Hydrogen

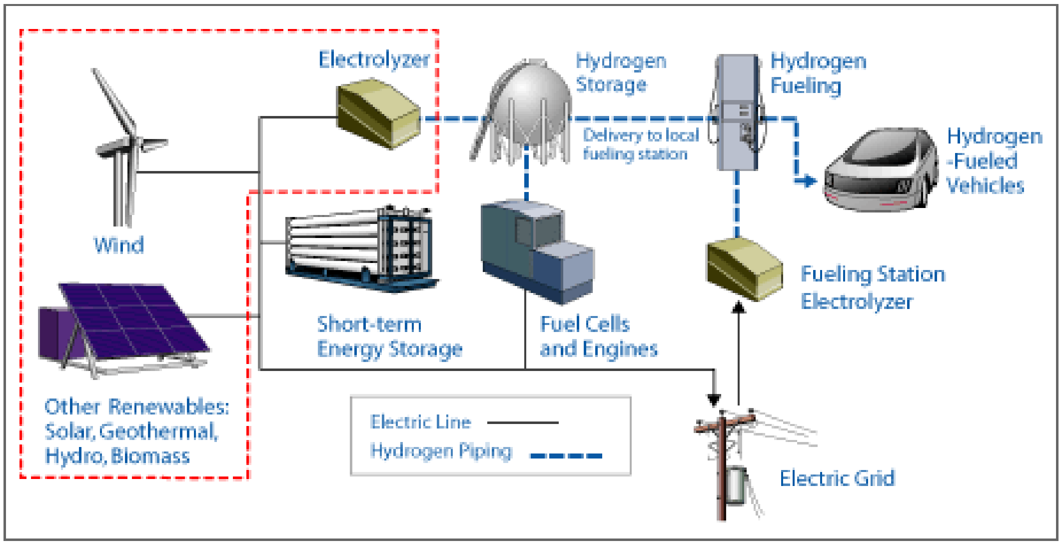

Figure 1: Hydrogen Grid and Storage Integration (NREL)

Hydrogen is the most abundant element in the universe, but on earth it rarely occurs naturally in its pure state. Instead, hydrogen is usually combined with other elements such as oxygen or carbon. According to the United States Department of Energy, hydrogen can be used to store and transport energy, but it is not itself a source of energy. Pure hydrogen can be produced using a variety of sources including fossil fuels such as coal and natural gas, or renewable sources such as biomass, wind, solar, geothermal, and water. Currently, about 95 percent of hydrogen in the United States is made from natural gas for use in petroleum processing and fertilizer production.

In 2003, President Bush dedicated $1.2 billion over five years to the Hydrogen Fuel Initiative, a USDOE program for hydrogen fuel cell (see fuel cell section below) research and development. The USDOE hydrogen programs have primarily focused on research and development for the transportation sector with the goal of mass-market, hydrogen-powered electric vehicles by 2020. In 2010, Congress appropriated $244 million to the DOE Hydrogen Program.

Producing Hydrogen

Currently about 10-11 million metric tons of hydrogen is produced in the United States each year, enough to power 20-30 million cars or five to eight million homes. The majority of this production takes place in California, Louisiana, and Texas.

All technologies to produce pure hydrogen involve breaking the chemical bonds between hydrogen and its companion elements. In the United States the most common way hydrogen is produced is through *steam reforming*, a process through which steam is used to break the bonds between hydrogen and carbon in methane (natural gas), thus producing pure hydrogen. This process is inexpensive compared to other methods; however it releases greenhouse gases as a byproduct.

Electrolysis is another relatively common technology to produce hydrogen using electricity to split water into hydrogen and oxygen atoms. This method in and of itself does not generate emissions, but it does require a substantial amount of electricity and, depending on how the electricity is generated, can have a high greenhouse gas input. While new technologies are being developed to reduce costs and improve efficiency of electrolysis, this is currently an expensive process. Similar technologies are in development to use microbes or semiconductors to harness light energy instead of electricity to split water molecules. In addition, there are multiple other technologies in the development phase seeking to produce hydrogen more efficiently and with a lower carbon footprint.

Hydrogen Storage

Hydrogen storage for large-scale use has been a challenge due to hydrogen's low-energy content per volume. Hydrogen can be stored as a *compressed hydrogen gas* in high-pressure tanks, as *cryogenic liquid hydrogen* in insulated tanks, as a compound within other materials, or on the surface of other materials. Liquid hydrogen has a higher energy density per volume than hydrogen gas but is costly to produce due to the energy needed for cooling. According to USDOE, "hydrogen storage in materials offers great promise, but additional research is required to better understand the mechanism of hydrogen storage in materials under practical operating conditions and to overcome critical challenges related to capacity, the uptake and release of hydrogen, management of heat during refueling, cost, and life cycle impacts."

One storage concept discussed in Oregon is the hydrogen hub. A hydrogen hub would use hydroelectric or wind power to synthesize ammonia, a hydrogen-rich compound, to take advantage of excess energy that would otherwise be lost (for instance during spring run-off when energy demand is low, but hydroelectric generation is high). During peak power demand, the ammonia would be burned to produce electricity with water vapor and nitrogen gas as byproducts. A hydrogen hub has not been built.

Fuel Cells

A fuel cell uses oxygen and hydrogen to create electricity through a chemical process instead of combustion. The fuel input may be pure hydrogen or a hydrogen-rich compound such as methanol, ethanol, or other hydrocarbons. Fuel cells that use pure hydrogen as the fuel emit only heat and water as byproducts. Fuel cells are adaptable to scale and can be used in a variety of applications including: utility-sized power plants, back-up generators, powering portable battery-powered devices (e.g., laptop computer), and vehicles. Cost and durability are the primary challenges for fuel cell adoption, although other technical challenges exist based on the type of technology and its intended application.

Distributing Hydrogen

Hydrogen is currently transported by pipeline, in high-pressure tube trailers, or as liquefied hydrogen. Currently, hydrogen is primarily produced near the location where it is used, as a large scale infrastructure for delivery does not exist. Due to gaseous hydrogen's low-energy density per volume, transport using tube trailers is typically cost effective over distances less than 200 miles from the point of production. Hydrogen can also be transported in chemical carriers, such as ethanol, for easier transport to be converted at the site of use.