Green Energy: An A-to-Z Guide, Dustin Mulvaney & Paul Robbins

Hydroelectric Power

Kristen Casalenuovo

Hydroelectric power is the electrical power generated from the gravitational potential energy of falling water. This well-established technology catapults water to the status of leading renewable energy resource for electrical generation in the United States and worldwide. According to the Energy Information Administration, it accounted for 71 percent of renewable generation in the United States and 63 percent worldwide in 2007. These amounts correspond to 6 percent of the total electrical energy generated in the United States and 24 percent of the world total. Hydroelectric power's significant contribution to the electrical energy supply results from the simple concepts for its plant design, its economic and environmental advantages over other resources, and its ability to meet consumer energy needs immediately on demand. With all the advantages of hydropower, there are also social and environmental concerns resulting from the construction of dams and the spinning of underwater turbines. These impacts are well understood and can be prevented with proper technologies and planning.

Hydroelectric power facilities like the massive Hoover Dam, pictured here, provide up to 24 percent of the world's total electrical energy supply.

Source: U.S. Department of Agriculture, National Resources Conservation Service/Lynn Betts

Generation

Generating hydroelectric power from falling water is a mechanically simple process. Water released from a dammed reservoir or on its natural path downstream falls from a certain height to flow through turbines. As it falls, the water's gravitational potential energy is converted into the kinetic energy of its motion. The water flows through a series of turbines that are connected by a common shaft to the rotor of an electrical generator. The mechanical energy of the rotating turbines is converted into electrical energy by the generator through the principle of electromagnetic induction. The generator consists of electromagnets mounted on its rotor and coils of copper wire on its stationary stator. As the magnetic field rotates, it induces a current in the stator coils that supplies electrical power to the national grid to be transmitted and distributed to consumers. The amount of electrical power generated from the falling water depends on its flow rate, the amount flowing through a given volume over time, and the head—the height difference from the reservoir to the turbine. The total power output of the world's hydroelectric plants is 675,000 MWe, enough to supply the annual energy needs of 1 billion people.

Hydropower plants fall under six major technologies: impoundment, run-of-river, kinetic hydropower, microscale, diversion, and pumped storage. All systems except pumped storage are considered conventional hydropower. Impoundment hydropower schemes use a dam to store water in a high reservoir and release it on demand to flow down through a penstock, through turbines, and finally into the river beyond the dam. In contrast, run-of-river systems work with the natural flow of water from higher to lower regions. Because the power of falling water is proportional to both its flow rate and the head, run-of-river schemes can easily be integrated into the existing layout of the river. The same amount of power is produced with either combination of small flow rate and high head or large flow rate and low head. A similar scheme is kinetic hydropower, which puts turbines on riverbeds. Both technologies are attractive alternatives to impoundment because they have minimal to zero visibility in the natural landscape. Microscale projects produce up to 100 kW of power with minimal environmental consequences as opposed to larger designs. Diversion hydropower plants divert a portion of a river through a canal or penstock and may or may not require a dam. Finally, pumped storage designs are net energy consumers but offer the unique ability to store large amounts of excess grid energy in the form of hydropower.

Hydropower is an attractive renewable resource because of its capability to be stored and to respond quickly to unexpected surges in demand. The ability to store hydropower is achieved through pumped storage schemes. Hydroelectric plants incorporating this method have a high-level reservoir and a lower reservoir with the same volume capacity. Excess electrical energy from the grid generated during periods of low demand is used to pump water into the higher reservoir. This excess energy generally comes from coal-fired or nuclear power plants. Certain designs enable generators to work in reverse as pumps, converting excess electrical energy from the grid to mechanical energy of the turbines pumping water back into the higher reservoir. Although energy losses are inevitable, efficient turbine generators can recover up to 80 percent of the original input. During peak demand, the water is released to flow through the turbines into the lower reservoir. The response time is extremely fast: Turbines kept spinning in air can produce at full capacity in a matter of seconds. Even nonmoving turbines can be brought to full speed in one minute. At this time, pumped storage plants provide the most practical and cost-effective means of large-scale grid power storage. Other means of grid power storage are industrial-sized battery systems at power plants using energy input from intermittent renewable resources such as solar and wind.

Economic Advantages

Hydropower plants are an economically practical investment because of their long lifetime and minimal operational costs. The capital cost for an electrical power plant includes the costs of up-front engineering and construction, purchase of land, permit and legal expenses, fuel cost, operation, and maintenance. The lifetime and generating capacity of the equipment and the available subsidies for capital loans and tax credits are also important factors. Considering all these, the capital cost per kilowatt of power capacity over the lifetime of the plant is used to gauge the economic benefits of investing in a particular type of power production. For hydro, as with most renewable resources, the fuel costs are zero, so that immediately helps it compete with fossil fuels. The lifetime of dam structures is typically 50–100 years, and the equipment for hydropower schemes have lifetimes ranging from 25–50 years. Compare this with the lifetime of a nuclear power plant, which is only 30–40 years. Operation and maintenance costs are almost negligible for hydropower plants, averaging about 0.7 cents/kWh of electrical energy produced. Many hydropower plants are automated or require only a few employees. The major factor for the capital cost of hydropower is the engineering and construction of the site. Greenfield development, or flooding a valley for the reservoir rather than building a dam on an existing river, is the most expensive option. It is also the only option for countries that have exhausted their available hydropower potential and for pumped storage projects.

Incentives provide renewable energy technologies, including hydropower, a way to be more competitive in the market with fossil fuel and nuclear generation schemes. The Energy Improvement and Extension Act of 2008 allocated $800 million toward clean renewable energy bonds. Business entities such as electrical cooperatives, local governments, and certain lenders can use clean renewable energy bonds as no-interest loans to finance the construction of renewable energy projects. The U.S. Department of Energy also issues loan guarantees with over $10 billion in authority to any projects that reduce greenhouse gas emissions and air pollutants. The Energy Policy of 2005 granted $10 million in appropriations over a decade for hydroelectric plants to receive payments of 1.8 cents/kWh of electrical energy generated and sold up to $750,000 per year. Green certification programs assist hydropower production by attracting business from consumers who opt to use only electrical energy generated from renewable sources. With 70 planned projects under way, these incentives are expected to increase hydroelectric generation by 11 percent over the next decade.

Hydroelectric energy continues to flourish because there is still untapped potential capacity, and its wholesale price is the most affordable in the market. According to a study by the U.S. Department of Energy, the total undeveloped hydropower potential capacity in the United States is 30,000 MW. A 2007 report by the Energy Information Administration compared the capital cost of constructing power plants based on the resource and technology, listing conventional hydropower as $1,500/kW. This estimate is higher than the capital costs of a coal-fired plant with scrubber ($1,290/kW) and a wind power plant ($1,208/kW). However, hydropower fares much better against other alternative technologies such as solar thermal ($3,149/kW), geothermal ($1,880/kW), and advanced nuclear ($2,081/kW). The lowest capital cost of all the existing technologies is for an advanced open cycle gas turbine using natural gas at only $398/kW. This type of plant is also one of the fastest to construct, taking only two to three years to go online from groundbreaking. Thanks to incentives and long lifetimes, hydroelectric energy actually costs less for utilities to purchase—1 cent/kWh compared with 2–3 cents/kWh from fossil fuel plants. Although the economic advantages over other plant technologies are debatable, the environmental implications of hydroelectric power compared to fossil fuels and nuclear are much cleaner.

Environmental and Social Advantages

Using hydroelectric power helps to offset the emissions resulting from combustion of fossil fuels and reduces reliance on finite and imported fuel sources. Hydropower is based on the natural hydrological cycle driven by the sun, so it is a renewable energy source, and there are no related fuel costs. Water is a clean fuel source, so it immediately trumps fossil fuels and nuclear power in terms of air pollution concerns. Hydroelectric power is virtually emissions free beyond initial construction of the plant. Its generation releases no carbon dioxide, and other greenhouse gas emissions such as oxides of sulfur and nitrogen are negligible. In addition, hydroelectric generation produces no particulates or chemical compounds directly harmful to human health, and there is no danger of radioactive waste, as with nuclear power.

Hydropower plants increase the diversity, reliability, and affordability of a nation's electrical energy supply. The grid storage capability of hydroelectric pumped storage plants enables generation from intermittent renewable resources such as solar and wind to be more economically feasible. The ability to control the flow of water and the rapid response time to demand mean hydroelectric power increases the reliability of the electrical energy market. Because hydropower does not depend on the fluctuating market prices of a fuel, the price of the electrical energy it generates is less expensive and more stable. Water for fuel also means countries may generate electrical energy domestically using local resources without having to depend on or negotiate with volatile governments. Domestic hydropower generation boosts rural economies that need it the most, creating jobs and expanding access to health and education.

Flood control, irrigation, and recreation are indirect social benefits of hydropower dams and ultimately depend on the location and planning of the site. Multiuse dams provide a constant supply of irrigation water for agricultural use or for drinking water. Reservoirs can provide a back-up water supply in times of drought. Large hydropower dams can be used to control floods, which protects human populations and ecosystems living downstream of the plant. Many impoundment hydropower reservoirs are enjoyed by the public for recreational activities such as fishing, swimming, and boating. In some cases, a visual improvement to the landscape is achieved with the addition of these lake reservoirs. Some hydroelectric installations such as the Hoover Dam even become popular tourist attractions.

Social and Environmental Concerns

Fish mobility and mortality are affected by the dams and turbines of hydropower plants. The upstream migration of fish such as salmon to spawn sites is hindered by the presence of dams. However, this problem can be minimized through the installation of fish ladders or elevators or by trapping the fish and manually transporting them farther upstream. Fish migrating downstream toward the ocean also can be injured or killed during their passage through turbines. To prevent these mortalities, hydropower plants divert fish with screens, lighting, and sound devices in front of the penstock or turbine intake.

Fish are not the only creatures whose lives and habitats are endangered by the installation of hydroelectric plants. The displacement of entire human populations because of the building of dams is a major social issue. People living in valleys used for the reservoir site must be completely relocated, losing their livelihoods and communities. The World Commission on Dams estimates that anywhere from 40 to 80 million people have been forced to relocate because of the construction of dams. Others who live on the banks of rivers that overflow because of hydropower dams face potentially devastating floods. Catastrophes resulting from dam failures are responsible for hundreds of thousands of human deaths. The 1975 failure of the Banqiao Dam in China as a result of a monumental surge of rainfall led to the deaths of 26,000 people from the flooding, and another 145,000 died from the ensuing epidemics and famines. Human civilizations and ecosystems are equally at risk.

Maintaining the river's water quality and its ecosystems are fundamental to minimizing the environmental impact of hydropower. Impoundment hydropower plants must ensure that a minimum water flow is met to maintain the ecosystems along riverbanks. The amount of dissolved oxygen in water is reduced by underwater turbines, creating dead zones in riverbank habitats and further endangering marine life. Projects are underway to develop advanced turbine technology that will prevent fish injury and mortality and improve compliance with water quality standards. Aeration techniques can also be applied to oxygenate the water. In some locations, diversion of the water supply can cause wells to dry, vegetation to die, and wildlife to suffer. Dams can disrupt the natural flow of soil and nutrients into an ecosystem. The buildup of this silt can also lower the effective volume of the reservoir and subsequently reduce the capacity of the hydropower plant.

When land is artificially flooded for the installation of a hydropower reservoir, the carbon that was trapped inside the plants is released. When the plant matter decays anaerobically under water, dissolved methane is produced and later released into the atmosphere as it passes through the turbines. This process does not just occur during the initial flooding. There may be a continuous supply of decaying plant material along the reservoir banks, depending on the weather and seasonal changes in the water depth. Hydropower plants in tropical climates are especially at risk because the weather is more conducive to decay-related greenhouse gas emissions. These findings call into question the renewable nature of hydropower, which critics claim may result in more greenhouse gases than fossil fuel plants of the same size. However, proper sustainable planning and construction such as clearing the forests before flooding can prevent these decay-related emissions. They are not an inherent factor of hydroelectric generation.

Kristen Casalenuovo Virginia Commonwealth University 10.4135/9781412971850.n73 **See Also:**

- Green Energy Certification Schemes
- Microhydro Power
- On-Site Renewable Energy Generation
- Renewable Energies
- Three Gorges Dam

Further Readings Energy Information Administration. “Electricity Data, Electric Power Capacity and Fuel Use, Electric Surveys and Analysis.” (Accessed January 2009). Energy Information Administration. “Estimated Capital Cost of Power Generating Plant Technologies.” (Accessed January 2009). U.S. Government “2009 Ultimate Guide to Hydropower, Hydroelectric Power, Dams, Turbine, Safety, Environmental Impact, Fish Passage, Impoundment, Pumped Storage, Diversion, Run-of-River.” Progressive Management (2008). Von Schon H.A.E.C. Hydro-Electric Practice: A Practical Manual of the Development of Water Power, Its Conversion to Electric Energy, and Its Distant Transmission. France Press, 2008.