International Partnership for the Hydrogen Economy

Fuel Cells: A Hydrogen Enabling Technology

Overview

Fuel cells are one of the key enabling technologies for a future hydrogen economy. They have the potential to replace the internal combustion engine in vehicles and to provide power in stationary and portable power applications.

Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants and passenger vehicles. They produce much smaller quantities of greenhouse gases. If pure hydrogen is used as a fuel, fuel cells emit only heat and water as a byproduct.

Cost and durability are the major challenges to fuel cell commercialization.

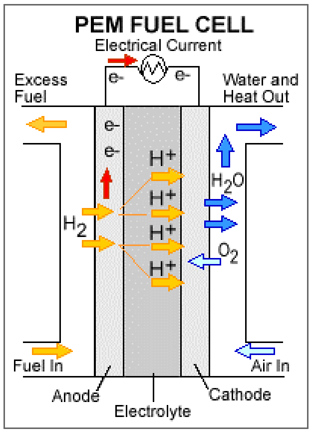
How the Fuel Cell Works

A fuel cell is a device that generally uses hydrogen and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte and two catalyst-coated electrodes. Hydrogen is fed into the anode and oxygen is fed into the cathode. In the case of a PEM Fuel Cell, a catalyst strips electrons from the hydrogen atom. Freed of the electrons, the protons pass through the electrolyte. The electrons take a different path to the cathode creating an electric current that can be utilized. At the cathode, another catalyst rejoins the hydrogen atom, which then combines with oxygen to create a molecule of water. [See Box]

Benefits of Fuel Cells

- ***Efficient -*** Fuel cell vehicles are expected to achieve efficiencies of 40 to 45 percent. On average, an internal combustion engine converts about 15 percent of the energy in gasoline to turn a car’s wheels. Fuel cell power plants producing electricity and thermal energy are expected to achieve efficiencies of 80 percent or more when used as combined heat and power plants.

- ***Clean -*** The only emission from the tailpipe of a fuel cell vehicle operating on hydrogen is water vapor. Fuel cell vehicles that use an on-board fuel reformer will emit two-thirds less pollution than a gasoline combustion engine. A similar comparison applies to stationary and portable fuel cell applications.



Reliable - Fuel cell systems are highly reliable, which is very desirable for stationary applications that require a high-quality uninterrupted power supply.

- ***Versatile –*** Fuel cells can operate on a wide load range and scale from micro production to megawatt production.

Types of Fuel Cells

- **Polymer Electrolyte Membrane (PEM) Fuel Cells**—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells operate at relatively low temperatures, around 80°C. Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. PEM fuel cells are used primarily for transportation applications and some stationary applications. However, this technology requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. [See Box]

- **Alkaline Fuel Cells (AFCs)** use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100°C and 250°C. However, newer AFC designs operate at lower temperatures, roughly 23°C to 70°C. They are frequently used in remote locations and have demonstrated efficiencies near 60 percent in space applications. The disadvantage of this fuel cell type is that it is easily “poisoned” by carbon dioxide (CO_2).

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- **Solid Oxide Fuel Cells** use a hard, non-porous ceramic compound as the electrolyte. SOFCs are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent. Solid oxide fuel cells operate at very high temperatures—around 1,000°C, removing the need for precious-metal catalyst, thereby reducing cost.). However, the high temperature results in a slow startup and requires significant thermal shielding to retain heat and protect personnel. The high operating temperatures also place stringent durability requirements on materials.

- **Phosphoric Acid Fuel Cells (PAFCs)** use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). PAFCs are typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses. PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate.

- **Molten Carbonate Fuel Cells (MCFCs)** are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide ($LiAlO_2$) matrix. Since they operate at temperatures of 650°C and above, non-precious metals can be used as catalysts at the anode and cathode to reduce costs. Unlike alkaline, phosphoric acid, and PEM fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life.

The Challenges

- **Cost.** The cost of fuel cell power systems must be reduced before they can be competitive with conventional technologies. Currently the costs for automotive internal combustion engine power plants are about $25-$35/kW; for transportation applications, a fuel cell system needs to cost $30/kW for the technology to be competitive. For stationary systems, the acceptable price point is considerably higher ($400-$750/kW for widespread commercialization and as much as $1000/kW for initial applications).

- **Durability and Reliability.** The durability of fuel cell systems has not been established. For transportation applications, fuel cell power systems will be required to achieve the same level of durability and reliability of current automotive engines, i.e., 5,000 hour lifespan (241,000 km equivalent), and the ability to function over the full range of vehicle operating conditions (40°C to 80°C). For stationary applications, more than 40,000 hours of reliable operation in a temperature at -35°C to 40°C will be required for market acceptance.

- **System Size.** The size and weight of current fuel cell systems must be further reduced to meet the packaging requirements for automobiles. This applies not only to the fuel cell stack, but also to the ancillary components and major subsystems (e.g., fuel processor, compressor/expander, and sensors) making up the balance of power system.

- **Air, Thermal, and Water Management.** Air management for fuel cell systems is a challenge because today's compressor technologies are not suitable for automotive fuel cell applications. In addition, thermal and water management for fuel cells are issues because the small difference between the operating and ambient temperatures necessitates large heat exchangers. Another challenge is to develop a reliable and durable membrane that operate in low humidity conditions so as to eliminate the need for complicated water management equipment.

- **Improved Heat Recovery Systems.** The low operating temperature of PEM fuel cells limits the amount of heat that can be effectively utilized in combined heat and power (CHP) applications. Technologies need to be developed that will allow higher operating temperatures and/or more effective heat recovery systems and improved system designs that will enable CHP efficiencies exceeding 80%. Technologies that allow cooling to be provided from the low heat rejected from stationary fuel cell systems (such as through regenerating desiccants in a desiccant cooling cycle) also need to be evaluated.

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Partners in the IPHE are collaborating to improve fuel cell technologies to advance toward the hydrogen economy. For more information, please visit www.iphe.net.