

Hydrogen provides a promising method to help the U.S. achieve energy independence, make strides in environmental stewardship, and develop a thriving economy. Hydrogen produced through renewable energy sources, most commonly with a device which uses electricity to separate water into hydrogen and oxygen called an electrolyzer, is an emissions-free way to carry energy. Hydrogen is plentiful and can safely be harnessed for a variety of stationary and mobile applications.

Introduction to Renewable Electricity

With the exception of hydroelectric power, less than 1% of the electricity generated in the U.S. today is produced by renewable energy. The primary reason is cost. While hydropower is cost competitive today but limited geographically, wind, geothermal, and ocean power are rapidly becoming cost competitive with traditional electricity generation, and the cost of solar energy is beginning to decrease as efficiency and manufacturability progress is made. Although biomass can be burned to produce electricity and an emerging technology called microbial electrolysis cells (electrohydrogenesis) has been shown to produce hydrogen biologically, these topics are covered in other Fact Sheets of this series. Following are brief descriptions of the most common sources of renewable electricity:

Wind turbines convert wind energy into electricity. Wind power is the fastest growing electricity source in the world, and utilities throughout the U.S. are installing wind farms (see photo) for additional power generation. Large turbines can be up to 180 meters tall and produce 1.5 to 5 megawatts of power. (By comparison, the average household light bulb requires 60-100 watts). Small turbines are also available to provide power for homes or remote locations. Wind turbines can be sited and installed faster than many conventional power plants, and technology advancements are making it possible to generate electricity from low wind speeds. Also, despite a common misperception about turbines' impact on avian populations, they account for a fraction of 1% of bird fatalities caused by human influences (the two major contributors being buildings and domestic cats).



Three wind turbines - part of a larger group, or *wind farm*

Geothermal electricity generation utilizes the earth's heat to produce steam to drive turbines which produce electricity. In the U.S., traditional geothermal technology has had limited growth potential because of geographic constraints, but emerging Enhanced Geothermal System Technologies may extend this capability to larger regions of the country. Geothermal energy provides constant, predictable electricity generation. There are environmental issues relating to water temperature and dissolved solids in the water; however, geothermal plants are very efficient, operating close to maximum output at all times, while producing no greenhouse gas emissions. An array of solar photovoltaic (PV) panels

Hydropower captures the energy of flowing water to produce electricity, and is the most widely-used renewable energy technology. There are a variety of hydropower technologies, but the most common is impoundment hydropower, which uses a dam to store and release water. This technology does have an impact on the local environment. Other, lower impact hydropower technologies are in use, but they generally provide electricity on a smaller scale. Electricity produced by large hydropower costs about \$0.0085 per kilowatt-hour¹, considerably less than nuclear, coal, and natural gas production. Many of the large hydropower sites in the United States have already been utilized, so there are few opportunities to create new capacity. The smaller, lower impact hydropower technologies have the most opportunity for growth.



Impoundment hydropower technology at work in a traditional dam

Ocean Power technologies can take energy from the oceans to generate power. There are four sources of ocean energy that we can capture: tidal power, wave power, current power, and ocean thermal energy.

Tidal power takes advantage of the differences between high and low tides in coastal areas. It can trap water similar to a dam or use tidal flows to directly spin turbines.

Wave power can be used both on and off shore. On-shore technologies can engineer waves to be taller when they hit land, then capture the water in reservoirs, or they can use the rise and fall of water to compress columns of air attached to low-pressure turbines. Off-shore technologies ride the waves and use the bobbing motion to generate power. In a similar fashion,

Current Power takes advantage of water motion in large ocean currents, often at significant distances below the surface or even on the seabed, **Ocean thermal** energy uses the difference in deep ocean temperatures from surface water temperatures. Since differences of 20°C (36°F) are needed, ocean thermal is best suited for use in tropical areas.

These technologies are limited by the strength of the tides, currents, and waves, temperature differences, and geographic feasibility. They are likely to be expensive in the near term, but could be commercial as costs fall and fossil fuel prices rise.

Solar Photovoltaics (PV) convert the sun's energy directly into electricity. Most solar PV cells are made of thin silicon wafers and are approximately 16-18% efficient at converting the sun's energy to electricity. Solar PV is used in a range of both off- and on grid applications and is easily scalable.



An array of solar photovoltaic (PV) panels

Concentrated Solar Power (CSP) uses lenses and mirrors to concentrate sunlight. The sunlight is focused onto a thermal receiver, which then converts the sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity. There are three main types of CSP systems: parabolic troughs, dish/engine systems, and central receiver systems, which can be applied to off-grid systems of just a few kW to grid-connected systems of 350 MW and up.

Hydrogen Production through Electrolysis

The main commercial advantages of hydrogen production by electrolysis are its scalability and the emission-free production of hydrogen (when produced via renewable energy). Conventional electrolysis is the most common method used to produce renewable hydrogen. Electrolysis involves the separation of water into hydrogen and oxygen, using an electric current. Although some electrolyzers use chemicals or intense heat to help the separation, conventional electrolysis uses no chemicals, and works at room temperature.

Electrolysis separates water into its constituent elements--hydrogen and oxygen--by charging water with an electrical current. The charge, coming from two poles in the water, breaks the chemical bond between the hydrogen and oxygen and splits apart the atomic components, creating oppositely charged particles (see diagram). Because opposite charges attract, the negative pole (cathode) attracts the positive particle (with the hydrogen molecules), and the positive pole (anode) attracts the negative particle (with the oxygen molecules). As the particles reach the poles, the hydrogen and oxygen gases rise and are collected separately. (It takes about 53 kilowatt-hours¹ to produce 1 kilogram of hydrogen assuming a 75% efficient electrolyzer).

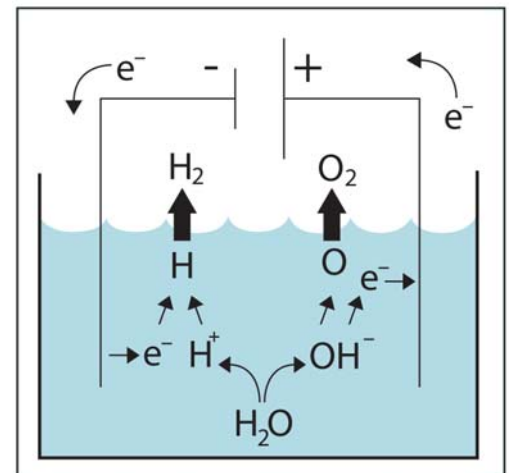


Diagram showing the process of conventional electrolysis

Barriers to Hydrogen Production through Electrolysis

There are challenges to setting up mainstream electrolyzer use for hydrogen production, primarily high capital costs and the cost of electricity. For example, PV electricity today costs approximately \$.30/kw-hr, perhaps ten times what is needed to make electrolysis cost competitive, and the cost of electrolyzers themselves must be significantly reduced to enable large-scale implementation. Many of the renewables have siting, social, or environmental concerns which also must be overcome. However, all these barriers are being addressed aggressively by government and industry, and it is worth considering whether the benefits warrant greater investment today.

Why Hydrogen Production from Renewables?

Hydrogen provides the connecting point between renewable electricity production and transportation, stationary and portable energy needs. When the electricity from solar photovoltaics, wind, geothermal, ocean and hydro technologies is used to produce and store hydrogen, the renewable source becomes more valuable and can meet a variety of needs. In transportation applications, hydrogen provides a way to convert renewable resources to fuel for vehicles. Renewably produced hydrogen for transportation fuel is one of the most popular hydrogen economy goals, as it can be domestically produced and emissions free.

Renewables often produce power intermittently (e.g., only when the sun is out or the wind is blowing), so hydrogen can also increase stationary power reliability when used as an electricity storage medium. Hydrogen, renewably produced during off-peak periods and stored, can provide constant power using fuel cells or engines when the renewable source isn't available.

To have a highly effective and efficient renewable-hydrogen system, the hydrogen should be used at choice times. At the time when renewable resources are available (e.g. the sun is shining), and electricity is needed, the electricity should be used directly. To meet an even higher electricity demand, energy can be supplied directly from renewables sources as well as from the hydrogen stores. As demand decreases, extra electricity from renewables can be converted and stored as hydrogen. This entire portfolio of options is what makes renewable-hydrogen systems effective in providing flexible, reliable energy in whichever form is needed most. There are few other options today for electricity storage at a large scale. Batteries are not practical and too

costly, and pumped water systems and compressed air energy storage systems are only implementable in limited geographical areas.

Renewable Energy for a Hydrogen Future

In the near term, hydrogen produced in the U.S. may be from fossil fuels, but industry and governments have their sights on increasing hydrogen production from renewables. Hydrogen can help renewable electricity technologies mature and become more cost-competitive. In the meantime, hydrogen production from fossil fuels can use low cost, existing infrastructure along with emerging methods to capture and store greenhouse gas emissions to provide hydrogen while minimizing environmental impact.

Renewables are an emissions-free way to produce hydrogen by electrolysis, and, conversely, hydrogen offers a way for renewables to generate transportation fuel and reliable power. The versatility of renewable technologies allows them to be adapted to meet diverse energy needs. Though costs for some renewable technologies are higher than traditional generation sources, technology advancements and increased market penetration are reducing prices. Additionally, the environmental benefits help to compensate for the higher costs. When taken as a whole, the future conjunction of hydrogen and renewable energy technology is a promising one. Diagram showing the process of conventional electrolysis



¹ A kilowatt-hour refers to a unit of electric energy equal to the work done by one kilowatt acting for one hour. In 1999, the typical U.S. household used 10,000 kilowatt-hours per year. It can meet very small loads, such as a pump for livestock watering, or larger loads, such as the power needs of an office building. PV's versatility allows it to be incorporated into building materials, mounted over parking lots to provide shade or mounted directly on the ground. The primary barrier to PV technologies is the high capital cost, but improved efficiency, technology advancements and economies of scale are reducing prices.