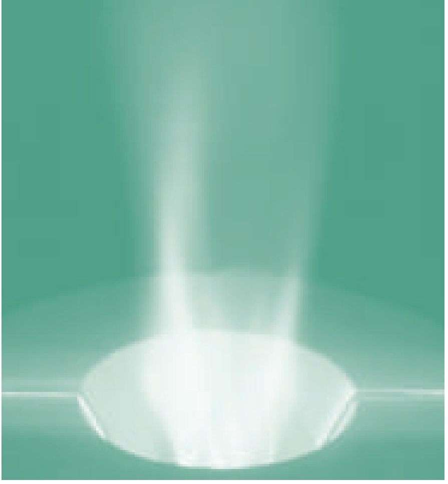
HYDROGEN energy FOR TOMORROW



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ADVANCED HYDROGEN UTILIZATION TECHNOLOGIES

Hydrogen's potential use as a fuel and an energy carrier includes powering vehicles, running turbines or fuel cells to produce electricity, and cogenerating heat and electricity for buildings. Research in hydrogen utilization is focused on technologies that will most directly facilitate the progression to a hydrogen energy economy. These include fuel cells, internal combustion engines, and hydrogen burners.

FUEL CELLS

A fuel cell consists of a catalytically-activated electrode for the fuel (anode) and the oxidant (cathode), and an electrolyte to conduct ions between the two electrodes. Hydrogen and oxygen ions are combined to form water and produce a flow of electrons from the anode to the cathode, generating an electric current.

While larger fuel cells—greater than 200 kilowatts—are being commercialized for on-site cogeneration of electricity and steam heat, fuel cells for transportation are in much earlier stages of development. Fuel cells are presently too large, too heavy, and too expensive to produce for a commercial application in powering vehicles. With the resolution of these problems, however, hydrogen-powered fuel cell vehicles will be pollution free and about three times as energy efficient as comparable gasoline-fueled vehicles.

There are several configurations of fuel cells, classified by the type of electrolyte used. The most mature technology for near-term use in large vehicles is the phosphoric acid fuel cell. The proton-exchange membrane fuel cell is a prime candidate for mid-term use in several areas, including automobiles. The solid oxide fuel cell is being developed for longer term utility applications.

PHOSPHORIC ACID FUEL CELL

A phosphoric acid fuel cell (PAFC) consists of an anode and a cathode made of finely dispersed platinum catalyst on carbon paper, and a silicon carbide matrix that holds the phosphoric acid electrolyte. PAFCs produce a cell voltage of 0.66 volts at atmospheric pressure and 200°C, and a current density of 240 milliampere per square centimeter (mA/cm^2). Overall fuel-to-electricity energy conversion efficiency is about 40%.

PAFCs are the most advanced of the fuel cell designs, and are being commercialized for stationary power applications and for demonstrations in larger fleet vehicles, such as buses. The power density of a PAFC is too low for use in an automobile, however, and it cannot generate power at room temperature. Because of these limitations, the optimum use of PAFCs is in steady operating modes. Researchers are studying other fuel cell alternatives for vehicle applications.

PROTON-EXCHANGE MEMBRANE FUEL CELLS

The proton-exchange membrane (PEM) fuel cell uses a fluorocarbon ion exchange with a polymeric membrane as the electrolyte. The hydrogen proton migrates across the membrane and water is evolved at the cathode. The PEM operates at a relatively low temperature of about 80˚C and can start up from ambient temperature at partial load. These characteristics, plus its high power density, make the PEM cell more adaptable to automobile use than the PAFC.

Current densities of up to 4 A/cm^2 have been reported for single PEM cells. An assembly of PEM cells has not been able to achieve this level because at high current densities localized overheating limits the attainable density to about 1 A/cm^2. As research overcomes this problem, higher current densities will allow the weight and volume of a PEM fuel cell to be more practical for vehicle use.

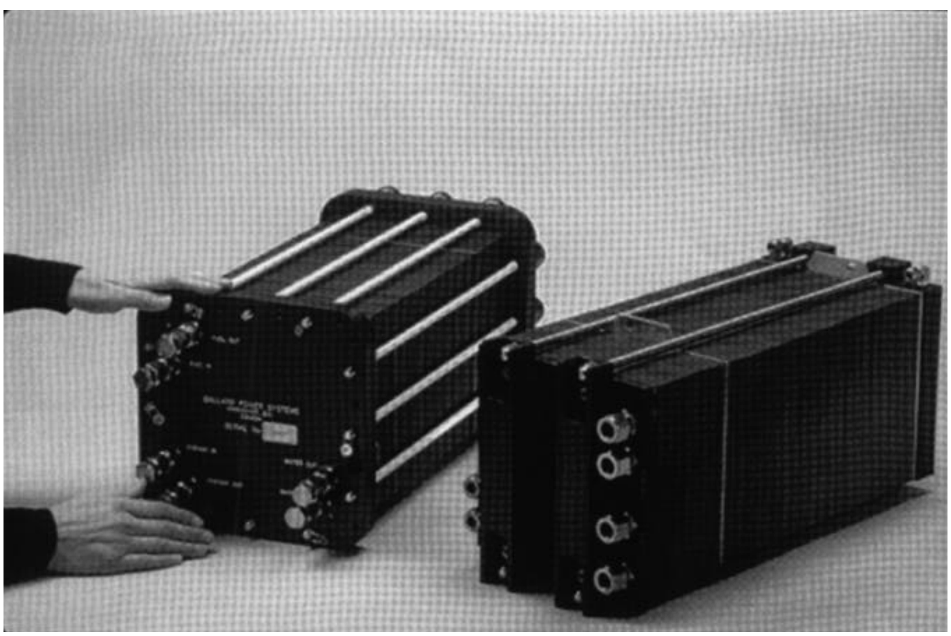
SOLID OXIDE FUEL CELLS

Solid oxide fuel cells (SOFC) under development use a thin layer of zirconium oxide as a solid electrolyte, a lanthanum manganite cathode, and a nickel-zirconia anode. When heated to about 1000˚C, the oxide becomes a suitable conductor of oxygen ions but not electrons.

A tubular arrangement of the cathode, anode, and electrolyte is the most advanced of the SOFC designs; 20-kilowatt demonstration units have been installed in Japanese utilities. A planar configuration consists of alternating flat plates of a trilayer containing an anode, an electrolyte, and a cathode. A monolithic configuration adds a layer of anode and cathode material corrugated on either side of the trilayers to form flow channels for the fuel and air streams.

Planar SOFCs are easier to fabricate than the monolithic configuration, which is co-sintered into a solid, ceramic structure, but monolithic configurations have the highest power density of the designs. All SOFC designs have fewer components and ultimately may need less maintenance and be less expensive than other fuel cell types.

As an illustration *of rapid technology advancement in proton-exchange membrane fuel cell technology, the cell on the left is a previous generation and can generate 5kW of power; the cell on the right is about the same size, but can generate 13 kW of electricity. Each cell can fit within the engine compartment of a diesel bus.*



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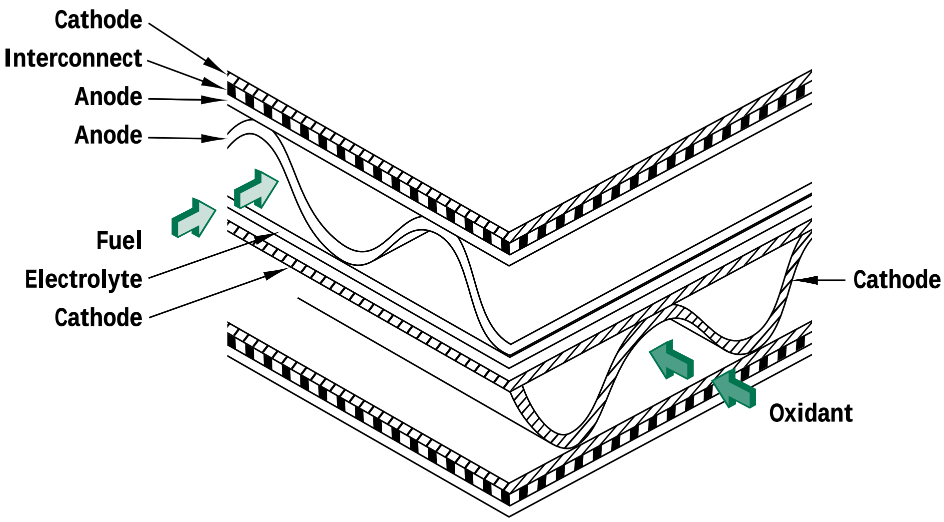

A monolithic solid oxide fuel cell *combines three layers of an anode-electrolyte-cathode sequence, with the center layer containing corrugated anodes and cathodes to allow the flow of hydrogen fuel and air. The entire system is sintered into a single ceramic block.*

INTERNAL COMBUSTION ENGINES

Hydrogen use in an internal combustion (IC) engine was demonstrated over 100 years ago. Hydrogen-fueled IC engines offer the potential of no carbon and very low nitrogen oxide emissions, combined with high thermal efficiency. To be competitive and cost-effective, however, key problems must be solved in engine combustion, fuel delivery, and practical storage.

The primary research goal is to develop an optimized hydrogen IC engine with about 80 miles per gallon equivalent performance in an ultra-low emission vehicle. Fuel efficiencies of 80 to 90 miles per gallon energy equivalent have been realized in simulations using a hybrid hydrogen-electric vehicle. The research challenge is to achieve high efficiency and low emissions while overcoming the problems of preignition and flashback that have been common with hydrogen fuel in the past.

Flashback is the improperly timed explosion of the fuel and air mixture that occurs when the exhaust valve of the IC engine is open. This is a risk that is more significant with hydrogen fuel than hydrocarbon fuels because hydrogen's flame speed is two to ten times greater than that of hydrocarbons.

Two key areas of investigation are the fuel delivery system and the ignition system. In a carburetion system, premixing creates a lean, homogeneous charge that keeps nitrogen oxide emissions low. A fuel-injected system better prevents preignition of the fuel-air mixture and flashback.

These engines can be used for both transportation and stationary power applications. Researchers are studying direct power from an IC engine fueled by hydrogen or mixed fuels, such as hydrogen-methane; and hybrid power systems, where an IC engine operating at a single speed and load runs an electric motor.

Research is also focused on reducing nitrogen oxide emissions in fuel injection systems by diluting the intake air charge in a direct-injection IC engine. Dilution can be accomplished by recirculating exhaust gases or by scavenging. These techniques work by reducing the flame temperature and oxygen availability of the hydrogen/oxidizer mixture. This subsequently reduces the formation of nitrogen oxides, which is highly sensitive to temperature.

HYDROGEN BURNERS

Research is focusing on the development of a safe and environmentally benign hydrogen burner that can generate electricity for utilities and provide heat to industry and homes. Burning hydrogen eliminates most emissions that come from carbon-based fuels, including carbon dioxide and carbon monoxide.

The burning of any fuel in air, however, produces some amount of nitrogen oxides, and burner research is focusing on eliminating these emissions from hydrogen combustion. One way to do this is to remove nitrogen from the fuel mix completely, by burning pure hydrogen and pure oxygen derived directly from the electrolysis process. This is an expensive alternative, however, and researchers are looking at more cost-effective methods.

Nitrogen oxide emissions can be minimized by reducing the peak combustion temperature and the time spent at the peak temperature. Typical thermal efforts reduce the peak temperature by recirculating cooler inert gases through the combustion process or injecting steam. Nitrogen oxides can also be reduced to essentially zero by premixing the fuel and oxidizer to reduce the amount of fuel in proportion to the oxidizer—a "lean" mixture. A sufficiently lean mixture can reduce the combustion temperatures to 1400°C to 1500°C, although it can also increase the occurrence of flashback.

Researchers are investigating the combustion fluid dynamics required to completely oxidize hydrocarbon and hydrogen fuels. Because the momentum flux of the oxidizer (air) is the primary variable in resolving these problems, an improved hydrogen burner will also work efficiently with natural gas and liquid petroleum gas. This flexibility should accelerate the utilization of hydrogen by facilitating the use of hybrid fuels.

CONCLUSION

Researchers are working on many other technologies for the practical and cost-effective utilization of hydrogen energy. Additional applications and technologies will develop as hydrogen production, transport, and storage capabilities become integrated into the energy economy. To learn more about hydrogen utilization technologies or to inquire about opportunities for your company to be involved in the U.S. Department of Energy's cooperative research programs, please contact:

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