Hydropower

What Is Hydropower?

Hydropower (from the Greek word *hydor,* meaning water) is energy that comes from the force of moving water. The fall and movement of water is part of a continuous natural cycle called the **water cycle**.

Energy from the sun evaporates water in the Earth's oceans and rivers and draws it upward as water vapor. When the water vapor reaches the cooler air in the atmosphere, it condenses and forms clouds. The moisture eventually falls to the Earth as rain or snow, replenishing the water in the oceans and rivers. Gravity drives the moving water, transporting it from high ground to low ground. The force of moving water can be extremely powerful.

Hydropower is called a **renewable** energy source because the water on Earth is continuously replenished by precipitation. As long as the water cycle continues, we won't run out of this energy source.

History of Hydropower

Hydropower has been used for centuries. The Greeks used water wheels to grind wheat into flour more than 2,000 years ago. In the early 1800s, American and European factories used the water wheel to power machines.

The water wheel is a simple machine. The water wheel is located below a source of flowing water. It captures the water in buckets attached to the wheel, and the weight of the water causes the wheel to turn. Water wheels convert the potential energy (gravitational potential energy) of the water into motion. That energy can then be used to grind grain, drive sawmills, or pump water.

In the late 19th century, the force of falling water was used to generate electricity. The first hydroelectric power plant, built on the Fox River in Appleton, WI in 1882, powered multiple homes and businesses. In the following decades, many more hydroelectric plants were built. At its height in the early 1940s, hydropower provided 33 percent of this country's electricity.

By the late 1940s, the best sites for big dams had been developed. Inexpensive fossil fuel plants also entered the picture. At that time, plants burning coal or oil could make electricity more cheaply than hydro plants. Soon these fossil fuel plants began to underprice the smaller hydroelectric plants. It wasn't until the oil shocks of the 1970s that people showed a renewed interest in hydropower.

Hydro Dams

It is easier to build a hydropower plant where there is a natural waterfall. That's why both the U.S. and Canada have hydropower plants at Niagara Falls. Dams, which create artificial waterfalls, are the next best way.

Dams are built on rivers where the terrain will produce an artificial lake or **reservoir** above the dam. According to the Army Corps of Engineers, there are more than 92,000 dams in the United States, but most were not built specifically for electricity generation. Most dams were built for recreation, flood control, fire protection, and irrigation, and fewer than 3,000 are federally owned.

Hydropower at a Glance, 2024

Classification:
- renewable

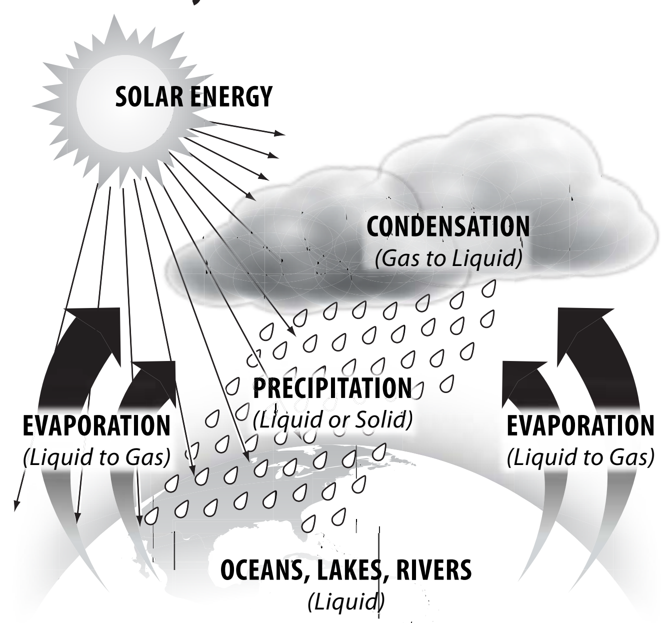
Major Uses:
- electricity

U.S. Energy Consumption:
- 0.826 Q
- 0.88%

U.S. Energy Production:
- 0.826 Q
- 0.80%

Data: Energy Information Administration

The Water Cycle



A dam serves two purposes at a hydropower plant. First, a dam increases the **head**, or height, of the water. Second, it controls the flow of water. Dams release water when it is needed for electricity production. Special gates called **spillway gates** release excess water from the reservoir during heavy rainfalls.

Hydropower Plants

As people discovered centuries ago, the flow of water represents a huge supply of **kinetic energy** that can be put to work. Water wheels are useful for generating motion energy to grind grain or saw wood, but they are not practical for generating electricity, as they are too bulky and slow.

Hydroelectric power plants are different. They use modern turbine generators to produce electricity, just as thermal (coal, natural gas, nuclear) power plants do, except they do not produce heat to spin the turbines.

Hydropower

How a Hydropower Plant Works

A typical hydropower plant is a system with three parts:

- a power plant where the electricity is produced;
- a dam that can be opened or closed to control water flow; and
- a reservoir (artificial lake) where water can be stored.

To generate electricity, a dam opens its gates to allow water from the reservoir above to flow down through large tubes called **penstocks**. At the bottom of the penstocks, the fast-moving water spins the blades of turbines. The turbines are connected to generators to produce electricity. The electricity is then transported via huge transmission lines to a local utility company.

Head and Flow

The amount of electricity that can be generated at a hydro plant is determined by two factors: head and flow. **Head** is how far the water drops. It is the distance from the highest level of the dammed water to the point where it goes through the power-producing turbine.

Flow is how much water moves through the system—the more water that moves through a system, the higher the flow. Generally, a high-head plant needs less water flow than a low-head plant to produce the same amount of electricity.

Storing Energy

One of the biggest advantages of a hydropower plant is its ability to store energy. The water in a reservoir is, after all, stored energy. Water can be stored in a reservoir and released when needed for electricity production.

During the day when people use more electricity, water can flow through a plant to generate electricity. Then, during the night when people use less electricity, water can be held back in the reservoir.

Storage also makes it possible to save water from winter rains for generating power during the summer, or to save water from wet years for generating electricity during dry years.

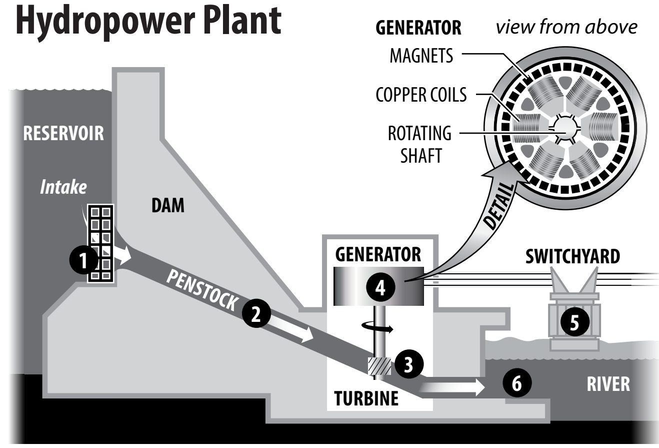
Pumped Storage Systems

Some hydropower plants use pumped storage systems. A **pumped storage system** operates much like a public fountain does; the same water is used again and again.

At a pumped storage hydropower plant, flowing water is used to make electricity and then stored in a lower pool. Depending on how much electricity is needed, the water may be pumped back to an upper pool. Pumping water to the upper pool requires electricity, so hydro plants usually use pumped storage systems only when there is peak demand for electricity.

Pumped storage hydro is the most reliable energy storage system used by American electric utilities. Most power plants have no energy storage systems. They must turn to gas- and oil-fired generators or renewables when people demand lots of electricity. Many also have no way to store any extra energy they might produce during normal generating periods.

Hydropower Plant



1. Water in a reservoir behind a hydropower dam flows through an intake screen, which filters out large debris but allows fish to pass through.
2. The water travels through a large pipe, called a penstock.
3. The force of the water spins a turbine at a low speed, allowing fish to pass through unharmed.
4. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
5. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.
6. Water flows out of the penstock into the downstream river.

Hydropower Production

How much electricity do we get from hydropower today? Depending on the amount of rainfall, hydro plants produce from five to ten percent of the electricity produced in this country. In 1997, 10.21 percent of electricity came from hydropower—a historical high. However, in the last 15 years, U.S. hydroelectricity has decreased relative to other renewable sources. In some states, like Washington, Idaho, and Oregon, hydropower can account for more than half (50 to 70 percent) of each state's electricity generation.

Today, there is approximately 80,000 megawatts of conventional hydro-generating capacity in the United States and almost 102,000 megawatts when including pumped storage. That's enough to power 25 million homes. In 2024, hydropower accounted for 5.49% of U.S. electricity. The biggest hydro plant in the U.S. is located at the Grand Coulee Dam on the Columbia River in northern Washington State. The U.S. also gets some hydropower-generated electricity from Canada. Some New England utilities buy this imported electricity.

What does the future look like for hydropower? The most economical sites for hydropower dams in the U.S. have already been developed, so the development of new, large hydro plants is unlikely.

Existing plants can be modernized with turbine and generator upgrades, operational improvements, and additional generating capacity. Plus, many flood-control dams not equipped for electricity production could be retrofitted with generating equipment.

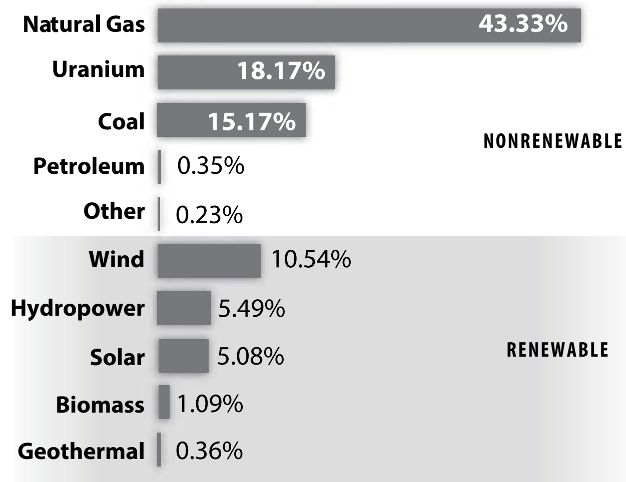
Hydropower for Baseload Power

Demand for electricity is not steady; it goes up and down. People use more electricity during the day when they are awake and using electrical appliances and less at night when they are asleep. People also use more electricity when the weather is very cold or very hot.

Electric utility companies have to produce electricity to meet these changing demands. **Baseload power** is the electricity that utilities have to generate all the time. For that reason, baseload power should be cheap and reliable. Hydropower meets both of these requirements. Generating electricity with hydropower is one of the cheapest ways to generate electricity in the U.S., and the fuel supply—flowing water—is always available.

Hydro plants are more energy efficient than most thermal power plants, too. That means they waste less energy to produce electricity. In thermal power plants, a lot of energy is lost as heat. Hydro plants are about 90 percent efficient at converting the kinetic energy of the moving water into electricity.

U.S. Electricity Net Generation, 2024



*Total may not equal 100% due to independent rounding.
Data: Energy Information Administration
Other: purchased steam, tire-derived fuels, electricity used for storage, etc.

Economics of Hydropower

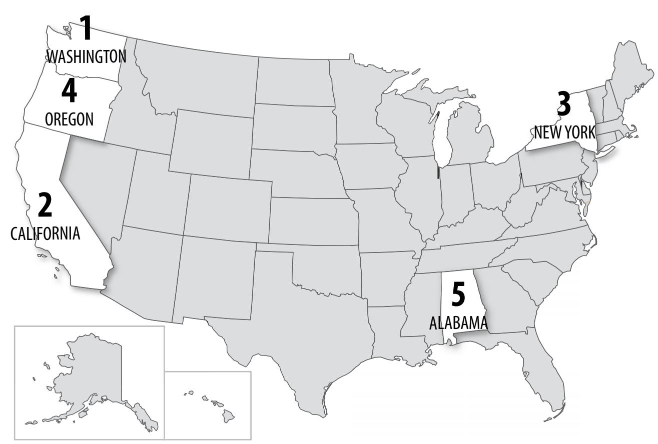
Hydropower is the cheapest way to generate electricity today. No other energy source, renewable or nonrenewable, can match it. It can cost as little as about two cents per kilowatt-hour (kWh) to produce electricity at a typical hydro plant. In comparison, it often costs coal plants about four cents per kWh and nuclear plants about three cents per kWh to generate electricity.

Producing electricity from hydropower is cheap because, once a dam has been built and the equipment installed, the energy source—flowing water—is free.

Hydropower plants also produce power cheaply due to their sturdy structures and simple equipment. Hydro plants are dependable and long-lived, and their maintenance costs are low compared to coal or nuclear plants.

One requirement may increase hydropower's costs in the future. The procedure for licensing and relicensing dams has become a lengthy and expensive process. Many environmental impact studies must be undertaken and multiple state and federal agencies must be consulted. It takes up to seven years to get a license to build a hydroelectric dam to continue operations.

Top Hydropower Producing States, 2024



Data: Energy Information Administration

Hydropower and the Environment

Hydropower dams can cause several environmental problems, even though they burn no fuel. Damming rivers may permanently alter river systems and wildlife habitats. For example, fish may no longer be able to swim upstream.

Hydro plant operations may also affect water quality by churning up dissolved metals that may have been deposited by industry long ago. Hydropower operations may increase silting, change water temperatures, and change the levels of dissolved oxygen. Water quality and the ecosystems around a dam are closely monitored. Some of these problems can be managed by constructing **fish ladders**, dredging the silt, and carefully regulating plant operations.

Hydropower has advantages, too. Hydropower's fuel supply (flowing water) is clean and is renewed yearly by snow and rainfall. Furthermore, hydro plants do not emit pollutants into the air because they burn no fuel. With growing concern over greenhouse gas emissions and increased demand for electricity, hydropower may become more important in the future.

Hydropower facilities offer a range of additional benefits. Many dams are used to control flooding and regulate water supply, and reservoirs provide lakes for recreational purposes, such as boating and fishing.

Marine Hydrokinetic Technologies

Tidal Energy

The **tides** rise and fall in eternal cycles. The waters of the oceans are in constant motion. We can use some of the ocean's energy, but most of it is out of reach. The problem isn't harnessing the energy as much as transporting it. Generating electricity in the middle of the ocean just doesn't make sense, since there's no one there to use it. We can use only the energy near shore, where people need it.

Tidal energy is a promising source of ocean energy for today and the near future. Tides are changes in the level of the oceans caused by the rotation of the Earth and the gravitational pull of the moon and sun. Near shore, water levels can vary up to 40 feet, depending on the season and local factors. Only about 20 locations in the U.S. have good inlets and a large enough tidal range—about 10 feet—to produce energy economically.

Tidal energy plants capture the energy in the changing tides. A low dam, called a **barrage**, is built across an inlet. The barrage has one-way gates called sluices that allow the incoming flood tide to pass into the inlet. When the tide turns, the water flows out of the inlet through huge turbines built into the barrage, producing electricity. The oldest and largest tidal plant, La Rance in France, has been successfully producing electricity since 1966.

Some tidal plants have very high development costs. It is very expensive and takes a long time to build the barrages, which can be several miles long. Other options for tidal energy can be less costly. Tidal turbines work very much like wind turbines underwater, capturing the kinetic energy of the moving water with spinning blades. There are many designs for tidal turbines. Also, tidal plants produce electricity less than half of the time. The seasons and cycles of the moon affect the level—and the energy—of the tides. The tides are very predictable but not controllable. On the other hand, the fuel is free and non-polluting, and the plants have very low operating costs. The plants should run for a hundred years with regularly scheduled maintenance.

Tidal power is a renewable energy source. Though they produce no air pollution, the plants do affect the environment. During construction, there are major short-term changes to the ecology of the inlet. Once the plants go into operation, there can be long-term changes to water levels and currents. However, the plants in operation have reported no major environmental problems.

The United States has only a few sites where tidal energy could be produced economically. In 2012, Maine deployed the country's first commercial tidal power system connected to the grid. It was located in the Cobscook Bay and had the capacity to power up to 2,000 homes while it was grid-connected. More testing is underway in the same area. Alaska is exploring the possibility of incorporating tidal power into the Railbelt grid. The keys to a successful tidal energy project are to lower construction costs, increase output, and protect the environment.

Wave Energy

Research and development of wave energy is happening all over the globe. Worldwide, many conceptual designs of wave energy conversion devices have been developed, but only a few have been built as full-scale prototypes and tested under real world conditions. So far, no particular technology is considered an ultimate solution. Off the coast of Oregon, PacWave, the first utility-scale, grid connected wave energy test site in the U.S. allows developers and researchers to test their prototypes.

OSCILLATING WAVE SURGE FLAP DEVICE

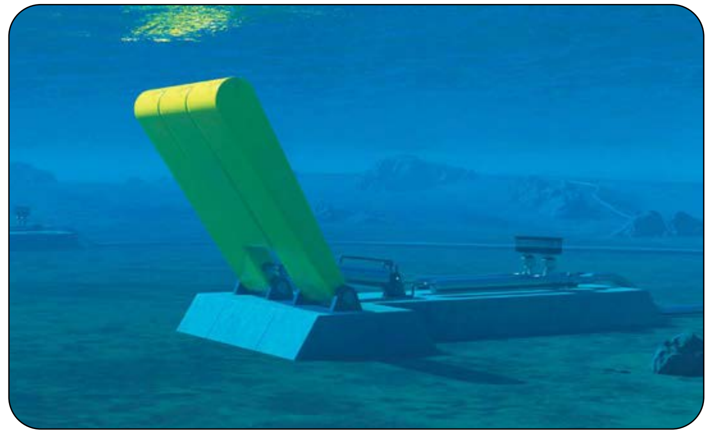


Image courtesy of IKM 3D UK

Wave energy devices use the energy of the waves to move and generate electricity. Devices can be anchored to the seafloor, like this surge flap, or floating on the surface like buoys.

Wave energy devices turn motion or mechanical energy into electric current. Wave energy technology can be grouped into a few major categories, each with a different method for harnessing energy from waves: attenuators, point absorbers, overtopping devices, pressure differential, oscillating water columns, and oscillating wave surge converters. Attenuators float on the surface and generate electricity as waves move segments of the device up and down. Point absorbers are devices like buoys that bob vertically to generate electricity. Overtopping devices capitalize on waves flowing over a barrier. Oscillating devices and pressure differential devices are situated underwater and generate electricity as waves move the devices. Wave energy technologies must survive the harsh ocean environment, efficiently extract energy from waves while being able to be connected to the electric grid, and must ensure the local environment is not harmed during operation.

OTEC

Oceans cover about 70 percent of the Earth's surface. Radiant energy from the sun is absorbed by the ocean's surface and some of it is transformed into heat. Deep ocean water does not receive any sunlight and stays at a cool, constant temperature year round. The difference in temperature between these ocean layers can be used to generate electricity in an Ocean Thermal Energy Conversion (**OTEC**) plant. An Ocean Thermal Energy Conversion power plant uses a heat engine to capture energy as heat flows naturally from hot to cold.

OTEC systems are presently not very efficient, and pumping water is a giant engineering challenge. OTEC systems work best when conditions allow for a 20˚C temperature gradient, which limits its use to tropical regions where surface waters are very warm and the water is very deep. Hawaii, with its tropical climate, has experimented with OTEC since the 1970s. A small grid-connected facility was built in Hawaii in 2015 and has the capacity to power a neighborhood or small military installation.