Hydroelectric Power

Hydroelectricity is produced from the energy of falling water. Among renewable energy sources, it is the most technically mature; only wood makes a larger contribution worldwide.

Development

The earliest reference to the use of the energy of falling water is found in the work of the Greek poet Antipater (4th century B.C.). The Romans used waterwheels, but first slavery and then widespread underemployment removed any incentive to develop them further. Only after war and famine ravaged Europe in later centuries did labor-saving water mills come into wider use. By 1800, tens of thousands of such mills had been built in Europe and New England.

Water power was first used to produce electricity at a plant completed on the Fox River near Appleton, Wis., on Sept. 30, 1882. Since that time the contribution of hydroelectric power to world use of electricity has risen steadily. By the year 2000 it accounted for about 20% of global electricity production and 5% of total world energy use.

Total world hydroelectric power production today amounts to approximately 2,574 billion kilowatt hours (kW h). The United States is the leader in electricity generation from falling water. Canada is second and Brazil, with its giant Paraná River complex, a recent third. China and Russia, and between them, these five nations produce over 50% of the world's total hydroelectric power.

Distribution

Hydroelectric power potential is distributed among the continents in rough proportion to land area; China alone has 10% of the world's potential. Mountainous regions and large river valleys are the most promising. The Amazon, Orinoco, and Congo rivers and the rivers fed by Himalayan snows offer sites for large-scale development. Many such regions, however, lie far from industrial centers, including unpopulated areas of Alaska, northern Canada, and Siberia.

Europe and Japan are among the regions that have done the most to harness hydroelectric energy. Europe has exploited almost 60% of its potential. Although it has only one-fourth of Asia's resources, it generates nearly
twice as much hydroelectric power. Japan embarked on a major dam-building program beginning in the 1970s. By contrast, Africa has developed little of its potential, and most of that development is concentrated in several large dams—Egypt's Aswan, Cabora Bassa in Mozambique, and Kariba North and South, in Zambia and Zimbabwe.

In some areas of the world, hydroelectric power is the main source of electricity. More than 35 nations already obtain more than two-thirds of their electricity from falling water. These countries include Brazil (91%), Colombia (71%), North Korea (65%), and Paraguay, whose 99.6% comes from the Paraná complex it shares with Brazil. Norway gets 99% of its electricity and 50% of all its energy from falling water. In South America, 73% of the electricity used comes from hydroelectric power, compared with 44% in the developing world as a whole.

**Power Plants**

The amount of electricity that can be produced at a site is a function of the volume of water at that location and the head, or distance through which the water falls. A conventional hydroelectric plant consists of a dam, which creates head and stores water; penstocks, which conduct water to hydraulic turbines; draft tubes, which quickly release water discharge from the turbine, creating a vacuum effect below the turbine blades and increasing the effective head; generators, which are connected to and driven by the turbines; transformers, which increase voltage for more efficient transmission; and a switchyard (see power, generation and transmission of).

In regions where most favorable sites have been tapped and thermal power plants are numerous, hydroelectric plants can be turned into what are called peaking units. That is, because electricity demand in an area can vary widely over a period of time, sources that can easily be turned on or off are needed to meet demand peaks. Because the water stored behind a dam can be released at any time, hydroelectric plants can become sources of peaking power if additional turbines are installed. Pumped-storage facilities further exploit this flexibility by using off-peak power from continuously running coal and nuclear plants to pump water uphill into storage reservoirs. Water is then released as needed to run back downhill through the turbines, which recoup two-thirds on the energy used for pumping. Peaking and pumped storage have drawbacks, however; it is often less costly to lower peak demand through conservation and load-management techniques than to meet it with peaking units, and pumped-storage plants tend to be large, expensive, and difficult to site.

**Dam Construction**

Modern dam building began with the establishment of the Tennessee Valley Authority (TVA) in the United States in 1933. This comprehensive approach to the development of river basins has become the model everywhere. Today's large dams rank among humanity's greatest engineering feats. For example, the Itaipú Dam, completed in 1982 on the Paraná River between Brazil and Paraguay, can generate 12,600 MW, making it the largest power complex on Earth. (It also demonstrates the need for international cooperation at such sites; unresolved conflicts over water rights remain a major barrier to the development of hydroelectric power in the Middle East, the Himalayan region, and elsewhere.) The lakes created by major dams also number among the planet's largest freshwater bodies. Ghana's Lake Volta covers 8,500 km² (3,280 mi²), an area the size of Lebanon.
Hydroelectric dam projects figure prominently in the economic and investment plans of many developing countries. Egypt electrified virtually all of its villages with power from Aswan, and companies attracted by the power of the São Francisco River have brought almost a million new jobs to impoverished northeastern Brazil. The construction of a large dam in a developing country does not necessarily improve the standard of living for the poor rural majority, however, because the energy-intensive industries that almost invariably are located near large dams seldom provide many jobs for unskilled local people.

From the 1950s through the end of the century, large-scale hydropower development in these countries (and in peripheral regions of industrialized nations) occurred primarily because energy-intensive industries needed cheap electricity and because global-lending institutions were willing to advance multibillion-dollar loans. (Itaipú's final cost reached some $20 billion, and China's Three Gorges Dam project could cost $25 billion.) The World Bank has often been involved to some degree in funding for very large hydropower dams, although in recent years the bank has been far more critical of dam proposals, mainly because of their potential environmental impacts.

Capital for hydroelectric projects is most readily available when sales of power guarantee a steady, predictable flow of revenue. In sparsely inhabited regions such as the Amazon basin, New Guinea, Quebec, and Siberia, the need for power to extract and smelt minerals provides the principal impetus for these projects. Where prime sites are not close to rich mineral deposits, the main economic force behind large-dam construction is the aluminum-smelting industry.

**Environmental Effects**

Large dams change a self-regulating ecological system into one that must be managed. Placed on a river without thought to their upstream and downstream impacts, they can bring disaster. Because lakes cannot survive some of the abuses that rivers can, traditional farming and waste-disposal practices must also be changed. The dams themselves can be threatened by the silting of reservoirs caused by soil erosion, which may drastically curtail a dam's ability to store water and generate energy. The Sanman Gorge Dam in central China, for example, has lost approximately three-fourths of its 1,000-MW capacity to sediment from the Yellow River. In Nepal, deforestation and farming on steep lands threaten to incapacitate the few dams already built on Himalayan rivers.

A primary motivation for building large dams is to trap water for irrigation. Dams mitigate the effects of droughts, increase agricultural productivity, and extend agriculture to dry, uncultivated areas. Farmland created in this way has a price, however—the loss of the river bottomlands that will be flooded by the dam. In addition, where dams have curtailed the spring floods that once deposited rich silt on the land, artificial fertilizers must now be applied to preserve fertility, and fertilizer production can consume much of the dam's power output.

The impact of large dams on fisheries is unpredictable. Gauging impacts is especially difficult in tropical Africa, Asia, and Latin America, where many important but unstudied fish species live. Where fish species migrate long distances to breed, dams can decimate their stocks. The rich Columbia River salmon fisheries in North America declined sharply after dams were built there, despite programs to build fish ladders and to restock the river. By the late 20th century, pressure was increasing to remove some of the dams in order to restore salmon fisheries, and a few of the smaller dams were slated for removal.
On human populations the impact of large hydroelectric projects can be enormous. Some 80,000 people were displaced by Lake Nasser in Egypt and Sudan, 75,000 by Lake Volta in Ghana; China's planned Three Gorges Dam could force some 2 million people to evacuate. Plans to resettle and reemploy displaced people figure prominently in few dam projects, but some native peoples have won substantial concessions. Those in the area inundated by Quebec's giant James Bay project, for example, delayed construction through the courts and forced the government to grant them $250 million, title to 12,900 km$^2$ (4,980 mi$^2$) of land, and preferential employment rights on the project.

Dams can also endanger little-known plant and animal species. Many tropical plants or animals with potentially high economic value will be lost forever if dam reservoirs are built, because so many tropical species have yet to be named. Even where threatened species have been identified, pressure to destroy their habitats can be irresistible.

**Small-Scale Hydroelectric Power**

Large dams are not the sole option of developing nations. Hydroelectric power can also be harnessed at much smaller sites, with capacities between 1 kW and 1 MW. By constructing small dams, developing countries can unleash the 5% to 10% of their hydroelectric power resources that the World Bank conservatively estimates exists at small sites. Small dams could provide roughly as much additional electricity as these countries derive from hydroelectric power at present.

The economics of building small dams for power production varies widely. Because relatively fixed engineering and site-preparation costs can be spread over a larger power output, larger dams seem to enjoy considerable economies of scale. Small-scale projects look more favorable, however, if the hidden or discounted social costs of larger dams are considered. Besides generating revenues, small plants can also aid economic development by converting poorer countries' most abundant and least-used resource—labor—into critically needed capital. They can also catch silt-laden storm waters, thus protecting downstream dams from sedimentation.

Among developing nations, China alone has placed high priority on small-scale hydroelectric development, building an estimated 90,000 small-scale units with some 6,300 MW of generating capacity from 1968 to the century's end, mainly in the rainy southern half of the country. In more than one-fourth of the nation's counties, these small dams are already the main source of electricity. China added 1,500 MW of power annually through 1990 and projected an additional 2,000 MW per year for the ten years following—although its government's enthusiasm for building huge dam projects such as Three Gorges and the other large dams planned downstream on the Yangtze River may have cut into small-scale dam planning. Nevertheless, it is estimated that in terms of total numbers, as many dams have been built in China as in all of the rest of the world.

In the United States, growing interest in such plants followed legislation such as the Public Utilities Regulatory Policies Act (1978), which states that large utilities must buy electric power fed into their lines from small, privately owned generators. Low oil prices in the 1990s, however, made oil-powered electricity generation much less costly and reduced the use of small hydropowered dams.
Outlook

If all the energy contained in the water flowing toward the oceans were harnessed, up to 73 trillion kW h could be produced annually. The potential of tidal energy from the oceans could add to this figure. Given technical, financial, and environmental constraints, probably no more than 19 trillion kW h could actually be tapped. (In 1996 the World Bank noted that "the changes introduced in the Bank's environmental and resettlement guidelines mark a significant shift in the Bank's threshold of acceptibility for dams. 37 [of 50 dams reviewed by the bank] fall short of current standards [but, using the old standards, only 5 are deficient].")

In the United States and such other industrialized nations as Sweden, the desire to preserve prime agricultural land and unique scenic and recreational resources has already placed some large hydroelectric sites off-limits.

By the year 2020, the World Energy Conference optimistically projects, hydroelectric power might supply some 8 trillion kW h of power, which is almost six times the present level. This potential will not materialize, however, unless the environmental and social problems are solved and unless such economically impoverished but resource-rich countries as the Democratic Republic of Congo (Zaire), China, and Nepal attract investment capital and create markets for hydroelectricity.

Daniel Deudney

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