Hydrogen can be produced using a variety of resources including biomass, hydro, wind, solar, geothermal, nuclear, coal with carbon capture, utilization and storage, and natural gas. This diversity of sources makes hydrogen a promising energy carrier and enables hydrogen production almost anywhere in the world.

Hydrogen Production

Hydrogen is an energy carrier, not an energy source—hydrogen stores and delivers energy in a usable form, but it must be produced from hydrogen-containing compounds.

Hydrogen can be produced using diverse, domestic resources including fossil fuels, such as natural gas and coal (preferentially with carbon capture, utilization, and storage); biomass grown from renewable, non-food crops; or using nuclear energy and renewable energy sources, such as wind, solar, geothermal, and hydroelectric power to split water. This diversity of potential supply sources is an important reason why hydrogen is such a promising energy carrier.

Hydrogen can be produced at large central plants, at medium scale semi-central plants, or in small distributed units located at or very near the point of use, such as at refueling stations or stationary power sites.

How Is Hydrogen Produced?

Researchers are developing a wide range of technologies to produce hydrogen economically from a variety of resources in environmentally friendly ways.

Natural Gas Reforming

Hydrogen can be produced from natural gas using high-temperature steam. This process, called steam methane reforming, accounts for about 95% of the hydrogen used today in the U.S. Another method, called partial oxidation, produces hydrogen by burning methane in air. Both steam reforming and partial oxidation produce a "synthesis gas" or "syn gas," which is then reacted with additional steam to produce a higher hydrogen content gas stream.

Renewable Electrolysis

Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using any of a number of resources. However, to minimize greenhouse gas emissions,

electricity generation using renewable energy technologies (such as wind, solar, geothermal, and hydroelectric power), nuclear energy, or natural gas and coal with carbon capture, utilization, and storage are preferred.

Gasification

Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of air/oxygen and steam. A subsequent series of chemical reactions produces a syn gas, which is then reacted with steam to produce a gas stream with an increased hydrogen concentration that then can be separated and purified. With carbon capture and storage, hydrogen can be produced directly from coal with near-zero greenhouse gas emissions. Since growing biomass consumes carbon dioxide from the atmosphere, producing hydrogen through biomass gasification results in near-zero net greenhouse gas emissions.

Renewable Liquid Reforming

Biomass can also be processed to make renewable liquid fuels, such as ethanol or bio-oil, which are relatively convenient to transport and can be reacted with high-temperature steam to produce hydrogen at or near the point of use. Researchers are also exploring a variation of this technology known as aqueous-phase reforming.

Nuclear High-Temperature Electrolysis

Heat from a nuclear reactor can be used to improve the efficiency of water electrolysis to produce hydrogen. By increasing the temperature of the water, less electricity is required to split it into hydrogen and oxygen, which reduces the total energy required.

High-Temperature Thermochemical Water-Splitting

Another water-splitting method uses high temperatures generated by solar concentrators (mirrors that focus and intensify sunlight) or nuclear reactors to drive a series of chemical reactions to split water into hydrogen and oxygen. All of the intermediate process chemicals are recycled within the process.

Biological

Certain microbes, such as green algae and cyanobacteria, produce hydrogen by splitting water in the presence of sunlight as a byproduct of their natural metabolic processes. Other microbes can extract hydrogen directly from biomass.

Photoelectrochemical (PEC)

Hydrogen can be produced directly from water using sunlight and a special class of semiconductor materials. These highly specialized semiconductors absorb sunlight and use the light energy to directly split water molecules into hydrogen and oxygen.

What Are the Challenges?

The greatest challenge for hydrogen production, particularly from renewable resources, is providing hydrogen that is cost competitive. For transportation, a key driver for energy independence, hydrogen must be cost-competitive with conventional fuels and technologies on a per-mile basis. This means that the cost of hydrogen—regardless of the production technology, and including the cost of delivery—must be less than $4/gallon gasoline equivalent (untaxed and dispensed).

To reduce overall hydrogen cost, research is focused on improving the efficiency of hydrogen production technologies as well as reducing the cost of capital equipment, operations, and maintenance.

Research Directions

Hydrogen production technologies are in various stages of development. Some technologies, such as steam methane reforming, are already commercial and can be used in the near term. Others, such as high-temperature thermochemical water-splitting, biological, and photoelectrochemical, are in early stages of laboratory development and considered potential pathways for the long-term.

Related research includes developing new hydrogen delivery methods and infrastructure, improving carbon sequestration technology to ensure that coal-based hydrogen production releases almost no greenhouse gas emissions, and improving biomass growth, harvesting, and handling to reduce the cost of biomass resources used in hydrogen production.

For More Information

More information on the Fuel Cell Technologies Office is available at http://www.hydrogenandfuelcells.energy.gov.

Examples of H2 Production Approaches: Technologies, Scales, and Timeframe

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