2.2.5 HYDROGEN USE

Technology Description

Almost all of the hydrogen produced in the United States each year (about 9 million tons) is currently used as an industrial feedstock, primarily in the fertilizer and petroleum-refining industries. During the next 20-30 years, solutions for energy security and environmental concerns may be based on development of domestic hydrogen-based energy systems for vehicle and electric power applications. Hydrogen's use as an energy carrier is gaining worldwide interest with development of efficient, clean fuel cell systems that could potentially replace the internal combustion engine in vehicles and provide power in stationary and portable power applications. If pure hydrogen is used as a fuel, fuel cells emit only heat and water as byproducts.

Hydrogen can also be used as a cleaner-burning fuel in internal combustion engines (after slight modifications) and in gas turbines or turbine/fuel cell hybrid systems to provide electric power.

A fuel cell is a device that uses hydrogen (or a hydrogen-rich fuel) and oxygen to create an electric current via an electrochemical reaction. This process is inherently much more efficient than combustion processes, which lose a significant amount of the embodied energy in the fuel to heat. A single fuel cell consists of an electrolyte and two catalyst-coated electrodes (a porous anode and cathode) and produces enough electricity for only the smallest applications. To provide the power needed for larger applications – such as powering a vehicle – individual fuel cells are combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. The fuel cell stack is the "heart" of the energy system, which also includes compressor systems, current converters, thermal and water management systems, some stationary applications, and fuel-processor systems.

There are several types of fuel cells currently under development, classified primarily by the kind of electrolyte they employ. Each has its own advantages, limitations, and potential applications. This technology brief will focus on the fuel cells most suitable for transportation and distributed power generation applications – the polymer electrolyte membrane (PEM) fuel cell system. The PEM fuel cell is a low-temperature fuel cell that offers high-power density, low weight and volume, and rapid-start capabilities. It requires a noble-metal catalyst (e.g., platinum) and operates on pure hydrogen. Other types of fuel cells, which are generally more suitable for larger power facilities (e.g., molten carbonate and solid oxide) are covered elsewhere in this report (see sections 2.1.1 and 2.1.3). Hydrogen's use in gas turbines and internal combustion engines is also covered separately in this report (see sections 2.1.2 and 1.1.1).

System Concepts and Representative Technologies

- Due to their fast start-up time, low sensitivity to orientation, and favorable power-to-weight ratio, polymer electrolyte membrane (PEM) fuel cells are the current focus for use in light-duty vehicles. Their ability to cycle on and off, provide higher durability due to low-temperature operations, and offer a relatively small footprint also makes them suitable for distributed power applications.
- PEM fuel cell vehicles with electric power trains operating on pure hydrogen supplied to onboard storage systems. These hydrogen vehicles are fueled at distributed refueling stations.
- PEM fuel cell systems for distributed stationary power applications, including backup power units, grid management, power for remote locations, stand-alone power plants for cities or towns, distributed power generation for buildings and industrial facilities, and combined heat and power generation.
- For fuel cells and fuel cell stacks: membrane electrode assemblies and high-temperature membranes, non- or low-platinum catalysts, and bipolar plates.

- Compressor/expander technologies to enable pressurized operation of fuel cells
- Thermal- and water-management technologies to recover and utilize waste heat and water
- Physical and chemical sensors to detect hydrogen leaks and monitor hydrogen purity
- Fuel-flexible fuel processors for stationary applications.

Technology Status/Applications

- Industrial participation in PEM system development is expanding, with all major automobile manufactures and several fuel cell-specific companies investing in development and demonstration activities for both vehicles and power generation.
- Current PEM fuel cell systems do not offer the cost or performance required by end users. Researchers and technology developers are working to overcome a variety of technical barriers to make these systems commercially viable.
- Residential PEM fuel cell units, typically 5-7kW in size, are being developed and demonstrated by several companies. PEM fuel cell-powered buses, taxis, and passenger vehicles are also being demonstrated in limited numbers around the world. For the most part, these demonstration units are essentially custom-built by the manufacturers. Facilities to manufacture these systems in large quantities are still in development.

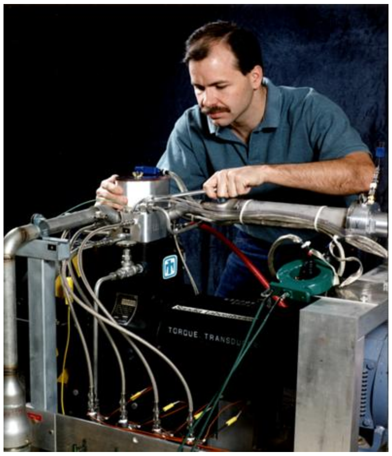
Current Research, Development, and Demonstration

RD&D Goals

- By 2010, develop a 60% peak-efficient, durable, PEM fuel cell power system for transportation at a cost of $45/kW, and a distributed generation (50-250 kW) PEM fuel cell system operating on natural gas or propane that achieves 40% electrical efficiency and 40,000 hours durability at $400-750/kW.
- By 2015, reduce the cost of PEM fuel cell power systems to $30/kW for transportation systems.

RD&D Challenges

Cost and durability are the major barriers to fuel cell commercialization. For transportation applications, which have the most stringent cost and durability requirements, fuel cell costs need to be decreased by a factor of 5,l and durability needs to be increased by a factor of 3 to be competitive with current vehicle technologies. R&D challenges include:



- Durable electrodes with low precious-metal content
- High-volume fabrication processes for membrane electrode assemblies and bipolar plates
- Improved air electrode performance to raise cell voltage, increase fuel cell stack efficiency, and reduce number of cells per stack
- Membranes that operate at higher temperatures (e.g., 120^{o}C for transportation and 150^{o}C for distributed power) and low humidity to facilitate heat rejection and increase carbon monoxide tolerance of the anode
- Compact, lightweight, efficient balance-of-plant components, such as air compressors, humidifiers, heat exchangers, and sensors
- Durability studies and accelerated aging test methods
- Systems analysis and analytical capability

RD&D Activities

- The overall strategy of the HFCIT Program is to conduct a comprehensive and balanced program that includes mid- and long-term research and development of hydrogen production, storage, and utilization technologies; integrated systems and technology validation using close collaboration with industry that develops, demonstrates, and deploys critical technologies emerging from research and development; and an analysis element that helps determine the performance and cost targets that technologies must meet to achieve goals of the HFCIT Program, as well as specific project objectives determined by peer review.
- DOE's HFCIT Program is carried out by national laboratories, universities, and the private sector, including cost-shared industry-led efforts; and CRADA collaborations between industry and the labs.

Recent Progress
• Reduced the high-volume cost of automotive fuel cells from $275/kW (2002) to $200/kW (2004) using innovative processes developed by national laboratories and fuel cell developers for depositing platinum catalyst • Achieved 54% efficiency in a stationary fuel cell stack assembly – on target to meet overall system electrical efficiency go/no-go target of 40% in 2010 • 5 kW stationary fuel cell system stack assembly efficiency is on track to meet overall system efficiency target of 32% in FY05 • Achieved long-term, 8X mass specific activity improvement of low Pt-content (Pt-Pd BNL) cathode catalysts • Demonstrated a bipolar plate manufacturing process (at 20 parts per hour) that produces plates with target properties and acceptable performance
Commercialization and Deployment Activities
• Major industrial companies are pursuing R&D in PEM fuel cells with a mid-term (5-10 years) time frame for deployment of these technologies for both stationary and vehicular applications. These companies include General Motors, Ford, Daimler-Chrysler, Toyota, Honda, United Technology Corporation Fuel Cells, Xcellsis, and Ballard.