There are several other fuel cells in the research labs and in development today. With this wide array of technologies and the myriad of applications, fuel cells are poised to revolutionize the way we think about and use energy today and in the future.

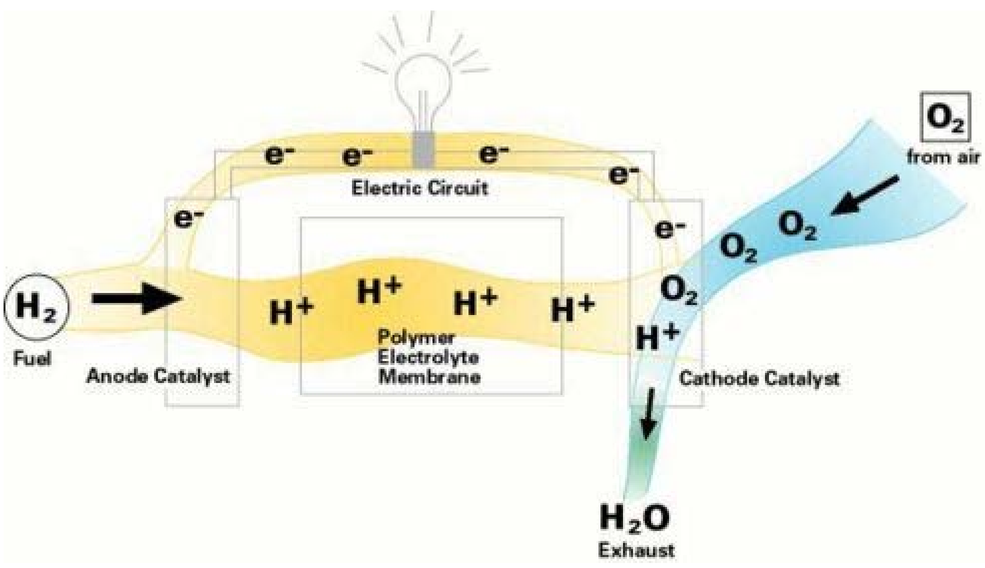
Different Types of Fuel Cells

by Sandra Curtin, www.fuelcells.org

With the current debates over energy, more people are aware of the benefits and potential applications of fuel cells. However, few would be able to describe the basic chemistry differentiating the application, power output and energy efficiencies of the various types of fuel cells; much less the unique challenges each face. Hence, a simple lesson in fuel cells is in order.

The Science

Fuel cells produce energy without combustion by an electrochemical process using hydrogen fuel. A fuel cell consists of two electrodes sandwiched around an electrolyte. Hydrogen is fed to one of the electrodes. Oxygen (from the air) enters the fuel cell through the other. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they are reunited with the hydrogen and oxygen to form water molecules.



When a fuel cell system is equipped with a “fuel reformer,” the fuel cell can utilize hydrogen from a number of hydrocarbon fuels including natural gas, methanol, propane, biomass, and gasoline. In principle, any hydrogen compound will do. The emissions from reforming these various hydrocarbon fuels would still be cleaner than those from a combustion process. It is also possible to obtain hydrogen by separating water in an electrolyzer, or by extracting it from a compound that contains no carbon, such as ammonia or boron compounds.

Fuel Cell Types

Fuel cells are a family of technologies. Fuel cell types are characterized by their electrolytes and temperature of operation.

Proton exchange membrane (PEM) fuel cells have a solid polymer membrane as an electrolyte. Due to membrane limitations, PEMs usually operate at low temperatures (60-100°C/140-212°F), but new developments have produced higher temperature PEMs (up to 200°C/392°F). Since platinum is the most chemically active substance for low temperature hydrogen separation, it is used as the catalyst. Hydrogen fuel is supplied as hydrogen gas or is reformed from methanol, ethanol, natural gas or liquefied petroleum gas and then fed into the fuel cell. The power range of existing PEMs is about 50W to 150kW.

The advantages of using PEM fuel cells include: 1) low weight and volume with good power-to-weight ratio, 2) low temperature operation, so less thermal wear to components, and 3) quick starts, with full power available in minutes or less. These advantages make PEMs well-suited to automotive and specialty vehicle applications such as scooters and forklifts. Many on-road trials are providing information to make PEMs competitive with internal combustion engines. Quick-starting PEMs can also provide back-up power to telecommunications and other sites requiring uninterrupted power supplies (UPS). PEMs additionally offer efficient operation – up to 50% electrical efficiency for the fuel cell itself and over 85% total efficiency when waste heat is captured for small-scale space and water heating (combined heat and power, or CHP). Hundreds of CHP and UPS PEM units have been deployed in demonstrations, and a number of units are now available for sale.

Several challenges face PEMs. Platinum catalysts are expensive and also subject to CO poisoning from hydrocarbon fuels, so catalyst improvements, non-precious metal catalysts and other alternatives are under investigation. Membranes more resistant to chemical impurities are also being developed. Alternate storage methods, such as metal hydrides and carbon nanostructures, may address hydrogen storage limitations preventing fuel cell cars from achieving typical driving range (300-400 miles/tank). Cold starts from frozen internal water are improving – a US Department of Energy goal is to achieve cold starts from -20°C (-4°F) in 30 seconds or less.

Direct methanol fuel cells (DMFCs) differ from PEMs because they use unreformed liquid methanol fuel rather than hydrogen. DMFCs operate at slightly higher temperatures than PEMs (50-120°C/120-248°F) and achieve around 40% efficiency. Since they are refuelable and do not run down, DMFCs are directed toward small mobile power applications such as laptops and cell phones, using replaceable methanol cartridges at power ranges of 1-50 W. Many of the major electronics companies are demonstrating miniature DMFCs powering their equipment and smaller fuel cell companies are partnering with military and communications contractors. The United Nations recently declared that methanol cartridges were safe for shipment in airplane cargo holds. Developers are currently addressing membrane corrosion, fuel crossover and miniaturization challenges. DMFCs are poised for widespread commercial availability in 2006, and some companies, such as SFC Smart Fuel Cell AG, are selling products now.

The **phosphoric acid fuel cell** (PAFC) is the fuel cell technology, with the greatest experience in consumer applications. More than 200 PAFC fuel cell systems are installed all over the world, providing power and useful steam heat to hospitals, nursing homes, hotels, office buildings, schools, utility power plants, an airport terminal, landfills and waste water treatment plants. UTC Fuel Cells (formerly ONSI and International Fuel Cells) paved the way for the technology, selling systems since the early 1990's and recently reaching the milestone of more than one billion kilowatt-hours of energy with its PureCell™ 200 power plant solution. PAFCs use liquid phosphoric acid as an electrolyte with a platinum catalyst. Anode and cathode reactions are similar to PEMs, but operating temperatures are slightly higher (150-200°C/302-392°F) making them more tolerant to reforming impurities. PAFCs use hydrocarbon sources such as natural gas, propane or waste methane. PAFCs are typically used for medium to large-scale stationary power generation, attaining a 36-42% electrical efficiency and an overall 85% total efficiency with co-generation of electricity and heat. The power range of existing PAFCs is 25-250 kW. However, if several units are linked, PAFCs can achieve a combined power output greater than 1 MW (an 11 MW PAFC power plant is operating in Japan).

Fast-starting **alkaline fuel cells** (AFCs) have been used by NASA to produce power and drinking water for astronauts since the 1960s Gemini missions. AFCs operate in an electrolyte solution of potassium hydroxide and can use a variety of non-precious metal catalysts at operating temperatures of 23-250°C (74-482°F). Fueled by hydrogen gas, AFCs have a high chemical reaction rate and offer an electrical efficiency of 60-70%. However, AFCs are poisoned easily by small quantities of carbon dioxide, so they are mostly used in controlled aerospace and underwater applications. AFCs in Space Shuttle applications produce 12 kW of power.

Solid oxide fuel cells (SOFCs) are one of the high temperature fuel cells, operating at 800-1000 °C (1472-1832°F) High temperature operation eliminates the need for precious metal catalysts and can reduce cost by recycling the waste heat from internal steam reformation of hydrocarbon fuels. SOFCs are tolerant to CO poisoning, allowing CO derived from coal gas to also be employed as source of fuel. These fuel cells use a solid ceramic electrolyte and produce a power output of 2-100 kW and can attain 220 kW-300 kW when used in a SOFC/gas turbine hybrid system. Demonstrated electrical efficiencies are 45-55%, with total efficiencies of 80-85% with cogeneration of waste heat. SOFCs are well-suited for medium-to-large scale, on-site power generation or CHP (hospitals, hotels, universities), and are also being marketed for telecommunications back up and as auxiliary power units (APUs) for military vehicle on-board equipment.

Molten carbonate fuel cells (MCFCs) operate at 600-750°C (1112-1382°F) and use a molten alkali carbonate mixture for an electrolyte. MCFCs typically range between 75-250 kW, but when using combined units, have produced up to 5 MW of power. Electrical efficiencies are 50-60%, with total efficiencies of 80-85% with cogeneration of waste heat. To date, MCFCs have operated on hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products.

The challenges to both SOFC and MCFC development include slow start up, strong thermal shielding requirements, and difficulty in developing durable materials for the high temperature operating environment. Developers and the US government (Solid State Energy Conversion Alliance) are also working on lower cost, greater durability, low-temperature SOFCs (about 800°C), as well as more powerful SOFC/gas turbine hybrids (1 MW or greater). Current MCFC research focuses on reduction of size and cost, as well as possible integration with gas turbines to increase performance.

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