What is a Fuel Cell?

A fuel cell is a device that produces a chemical reaction between substances, generating an electric current in the process. It is an **electrochemical energy conversion device**. Everyone uses another electrochemical energy conversion device—a battery. A battery contains substances that produce an electric current as they react. When all of the substances have reacted, the battery is dead; it must be replaced or recharged.

With a fuel cell, the substances (in this case, hydrogen and oxygen) are stored outside of the device. As long as there is a supply of hydrogen and oxygen, the fuel cell can continue to generate an electric current, which can be used to power motors, lights, and other electrical appliances. There are many types of fuel cells, but the most important technology for transportation applications is the **polymer electrolyte** (or proton exchange) **membrane** or **PEM** fuel cell. A PEM fuel cell converts hydrogen and oxygen into water, producing an electric current during the process.

The **anode** is the negative side of the fuel cell. The anode has channels to disperse the hydrogen gas over the surface of the **catalyst**, which lines the inner surfaces of the anode and **cathode**. Hydrogen gas under pressure enters the fuel cell on the anode side and reacts with a catalyst.

The catalyst is a special material—usually made of platinum—that facilitates the reaction of hydrogen and oxygen. The catalyst splits the hydrogen gas into two hydrogen ions ($2H^+$) and two electrons ($2e^-$). The electrons flow through the anode to an external **circuit**, through a load where they perform work, to the cathode side of the cell.

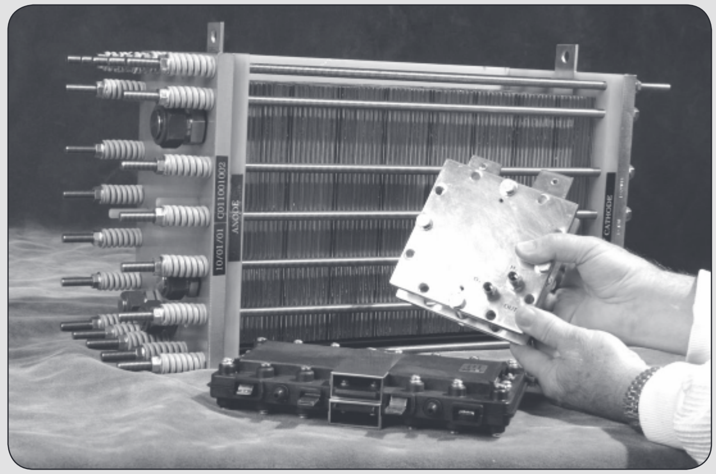


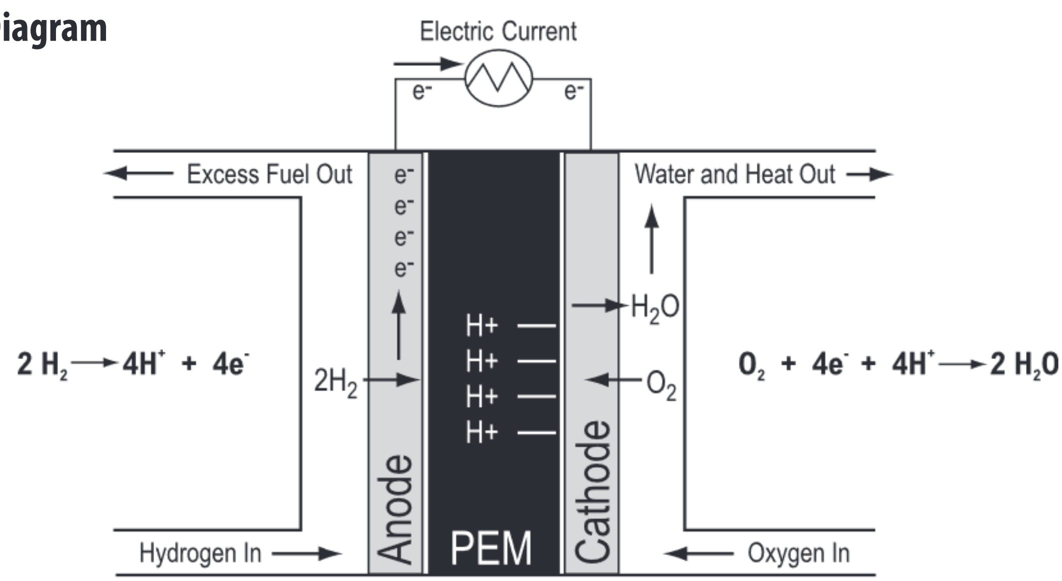
Image courtesy of DOE/NREL, credit Matt Stiveson

A 5 kW fuel cell (large cell), 25 watt fuel cell (three cell stack), 30 watt fuel cell (smaller cell held in hands).

The polymer electrolyte membrane is a specially treated material that conducts positive ions (protons), but blocks electrons from flowing through the **membrane**. Electrons flow through a separate circuit (that can be used to do work) as they travel to the cathode.

The cathode is the positive side of the fuel cell. It has channels to distribute oxygen gas to the surface of the catalyst. The oxygen reacts with the catalyst and splits into two oxygen atoms. Each oxygen atom picks up two electrons from the external circuit to form an oxygen ion (O^{--}) that combines with two hydrogen ions ($2H^+$) to form a water molecule (H_2O).

PEM Cell Diagram



The Challenges of Hydrogen

Hydrogen Storage

Hydrogen can be stored in many ways, but all have advantages and disadvantages. Safety, cost, efficiency, and ease of use are important considerations.

- Hydrogen can be stored as a gas at standard temperature and pressure. Hydrogen can be stored safely this way, but it is not efficient; a small amount of hydrogen energy takes up a very large amount of space.
- Hydrogen gas can be compressed and stored in high-pressure tanks. Hydrogen gas takes up less space when it is compressed, but it still has much lower energy content than the same volume of gasoline. A compressed hydrogen tank would have to be many times larger than a gasoline tank to hold an equivalent amount of energy. It also takes energy to compress the gas, and the storage tanks to hold the hydrogen must meet strict safety standards since any compressed gas can be dangerous.
- Hydrogen gas can be liquefied (turned into a liquid) by compressing it and cooling it to a very low temperature (–253°C). But it requires a lot of energy to compress and cool the gas, and storage tanks must be reinforced and super-insulated to keep the liquid hydrogen cold.
- Hydrogen can also be stored using materials-based technologies—within the structure or on the surface of certain materials, as well as in chemical compounds that undergo chemical reactions to release the hydrogen. With these technologies, hydrogen is tightly bound with other elements in a compound (or storage material), which may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure at near room temperature.

Hydrogen can be stored in materials through **absorption**, in which hydrogen is absorbed directly into the storage material; **adsorption**, in which hydrogen is stored on the surface of the storage material; or in compound form, in which hydrogen is contained within a chemical compound and released in a chemical reaction.

HYDROGEN STORAGE TANK

Image courtesy of DOE/NREL, photo credit Keith Wipke

Hydrogen can be stored in high-pressure tanks.

PIPELINES

Hydrogen can be transported via pipeline, truck, rail, and barge.

Hydrogen Distribution

Today, most hydrogen is transported short distances, mainly by pipeline. There are about 1,213 miles of hydrogen pipelines in the United States. Longer distance distribution is usually by tanker trucks carrying hydrogen in liquefied form. There is no nationwide hydrogen **distribution system**.

The cost of building a new nationwide system of pipelines for hydrogen would be very costly. Researchers are looking into ways to use the existing natural gas pipeline system, but there are problems to be solved. Hydrogen can permeate the natural gas pipes and fittings, causing them to become brittle and rupture.

For many applications, distributed generation (producing hydrogen where it will be used) may be a solution. Buildings and fueling stations can use small reformers to produce the hydrogen they need from other fuels such as natural gas and ethanol.

Wind turbines, solar panels, and other renewables can power electrolyzers (systems that split water into hydrogen and oxygen by electrolysis) to also produce hydrogen close to where it will be used.

Hydrogen Safety

Like any fuel we use today, hydrogen is an energy-rich substance that must be handled properly to ensure safety. Several properties of hydrogen make it attractive compared to other volatile fuels when it comes to safety. Important hydrogen properties relating to safety are described below.

- Hydrogen is much lighter than air and rises at a speed of almost 20 meters per second—two times faster than helium and six times faster than natural gas. When released, hydrogen quickly rises and dilutes into a non-flammable concentration.
- An explosion cannot occur in a tank or any contained location that contains only hydrogen; oxygen would be needed.
- Hydrogen burns very quickly, sometimes making a loud noise that can be mistaken for an explosion.
- The energy required to initiate hydrogen **combustion** is significantly lower than that required for other common fuels such as natural gas or gasoline.
- Hydrogen is odorless, colorless, and tasteless—so it is undetectable by human senses. Hydrogen equipment, and facilities where hydrogen is used, have leak detection and ventilation systems. Natural gas is also odorless, colorless, and tasteless; industry adds an odorant called mercaptan to natural gas so people can detect it. Odorants cannot be used with hydrogen, however, because there is no known odorant "light enough" to travel with hydrogen (remember, it's the lightest element in the universe).
- Although the flame itself is just as hot, a hydrogen flame produces a relatively small amount of radiant heat compared to a hydrocarbon flame. This means that hydrogen flames can be difficult to detect (they're also nearly invisible in daylight) but, with less radiant heat, the risk of sparking secondary fires is reduced with a hydrogen flame.
- Any gas except oxygen can cause asphyxiation (oxygen deprivation) in high enough concentrations. Since hydrogen is buoyant and diffuses rapidly, it is unlikely that a situation could occur in which people were exposed to high enough concentrations of hydrogen to become asphyxiated.
- Hydrogen is non-toxic and non-poisonous. It will not contaminate groundwater and a release of hydrogen is not known to contribute to air or water pollution.

Hydrogen and Our Energy Future

Hydrogen offers the promise of a clean and secure energy future, but its widespread use by consumers nationwide will require major changes in the way we produce, deliver, store, and use energy.

Some fuel cells are commercially available today for specific applications—fueling fork lifts, providing emergency back-up power, and powering some portable equipment—but there are several important technical challenges that must be solved before we see hydrogen at local fueling stations and fuel cell vehicles in auto dealer showrooms.

HYDROGEN FLAME

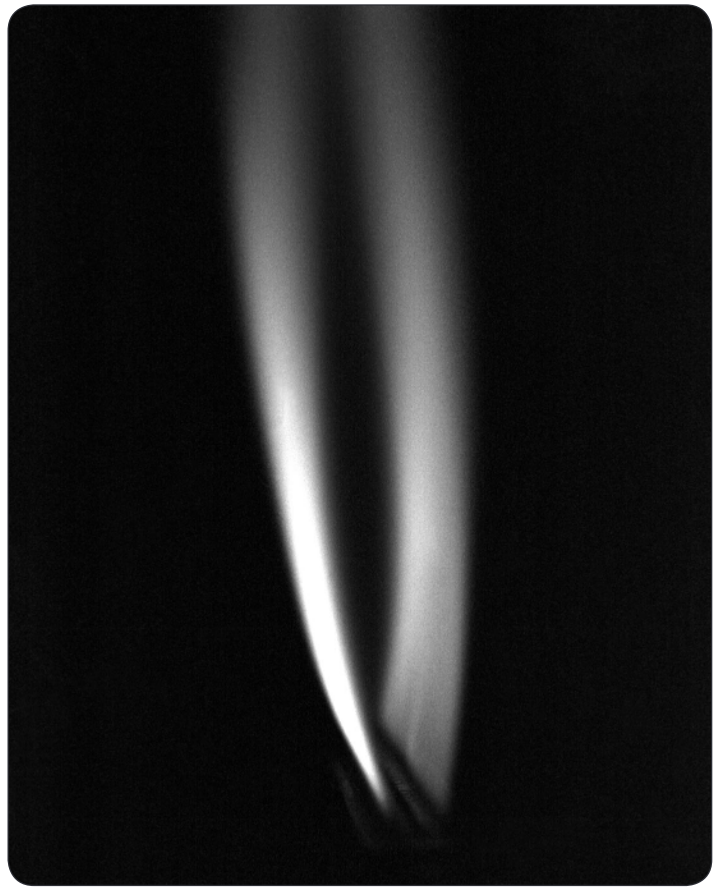


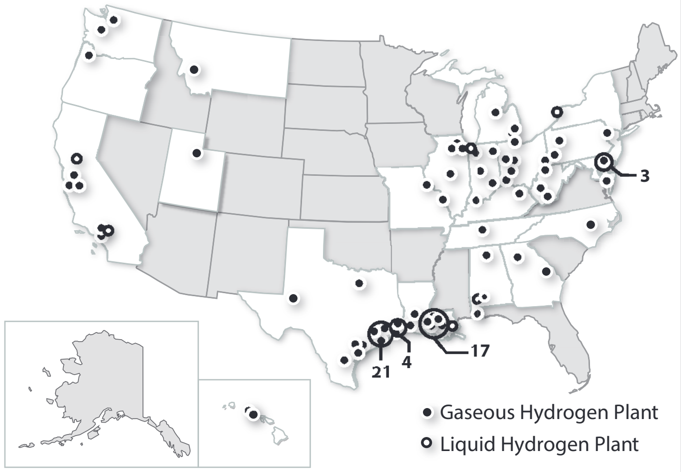
Image courtesy of DOE/NREL, photo credit Warren Gretz

RESEARCH AND DEVELOPMENT

Image courtesy of DOE/NREL, photo credit Robert Remick

Researchers are designing and testing hydrogen sensors. Because hydrogen is colorless and odorless, sensors are key safety elements of hydrogen facilities.

Hydrogen Production Plants



Data: U.S. Department of Energy Hydrogen Analysis Resource Center

Reducing the cost of hydrogen: The cost of hydrogen, including the cost of producing and delivering it, must be similar to or less than the cost of fuels we use today. Researchers are working to lower the cost of production equipment and to find ways to make production processes more efficient, which will lower the cost of hydrogen for consumers.

Reducing fuel cell cost and improving durability: Fuel cells are currently more expensive than conventional power systems such as the engines used in cars today. Researchers are working to develop technologies that will lower the cost of fuel cells and ensure that fuel cell systems can operate reliably for long periods of time in a wide range of weather and temperature conditions.

Improving hydrogen storage technology: Most people expect to be able to drive their cars more than 300 miles before having to refuel. Even in a highly efficient fuel cell vehicle, today's hydrogen storage technology does not allow drivers to travel more than 300 miles between fill-ups. Scientists are researching ways to improve storage technology and to identify new ways to store hydrogen on board a vehicle to achieve a 300+ mile driving range.

Educating consumers: In addition to research, hydrogen education is also necessary to support a hydrogen economy. Consumers must be familiar with hydrogen in order to feel as comfortable driving and refueling a hydrogen fuel cell vehicle as they do driving and refueling a gasoline vehicle. Government, industry, and the education system also need knowledgeable students with an interest in hydrogen to become the future researchers, engineers, scientists, technicians, and educators.

Jobs in Fuel Cell Technologies

Adapted from the U.S. DOE Office of Energy Efficiency and Renewable Energy

Currently, fuel cell technologies are in small, specific markets. However, as research and development continues to bring the cost of fuel cell technologies down, it is expected that the industry will grow significantly. In one scenario, vehicle applications of fuel cells could open up 675,000 new jobs between 2020 and 2050.

Employment opportunities will open up in businesses that develop, manufacture, operate, and maintain the fuel cell systems. Jobs will also become available in business that produce and deliver the hydrogen and other fuels used by these systems.

Fuel Cell Technology Jobs

- Mechanical engineers
- Chemists
- Chemical engineers
- Electrical engineers
- Materials scientists
- Laboratory technicians
- Factory workers
- Machinists
- Industrial engineers
- Power plant operators
- Power plant maintenance staff
- Bus, truck, and other fleet drivers
- Vehicle technicians
- Fueling infrastructure installers
- Hydrogen production technicians

For more information on training programs, colleges, and universities offering programs in fuel cell and hydrogen science, visit www.fuelcells.org/education-and-careers/#ed.

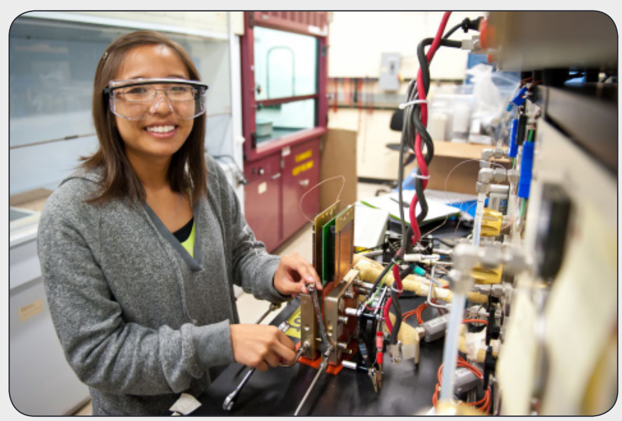


Image courtesy of DOE/NREL, photo credit Dennis Schroeder

Today, many jobs related to hydrogen are found in science labs. In the future, a wide variety of jobs will be available.