Hydrogen can be the driving force of cars and buses in two ways: via direct combustion and through its utilization in fuel cells. Ford Motor Company introduced the car model P2000, which uses hydrogen instead of gasoline, and Honda introduced the car model FCX, which is powered by fuel cells.

In aviation, hydrogen has great potential as well. In the 1950s, the B27 was running on liquid hydrogen, and in 1988 the TU 155 proved the feasibility of a passenger aircraft to be powered by liquid hydrogen. CRYOPLANE, a European research consortium, conducted a systems analysis of hydrogen as an aviation fuel. It considered applicability, safety, and environmental issues. The main findings of the technical assessment were that hydrogen is a suitable alternative to kerosene (used in aircraft), there are no barriers to the implementation of its use, and there are great long-term benefits.

Hydrogen also holds great promise for use in fuel cells, devices that convert electrochemical energy. Fuels cells are fueled by hydrogen and oxygen to produce electricity, heat, and water. They are made up of three segments: the anode, the electrolyte, and the cathode. Hydrogen is fed to the anode and oxygen to the cathode. Activated by a catalyst, hydrogen atoms separate into protons and electrons, which, with an external circuit, create electricity. Currently, six major fuel cell technologies are under development: polymer electrolyte membrane (PEM), phosphoric acid, direct methanol, alkaline, molten carbonate, and solid oxide, which is the dominant one. Fuel cell technology has great potential, as it can find applications in all areas, from small mobile electric devices, such as cell phones, to cars such as the Honda FCX.

Hydrogen as a fuel has a great advantage over hydrocarbons. Its combustion and its use in fuel cells have a negligible environmental impact. It is obvious that its environmental performance depends on its production technology.

The principal hydrogen generation technologies are reformation of hydrocarbons and water electrolysis. Reformation generates CO_2 as a by-product. In addition, the electricity required in electrolysis has its own environmental burden. Hydrogen has great potential to be a clean energy carrier if a way is found to overcome these constraints. Carbon sequestration technologies hold the potential to minimize CO_2 production, and renewable energy sources are generating clean electricity. The combination of these new technologies could give life to the future of clean hydrogen production.

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See Also: Black, Joseph; Carbon Sequestration; Cold Fusion; Einstein, Albert; Fuel Cells; Gasification; Nuclear Fusion; Potential Energy.

Hydropower

Category: Energy Technology.

Summary: Hydropower is currently the most common source of renewable energy, accounting for more than 3,400 terawatts, or about 16 percent of global electricity production, in 2010.

Humans have used the force of water for thousands of years. The Greeks used waterwheels for grind-

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A small hydroelectric dam on a river in Scotland. The most common type of hydroelectric power plant is an impoundment facility, which uses a dam like this to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which then activates a generator to produce electricity.

ing wheat into flour more than 2,000 years ago. In China, Tu Shih recorded the use of water power for cast-iron manufacture in 31 C.E. The Roman engineer Vitruvius wrote about waterwheels in the 1st century B.C.E., and in the 4th century C.E. Romans built an elaborate, 16-waterwheel flour mill in the south of France at Barblégal, near Arles. Similar mills have been found in Tunisia and Israel. Other uses for mechanical energy generated by hydropower were sawing wood and powering textile mills and manufacturing plants.

The technology to use falling water to create hydroelectricity has existed for a long time. The evolution of the modern hydropower turbine began in the mid-1700s when a French hydraulic and military engineer, Bernard Forest de Bélidor, wrote *Architecture Hydraulique*. In this four volume work, he described using a vertical-axis versus a horizontal-axis machine. During the 1700s and 1800s, water turbine development continued. In 1880, an arc-light dynamo invented by Charles Brush was driven by a water turbine and used to provide theater and storefront lighting in Grand Rapids, Michigan; in 1881, a Brush dynamo connected to a turbine in a flour mill provided street lighting at Niagara Falls, New York.

Early applications of hydropower used direct current (DC), which limited the range of applications. The shift to alternating current (AC) came when the electric generator was coupled with the turbine, which resulted in the United States' (and the world's), first hydroelectric plant, located in Appleton, Wisconsin, in 1882.

From Water to Watts

Hydropower uses moving water to power machinery or generate electricity. On a global scale, water constantly moves through the hydrologic cycle, evaporating from water bodies such as lakes and oceans to form clouds, which precipitate water over land as rain or snow, which then flows back to the ocean. The energy of this water cycle, which is driven by the sun, can be harnessed for mechanical tasks, such milling grains, pressing oil-containing seeds, sawing wood, and turning a turbine to generate electricity. As hydropower uses a fuel—water from the hydrologic cycle—that is not consumed in the process, it is, in principle, a renewable form of energy. The use of hydropower can make a contribution to saving exhaustible energy sources such as fossil fuels. Each 600 kilowatt-hours of electricity generated with a hydroplant is equivalent to approximately 1 barrel of oil (assuming an efficiency of 38 percent for the conversion of oil into electricity).

The basic principle of hydropower is that if water can be piped from a certain level to a lower level, the resulting water pressure can be used to do work. If the water pressure is allowed to move a mechanical component, then that movement involves the conversion of the potential energy of the water into mechanical energy. Hydraulic turbines, or hydroturbines, convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grinding mill, or some other useful device.

To know the power potential of water in a river, it is necessary to know the flow in the river and the available head. The *flow* of the river is the amount or volume of water (in cubic meters or liters) that passes in a certain amount of time a cross-section of the river. Flows are normally given in cubic meters per second (m^{3}/s) or in liters per second (l/s). *Head* is the vertical difference in level (in meters) the water falls down. The theoretical power (P) available from a given head of water is in exact proportion to the head H and the flow Q

$$P = Q \times H \times c$$

where the constant c is the product of the density of water and the acceleration due to gravity (g). If P is measured in watts, Q in m^{3}/s, and H in meters, the gross power of the flow of water is

$$P = 1000 \times 9.8 \times Q \times H$$

This available power will be converted by the hydroturbine into mechanical power. As a turbine has an efficiency lower than 1, the generated power will be a fraction of the available gross power.

Advantages and Disadvantages

Hydropower has several advantages. Perhaps most important, it is a long-term renewable resource. Given a reasonable head, it is also a concentrated energy source. The available energy it can produce is predictable and nonpolluting. Hydropower dams and reservoirs can assist in flood control; by the same token, if a drought occurs, a dam creates a reservoir containing a water supply. Hydroelectricity generation is 90 percent efficient, whereas fossil-fueled energy is only 30 to 40 percent efficient. Hydropower infrastructure offers a form of storing energy for other industrial, agricultural, recreational, and personal uses. It is reliable and quick in reacting to changes in demand and supply of electricity, helping to balance the intermittent character of other renewable sources, such as wind and solar power. Finally, hydropower is cost-efficient, with low operating and maintenance expenses and with a projected life span of up to 70 years for large facilities.

On the other hand, there are disadvantages to hydropower as well. It is a site-specific technology, and for large-scale production geared toward populous urban centers, the sites that are well suited to the harnessing of water power and also close to a location where the power can be economically exploited are not very common. There is always a maximum useful power output available from a given hydropower site, which limits the level of expansion of activities that make use of the power. Damage is caused by flooding above the dams. Building new large-scale facilities (dams, reservoirs, and related infrastructure) is associated with high initial construction costs, as well as the costs of relocating people because of the adjustment of water levels related to damming. Marine transportation is limited unless locks are constructed. Finally, large-scale hydropower has significant environmental impacts: Migratory travel by aquatic life such as fish is restricted with the dam structure; plant and animal habitats may be destroyed; some water areas may dry up and agricultural land can be degraded; silt buildup in reservoirs and river bottoms can cause transportation hazards and ecological damage; some essential minerals (fertilizers) do not get distributed below the dam; and archaeological artifacts, such as holy grounds, can be destroyed.

Sizes of Hydropower

Facilities range in size from large power plants that supply many consumers with electricity to small and microhydropower plants that individuals operate for their own energy needs or to sell power to utilities. Internationally, no common definitions of hydropower sizes exist, although it is generally understood that small hydropower has a capacity of less than 10 megawatts, in line with the recommendations by the World Commission on Dams. However, some countries set that limit at 15 megawatts (such as India) or even 25 megawatts (China) or 30 megawatts (United States). Large-scale hydropower consequently includes all plants above the upper limit of small-scale hydropower.

There are three categories of small-scale hydropower: microhydropower, minihydropower, and small hydropower. However, again no standards exist. In the United States, for example, microhydropower is usually considered to include installations generating less than 100 kilowatts and minihydropower between 100 kilowatts and 1 megawatt; in China, minihydropower runs up to 500 kilowatts and small hydropower up to 25 megawatts.

The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released to meet changing electricity needs, to maintain a constant reservoir level, or to provide water downstream of the dam. A diversion, sometimes called a run-of-the-river (or run-of-river) facility, channels a portion of a river through a canal or penstock. It may not require the use of a dam.

Small-scale hydropower stations combine the advantages of hydropower with those of decentralized power generation, without the disadvantages of large-scale installations. Small-scale hydropower has few disadvantages: There is no costly distribution of energy and no huge environmental costs (as with large hydropower). It is independent of imported fuels, and there is no need for expensive maintenance. Small-scale hydropower can be used in a decentralized manner, locally implemented and managed. Power generated with a small hydro station can be used for agro-processing, local lighting, water pumps and small businesses.

The context of small hydropower can be described as follows:

- It is decentralized, with small demand for power (from small industries, farms, households, and rural communities).
- The distribution network involves only low voltages (eventually the subregional grid).
- It is owned by an individual, cooperative, or community with semiskilled workers.
- It requires only short planning horizons and construction periods, using locally available materials and skills.
- Depending on the amount of power it generates, it can have a substantial impact on local standards of living (expanding access to previously inadequate power supplies or providing power where none existed).
- As only some information is available about the potential power, often not more than 10 percent of the potential is used.

Based on the advantages and the context as described above, microhydropower and small hydropower could play an important role in the electrification of remote rural areas in developing countries.

Pumped-Storage Hydropower

Pumped-storage hydroelectricity is a type of hydroelectric power generation used by some power plants for load balancing. The method stores energy in the form of water, pumped from a lower-elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines. Although losses from the pumping process make the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest. Pumped storage is the largest-capacity form of grid energy storage now available.

At times of low demand for electricity, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating electricity. Reversible turbine/generator assemblies act as pump and turbine (usually a Francis turbine design). Nearly all facilities use the height difference between two natural bodies of water or artificial reservoirs. Pure pumped-storage plants simply shift the water between reservoirs, while the "pump-back" approach is a combination of pumped storage and conventional hydroelectric plants that use natural stream flow.

Taking into account evaporation losses from the exposed water surface and conversion losses, approximately 70 to 85 percent of the electrical energy used to pump the water into the elevated reservoir can be regained. The technique is currently the most cost-effective means of storing large amounts of electric energy on an operating basis, but capital costs and the presence of appropriate geography are critical decision factors.

Tidal and Wave Power

Tidal power, also called tidal energy, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power. The first large-scale tidal power plant, the Rance Tidal Power Station in France, started operation in 1966.

Small tidal "mills" were used in southern England and northern France in the Middle Ages. Tidal flows in bays and estuaries offered the potential to drive cereal-grinding apparatus in areas that were too low-lying to allow the use of conventional waterwheels. In the 20th century, tides were seriously reexamined as potential sources of energy to power industry and commerce.

Wave power converts the energy contained in ocean waves into usable energy. Wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents. Wave power generation is not currently a widely employed commercial technology, although there have been attempts at using it since at least 1890. In 2008, the first experimental wave farm was opened in Portugal, at the Aguçadoura Wave Farm.

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See Also: Climate and Weather; Fundamentals of Energy; Kinetic Energy; Microhydropower; Natural Energy Flows; Potential Energy; Three Gorges Dam; Tidal Power.