Hydrogen Fuel Cells

DOE Hydrogen Program

Overview

Hydrogen is a versatile energy carrier that can be used to power nearly every end-use energy need. The fuel cell — an energy conversion device that can efficiently capture and use the power of hydrogen — is the key to making it happen.

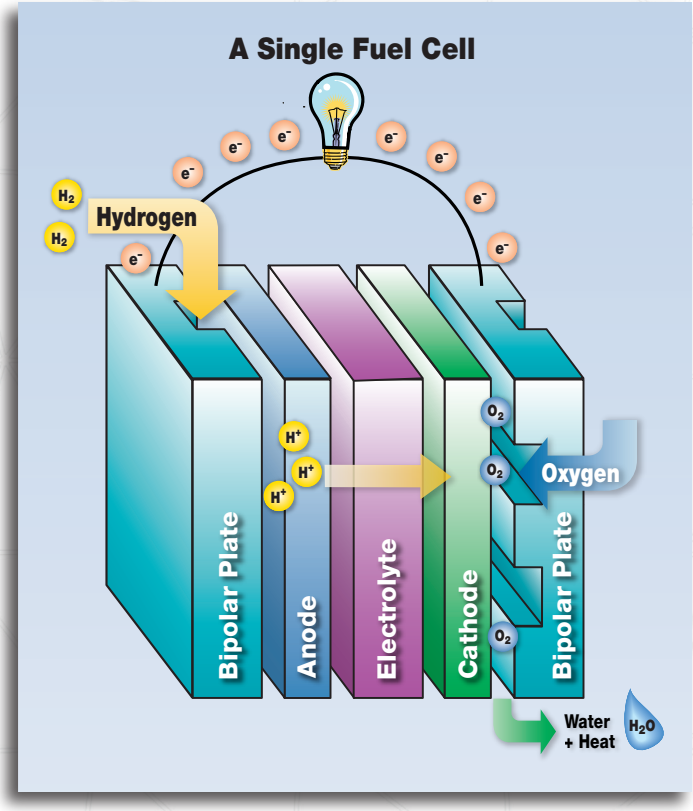
- Stationary fuel cells can be used for backup power, power for remote locations, distributed power generation, and cogeneration (in which excess heat released during electricity generation is used for other applications).
- Fuel cells can power almost any portable application that typically uses batteries, from hand-held devices to portable generators.
- Fuel cells can also power our transportation, including personal vehicles, trucks, buses, and marine vessels, as well as provide auxiliary power to traditional transportation technologies. In a hydrogen economy, hydrogen will play a particularly important role by replacing the imported petroleum we currently use in our cars and trucks.

Why Fuel Cells?

- Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and potentially useful heat as the only byproducts.
- Hydrogen-powered fuel cells are not only pollution-free, but also can have two to three times the efficiency of traditional combustion technologies.
  - A conventional combustion-based power plant typically generates electricity at efficiencies of 33 to 35 percent, while fuel cell systems can generate electricity at efficiencies up to 60 percent (and even higher with cogeneration).
  - The gasoline engine in a conventional car is less than 20% efficient in converting the chemical energy in gasoline into power that moves the vehicle, under normal driving conditions. Hydrogen fuel cell vehicles, which use electric motors, are much more energy efficient and use 40-60 percent of the fuel's energy — corresponding to more than a 50% reduction in fuel consumption, compared to a conventional vehicle with a gasoline internal combustion engine.
- In addition, fuel cells operate quietly, have fewer moving parts, and are well suited to a variety of applications.

How Do Fuel Cells Work?

A single fuel cell consists of an electrolyte sandwiched between two electrodes, an anode and a cathode. Bipolar plates on either side of the cell help distribute gases and serve as current collectors. In a Polymer Electrolyte Membrane (PEM) fuel cell, which is widely regarded as the most promising for light-duty transportation, hydrogen gas flows through channels to the anode, where a catalyst causes the hydrogen molecules to separate into protons and electrons. The membrane allows only the protons to pass through it. While the protons are conducted through the



membrane to the other side of the cell, the stream of negatively-charged electrons follows an external circuit to the cathode. This flow of electrons is electricity that can be used to do work, such as power a motor.

On the other side of the cell, oxygen gas, typically drawn from the outside air, flows through channels to the cathode. When the electrons return from doing work, they react with oxygen and the hydrogen protons (which have moved through the membrane) at the cathode to form water. This union is an exothermic reaction, generating heat that can be used outside the fuel cell.

The power produced by a fuel cell depends on several factors, including the fuel cell type, size, temperature at which it operates, and pressure at which gases are supplied. A single fuel cell produces approximately 1 volt or less — barely enough electricity for even the smallest applications. To increase the amount of electricity generated, individual fuel cells are combined in series to form a stack. (The term "fuel cell" is often used to refer to the entire stack, as well as to the individual cell.) Depending on the application, a fuel cell stack may contain only a few or as many as hundreds of individual cells layered together. This "scalability" makes fuel cells ideal for a wide variety of applications, from laptop computers (50-100 Watts) to homes (1-5kW), vehicles (50-125 kW), and central power generation (1-200 MW or more).

Comparison of Fuel Cell Technologies

In general, all fuel cells have the same basic configuration — an electrolyte and two electrodes. But there are different types of fuel cells, classified primarily by the kind of electrolyte used. The electrolyte determines the kind of chemical reactions that take place in the fuel cell, the temperature range of operation, and other factors that determine its most suitable applications.

Fuel Cell Type	Operating Temperature	System Output	Efficiency	Applications
Alkaline (AFC)	90–100ºC 194–212ºF	10kW–100kW	60–70% electric	• Military • Space
Phosphoric Acid (PAFC)	150–200ºC 302–392ºF	50kW–1MW (250kW module typical)	80–85% overall with combined heat and power (CHP) (36–42% electric)	• Distributed generation
Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM)*	50–100ºC 122–212ºF	<250kW	50–60% electric	• Back-up power • Portable power • Small distributed generation • Transportation
Molten Carbonate (MCFC)	600–700ºC 1112–1292ºF	<1MW (250kW module typical)	85% overall with CHP (60% electric)	• Electric utility • Large distributed generation
Solid Oxide (SOFC)	650–1000ºC 1202–1832ºF	5kW–3 MW	85% overall with CHP (60% electric)	• Auxiliary power • Electric utility • Large distributed generation

Source: Argonne National Laboratory

**Direct Methanol Fuel Cells (DMFC) are a subset of PEMFCs typically used for small portable power applications with a size range of about a subwatt to 100W and operating at 60–90°C.*

Challenges and Research Directions

Reducing cost and improving durability are the two most significant challenges to fuel cell commercialization. Fuel cell systems must be cost-competitive with, and perform as well or better than, traditional power technologies over the life of the system.

Ongoing research is focused on identifying and developing new materials that will reduce the cost and extend the life of fuel cell stack components including membranes, catalysts, bipolar plates, and membrane-electrode assemblies. Low cost, high volume manufacturing processes will also help to make fuel cell systems cost competitive with traditional technologies.

Did you know...

Hydrogen is an energy carrier, not an energy source, meaning that it stores and delivers energy in a usable form.

Hydrogen can be produced using abundant and diverse domestic energy resources, including fossil fuels, such as natural gas and coal; renewable energy resources, such as solar, wind, and biomass; and nuclear energy.

A hydrogen economy would not only reduce our dependence on imported oil, but also benefit the environment by reducing emissions of greenhouse gases and criteria pollutants that affect our air quality.

The President's Hydrogen Fuel Initiative accelerates the research and development of hydrogen, fuel cell, and infrastructure technologies that would enable hydrogen fuel cell vehicles to begin to reach the commercial market.

Under the President's Hydrogen Fuel Initiative, the DOE Hydrogen Program works with industry, academia, national laboratories, and other federal and international agencies to overcome critical technology barriers, address safety issues and facilitate the development of model codes and standards, validate hydrogen fuel cell technologies in real world conditions, and educate key stakeholders in the transition to a hydrogen economy.