# Hydrogen

## What Is Hydrogen?

**Hydrogen** is the simplest element known to exist. An atom of hydrogen has one proton and one electron. Hydrogen has the highest energy content of any common fuel by weight but the lowest energy content by volume. It is the lightest element and a gas at normal temperature and pressure.

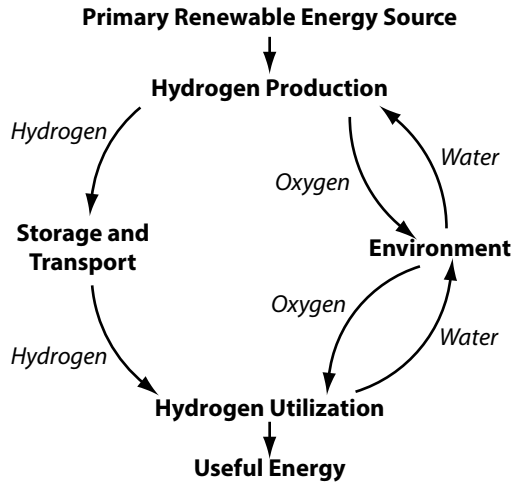
Hydrogen is also the most abundant gas in the universe, and the source of all the energy we receive from the sun. The sun is basically a giant ball of hydrogen and helium gases. In a process called **fusion**, hydrogen nuclei combine to form one helium atom, releasing energy as radiation.

This radiant energy is our most abundant energy source. It gives us light and heat and makes plants grow. It causes the wind to blow and the rain to fall. It is stored as chemical energy in fossil fuels. Most of the energy we use originally came from the sun.

Hydrogen as a gas ($H_2$), however, doesn't exist naturally on Earth. It is found only in compound form. Combined with oxygen, it is water ($H_2O$). Combined with carbon, it forms organic compounds such as methane ($CH_4$), coal, and petroleum. It is found in all growing things—**biomass**. Hydrogen is also one of the most abundant elements in the Earth's crust.

Every day we use fuels like natural gas and petroleum to produce electricity and power our vehicles. Electricity is a secondary source of energy. Secondary sources of energy—energy carriers—are used to store, move, and deliver energy in an easily usable form. We convert energy to electricity because it is easier for us to transport and use. Try splitting an atom, building a dam, or burning coal to run your television. Energy carriers make life easier.

### Hydrogen Life Cycle




Hydrogen is one of the most promising energy carriers. It is a high-efficiency, low-polluting fuel that can be used for transportation, heating, and power generation in places where it is difficult to use electricity. Hydrogen can come from either renewable or nonrenewable sources.

## How Is Hydrogen Made?

Since hydrogen gas is not found on Earth, it must be manufactured. There are several ways to do this. The most common process for commercial hydrogen is a process called **steam reforming**. High-temperature steam separates hydrogen from the carbon atoms in methane. The hydrogen produced by this method isn't used as a fuel but for industrial processes. This is the most cost-effective way to produce hydrogen today, but it uses fossil fuels both in the manufacturing process and as the heat source.

Another way to make hydrogen is by **electrolysis**—splitting water into its basic elements—hydrogen and oxygen. Electrolysis involves passing an electric current through water to separate the atoms ($2H_2O$ + electricity = $2H_2$ + $O_2$). Hydrogen collects at the cathode and oxygen at the anode.

Hydrogen produced by electrolysis is extremely pure, and electricity from renewable sources can power the process, but the process is very expensive at this time. Today, hydrogen from electrolysis (per Btu) can be more than 10 times more costly than natural gas and 1.5 times more costly than gasoline.

On the other hand, water is abundant and renewable, and technological advances in renewable electricity could make electrolysis a more attractive way to produce hydrogen in the future.

There are also several experimental methods of producing hydrogen. Photoelectrolysis uses sunlight to split water molecules into its components. A **semiconductor** absorbs the energy from the sun and acts as an electrode to separate the water molecules.

In biomass gasification, wood chips and agricultural wastes are superheated until they turn into hydrogen and other gases. Biomass can also be used to provide the heat.

Scientists have also discovered that some algae and bacteria produce hydrogen under certain conditions, using sunlight as their energy source. Experiments are underway to find ways to induce these microbes to produce hydrogen efficiently.

Nearly every region of the country (and the world) has one or more resources that can be used to produce hydrogen. It can be produced at large central facilities or at small distributed facilities for local use. One of its main advantages is its flexibility.

## Hydrogen Rainbow

Hydrogen may be assigned a color based on which renewable or nonrenewable source and process produces it. Green hydrogen is made from excess renewable sources (wind, solar, etc.) that power an electrolyzer. Blue hydrogen is produced from natural gas where carbon dioxide is captured and stored during steam reforming. Grey, black, and brown hydrogen are produced from natural gas steam reformation and coal gasification, where $CO_2$ is not captured and stored. Finally, pink, purple, or red hydrogen is generated through the use of nuclear energy to power electrolysis.

## Hydrogen Uses

The U.S. hydrogen industry currently produces roughly 8.6 billion cubic feet of hydrogen every day. Most of this hydrogen is used for industrial applications such as refining, treating metals, and food processing. However, there is space for hydrogen to gain momentum for use in transportation, energy storage, and more.

Liquid hydrogen is the fuel that is used to propel rockets. Hydrogen fuel cells can also be used on transport vessels and space stations to power electrical systems.

Hydrogen will join electricity as an important energy carrier, since it can be made safely from renewable energy sources and is virtually non-polluting. It can also be used as a fuel for zero-emissions vehicles, to heat homes and offices, to produce electricity, and to fuel aircraft. Cost and infrastructure are major obstacles.

The first widespread use of hydrogen could be as an additive to transportation fuels. Hydrogen can be combined with compressed natural gas (CNG) to increase performance and reduce pollution. Adding 20 percent hydrogen to CNG can reduce **nitrogen oxide ($NO_X$)** emissions by 50 percent in today's engines. An engine converted to burn pure hydrogen produces only water and minor amounts of $NO_X$ as exhaust.

A few hydrogen-powered vehicles are on the road today, but it will be some time before you can walk into your local car dealer and drive away in one. Today, just over 50 retail hydrogen fuel stations are operating, with most in California and one in Hawaii. There are an additional 20 stations in various stages of construction.

Can you imagine how huge the task would be to quickly change the gasoline-powered transportation system we have today? Just think of the thousands of filling stations across the country and the production and distribution systems that serve them. Change will come slowly to this industry, but hydrogen is a versatile fuel and can be used in many ways.

**Fuel cells** (batteries) provide another use option, just as they were utilized by NASA. Fuel cells basically reverse electrolysis—hydrogen and oxygen are combined to produce electricity. Hydrogen fuel cells are very efficient and produce only water as a byproduct, but they are expensive to build.

With technological advances, small fuel cells could someday power electric vehicles, and larger fuel cells could provide electricity in remote areas. Because of the cost, hydrogen will not produce electricity on a wide scale in the near future. It may, though, be added to natural gas to reduce emissions from existing power plants.

As the production of electricity from renewables increases, so will the need for energy storage and transportation. Many of these sources—especially solar and wind—are located far from population centers and produce electricity only part of the time. Hydrogen may be the perfect carrier for this energy. It can store the energy and distribute it to wherever it is needed.

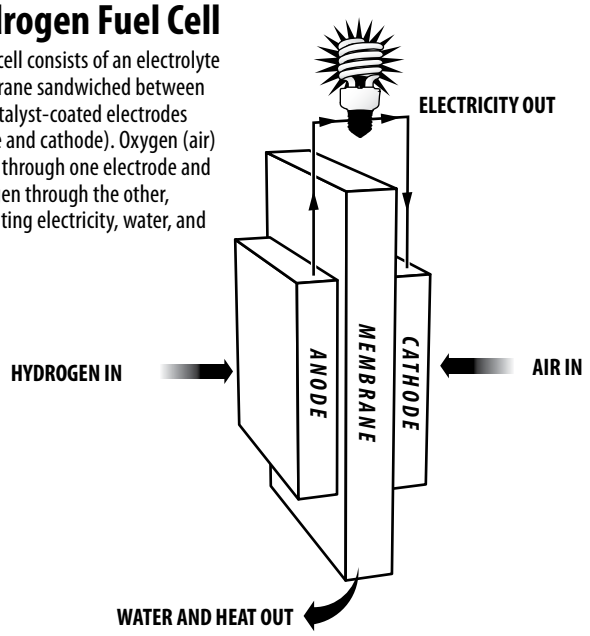
**ARTEMIS I SPACE LAUNCH SYSTEM AND ORION SPACECRAFT**

**Hydrogen was used as the fuel for NASA space shuttles and rockets, beginning in the 1980s. While the U.S. shuttles have since been retired, hydrogen is still used internationally to launch satellites and as a space fuel. The NASA Artemis project will use hydrogen as a propellant. Hydrogen is a perfect fuel for space travel as it has very high energy density while keeping weight down.**

Image courtesy of NASA

### Hydrogen Fuel Cell

A fuel cell consists of an electrolyte membrane sandwiched between two catalyst-coated electrodes (anode and cathode). Oxygen (air) passes through one electrode and hydrogen through the other, generating electricity, water, and heat.




## Future of Hydrogen

Before hydrogen can make a significant contribution to the U.S. energy picture, many new systems must be designed and built. There must be large production and storage facilities and a distribution system. Consumers must have the technology to use it.

The use of hydrogen may raise concerns about safety. Hydrogen is a volatile gas with high energy content. However, early skeptics had similar concerns about natural gas and gasoline—even about electricity. People were once afraid to let their children too near the first light bulbs. As hydrogen technologies develop, safety issues will be addressed. Hydrogen can be produced, stored, and used as safely as other fuels.

As a domestically produced fuel, hydrogen has the potential to reduce our dependence on foreign oil and provide clean, renewable energy for the future.