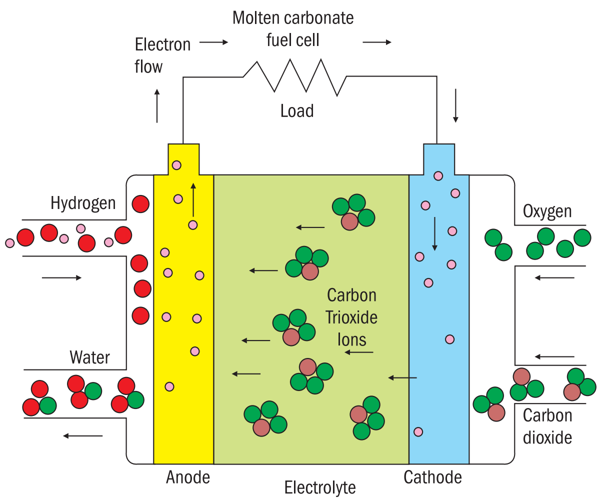


Figure 3 Drawing of a molten carbonate cell

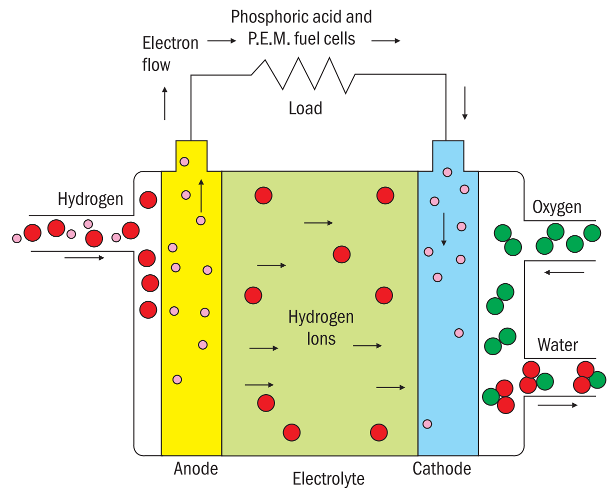


Figure 4 Drawing of how both phosphoric acid and PEM fuel cells operate

Table 1 Types of fuel cells

Type	*Abbreviation*	*Operating temperature*	*Uses*
Solid oxide	SOFC	500–1000 °C	All sizes of CHP
Direct alcohol	DAFC	50–100 °C	Buses, cars, appliances, small CHP
Polymer electrolyte	PEFC	50–100 °C	Buses, cars
Phosphoric acid	PAFC	200 °C	Medium CHP
Molten carbonate	MCFC	600 °C	Large CHP
Alkaline	AFC	50–250 °C	Used in space vehicles

Figure 5 A fuel cell stack

Fuel cell stack

With a fuel cell, chemicals constantly flow into the cell so it never goes dead—as long as there is a flow of chemicals into the cell, the electricity flows out of the cell. Most fuel cells in use today use hydrogen and oxygen as the chemicals. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell. Still, a single fuel cell produces enough electricity for only the smallest applications. Therefore, individual fuel cells are typically combined in series into a fuel stack.

Direct hydrogen fuel cells produce pure water as the only emission. This water is typically released as water vapour. Fuel cells release less water vapour than internal combustion engines producing the same amount of power.

Applications of fuel cells

There are many uses for fuel cells. They are put to use in the automobile industry. Fuel cells are powering buses, boats, trains, planes, scooters, forklifts, and even bicycles. There are fuel-cell-powered vending machines, vacuum cleaners, and highway road signs. Mini fuel cells for cellular phones, laptop computers, and portable electronics are on their way to the market. Hospitals, credit card centres, police stations, and banks are all using fuel cells to provide power to their facilities. Waste water treatment plants and landfills are using fuel cells to convert the methane gas they produce into electricity. Telecommunications companies are installing fuel cells at cell phone, radio, and 911 towers. The possibilities are endless.

Stationary uses

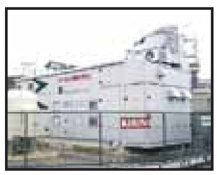
More than 2500 fuel cell systems have been installed all over the world—in hospitals, nursing homes, hotels, office buildings, schools, utility power plants—either connected to the electric grid to provide supplemental power and backup assurance for critical areas, or installed as a grid-independent generator for on-site service in areas that are inaccessible by power lines.

Fuel cell power generation systems in operation today achieve 40% fuel-to-electricity efficiency utilizing hydrocarbon fuels. Since fuel cells operate silently, they reduce noise pollution as well as air pollution, and when the fuel cell is sited near the point of use, its waste heat can be captured for beneficial purposes (cogeneration). In large-scale building systems, these fuel cell cogeneration systems can reduce facility energy service costs by 20% to 40% over conventional energy service and increase efficiency to 80%.

Telecommunications

With the use of computers, the Internet, and communication networks steadily increasing, there comes a need for more reliable power than is available on the current electrical grid, and fuel cells have proven to be up to 99.999% (five nines) reliable. Fuel cells can replace batteries to provide power for 1 kW to 5 kW telecom sites without noise or emissions, and are durable, providing power in sites that are either hard to access or are subject to inclement weather. Such systems would be used to provide primary or backup power for telecom switch nodes, cell towers, and other electronic systems that would benefit from on-site, direct DC power supply.

Landfills/waste water treatment plants/breweries



Fuel cells currently operate at landfills and waste water treatment plants across the country, proving themselves as a valid technology for reducing emissions and generating power from the methane gas they produce.

Transportation

Cars All the major automobile manufacturers have a fuel cell vehicle either in development or in testing right now and several have begun leasing and testing in larger quantities. Automakers and experts speculate that the fuel cell vehicle will not be commercialized until at least 2010.

Buses Over the last four years, more than 50 fuel cell buses have been demonstrated in North and

South America, Europe, Asia, and Australia. Fuel cells are highly efficient, so even if the hydrogen is produced from fossil fuels, fuel cell buses can reduce transit agencies' CO2 emissions. And emissions are truly zero if the hydrogen is produced from renewable electricity, which greatly improves local air quality. Because the fuel cell system is so much quieter than a diesel engine, fuel cell buses significantly reduce noise pollution as well.

Scooters In spite of their small size, many scooters are pollution powerhouses. Gas-powered scooters, especially those with two-stroke engines, produce tailpipe emissions at a rate disproportionate to their small size. These two-stroke scooters produce almost as much particulate matter and significantly more hydrocarbons and carbon monoxide as a heavy diesel truck. Fuel cell scooters running on hydrogen will eliminate emissions – in India and Asia where many of the population use them – which is a great application for fuel cells. .

Trains Fuel cells are being developed for mining locomotives since they produce no emissions. An international consortium is developing the world's largest fuel cell vehicle, a 109 metric tonne, and 1 MW

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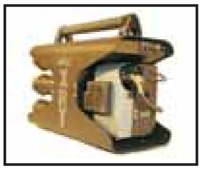
locomotive for military and commercial railway applications.

Planes Fuel cells are an attractive option for aviation since they produce zero or low emissions and barely make any noise. The military is especially interested in this application because of the low noise, low thermal signature, and ability to attain high altitude. Companies like Boeing are heavily involved in developing a fuel cell plane.



Portable power Fuel cells can provide power where no electric grid is available, and they are quiet, so using one instead of a loud, polluting generator at a campsite would not only save emissions, but also won't disturb nature. Portable fuel cells are also being used in emergency backup power situations and military applications. They are lighter than batteries and last a lot longer, especially important to soldiers carrying heavy equipment in the field.

Consumer electronics Fuel cells will change the telecommuting world, powering cellular phones, laptops, and palm pilots hours longer than batteries. Companies have already demonstrated fuel cells that can power cell phones for 30 days without recharging as aksi laptops for 20 hours. Other applications for micro fuel cells include pagers, video recorders, portable power tools, and low-power remote devices such as hearing aids, smoke detectors, burglar alarms, hotel locks, and meter readers. These miniature fuel cells generally run on methanol, an inexpensive wood alcohol also used in windshield wiper fluid.

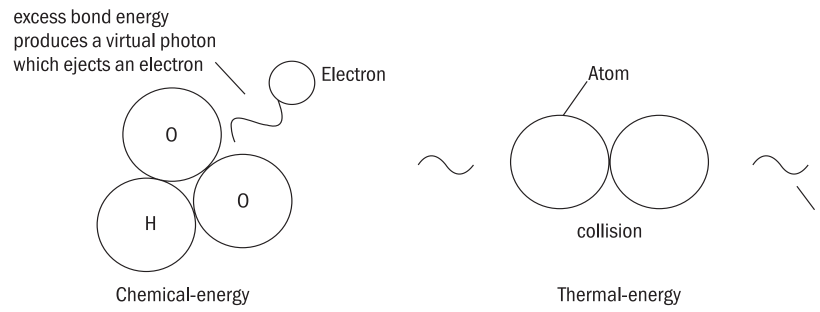


Figure 6 Virtual photons are closely coupled and real photons travel alone through space

Temperament vs temperature

A fuel cell creates electricity, which is a form of external energy, directly from the energy in chemical fuels without an intermediate conversion into thermal energy. When a hydrogen atom bonds to an oxygen molecule, not as much total energy is required in the newly formed water molecule as in the separate hydrogen and oxygen molecules. A certain amount of energy can be released. When the hydrogen–oxygen bonding occurs, the excess energy under ideal conditions can be released in a single package for each newly created bond. In other words, the excess energy is not dribbled out in multiple randomly sized amounts of energy. This single package is called a virtual photon and is illustrated in Figure 6. Photons are not marble-like objects but rather tiny localized vibrations of energy that travel through space. They cannot be detected and so are called virtual. They are referred to as a package because this energy does not split up while travelling to its destination and neither do the two packages join together. This virtual photon can under ideal conditions be transferred directly to other chemical system through, for example close contact, without being spilled to the surroundings. Such a transfer of energy can be equated to the transfer of grains of sugar from one tank to another through a pipe. No sugar would be spilled to the outside environment. Real photons on the other hand are packages of energy that have broken away as separate entities. It is as if the pipe between the tanks of sugar is missing and the sugar spills on the floor. Light is composed of such real photons.

We could use joules or BTU (British thermal unit) as a measure of the amount of energy that each real or virtual photon contains but it would be a very small fraction of a joule indeed. It is simpler to use a scale that merely represents the amount. We already use the scale called temperature to measure thermal energy. This represents the average collision energy between molecules. Real photons are created during these collisions, which are equal in energy to each collision as shown in above figure.

Fuel cells vs heat engines

The virtual photons that are transferred during the chemical reactions in a fuel cell have a very high temperament somewhere between 3500 K and 25 000 K. It is this extremely high temperament that allows the fuel cell to be theoretically so efficient. The amount of external energy that can be extracted from all types of internal energy is called the Carnot ratio. The Carnot ratio for virtual photons of 3500 K is however about 92% under normal conditions. This is much higher than for real photons in a gas turbine with a mean temperament of 1000 K and a Carnot ratio of 72%. The Carnot ratio is based on a particular ambient temperature of the surroundings. The Carnot ratio only relates to the absolute temperature scale where 0 °C = 273.15 K.

Heat engines such as gas turbines are considered to be inferior to fuel cells because they must convert the high-temperament chemical energy into low-temperature thermal energy first. A gas turbine cannot operate at the temperament of the chemical energy without melting. As can be seen from the graph when the temperament is reduced, the Carnot ratio is reduced. A large percentage of the Helmholtz energy that was available at the higher temperament is lost; it is converted into useless bound energy. The fuel cell does get hot but only because of the resistance and inefficiencies during the ion and electron flow during the production of electricity. Thus, many types of fuel cells can run efficiently at low temperatures while at the same time converting very high temperament energy.

Present highly advanced gas turbines do not achieve a mean temperature of more than 1150 K or 877 °C. In spite of these gas turbines (with addition of heat exchanging or steam turbines) can be highly efficient in the large sizes and produce little pollution. The latest is 57% efficient in converting fuel to electricity. In the future, ceramic gas turbines could reach 70% efficiency. This would result in a higher efficiency than what the fuel cell can achieve by itself. There is even some possibility of using energy transformers in the combustion process to increase the efficiency to 80%. In the future, medium and large power plants using SOFC (solid oxide fuel cell) will be fuel cell gas turbines combined cycles. In this way, the benefits of each type of conversion technology are utilized.

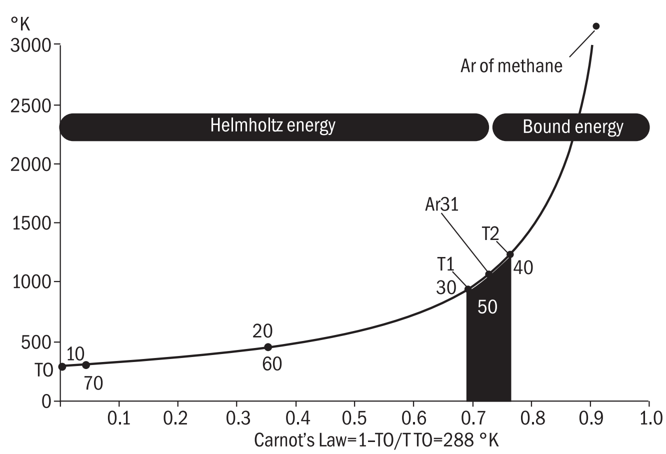


Figure 7 Comparison between fuel cells and heat engines

Fuel cell vehicles

Significant research and development is being carried out by several countries to reduce cost and improve performance. It is also found that effective and efficient ways are being invented by scientists to produce and store hydrogen and other fuels.

Automakers, fuel cell developers, component suppliers, government agencies, and others are working hard to accelerate the introduction of FCVs (fuel cell vehicles). Partnerships such as the DOE-led freedom car initiative and the California fuel cell partnership have been formed to encourage private companies and

government agencies to move these vehicles work together toward commercialization.

The advantages of FCVs are as follows.

- Cheaper to operate
- Pollution-free
- Competitively priced
- Free from imported oil

Advantages of fuel cells

- Fuel cells create electricity chemically rather than by combustion, which subject to thermodynamics law limits a conventional power plant.
- It is efficient enough to widely replace traditional ways of hydroelectric or even nuclear plants.
- Fuel cells are catalytic and relatively stable.
- Fuel cells generate electric power efficiently without pollution.
- This emerging technology has the potential to significantly reduce energy use and harmful emissions.

Conclusion

Fuel cells are an important enabling technology for the hydrogen economy and have the potential to revolutionize the way we power our nation, offering cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels. Fuel cells have the potential to replace the internal combustion engine in vehicles and provide power in stationary and portable power applications because they are energy-efficient, clean, and fuel-flexible. Overall saying one unit of energy saving is equal to twice of energy generated.