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Exploring Hydroelectricity

Student Guide

NEED

National Energy Education Development Project

SECONDARY

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What Is Energy?

Energy makes change; it does things for us. It moves cars along the road and boats on the water. It bakes cakes in the oven and keeps ice frozen in the freezer. It plays our favorite songs on the radio and lights our homes. Energy helps our bodies grow and allows our minds to think. Energy is defined as the ability to do work or produce change.

Energy is found in different forms, such as light, heat, sound, and motion. There are many forms of energy, but they can all be put into two categories: potential and kinetic.

Potential Energy

Potential energy is stored energy or the energy of position. There are several forms of potential energy, including:

- **Chemical energy** is energy that is stored in the bonds of atoms and molecules that holds these particles together. Biomass, petroleum, natural gas, and propane are examples of stored chemical energy.
- **Nuclear energy** is energy stored in the nucleus of an atom—the energy that binds the nucleus together. The energy can be released when small nuclei are combined (fusion) or large nuclei are split apart (fission). In both fission and fusion, mass is converted into energy, according to Einstein's Theory, $E = mc^2$.
- **Elastic energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of elastic energy.
- **Gravitational potential energy** is the energy of position or place. A rock resting on top of a hill contains gravitational potential energy because of its position. If a force pushes the rock, it rolls down the hill because of the force of gravity. The potential energy is converted into kinetic energy until it reaches the bottom of the hill and stops.

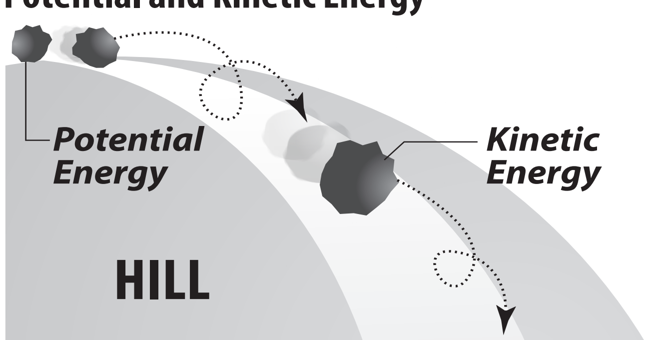
  The water in a **reservoir** behind a hydropower dam is another example of gravitational potential energy. The stored energy in the reservoir is converted into kinetic energy of motion as the water flows down a pipe called a **penstock** and spins a turbine. The **turbine** spins a shaft inside a **generator**, where magnets and coils of wire convert the motion energy into electrical energy. This electricity is transmitted over power lines to consumers who use it to accomplish many tasks.

Kinetic Energy

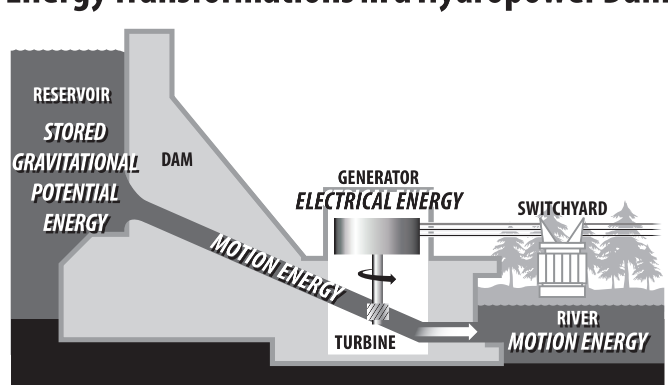
Kinetic energy is energy in motion—the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- **Electrical energy** is the movement of **electrons**. Everything is made of tiny particles called atoms. **Atoms** are made of even smaller particles—electrons, protons, and neutrons. Applying a force can make some of the electrons move. The movement of electrons in a wire is called electricity. Lightning is another example of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Solar energy is an example of radiant energy.
- **Thermal energy** is the internal energy in substances—the vibration and movement of the atoms and molecules within substances. The more thermal energy a substance posesses, the faster the atoms and molecules vibrate and move, and the hotter it becomes. Geothermal energy is an example of thermal energy.
- **Sound** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate. The energy is transferred through the substance in a longitudinal wave.
- **Motion** is the movement of objects and substances from one place to another. Objects and substances move when an unbalanced force acts on them according to Newton's Laws of Motion. Wind is an example of motion energy.

Potential and Kinetic Energy



Energy Transformations in a Hydropower Dam



Conservation of Energy

Your parents may tell you to conserve energy. “Turn out the lights,” they might say. But to scientists, conservation of energy means something quite different. The Law of Conservation of Energy states that energy is neither created nor destroyed. When we consume energy, it doesn’t disappear; we change it from one form into other forms. Energy can change form, but the total quantity of energy in the universe remains the same.

A car engine, for example, burns gasoline, converting the chemical energy in the gasoline into useful motion or mechanical energy. Some of the energy is also converted into light, sound, and heat. Solar cells convert radiant energy into electrical energy. Old-fashioned windmills changed kinetic energy in the wind into motion energy to grind grain.

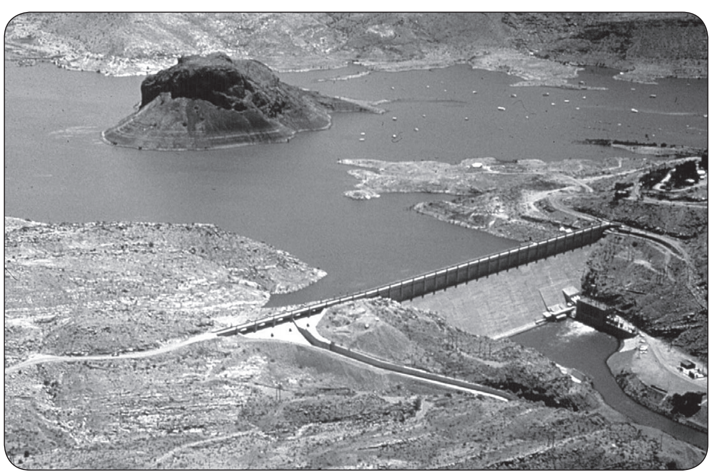
Energy Efficiency

Energy **efficiency** is the amount of useful energy produced by a system compared to the energy input. In theory, a 100 percent energy-efficient machine would convert all of the energy input into useful work. Converting one form of energy into another form always involves a loss of usable energy—usually in the form of heat—from friction and other processes. This ‘waste heat’ dissipates and is very difficult to recapture and use as a practical source of energy.

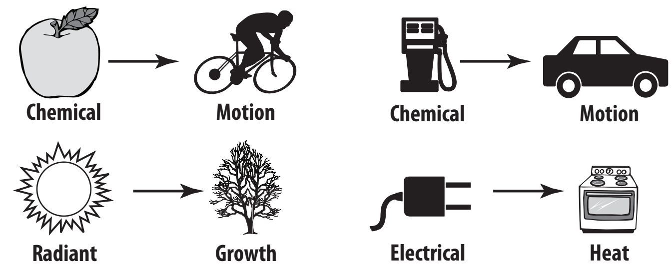
A typical coal-fired power plant converts about 35 percent of the chemical energy in the coal into electricity. A hydropower plant, on the other hand, converts about 90 percent of the kinetic energy of the water flowing through the system into electricity.

Most energy transformations are not very efficient; the human body is a good example. Your body is like a machine, and the fuel for your machine is food. Food gives you the energy to move, breathe, and think. Your body is about fifteen percent efficient at converting food into useful work. The rest of the energy is converted to thermal energy.

GRAVITY DAM

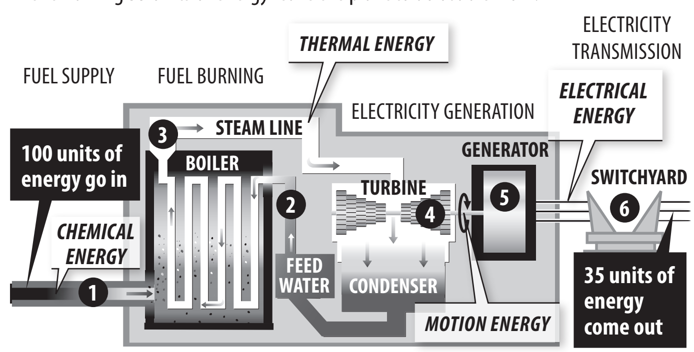


Energy Transformations



Efficiency of a Thermal Power Plant

Most thermal power plants are about 35 percent efficient. Of the 100 units of energy that go into a plant, 65 units are lost as one form of energy is converted to other forms. The remaining 35 units of energy leave the plant to do usable work.



Fuel Sources

How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned (except for uranium which is fissioned, not burned) to release thermal energy.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins a ring of magnets inside coils of copper wire. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

Sources of Energy

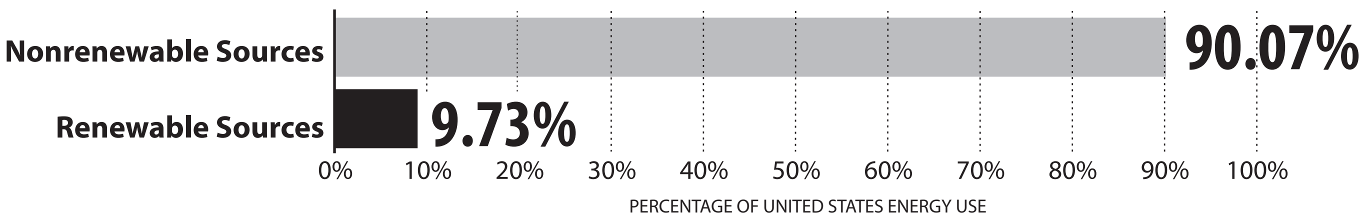
We use many energy sources to meet our needs. All of them have advantages and disadvantages—limitation or reliability of supply, and economic, environmental, or societal impacts. Energy sources are usually classified into two groups—renewable and nonrenewable.

In the United States, most of our energy comes from **nonrenewable energy sources**. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to generate electricity, heat homes, move cars, and manufacture all kinds of products from candy bars to tablets. They are called nonrenewable because their supplies are limited, and they cannot be replenished in a short period of time. Petroleum, for example, was formed hundreds of millions of years ago, before dinosaurs lived, from the remains of ancient sea plants and animals. We could run out of economically recoverable nonrenewable resources some day.

Renewable energy sources include biomass, geothermal, hydropower, solar, and wind. They are called renewable because they are replenished in a short time. Day after day the sun shines, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity.

HYDROPOWER

U.S. Consumption of Energy by Source, 2015



Nonrenewable Energy Sources and Percentage of Total Energy Consumption

PETROLEUM 36.57%
Uses: transportation, manufacturing
- Includes propane

NATURAL GAS 28.97%
Uses: heating, manufacturing, electricity
- Includes propane

COAL 15.97%
Uses: electricity, manufacturing

URANIUM 8.56%
Uses: electricity

PROPANE
Uses: heating, manufacturing

*Propane consumption is included in petroleum and natural gas figures.

Renewable Energy Sources and Percentage of Total Energy Consumption

BIOMASS 4.86%
Uses: heating, electricity, transportation

HYDROPOWER 2.38%
Uses: electricity

WIND 1.83%
Uses: electricity

SOLAR 0.44%
Uses: heating, electricity

GEOTHERMAL 0.22%
Uses: heating, electricity

Data: Energy Information Administration

Electricity

Electricity is different from primary energy sources like petroleum or wind—it is a **secondary source of energy**. That means we must use another energy source to produce electricity. Electricity is sometimes called an energy carrier because it is an efficient and safe way to move energy from one place to another, and it can be used for so many tasks. Since electricity is used for many tasks in our daily lives, it is needed and produced in large quantities each day.

A Mysterious Force

What exactly is the mysterious force we call electricity? It is moving electrons. And what are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms—every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

Atomic Structure

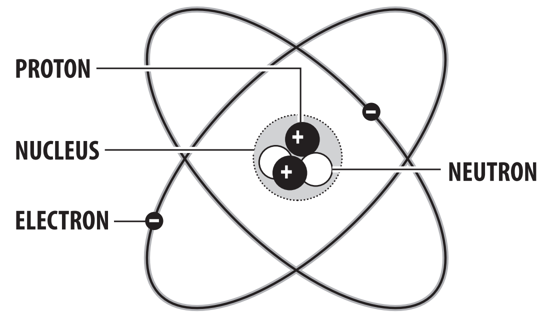
Atoms are made of smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons**, which carry a positive (+) charge, and **neutrons**, which carry no charge. Protons and neutrons are approximately the same size. The mass of a single proton is 1.67×10^{-24} gram. Nuclear energy is contained within the nucleus, because a strong nuclear force holds the protons and nuetrons together.

Protons and neutrons are very small, but electrons are much smaller—1836 times smaller, to be precise. Electrons carry a negative (-) charge and move around the nucleus in orbits a relatively great distance from the nucleus. If the nucleus were the size of a tennis ball, the diameter of the atom with its electrons would be several kilometers.

If you could see an atom, it might look a little like a tiny center of spheres surrounded by giant invisible clouds (or energy levels). Electrons are found in these energy levels and are held there by an electrical force. The protons and electrons of an atom are attracted to each other. They both carry an electrical charge. The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other.

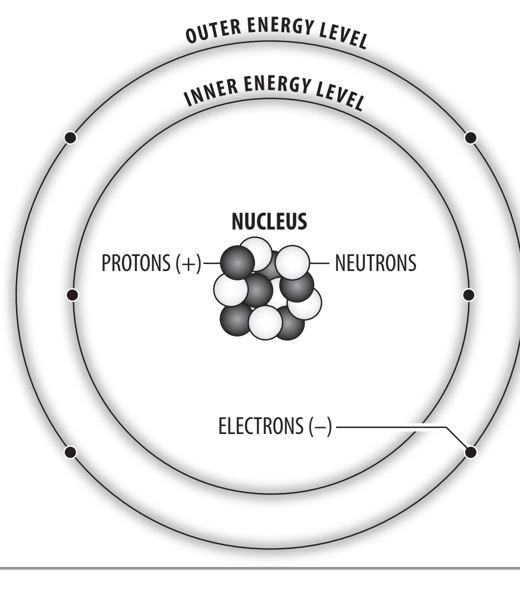
When an atom is in balance, it has an equal number of protons and electrons. The number of neutrons can vary.

Atom



Carbon Atom

A carbon atom has six protons and six neutrons in the nucleus, two electrons in the inner energy level, and four electrons in the outer energy level.



Elements

An **element** is a substance in which all of the atoms have the same number of protons. The number of protons is given by an element's **atomic number**, which identifies elements. A stable atom of hydrogen, for example, has one proton and one electron, with almost always no neutrons. A stable atom of carbon has six protons, six electrons, and typically six neutrons. The **atomic mass** of an element is the combined mass of all the particles in one atom of the element.

Electrons

The electrons usually remain a constant distance from the nucleus in **energy levels**. The level closest to the nucleus can hold two electrons. The next level can hold up to eight. Additional levels can hold more than eight electrons.

The electrons in the levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost level—the **valence energy level**—do not. In this case, these electrons—**valence electrons**—easily leave their energy levels. Other times, there is a strong attraction between valence electrons and the protons. Often, extra electrons from outside the atom are attracted and enter the valence energy level. When the arrangement of electrons changes in these ways, energy is gained or transformed. We call this energy from electrons electrical energy.

Applying a force can make the electrons move from one atom to another.

Electrical Energy

The positive and negative charges within atoms and matter usually arrange themselves so that there is a neutral balance. However, sometimes there can be a buildup of charges creating more negative than positive charges, or more positive charges than negative charges. This imbalance produces an electric charge. Unlike electric current where electrons are moving, these electrons don't move until there is another object for them to move to. This is called **static electricity**. When the charges become too unbalanced there is a discharge of electrical energy between positively and negatively charged areas. This is what causes lightning to jump from cloud to cloud, or between a cloud and the ground.

Magnets

In most objects the molecules that make up the substance have atoms with electrons that spin in random directions. They are scattered evenly throughout the object. Magnets are different—they are made of molecules that have north- and south-seeking poles.

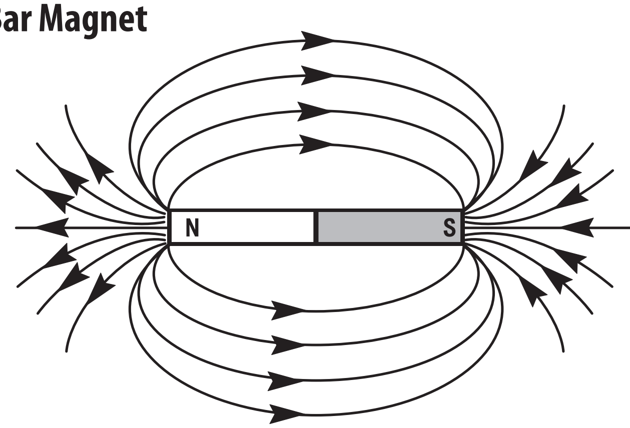
The molecules in a magnet are arranged so that most of the north-seeking poles point in one direction and most of the south-seeking poles point in the other.

Spinning electrons create small **magnetic fields** and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic fields. Magnets are different—most of the atoms' electrons spin in the same direction, which means the north- and south-seeking poles of the micro-magnets they create are aligned. Each micro-magnet works together to give the magnet itself a north- and south-seeking pole.

Several Common Elements

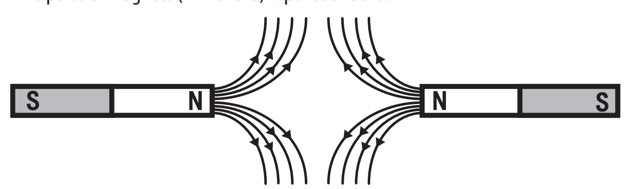
ELEMENT	SYMBOL	PROTONS	ELECTRONS	NEUTRONS
Hydrogen	H	1	1	0
Lithium	Li	3	3	4
Carbon	C	6	6	6
Nitrogen	N	7	7	7
Oxygen	O	8	8	8
Magnesium	Mg	12	12	12
Iron	Fe	26	26	30
Copper	Cu	29	29	34
Gold	Au	79	79	118
Uranium	U	92	92	146

Bar Magnet



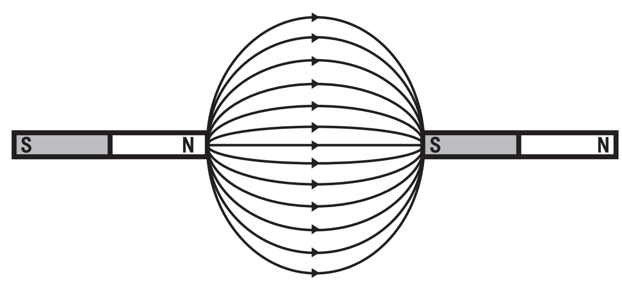
Like Poles

Like poles of magnets (N-N or S-S) repel each other.



Opposite Poles

Opposite poles of magnets (N-S) attract each other.



Electromagnetism

A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called **electromagnetism**. A changing magnetic field can produce electricity. Every time there is a change in an electric field, a magnetic field is produced. This relationship is used to produce electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their valence energy levels by the application of a magnetic field. If a coil of copper wire is moved around a changing magnetic field, or if magnets are moved around a coil of copper wire, an electric current is generated in the wire.

Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire. Magnets used to produce electric current are called **electromagnets**.

Generating Electricity

When it comes to the production of electricity, it's all turbines and generators. A turbine is a device that converts the flow of a medium such as air, steam, or water into motion energy to power a generator. A generator is an engine that converts motion energy into electrical energy using electromagnetism.

An electric generator is actually an electric motor that runs backward. Work is done to cause magnets to spin within coils of wire to produce electricity. Depending on the generator's design, work can also cause the wires to move. When the wire moves through the external magnetic field, electrons in the wire are pulled and move through the wire. These electrons can be directed out of the generator as electricity.

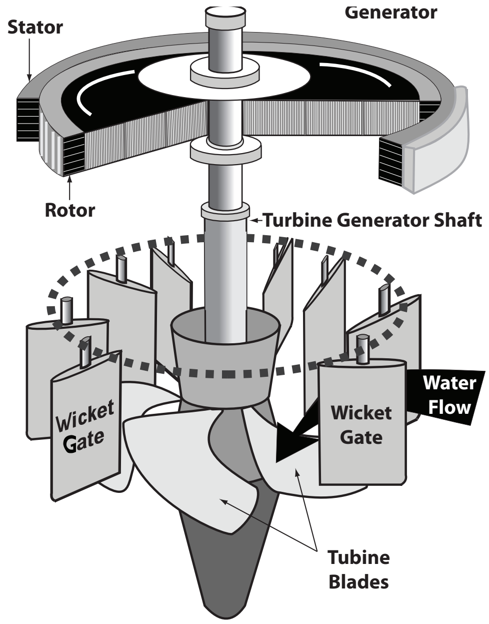
Although electric motors and generators may seem complicated, the principle of electromagnetism is simple. When electricity moves through a wire, a magnetic field is created around the wire. In an electric motor, the motor's wire is placed between external magnets. When electricity is sent through the wire, the magnetic field created around the wire interacts with the magnetic field of the external magnets. This interaction causes the wire to move. If the wire is designed so it is free to turn, the wire will spin and you have an electric motor.

Power plants use huge turbine generators to generate the electricity we use in our homes and businesses. Power plants use many fuels to spin turbines. They can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used to spin the turbines. They can split atoms of uranium in a nuclear power plant to heat water into steam. Geothermal power plants harness hot water and steam from underground reservoirs to spin turbines.

We can also harness the energy in flowing water and the energy in the wind to spin turbines. Photovoltaic (solar) cells are made with chemically infused silicon that allows them to convert radiant energy from the sun directly into electricity.

Once the electricity is produced, it is moved to our homes and businesses. It moves through large electrical lines. Electricity moves most efficiently under high voltage. When the electricity leaves a power plant, its voltage must be drastically increased. When it reaches our homes and businesses, the voltage must be reduced so it will not burn or damage things that use electricity. The voltage of electricity is easily increased or decreased by a **transformer.** Transformers are commonly seen in our neighborhoods. Electrical substations are a series of transformers used to increase or decrease voltage. If you have an overhead electrical line that goes into your house, you will see a transformer on the pole where the overhead line leaves the larger power line. Usually, these overhead transformers are grey cylinders. They reduce the voltage so that the electricity can safely enter your house.

Hydro Turbine Generator

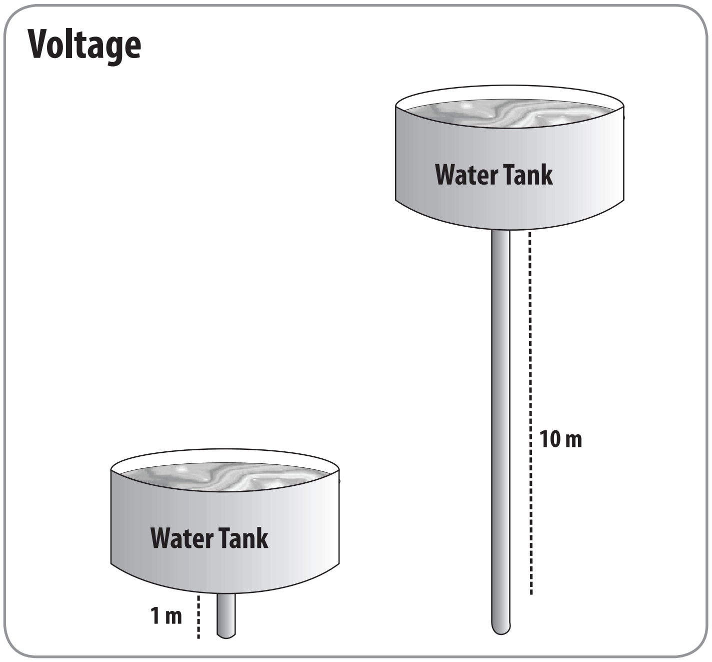


Measuring Electricity

We are familiar with terms such as watt, volt, and amp, but we do not always have a clear understanding of these terms. We buy a 13-watt light bulb, a tool that requires 120 volts, or an appliance that uses 8.8 amps, but we don't think about what those units mean.

Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second.

The amount of water depends on how much pressure is being applied—how hard the water is being pushed. It also depends on the diameter of the hose. The harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electrons through a wire depends on the pressure pushing the electrons and on the cross-sectional area of the wire.



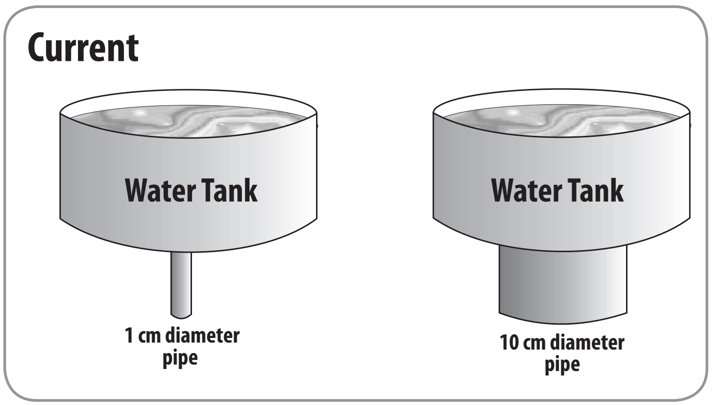
Voltage

The force or pressure that pushes electrons in a circuit is called **voltage**. Using the water analogy, if a tank of water were suspended one meter above the ground with a one-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you.

Voltage (V) is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts** (V). Just as the 10-meter tank applies greater pressure than the one-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a one-volt power supply.

AA batteries are 1.5 volt; they apply a small amount of voltage for lighting small flashlight bulbs.

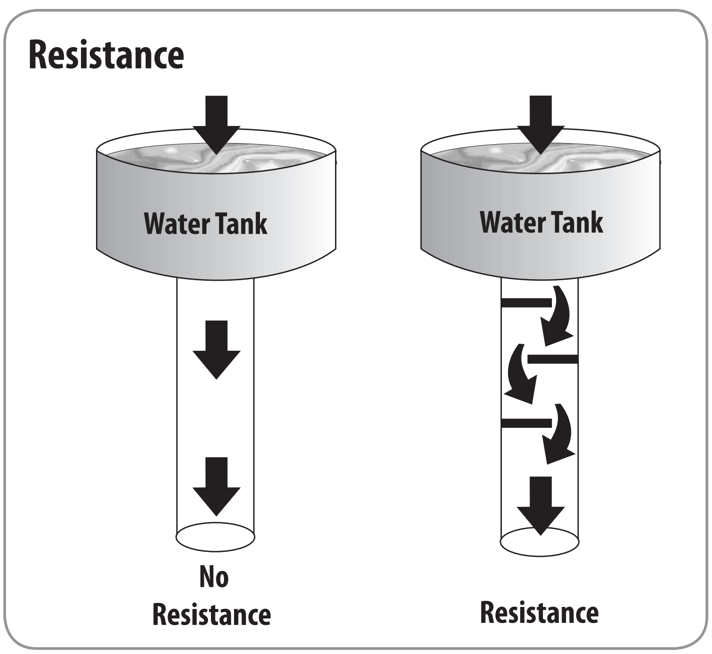
A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster. The standard voltage of wall outlets is 120 volts—a dangerous voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.



Current

The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point; electric **current** (I) is the number of electrons flowing past a fixed point.

With electricity, conducting wires take the place of the pipe. As the cross-sectional area of the wire increases, so does the amount of electric current (number of electrons) that can flow through it. Current is measured in **amperes** (A).



Resistance

Resistance (R) is a force that opposes the movement of electrons, slowing their flow. Using the water analogy, resistance is anything that slows water flow, such as a smaller pipe or fins on the inside of a pipe. In electrical terms, the resistance of a conducting wire depends on the properties of the metal used to make the wire and the wire's diameter. Copper, aluminum, and silver—metals used in conducting wires—have different resistance.

Resistance is measured in units called **ohms** (Ω). There are devices called **resistors**, with set resistances, that can be placed in circuits to reduce or control the current flow. Any device placed in a circuit to do work is called a **load**. The light bulb in a flashlight is a load. A television plugged into a wall outlet is also a load. Every load has resistance.

Ohm's Law

The relationship between voltage, current, and resistance is defined in **Ohm's Law**. George Ohm, a German physicist, discovered that in many materials, especially metals, the current is proportional to the voltage. He found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same. This relationship is called Ohm's Law and can be described using the formula to the right.

Electric Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. Electric power is the rate at which electricity is produced or consumed. Using the water analogy, electric power is the combination of the water pressure (voltage) and the rate of flow (current) that results in the ability to do work.

A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a one-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

Electric power is defined as the amount of electric current flowing due to an applied voltage. It is the amount of electrictiy required to start or operate a load for one second. Electric power is measured in **watts** (W).

Electrical Energy

Electrical energy introduces the concept of time to electric power. In the water analogy, it would be the amount of water falling through the pipe over a period of time. When we talk about using power over time, we are talking about using energy. Using our water example, we could look at how much work could be done by the water in the time that it takes for the tank to empty.

The electrical energy that a device consumes can be determined if you know how long (time) it consumes electric power at a specific rate (power). To find the amount of energy consumed, you multiply the rate of energy consumption (watts) by the amount of time (hours) that it is being consumed. Electrical energy is measured in watt-hours (Wh).

energy (E) = power (P) x time (t)
E = P x t or E = W x h = Wh

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, one would multiply the rate of travel by the amount of time traveled at that rate. If a car travels for one hour at 40 miles per hour, it would travel 40 miles.

distance = 40 mph x 1 hour = 40 miles

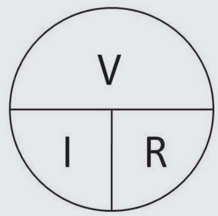
If a car travels for three hours at 40 miles per hour, it would travel 120 miles.

distance = 40 mph x 3 hours = 120 miles

Ohm's Law

- **Voltage = current x resistance**
  V = I x R or V = A x Ω
- **Current = voltage / resistance**
  I = V / R or A = V / Ω
- **Resistance = voltage / current**
  R = V / I or Ω = V / A

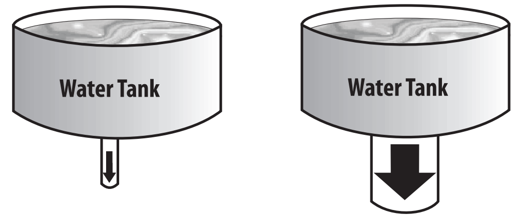
Formulas for Measuring Electricity



V = I x R
I = V/R
R = V/I

The formula pie works for any three variable equation. Put your finger on the variable you want to solve for and the operation you need is revealed.

Electric Power

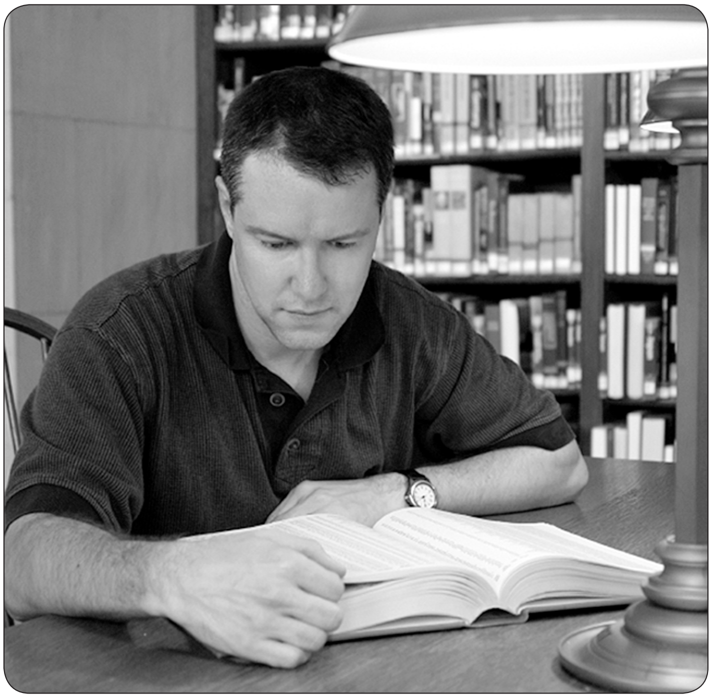


Electric Power Formula

- **Power = voltage x current**
  P = V x I or W = V x A

The distance traveled represents the work done by the car. When we look at power, we are talking about the rate that electrical energy is being produced or consumed. Energy is analogous to the distance traveled or the work done by the car.

A person wouldn't say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance represents the amount of work done. The same applies with electrical energy. You would not say you used 100 watts of light energy to read a book, because a watt represents the rate you use energy, not the total energy used. The amount of energy used would be calculated by multiplying the rate by the amount of time you read.



If you read for five hours with a 100-watt light bulb, for example, you would use the formula as follows:

energy = power x time (E = P x t)
energy = 100 W x 5 hours = 500 Wh

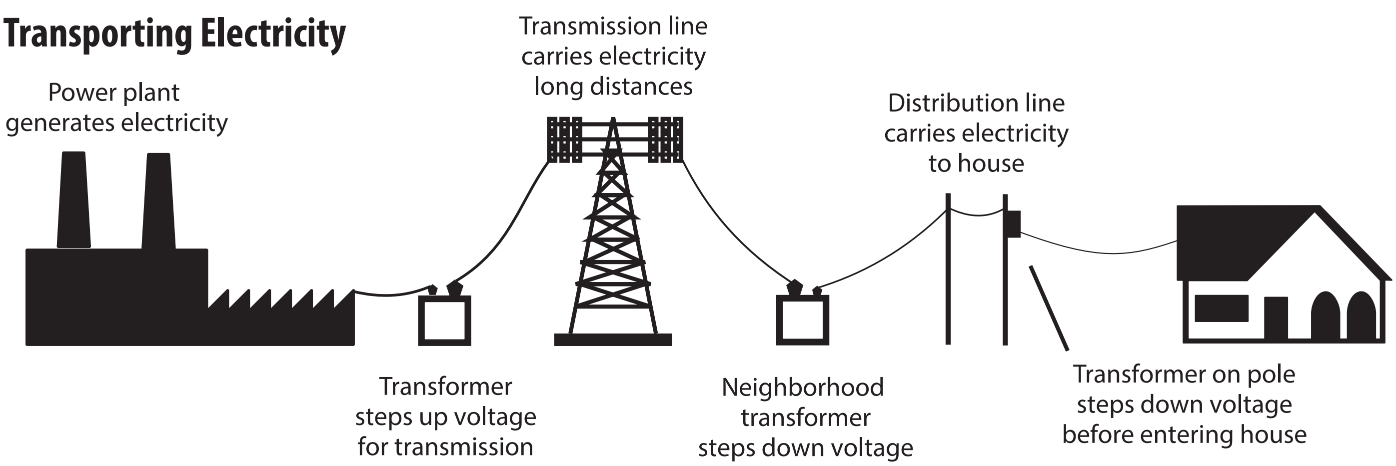
One watt-hour is a very small amount of electrical energy. Usually, we measure electric power in larger units called **kilowatt-hours** (kWh) or 1,000 watt-hours (kilo = thousand). A **kilowatt**-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers is about thirteen cents or $0.127.

To calculate the cost of reading with a 100-watt light bulb for five hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

500 Wh x (1 kW/1,000 W) = 0.5 kWh
0.5 kWh x $0.127/kWh = $0.64

Therefore, it would cost about six cents to read for five hours with a 100-watt light bulb.

Transporting Electricity



Demand for Electricity

Electricity cannot be easily stored in large quantities. It must be generated quickly to meet the fluctuating demand of consumers. Flexible generators, such as hydropower plants, are very important.

As we use more technology, the demand for electricity continues to grow. In the U.S. today, about 39 percent of the energy we consume is in the form of electricity. This percentage is expected to increase and poses many challenges for the nation, with no easy answers.

Global climate change is one important issue, since most U.S. electricity is produced by fossil fuels today. Should fossil fuel plants be required to do more to minimize carbon dioxide emissions? Should we build more nuclear power plants? Can we reduce demand with increased conservation and efficiency measures? Can renewable energy sources meet the increasing demand? How much are consumers willing to pay for a reliable supply of electricity, for a cleaner environment, for efficient technologies? These questions will only become more important.

Characteristics of Water

Water is vital to life on Earth. All living things need water to survive. Water covers 75 percent of the Earth's surface. Our bodies are about two-thirds water. Water is made of two elements, hydrogen and oxygen. Both are gases. Two atoms of hydrogen combine with one atom of oxygen to create a molecule of water. The chemical formula for water is H_2O.

Water is found in three forms: solid, liquid, and gas. The solid form is ice. The liquid form is water. The gas form is invisible and is called water vapor. Water can change between these forms in six ways:

- Freezing changes liquid water into ice.
- Melting changes ice into liquid water.
- Evaporation changes liquid water into water vapor.
- Condensation changes water vapor into liquid water. For example, morning dew on the grass comes from water vapor.
- Sublimation changes ice or snow into water vapor without passing through the liquid state. The ice or snow seems to disappear without melting first.
- Deposition changes water vapor into ice without the vapor becoming a liquid first. Water vapor falls to the ground as snow.

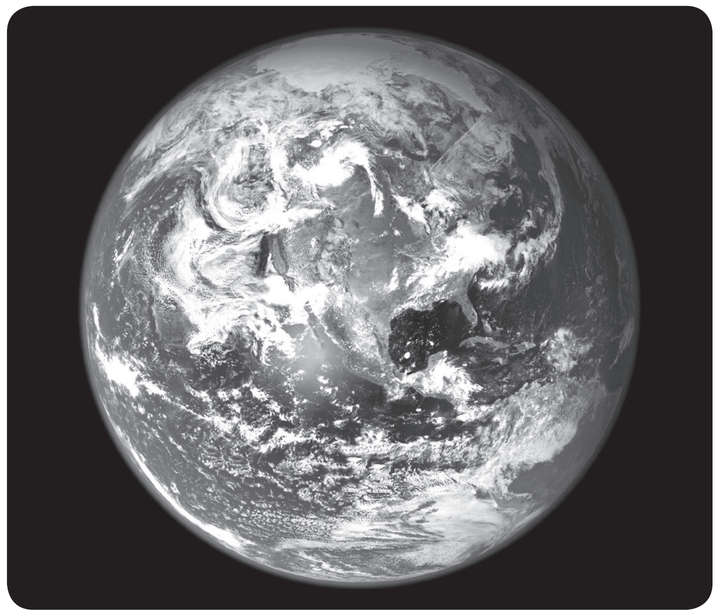


Image courtesy of NASA

Water covers most of the Earth's surface.

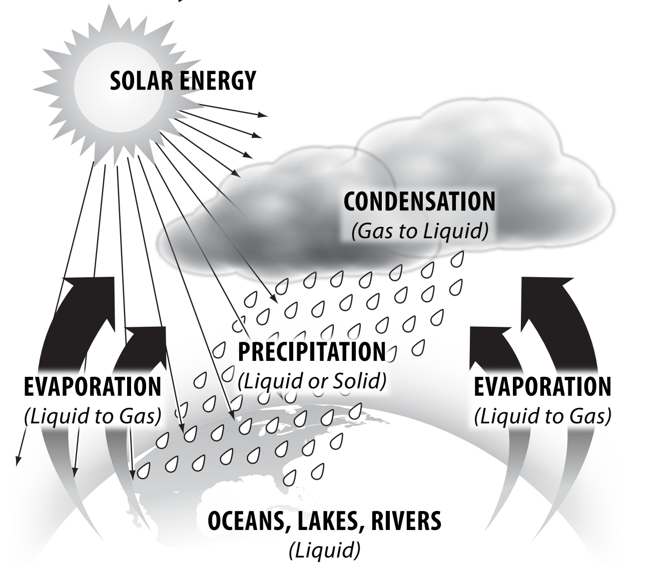
The Water Cycle

In our Earth system, water is continually changing from a liquid state to a vapor state and back again. Energy from the sun evaporates liquid water from oceans, lakes, and rivers, changing it into water vapor.

As warm air over the Earth rises, it carries the water vapor into the atmosphere where the temperatures are colder. The water vapor cools and condenses into a liquid state in the atmosphere where it forms clouds.

Inside a cloud, water droplets join together to form bigger and bigger drops. As the drops become heavy, they start to fall. Clouds release their liquid water as rain or snow. The oceans and rivers are replenished and the cycle starts again. This continuous cycle is called the **hydrologic cycle**, or water cycle.

The Water Cycle



Water as an Energy Source

Water has been used as an energy source for thousands of years. The ancient Greeks used the energy in flowing water to spin water wheels that crushed grapes for wine and ground grain to make bread.

In the 13th century, Chinese engineers built machines that used the energy in waves rising and falling with the tides to crush iron ore. The Italian inventor, Leonardo da Vinci, designed a wave machine in the 15th century.

Moving water provides energy in several different ways. **Hydropower** plants usually include dams across rivers to hold back water in reservoirs. This stored water is released to flow through turbines, spinning generators to produce electricity. The energy in the oceans' waves and tides can be harnessed to produce electric power as well.

Moving water is a safe, clean, and economical energy source. Water is sustainable, meaning we can use it over and over again. Using water as a source of energy does not reduce the amount of the water; it changes the speed and flow of the water and sometimes the temperature, but it does not change the amount of water.

Water is the world's leading source of renewable energy. When water is used to generate electricity, we call it hydropower or hydroelectricity. The prefix hydro comes from the Greek word for water and means water-related.

Harnessing Water Power

Humans have used the power of moving water for more than 2,000 years. The first references to watermills are found in Greek, Roman, and Chinese texts. They describe vertical water wheels in rivers and streams. These traditional water wheels turned as the river flowed, turning millstones that ground grain.

By the fourth century AD, watermills were found in Asia and northern Europe. In the early 11th century, William the Conqueror noted thousands of watermills in England. Most used stream and river power, but some worked with the tides.

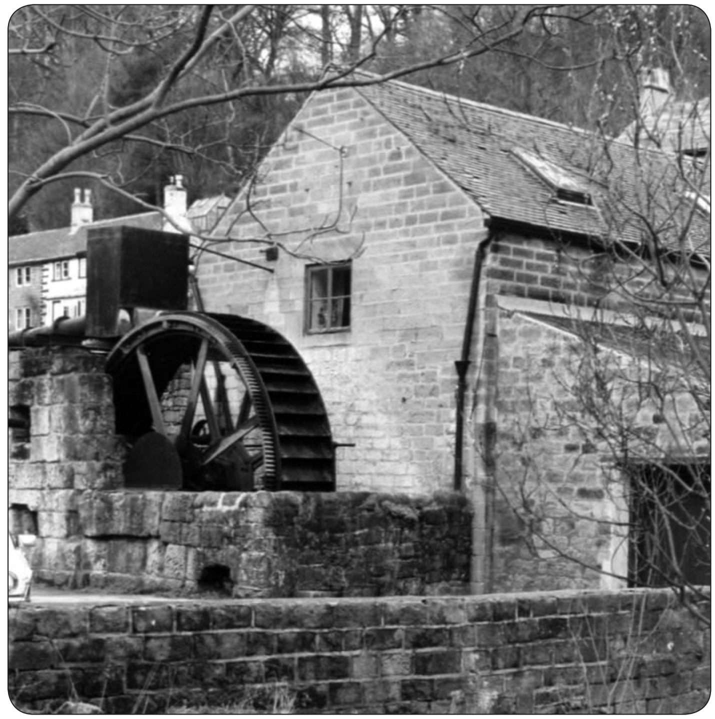
Early water wheels were designed to allow water to flow beneath the wheel. Later, millers diverted streams to flow over the tops of the wheels. More recently, wheels were placed on their sides—a more efficient method.

In the late 1700s, an American named Oliver Evans designed a mill that combined gears, shafts, and conveyors. After grain was ground, it could be transported around the mill. This invention led to water wheels being the main power source for sawmills, textile mills, and forges through the 19th century.

In 1826, a French engineer, Jean-Victor Poncelet, designed an even more efficient water wheel. The wheel was enclosed so that water flowed through the wheel instead of around it. This idea became the basis of the American-designed water turbine, patented by Samuel Howd in 1838. A water turbine forces every drop of potential power through a closed tube, providing much more water power than the traditional water wheel. James Francis improved on the water turbine design by reshaping the turbine's blades. Known as the Francis turbine, this modern water turbine is still in use today as a highly efficient producer of hydropower.

Generating electricity from hydropower began in the United States on July 24, 1880, when the Grand Rapids Electric Light and Power Company used flowing water to power a water turbine to generate electricity. It created enough power to light 16 lamps in the Wolverine Chair Factory. One year later, hydropower was used to light all the street lamps in the city of Niagara Falls, New York.

WATER WHEEL



A mid-nineteenth century water wheel.

TURBINE INSTALLATION

Image courtesy of U.S. Bureau of Reclamation

Workers install a Francis turbine at Grand Coulee Dam, 1947.

Dams Yesterday and Today

The oldest known man-made dams were small structures built over 5,000 years ago to divert river water to irrigate crops in Mesopotamia. Around 2,900 BCE, Egyptians in the city of Memphis built a dam around the city. The dam stopped periodic flooding of the Nile River and created a reservoir for irrigation and drinking water.

The Romans also built many dams in the first millennium, but most of their technical knowledge and engineering skills were lost during the fall of the Roman Empire. Dams did not become major civil projects until the end of the 19th century when the need for large dams coincided with the ability to build them.

Today, about half of the dams around the world were built for irrigation purposes, while about 18 percent were built and designed for electricity generation. There are approximately 84,000 dams in the United States, but less than three percent (2,200) were built specifically to generate electricity. The rest were built for recreation, fishing, flood control, crop irrigation, to support the public water supply, or to make inland waterways accessible to ships and barges. Some of these dams could be retrofitted with turbines and generators to produce electricity.

A Hydropower Plant

There are three main parts of a typical hydropower plant: the reservoir, dam, and power plant (turbines and generators). The reservoir stores the water until it is needed, but some facilities do not require a reservoir. The dam contains or holds back the water; there are openings in the dam to control its flow. The power plant converts the energy of the moving water into electricity.

A reservoir holds water behind the dam to create a larger height differential. The generation process begins with water flowing from the reservoir into openings on the upstream side of the dam, called penstocks, which are very large pipes. The water flows down the penstocks to turbines at the bottom, spinning the turbines to power the generators. Water flow is controlled by **wicket gates**.

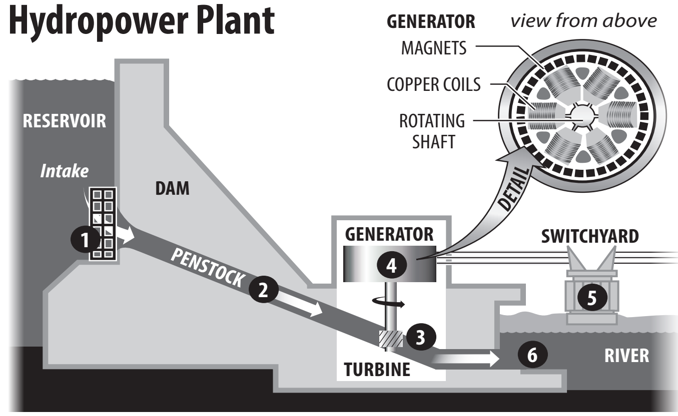
The distance the water drops from the reservoir to the turbine is called the **head**; the higher the drop, the greater the head. The amount of moving water is called the **flow**; more flow equals more force. The mass of the water in the reservoir applies the pressure to move the water; the greater the mass of water, the greater the pressure.

The generators produce electricity, which is sent to transformers and distribution lines where it begins its journey to consumers. The water that entered the penstocks returns to the river below the dam and continues its downstream journey.

Electricity from Hydropower

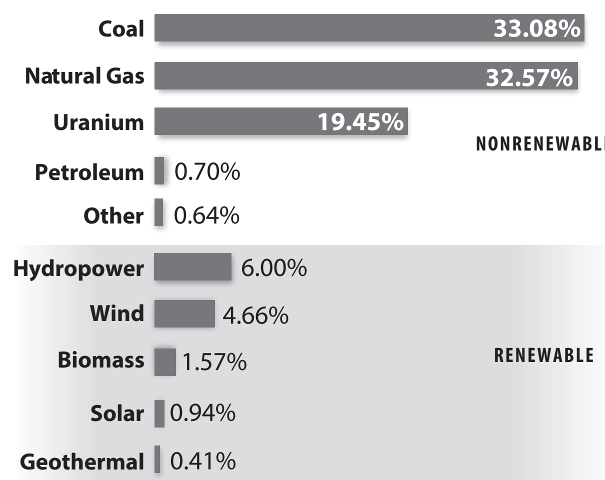
Most electricity from water in the United States and the world is produced by **conventional hydropower plants** using gravitational potential energy. 17 percent of the world's electricity is produced by hydropower, and 5–10 percent of U.S. electricity, depending on the supply of water. In 2015, 6.00 percent of U.S. electricity was produced by conventional hydropower. That's enough power to supply about 25 million households, or the equivalent of nearly 500 million barrels of oil. The total U.S. hydropower capacity is over 100,000 megawatts.

Hydropower Plant



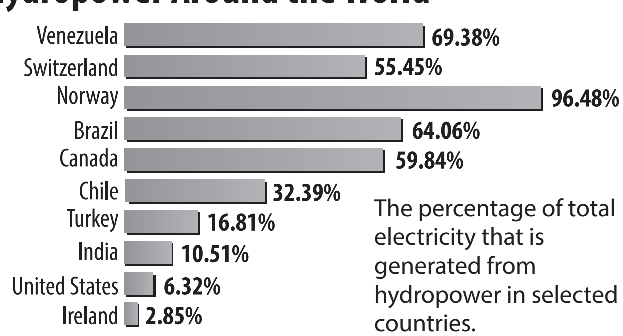
1. In most facilities, water in a reservoir behind a hydropower dam flows through an intake screen, which filters out large debris, but allows smaller fish to pass through.
2. The water travels through a large pipe, called a penstock.
3. The force of the water spins a turbine at a low speed, allowing 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.

U.S. Electricity Net Generation, 2015



*Total does not equal 100% due to independent rounding.
** Other: non-biogenic waste, fossil fuel gases.
Data: Energy Information Administration

Hydropower Around the World



The percentage of total electricity that is generated from hydropower in selected countries.

Data: EIA, 2014
2014 data used, as international data for 2015 was unavailable.

Types of Dams

A **dam** is either an overflow or non-overflow dam. An **overflow dam** allows excess water to spill over its rim. A **non-overflow dam** uses **spillways**—channels going through or around the dam—to control the pressure and potential energy of water behind the dam. This also allows a dam operator to divert water to a hydropower plant off-site when it is needed.

Dams are also categorized by the materials used in their construction and by their shape. Most dams are made of earth and clay, gravel or rock, stone masonry, wood, metal, or concrete.

A **gravity dam** uses only the force of gravity to resist water pressure. It holds back the water by the sheer force of its mass pressing downward. A gravity dam is built wider at its base to offset the greater water pressure at the bottom of the reservoir. Most gravity dams are made of concrete. The Grand Coulee Dam is an example of a concrete gravity dam.

An **embankment dam** is a gravity dam made of compacted rock or earth, with a water-resistant center that prevents water from seeping through the structure. The slopes of the dam are flatter on both sides, like the natural slope of a pile of rocks.

Like a gravity dam, an embankment dam holds back water by the force of gravity acting upon its mass. An embankment dam requires much more material to build than a gravity dam, since rock and earth are less dense than concrete.

An **arch dam** can only be built in a narrow river canyon with solid rock walls. It is built from one wall of a river canyon to the other and curves upstream toward the body of a reservoir. The curved shape diverts some of the immense force of the water toward the canyon walls. An arch dam is built of stone masonry or concrete and requires less material than a gravity dam. It is usually less expensive to build.

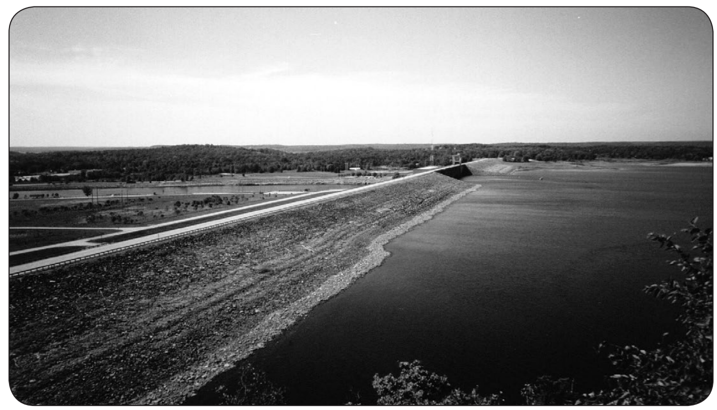
The Glen Canyon Dam, spanning the Colorado River in Arizona, is the tallest arch dam in the United States. It is 216 meters (710 feet) high. It was opened in 1966 to provide water storage for the arid U.S. Southwest and to generate electricity for the region's growing population.

A **buttress dam** consists of a relatively narrow wall that is supported by buttresses on the downstream side. Most buttress dams are made of concrete reinforced with steel.

Thick buttresses help the dam withstand the pressure of water behind it. While buttress dams use less material than gravity dams, they are not necessarily cheaper to build. The complex work of forming the buttresses may offset the savings on construction materials. A buttress dam is desirable in a location that cannot support the massive size of a gravity dam's foundation.

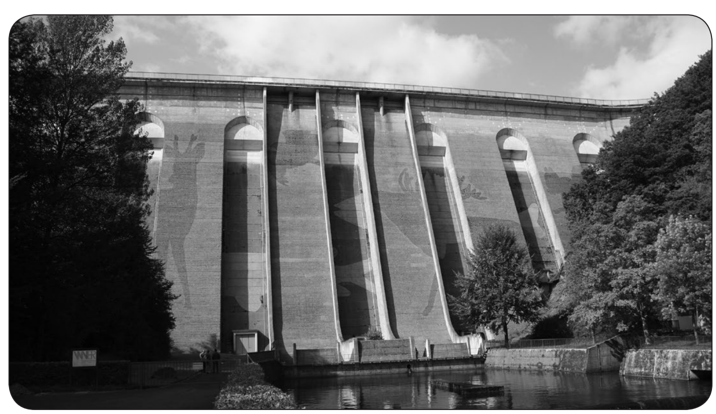
GRAVITY DAM

EMBANKMENT DAM



ARCH DAM

BUTTRESS DAM



Building Hoover Dam: Transforming the Desert Southwest

Hoover Dam is located in Black Canyon on the Colorado River, about 30 miles southeast of Las Vegas, NV. It was authorized by Congress in 1928 to provide electricity, flood control, and irrigation for the arid Southwest. It was built in the early 1930s at the height of the Great Depression, providing much needed jobs for thousands of workers.

Hoover Dam is a concrete arch-gravity dam, in which the power of the water is held back by the force of gravity, as well as the arch shape. It is 726.4 feet tall from the foundation rock to the roadway on the crest of the dam. There are towers and ornaments that rise 40 feet above the crest. The dam weighs more than 6,600,000 tons.

Before construction of the dam itself could begin, the Colorado River had to be diverted around the construction site. Four concrete-lined tunnels (each 50 feet in diameter and 4,000 feet long) were drilled through the canyon walls, two on each side of the canyon. Then temporary earthen **cofferdams** were built above and below the site to channel the river water through the tunnels and protect the construction site.

When these diversion tunnels were no longer needed, the upstream entrances for the two outer tunnels were closed by huge steel gates and concrete plugs were placed in the middle of the tunnels. Downstream sections of the tunnels are used as spillways for the dam. The two inner tunnels now act as penstocks and are connected to the power plant.The temporary cofferdams were torn down once the dam was completed.

There are 4,360,000 cubic yards of concrete in the dam, power plant, and other structures necessary to the operation of the dam. This much concrete would build a tower that is 100 feet square and 2 ½ miles high, or pave a standard highway that is 16 feet wide from San Francisco to New York City—a distance of more than 2,500 miles.

Setting the concrete produced an enormous amount of heat. The heat was removed by placing more than 582 miles of one-inch steel pipe in the concrete and circulating ice water through it from a refrigeration plant that could produce 1,000 tons of ice in 24 hours.

It took five years to build the dam, power plant, and other structures. During construction, a total of 21,000 men worked on the dam—an average of 3,500 men daily. A total of 96 men died due to construction of the dam, but no one is buried in the concrete, although stories to that effect have been told for years.

Before construction of the dam could begin, the following projects were necessary:

- the construction of Boulder City to house the workers;
- the construction of seven miles of highway from Boulder City to the dam site;
- the construction of 22.7 miles of railroad from Las Vegas to Boulder City and an additional 10 miles from Boulder City to the dam site; and
- the construction of a 222-mile-long power transmission line from California to the dam site to supply energy for construction.

Once the dam was completed and the Colorado River was contained, a reservoir formed behind the dam called Lake Mead, which is an attraction to boaters, swimmers, and fishermen. The Lake Mead National Recreation Area is home to thousands of desert plants and animals that adapted to survive in an extreme place where rain is scarce and temperatures soar.

Summarized from the U.S. Department of the Interior, Bureau of Reclamation website: www.usbr.gov/lc/hooverdam/faqs/damfaqs.html.

Conventional Hydropower

Conventional hydropower plants use the available water from rivers, streams, canal systems, or reservoirs to produce electrical energy. Conventional projects account for nearly 80 percent of hydropower generating capacity in the United States.

Some conventional projects include reservoirs and some do not. Projects with dams and reservoirs, known as **impoundment facilities**, store water and use it to generate electricity when there is the demand. Projects without reservoirs are known as diversion facilities or run-of-river projects. **Diversion projects** do not require dams; instead, a portion of a river is diverted or channeled through a canal or penstock.

Run-of-river projects have turbines installed in fast-flowing sections of the rivers, but they do not significantly impede the rivers' flow. The flow of water at run-of-river and diversion projects continues at about the same rate as the natural river flows.

RUN-OF-RIVER PROJECT

Image courtesy of U.S. Army Corps of Engineers

Chief Joseph Dam on the Columbia River in Washington.

Pumped Storage

Another type of hydropower plant is a pumped storage facility. A **pumped storage plant** circulates water between two reservoirs—one higher than the other. When the demand for electricity is low, the power plant uses electricity to pump water to the upper reservoir, where it is stored. During periods of high demand, the water is released from the upper reservoir through the powerhouse back to the lower reservoir to quickly generate electricity.

A pumped storage facility is in many ways like a huge battery that stores the potential energy of the water in the upper reservoir until there is a demand for electricity, which it can generate instantaneously by releasing the water.

PUMPED STORAGE PLANT

Image courtesy of U.S. Army Corps of Engineers

Seneca Pumped Storage Generating Station above Kinzua Dam on the Allegheny River in Warren County near Warren, PA.

Niagara Falls—Natural Wonder

Power plants at Niagara Falls produce one-quarter of the electricity used by Ontario and New York, but the hydropower does not come directly from the falls. Rushing water is diverted from the Niagara River, upstream from the falls, to Canadian and American powerhouses.

A treaty between Canada and the United States allows both countries to draw water upstream from the falls to produce hydroelectricity, but only up to specific amounts. How much water each country can draw is based upon tourism. Less water can be drawn during the day for the months of tourist season; more can be drawn at night and during the off-season.

NIAGARA FALLS

Hydropower Plant Capacity

Hydropower plants are rated by the amount of electricity they can generate—their capacity. A micro hydropower plant has a capacity of up to 100 kilowatts and a small hydropower plant has a capacity of up to 30 megawatts.

A micro or small hydroelectric power system can generate enough electricity to provide power to a home, farm, ranch, or village. Large hydropower facilities have capacities greater than 30 megawatts and supply many consumers.

Maneuvering Around Dams

The impact of dams on the migration of fish is an important ecological issue today. Some dams have **fish ladders** built in to allow fish to migrate upstream to spawn. Fish ladders are a series of small pools arranged like stair steps. The fish jump from pool to pool, each higher than the previous one, eventually bypassing the dam. Some dams employ elevators that can transport the fish up and over the dam, when a ladder isn't feasible during spawning season.

When the fish swim downstream, to return to the ocean, they need to bypass the dam again. Headed downstream, fish are diverted around dams through special spillways, or through the openings in the turbine if large enough.

Dams for electricity are not the only ones built across rivers. Sometimes **navigation dams** are built to make sure the water is deep enough for barges and ships to travel the length of the river.

When a dam is built across a river used by ships and barges, a canal is dug adjacent to the dam to allow continued navigation. The vessels bypass the dam through locks in the canal. Each lock has large upstream and downstream doors that can be opened and closed.

A vessel traveling upstream is moving from a lower water level to a higher water level. When the vessel enters a lock the doors are closed, and water is let in so that the water level in the lock rises. The vessel rises along with the water, until it is level with the upstream water level.

The upstream door opens, and the vessel moves on to the next lock. A vessel may need to go through several locks on the canal before it reaches the river on the other side of the dam.

Hydropower Plant Safety

Since the purpose of a dam is to contain a large quantity of water that could cause major destruction downstream if the dam fails, safety is an important issue. Some dams have failed in the past, but large dam failure is not considered a significant threat today. The major dams in use today were designed by engineers to last for generations, withstanding earthquakes, floods, and other potential hazards.

Dams are required by law to be monitored continuously and inspected routinely for potential safety problems. State and federal agencies, as well as dam owners, are involved in the process. Security procedures against terrorist attacks have also been put into place.

FISH LADDER

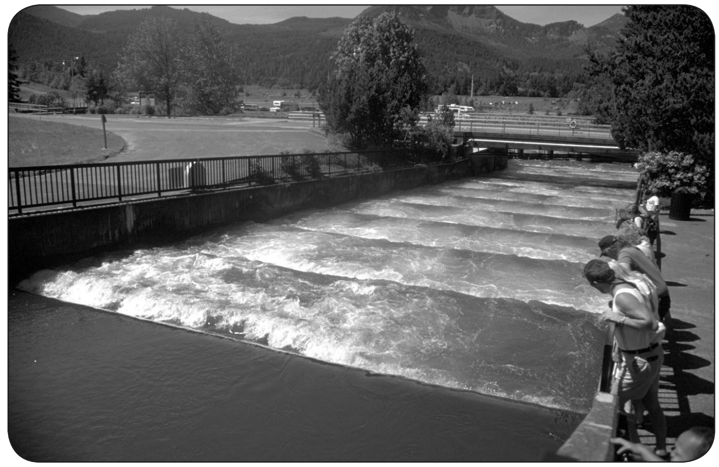


Image courtesy of Bonneville Power Administration

The fish ladder at Bonneville Dam on the Columbia River in the Pacific Northwest.

NAVIGATION DAM

Image courtesy of U.S. Army Corps of Engineers

An aerial view of the Soo Locks and the International Bridge at Sault Ste. Marie, MI.

SAFETY INSPECTIONS

Image courtesy of Tennessee Valley Authority

An engineer on TVA's Rope Access Team inspects one of the four spillway gates at Fontana Dam.

Federal Regulation

The **Federal Energy Regulatory Commission (FERC)** is the federal agency that has the authority to license non-federal hydropower projects on navigable waterways and federal lands. FERC issues initial hydropower licenses for periods of 30 to 50 years. When a license expires, one of three things happens:

- FERC relicenses the project;
- the Federal Government takes over the project; or
- the project is decommissioned.

FERC is charged with ensuring that all hydropower projects minimize damage to the environment. Many concerns about hydropower licensing or relicensing involve natural resource issues. Hydropower project operations generally alter natural river flows, which may affect fish populations and recreational activities, both positively and negatively. Project construction or expansion may also affect wildlife habitats, wetlands, or cultural resources. Land owners and communities downstream of the projects also want to be assured that the project dams are safe.

FERC staff prepares an environmental analysis of every hydropower proposal. This is done both for new projects (original license) and for existing projects (relicense). Before the environmental analyses are prepared, FERC staff may hold public meetings and may conduct site visits to the projects to identify issues relating to the construction or continued operation of projects. Citizens and interested groups have a number of opportunities to participate in the licensing process, to identify potential issues, and to share their views on how to address the effects of the projects on the natural and human environment.

Many hydropower projects built in the 1960s and 1970s have recently applied or been relicensed. It is the job of FERC to weigh all of the economic, environmental, and societal issues and grant or reject the relicensing applications.

With all non-federal hydropower projects, it is the primary responsibility of the owners to analyze existing conditions at the facilities and assess future environmental impacts, then prepare comprehensive reports for FERC.

Relicensing Issues

Supporters of increased hydropower argue that, unlike fossil-fueled electric power plants, hydropower projects do not pollute the air or increase emissions of greenhouse gases. Opponents have countered that hydropower can harm fragile aquatic environments.

Each group has its own set of issues concerning hydropower; those in favor of hydropower can encounter difficulties with relicensing authorities, while those who oppose hydropower may fight for dam removal. During the relicensing process, federal, state, and local groups may advocate for endangered or threatened species, as well as other region-specific issues.

There are many state and federal laws and regulations that must be followed during relicensing. Some of these laws include:

- Federal Power Act
- Energy Policy Act of 2005
- Clean Water Act (Section 401)
- National Environmental Policy Act
- Endangered Species Act
- National Historic Preservation Act
- Federal Code of Regulations for Recreation

One of the most prominent issues facing the Pacific Northwest hydroelectric industry involves endangered fish populations and the Columbia River. The Columbia River basin is one of the largest water systems in North America. It stretches from Canada down into seven states. The Columbia River and its **tributaries**, including the Snake River, are well developed in terms of hydropower, with 31 federally owned projects, 22 non-federal projects, and 8 Canadian dams. These hydro projects produce over 40 percent of the nation's electricity.

However, the Columbia and Snake Rivers are home to endangered and threatened migrating salmon and steelhead trout populations that must pass up to eight dams. The dams were originally built with fish ladders that mature fish have been successfully navigating upstream to spawn. Hundreds of millions of dollars have been spent to improve fish passage for juveniles swimming downstream to reach the ocean.

WILDLIFE

Image courtesy of U.S. Fish and Wildlife Service

The Federal Energy Regulatory Commission authorizes the initial construction of non-federal hydropower projects and reconsiders licenses every 30 to 50 years. The U.S. Fish and Wildlife Service conducts environmental reviews during relicensing.

The down river side of the Safe Harbor Hydroelectric Power Plant in southern Pennsylvania.

Advantages and Challenges of Hydropower

Using hydropower as an energy source offers many advantages over other sources of energy, but hydropower has significant disadvantages too because of the unique environmental challenges involved.

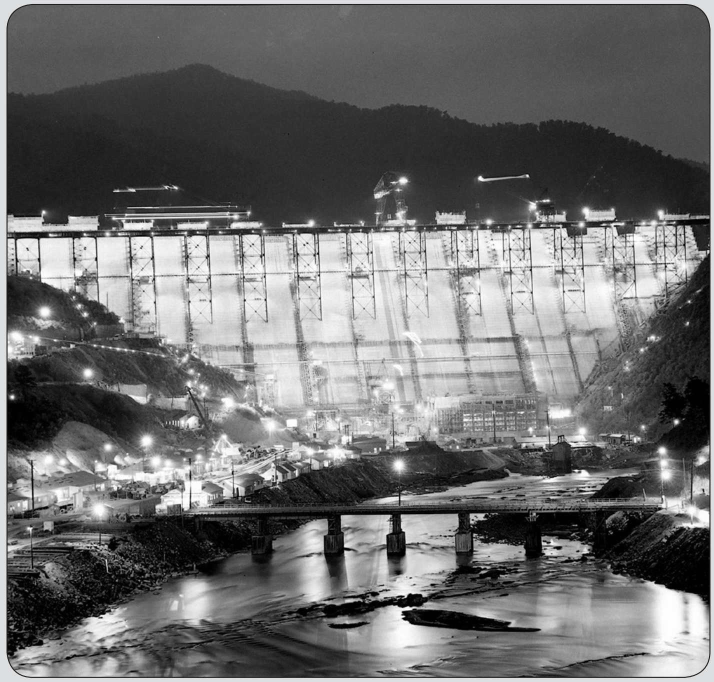
Advantages of Hydropower

- Hydropower is a clean energy source. It is fueled only by moving water, so it doesn't produce emissions. Hydropower does not increase the level of greenhouse gases in the atmosphere.
- Hydropower is a renewable energy source. It relies on the water cycle, which is driven by the sun. The total amount of water in a hydropower system does not change; the moving water is used to generate electricity and returned to the source from which it came.
- Hydropower is usually available when it is needed. Engineers can produce electricity on demand and control the amount of electricity generated.
- Hydropower is an established, proven, and domestic source of energy.
- Hydropower is an economical way to produce electricity. Maintenance costs of hydropower facilities are low. Once a plant is up and running, the water flow that powers it is free. The electricity generated by hydropower facilities is the cheapest electricity in the country.
- Hydropower is an efficient way to produce electricity. The average hydropower plant is 90 percent efficient at converting the energy in the moving water into electricity.
- Impoundment facilities create reservoirs that offer a wide variety of non-energy benefits to communities, such as recreational fishing, swimming, and boating. The reservoirs can also increase the property value of the adjacent land.
- Hydropower facilities can help regulate the water supply, providing drought and flood control. Many dams were designed primarily as flood control projects; the generating equipment was an additional benefit. During drought, the reservoirs provide a more reliable source of drinking water, as well as water for fragile downstream habitats.
- Hydropower dams are very safe and durable—built to last for hundreds of years.
- Hydropower is a flexible energy source in meeting electricity generating needs quickly. Hydropower plants can begin generating electricity within minutes of increased demand. Most hydropower plants can also provide reliable and dependable **baseload power**.
- Presently, less than three percent of existing dams in the U.S. contain generators. Without building any new dams, existing dams have the potential to generate 12,000 additional megawatts of power.

Challenges of Hydropower

- Hydropower plants are dependent on water supply. When there is a drought, for example, hydropower plants cannot produce as much electricity.
- A dam on a river can permanently change the ecology of a large land area, upstream and downstream, creating a different environment. When a dam is built, the resultant reservoir floods a large area of land upstream from the dam. The natural ecology of the river and adjacent land downstream is changed by a reduction in soil deposition.
- Hydropower facilities can impact water quality and flow. Reservoirs can experience low dissolved oxygen levels in the water, a problem that can be harmful to fish populations and downstream riparian (riverbank) habitats. Maintaining minimum flows of water downstream of a reservoir is also critical for the survival of riparian habitats.
- Some fish populations, such as salmon, migrate upstream to reach spawning grounds and then return to the ocean. Impoundment facilities block fish from completing this natural migration process. Fish ladders or elevators may be built to aid upstream fish passage. Downstream fish passage can be aided by diverting fish around the turbine intakes, by maintaining a minimum spill flow past the turbines, using screens or racks, and even underwater lights and sounds.
- Development of new hydropower reservoirs can be very expensive because dams have already been built at many of the more economical locations. New sites must compete with other potential uses of the land.

President Franklin D. Roosevelt signs the TVA Act in 1933.



The Fontana Dam in North Carolina as it nears completion in 1944.

The Tennessee Valley Authority: A Vision Born from Hydropower

The Tennessee Valley Authority (TVA) is a public utility established by Congress in 1933 as one of Franklin Roosevelt's solutions to the Great Depression. The Tennessee Valley was in bad shape in 1933. Much of the land had been farmed too hard for too long, depleting the soil. The best timber had been cut. TVA developed fertilizers, taught farmers how to improve crop yields, and helped replant forests, control forest fires, and improve habitats for wildlife and fish.

The most dramatic change in Valley life came with the advent of electricity generated by TVA dams that also controlled floods and improved navigation. Electricity brought modern amenities to communities and drew industries into the region, providing desperately needed jobs.

During World War II, the country needed more electricity and TVA engaged in one of the largest hydropower construction programs ever undertaken in the United States. At the program's peak in 1942, twelve hydropower projects and a steam plant were under construction at the same time, employing 28,000 workers. By the end of the war, TVA had completed a 650-mile navigation channel the length of the Tennessee River and had become the nation's largest electricity supplier.

Today, TVA's system consists of a mix of energy sources, including:

- 29 hydroelectric plants;
- 1 pumped storage hydroelectric plant;
- 8 fossil plants (coal);
- 3 nuclear plants;
- 16 natural gas plants;
- 1 diesel generator site;
- 14 solar energy sites; and
- 1 wind energy site.

Right: The dedication of the Douglas Dam in Dandridge, TN, 1943.

Images courtesy of Tennessee Valley Authority

TVA operates a system of 49 dams and reservoirs on the Tennessee River and its tributaries, as well as managing 293,000 acres of public land. TVA manages the 41,000-square-mile watershed as an integrated unit to provide a wide range of benefits, including:

- year-round navigation;
- flood control;
- electricity generation;
- recreational opportunities;
- improved water quality; and
- a reliable water supply to cool power plants and meet municipal and industrial needs.

A Case Study in Improving Ecology at a Dam

Observers in the Grand Canyon of the Colorado River have noticed a decline in the number of sandbars used as campsites. This decline is attributed to Glen Canyon Dam, which controls the flow of the Colorado River through the canyon. Most of the sediment and sand now gets trapped behind the dam.

The rapids that make the Grand Canyon so popular with white-water rafters are created by debris fans—piles of rock fragments—that tumble down from tributaries during intense rainfall. The debris fans used to be cleaned out yearly by floods of water that flowed through the canyon during spring snowmelt in pre-dam years.

Rapids are caused by large boulders that get stuck on the river bed.

The dam dramatically reduced the flow of water through the canyon. This drop in water flow limits the ability of the river to move rock debris. The dam also decreased backwater habitats and lowered the overall water temperature of the main river, leading to the extinction of four native fish.

The U.S. Department of the Interior, Bureau of Reclamation, which operates Glen Canyon Dam, released an unusually high flow of water during the spring of 1996 to see if it could rebuild beaches and restore other habitats that have deteriorated since the dam's completion in 1963. Two other high flows were released in November 2004 and March 2008.

Scientists found that periodic flooding is successful at rebuilding the sandbars. However, there were no measurable positive outcomes for native endangered fish populations. Additional studies and adaptive management strategies will continue at the dam.

HIGH FLOW

Image courtesy of U.S. Geological Survey

A Case Study in Removing a Small Dam—When the Costs Outweigh the Benefits

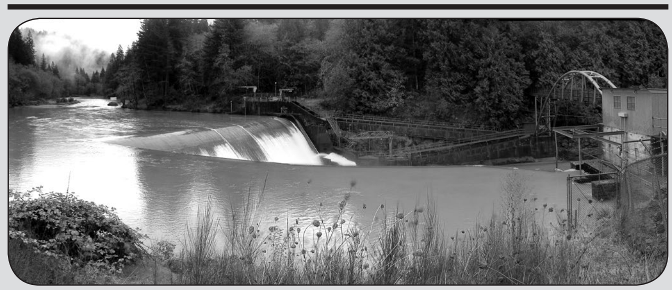
In May 1999, Portland General Electric (PGE) announced plans to decommission, or tear down, its 95-year-old hydropower project on the Sandy River in Oregon. The project eliminated expensive maintenance costs to the power plant, and avoided the cost of bringing fish protection up to today's standards. The project consisted of dismantling the following:

- the 47-foot-high Marmot Dam;
- a concrete-lined canal that took water from Marmot Dam to the Little Sandy River;
- the 16-foot-high Little Sandy Dam;
- a 15,000-foot-long wooden flume (artificial water channel); and
- a 22-megawatt powerhouse.

Marmot Dam was removed in 2007, restoring the Sandy to a free-flowing river for the first time in nearly a century. Within hours the Sandy River looked like a natural river. Torrents of water carried sediment downstream, helping create natural bends, bars, and logjams. The Little Sandy Dam was removed in 2008.

PGE donated about 1,500 acres of land to the Western Rivers Conservancy. This land formed a wildlife refuge and recreation area in the Sandy River Basin. Covering more than 9,000 acres, the area is managed by the U.S. Department of the Interiror, Bureau of Land Management.

BEFORE DEMOLITION



DURING DEMOLITION

Images courtesy of U.S. Geological Survey

New Hydropower Initiatives

The U.S. Department of Energy (DOE) Water Power Program researches, tests, evaluates, and develops innovative technologies capable of generating renewable, environmentally responsible, and cost-effective electricity from water resources. This includes hydropower as well as marine and **hydrokinetic** energy technologies.

Modernizing Existing Facilities

The Water Power Program's conventional hydropower activities focus on increasing generating capacity and efficiency at existing hydroelectric facilities, adding hydroelectric generating capacity at non-powered dams, and reducing environmental effects.

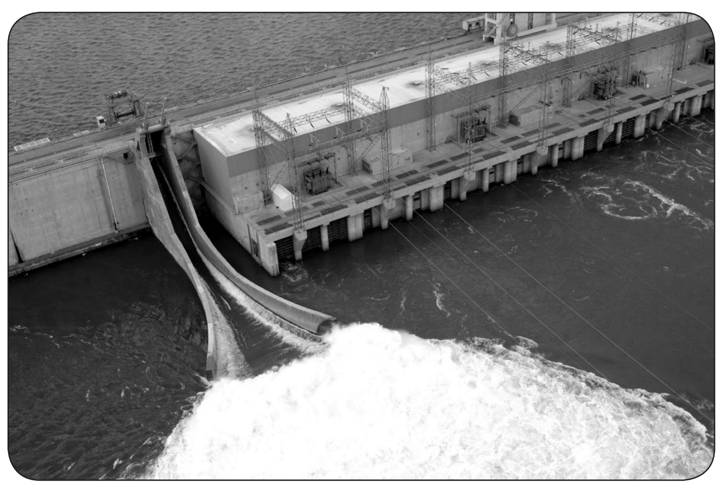
In 2009, the DOE awarded over $30 million in American Recovery and Reinvestment Act funding to modernize hydropower projects. The investment has created and continues to create jobs and increase renewable electricity generation without building any new dams. The projects will produce an estimated 187,000 megawatt-hours of electricity per year, which is enough to power 12,000 homes. The hydropower projects focus not just on installing or upgrading turbines, but also include generators, transformers, wiring, maintenance equipment, and fish and wildlife habitat improvements. These projects applied for and were granted funding from 2009-2014. While some are complete, others are still in completion. Over 50% of the funded projects center around capacity and efficiency upgrades. Some of the projects are outlined below.

- Alabama Power Company—Mitchell, AL. Up to $6 million will be used to upgrade turbines installed in the 1940s and 1960s. Four new high-efficiency maximize the use of the limited water available at the three sites. Generation has increased by 8-12 percent.
- Alcoa, Inc.—Robbinsville, NC. Up to $13 million was awarded for upgrading and replacing four 90-year-old turbines. New turbines, generators, and transformers increased generation by 47,200 megawatt-hours annually, which is a 23 percent increase. In addition, the project improved environmental conditions at the plant by removing lead and asbestos and reduces the potential for oil spills into the river by replacing water-cooled transformers.
- City of Tacoma, Department of Public Utilities—Potlatch, WA. Just under $5 million was awarded to add two turbines that increased generation by 13% annually. This project also focused on improving wildlife conditions in the river by incorporating an upstream fish collection pool that will allow for the reintroduction of native fish species above the dam for the first time since the 1920s.
- City of Boulder, CO. To upgrade a 100-year-old facility, about $1.2 million was awarded. Two older turbines were replaced by a single unit that operates more efficiently under variable flow conditions. Annual generation increased by as much as 30 percent, depending on flow.

FISH-FRIENDLY TURBINE

This fish-friendly turbine has openings large enough for fish to pass through.

FISH BYPASS



Images courtesy of Grant County Public Utility District

At the Wanapum Dam on the Columbia River, a fish-friendly turbine bypass that is designed to help salmon smolts pass through the dam without injury is being tested.

- Incorporated County of Los Alamos, NM. In April 2011, a project at the Abiquiu Hydroelectric Plant was the first hydropower project funded by the American Reinvestment and Recovery Act to be completed nationwide. Using $4.5 million, a new low-flow turbine/generator was installed. This high-efficiency turbine operates at flows above and below the older turbines, increasing annual generation 22 percent. Environmentally, the project will improve dissolved oxygen content of the water downstream.
- City of North Little Rock—Little Rock, AR. The city installed an automated maintenance device to clear debris obstructing the intake channel. This project used $450,000. Cleaning away the debris allows the facility to operate consistently near peak efficiency.

These projects and many other research projects are in various stages of completion, and are funded through grants and congressionally directed funds. For more information, visit the U.S. Department of Energy, Energy Efficiency and Renewable Energy's Wind and Water Power Technologies Office report entitled Hydropower Projects.

Advanced Turbine Systems

The Department of Energy also supports research into new technologies. Current hydropower technology, while essentially emission-free, can have undesirable environmental effects, such as fish injury and mortality from passage through turbines, as well as detrimental changes in the quality of downstream water. Advanced hydropower turbine technology could minimize the adverse effects yet preserve the ability to generate electricity from an important renewable resource.

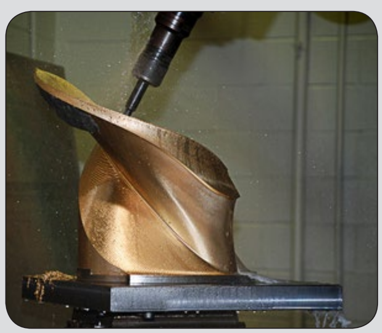
The goal of DOE's Advanced Hydropower Turbine System (AHTS) Program is to develop technology that will allow the nation to maximize the use of its hydropower resources while minimizing adverse environmental effects. Conceptual designs of environmentally friendly hydropower turbines have been completed under the DOE-industry program. Potential fish injury mechanisms caused by turbine passage have been identified.

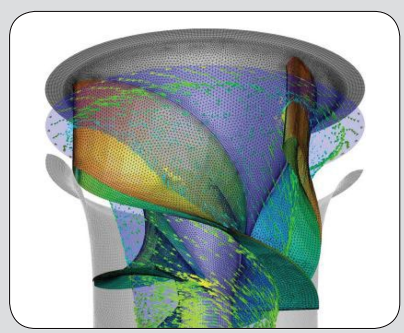
Potential benefits of advanced turbine technologies include:

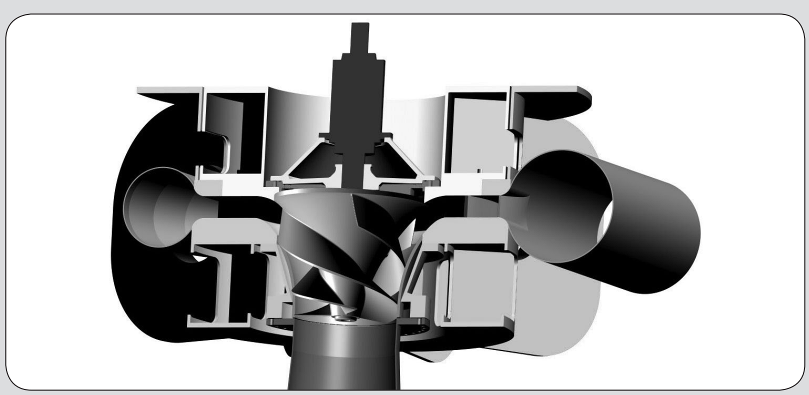
- Reduced fish mortality: Advanced turbine technology could reduce fish mortality resulting from turbine passage to less than two percent, in comparison with turbine-passage mortalities of five to 10 percent for the best existing turbines and 30 percent or greater for other turbines.
- Improved water quality: Advanced turbine technology would maintain a downstream dissolved oxygen level of at least six milligrams per liter, ensuring compliance with water quality standards.
- Reductions in carbon dioxide emissions: The use of environmentally friendly turbine technology would help reverse the decline in hydroelectric generation and reduce the amounts of CO_2 and other greenhouse gases emitted by consumption of fossil fuels.

Alden Lab

Founded in 1894, Alden Lab is the oldest hydraulic laboratory in the United States and one of the oldest in the world. Alden has developed a new hydraulic turbine runner to reduce fish injury and death as part of the DOE Advanced Hydropower Turbine System (AHTS) program. Results of pilot-scale tests indicate a 90.5 percent efficient turbine with fish passage survival of 94-100 percent.







Top Left: Milling the blade of the turbine.

Top Right: A 3D model of the turbine.

Bottom: A cross-section of a fish-friendly turbine.

Images courtesy of Alden Lab

Marine and Hydrokinetic Technologies

The ocean is in constant motion and contains energy that can be harnessed. Some devices harness the energy in the changing tides to generate electricity. Others harness the energy in the waves, while others rely upon underwater currents.

Tidal Barrage

A tidal power plant, or **tidal barrage**, is built across an **estuary**, the area where a river runs into the ocean. The water here rises and falls with the tides. A tidal barrage has gates and turbines at its base. As the tide rises, the water flows through the barrage, spinning the turbines, then collects in the estuary. When the tide drops, the water in the estuary flows back to the ocean. The water again turns the turbines, which are built to generate electricity when the water is flowing into or out of the estuary.

Tides are caused by the interaction of gravitational forces between the Earth, moon, and sun. The force from the moon is much more powerful since it is closer to the Earth. The moon pulls on the ocean water that is closest to it. This creates a bulge in the surface of the water, called a **tidal bulge**. Because the Earth is rotating, the water on the opposite side of the Earth also forms a tidal bulge. These bulges produce high tides. The influence of the sun is apparent when it is aligned with the moon and the tides become higher than at other times.

Between the tidal bulges are lower levels of water that produce low tides. The tidal bulges move slowly around the Earth as the moon does. Halfway between each high tide is low tide. Most shorelines have two high and two low tides each day. The Gulf of Mexico only experiences one high and one low tide each day because of its geographic location.

On most of the U.S. coast, the tidal range, or the difference between high and low tides, is only about three to six feet. When a high tide flows into a narrow bay where the water cannot spread out, the tidal range can be very large. These areas are potential locations for harnessing tidal power. The Bay of Fundy in Canada, near Maine, has the highest tides in the world, sometimes rising over 50 feet.

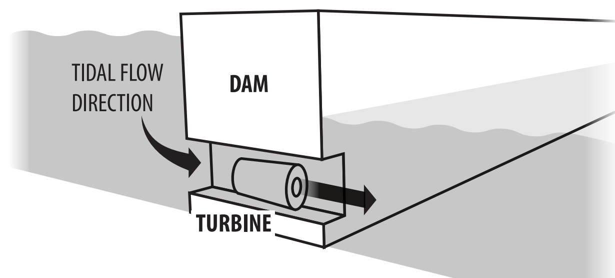
The main challenge with using **tidal power** (barrages, fences, and turbines), is geographical. There are few parts of the world with significant enough tides to support tidal power stations. Countries that currently use tidal power include Canada, China, France, Netherlands, New Zealand, Russia, South Korea, India, Sweden, the United Kingdom, and the United States. Tidal barrage systems are expensive to build, and their construction may harm local wildlife habitats.

Tidal Fences

Building large-scale tidal barrages is less likely than alternative methods of harnessing tidal power. One option is a **tidal fence**. Tidal fences are similar to tidal barrages in that they stretch across narrow areas of moving water. Unlike tidal barrages, tidal fences do not dam water, but allow it to flow freely. This makes them cheaper to install as well as having less impact on the environment. However, tidal fences may inhibit the movement of large marine mammals and ships.

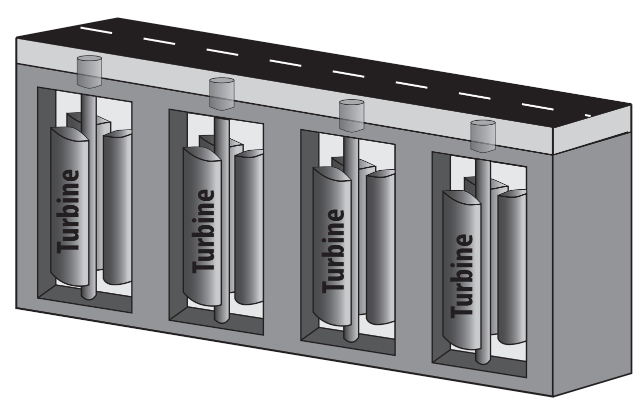
Tidal Bulge

Tidal Barrage



Tidal water is captured at high tide behind a dam. When the tide turns, the water is released to the sea, passing through a set of turbines.

Tidal Fence with Bridge



Tidal Turbines

Another source of tidal power relies on strong and steady underwater ocean currents that can be harnessed to generate power. This technology is known as hydrokinetic or tidal stream power. Underwater turbines work like submerged windmills, but are driven by flowing water rather than air. They can be installed in the ocean in places with high tidal current velocities or in places with fast enough continuous ocean currents. A major advantage of this energy resource is that it is as predictable as the tides, unlike wave energy, which relies on the weather.

Marine Current Turbines Ltd. has developed the world's largest grid-connected tidal stream system, known as SeaGen S. SeaGen S is a 1.2 megawatt commercial demonstration project. A single SeaGen S device began operation in Strangford Lough (a shallow bay situated on the east coast of Northern Ireland) in 2008.

SeaGen S is able to generate clean and sustainable electricity equivalent to the average needs of approximately 1,500 homes.

SeaGen S turbines can be raised above sea level to allow maintenance from small service vessels. This is an important feature because underwater maintenance by divers or remotely operated vehicles (ROVs) is difficult in locations with the strong currents needed for effective power generation.

Environmental impact studies report that this technology does not offer a serious threat to fish or marine mammals. The rotors turn slowly, a maximum of 14 **revolutions per minute**. The risk of impact from the rotor blades is extremely small, considering that most marine creatures that swim in areas with strong currents and have excellent perception and agility, giving them the ability to successfully avoid collisions with slow-moving underwater obstructions.

OpenHydro, an Irish energy technology company, has designed a different style of **tidal turbine**—one with an open center. These tidal turbines are designed to be installed on the ocean floor, with no portion of the structure above the water level. The blades of the turbine turn in both directions, producing electricity during both ebb and flow tides.

The open-center turbines are designed to minimize environmental impacts. For example, the open center allows for safe passage of fish. The machine uses no oils, grease, or other lubricating fluids, eliminating potential pollutants. The blade tips are enclosed in the unit, preventing injury to large and small marine animals. Also, data gathered from the turbines show that the units produce low levels of sound.

In 2012, Maine deployed the country's first commercial, grid-connected tidal power system. This system, operated by the Ocean Renewable Power Company, is located in The Bay of Fundy and is projected to eventually provide up to 5 MW of power to Maine communities.

TIDAL TURBINE

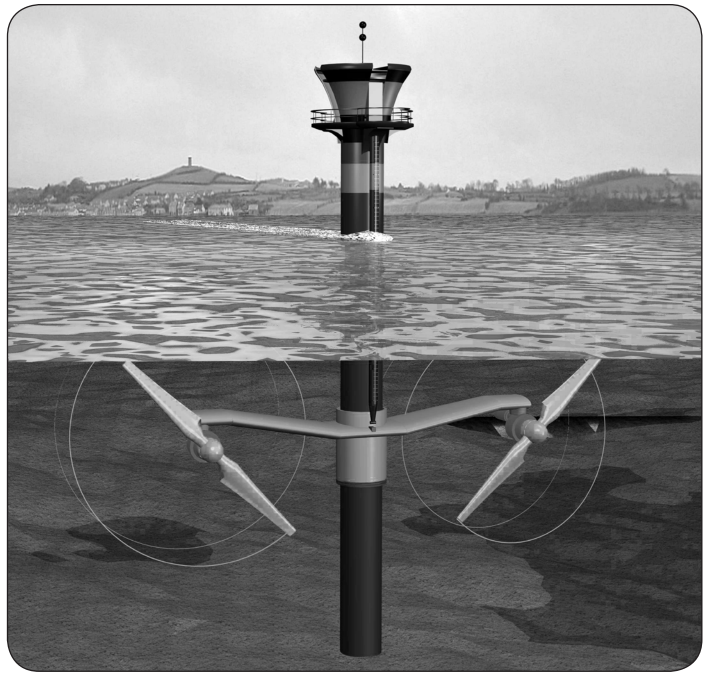


Image courtesy of Marine Current Turbines

An artist's rendering of the SeaGen S tidal turbine system. The SeaGen S consists of two large rotors, each driving a generator with a gearbox. The twin rotors—each 14-20 meters in diameter—are mounted on wing-like extensions on either side of a three-meter wide tubular steel monopile that is set into a hole drilled in the sea floor.

OPENHYDRO TIDAL ENERGY SYSTEM

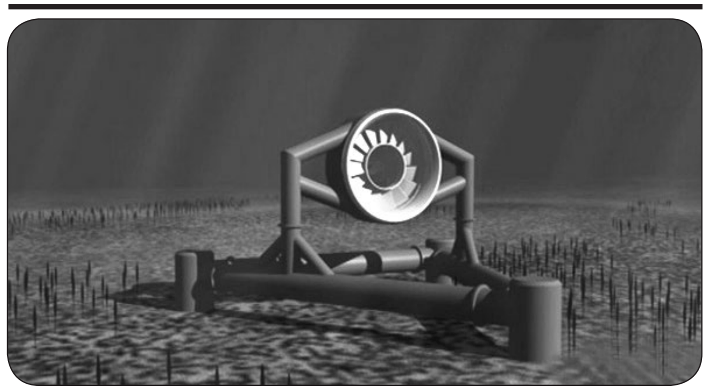


Image courtesy of OpenHydro

OpenHydro currently has tidal power projects planned in Europe, Canada, and in Admirality Inlet off the coast of Whidbey Island in Washington State.

New York City's East River Project

The city and state of New York have partnered with Verdant Power to harness the energy in the ebb and flow of the tides in Manhattan's East River. The Roosevelt Island Tidal Energy (RITE) Project is the first grid-connected (non-commercial) array of tidal turbines in the world. After completing a successful demonstration phase with six turbines that generated 70 megawatt-hours of electricity, the project received the first U.S. commercial license for tidal power. The next step is for the project to build out to one megawatt capacity with 30 tidal turbines.

Image courtesy of Verdant Power

Free Flow System turbine being installed in the East River, NY.

Waves

The main cause of surface ocean waves is wind; although, they can also be affected by tides, weather conditions, and underwater events. The size of waves depends on the speed of the wind, wind duration, and the distance of water over which the wind blows, known as the fetch. Usually, the longer the distance the wind travels over water, or the harder it blows, the higher the waves. A strong breeze of 30 miles per hour can produce 10-foot waves. Violent storm winds of 65 miles per hour can produce 30-foot waves.

As the wind blows over the water, there is friction between the wind and the surface of the water. The wind pulls the surface water in the direction it is going. The water is much denser than the air and cannot move as fast, so it rises and then is pulled back down by the force of gravity. The descending water's momentum is carried below the surface, and water pressure from below pushes this swell back up again. This tug of war between gravity and water pressure creates wave motion.

Ocean waves are, therefore, the up and down motion of surface water. The highest point of a wave is the **crest**; the lowest point is the **trough**.

The height of a wave is the distance from the trough to the crest. The length of a wave is the distance between two crests. Small waves may have lengths of a few inches while the crests of large storm waves may be several football fields apart. Waves usually follow one another, forming a train. The time it takes two crests in a train to pass a stationary point is known as the **period** of a wave. Wave periods tell us how fast the waves are moving.

In deep water, waves do not move water in the direction of the wind. With each up and down movement, the water rises to a crest, turns a somersault into a trough, and returns to about the same spot where it began. Near shore, the ocean becomes shallow; some somersaults hit the bottom and drag. The water at the top continues to somersault. The crests crowd together and get top heavy, tumbling over and rushing toward the shore, allowing for surfing and bodyboarding.

Harnessing Wave Energy

The energy in waves can be harnessed to generate electricity. There are two main types of wave energy generation devices, fixed and floating. Fixed generating devices are built into cliffs along a coast.

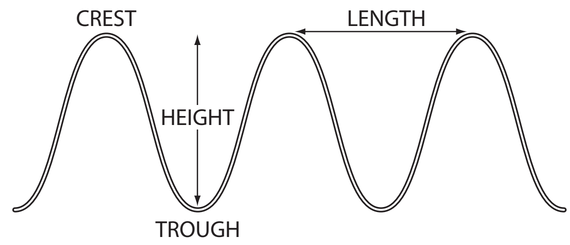
One **fixed device** is the **oscillating water column**. The column, or chamber, is partially submersed in the water. As the waves flow in and out of the chamber, the air inside the chamber is compressed and decompressed. The forced air spins a turbine. The generator attached to the turbine produces electricity.

Another fixed generating device is a tapered channel system known as a **TAPCHAN system**. It consists of a channel connected to a reservoir in a cliff. The channel gets narrower as it nears the reservoir, causing the waves to increase in height.

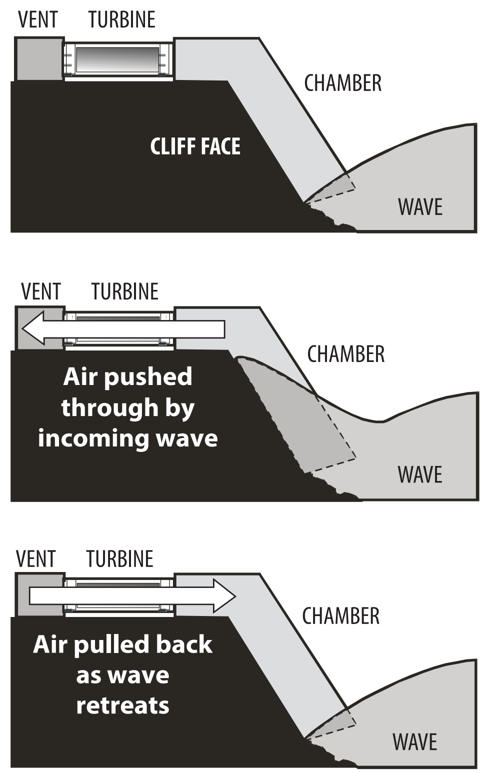
When the waves are high enough, they spill over the top of the channel into the reservoir. The stored water in the reservoir flows through a turbine, generating electricity.

A TAPCHAN system is not usable in all coastal areas. Ideal locations have consistent waves, good wave energy, and a tidal range of less than one meter.

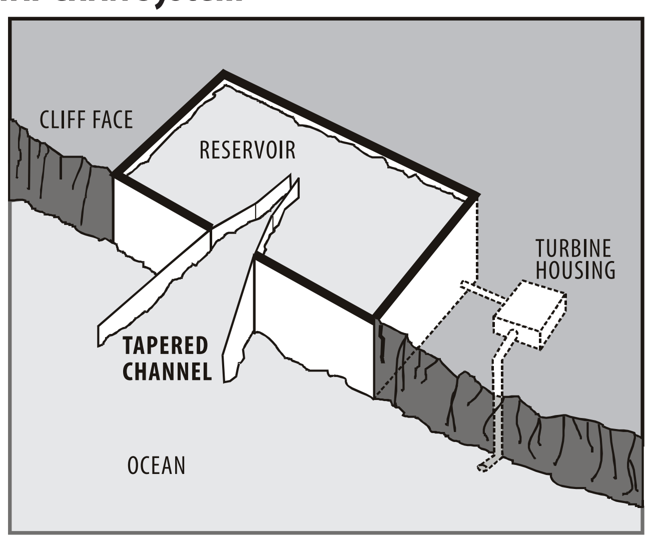
Wave Measurements



Oscillating Water Column



TAPCHAN System



Several floating wave energy generation devices are under development. They generate electricity as they are moved by the waves. One open-ocean method uses **Salter Ducks**—tethered cams that bob up and down with the waves on the surface of the water.

The nodding motion of the cams compresses oil in pistons inside the devices. The pressurized oil is released through a hydraulic motor that converts 90 percent of the harnessed energy into electricity.

A Scottish company, Pelamis Wave Power, has developed a floating wave energy converter known as Pelamis, named after the scientific name of a sea snake.

Each device is a series of five semi-submerged tubes that are linked to each other by hinged joints. Passing waves cause each tube to rise and fall like a giant sea snake. The motion tugs at the joints linking the segments. The joints act as a pumping system, pushing high pressure oil through a series of hydraulic motors, which in turn drive the electrical generators to produce electricity. The wave energy converters are anchored to the sea floor by moorings and then connected to the grid via subsea power cables.

In 2008, Pelamis Wave Power and the Portuguese utility Enersis built the world's first wave farm off the coast of Portugal. Three first-generation Pelamis machines had an installed capacity of 2.25 megawatts and generated sustained power to the electric grid. However, the project ended later that year, with the Pelamis machines being towed back into harbor, due to the financial collapse of Enersis' parent company.

In 2009, Portuguese electric companies EDP and Efacec purchased Enersis' share in the wave farm and have plans to install up to 26 second-generation Pelamis wave energy converters with an installed capacity up to 20 megawatts.

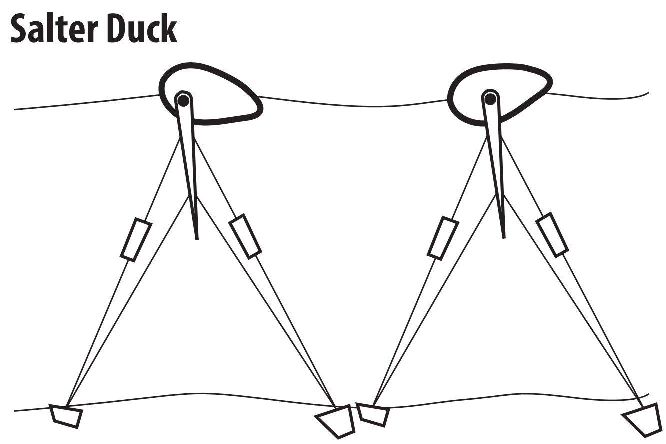
There aren't any large commercial wave energy plants, but there are a few small ones. Wave energy devices power the lights and whistles on buoys. While some countries like Japan have active wave power programs, the only projects in the U.S. are currently experimental.

Osmotic Power Plant

In 2009, a Norwegian energy group, Statkraft, opened the world's first osmotic power plant. **Osmotic power** is based on the natural process of osmosis—the diffusion of molecules through a semi-permeable membrane from a place of higher concentration to a place of lower concentration. It is a clean, renewable energy source.

In an osmotic power plant, seawater and freshwater are separated by a semi-permeable membrane—freshwater can move through the membrane but saltwater cannot. The salt content of the seawater draws freshwater through the membrane to dilute the salinity, increasing pressure on the seawater side of the membrane. The increased pressure is used to spin a turbine to generate electricity.

Though Statkraft worked over a decade on bringing a large-scale osmotic power plant online, the technology is not financially competitive and the company has stopped pursuing this project.



The Salter Duck generates electricty offshore using the movement of the waves to bob up and down on the surface of the water.

PELAMIS WAVE ENERGY CONVERTER

Image courtesy of Pelamis

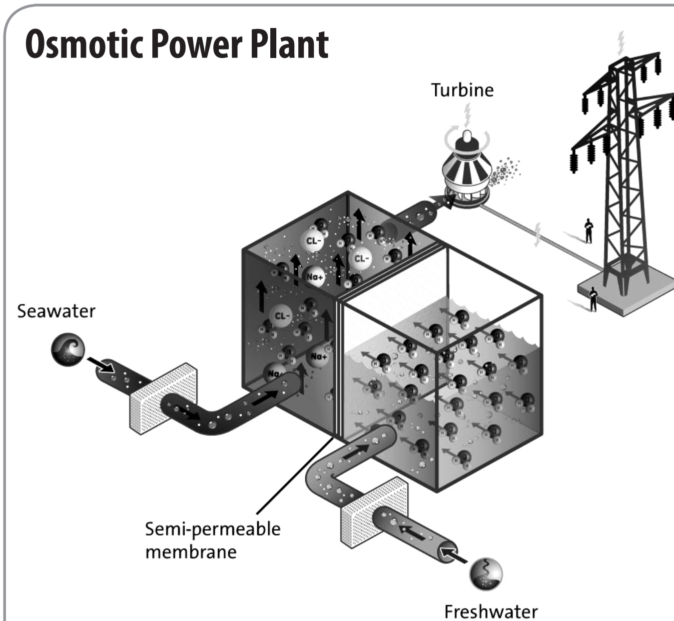


Image courtesy of Statkraft

Future of Hydropower

The future of hydropower includes both challenges and opportunities, and will continue to be a major part of the U.S. and global energy mix for many years. As the nation and the world develop strategies to deal with global climate change, hydropower will play a significant role by producing clean, economical electricity without carbon dioxide emissions.

Advances in turbine design and other mitigation strategies will continue to reduce the impact of conventional hydropower facilities on fish populations, water quality, and the environment. New technologies will also allow facilities to become more efficient and generate more electricity. The addition of power plants to existing dams will increase the overall capacity of the hydropower industry.

In late 2016, the U.S. Department of Energy awarded up to $40 million to researchers in the Pacific Northwest. The open-water wave energy testing facility, if approved, will be placed in Oregon and will utilize researchers at the Northwest National Marine Renewable Energy Center at Oregon State University to collect data and support innovations in wave energy with this grid-connected system.

The development and implementation of technologies that harness the power of moving water, whether it is from free-flowing streams, the tides, ocean currents, or waves, will also contribute to the future of hydropower in the United States and around the world.

TURBINE ROOM AT SAFE HARBOR

History of Hydropower Timeline

BCE	Hydropower used by the Greeks to turn water wheels for grinding grains more than 2,000 years ago.
Mid-1770s	French hydraulic and military engineer Bernard Forest de Bélidor wrote *Architecture Hydraulique*, a four-volume work describing vertical- and horizontal-axis machines.
1775	U.S. Army Corps of Engineers founded, with establishment of Chief Engineer for the Continental Army.
1880	Michigan's Grand Rapids Electric Light and Power Company, generating electricity by dynamo belted to a water turbine at the Wolverine Chair Factory, lit up 16 brush-arc lamps.
1881	Niagara Falls city street lamps powered by hydropower.
1882	World's first hydroelectric power plant began operation on the Fox River in Appleton, WI.
1886	About 45 water-powered electric plants in the U.S. and Canada.
1889	Two hundred electric plants in the U.S. use hydropower for at least part of their generation.
1901	First Federal Water Power Act. No one could build or operate a hydroelectric plant on a stream large enough for boat traffic without special permission from Congress.
1902	U.S. Bureau of Reclamation established.
1907	Hydropower provided 15 percent of U.S. electricity generation.
1920	Hydropower provided 25 percent of U.S. electricity generation. Federal Power Act established Federal Power Commission authority to issue licenses for hydro development on public lands.
1933	Tennessee Valley Authority was established, taking charge of hydroelectric potential of the Tennessee River and its tributaries.
1935	Federal Power Commission authority was extended to all hydroelectric projects built by utilities engaged in interstate commerce.
1936	Hoover Dam began operating on the Colorado River. Using multiple Francis turbines, the Hoover Dam plant produces up to 130,000 kilowatts of power.
1937	Bonneville Dam, the first federal dam, begins operation on the Columbia River. Bonneville Power Administration established.
1940	Hydropower provided forty percent of the nation's electricity generation. Conventional capacity tripled in United States since 1920.
1977	Federal Power Commission disbanded by Congress. A new agency was created, the Federal Energy Regulatory Commission (FERC).
1980	Conventional hydropower plant capacity nearly tripled in United States since 1940.
2006-2009	Verdant power tested six full scale tidal turbines in the East River in New York. It was the first of its kind in the world.
2009	The U.S. Department of Energy awarded over $30 million in American Recovery and Investment Act funds to hydropower projects for modernization.
2012	The Three Gorges Dam on the Yangtze River in China came online. It is the largest hydroelectric project in the world and took over six years to construct. It generates the electrical equivalent of fifteen nuclear reactors, but is highly controversial due to the environmental and social issues related to its construction.
2012	Maine deployed the U.S.'s first commercial, grid-connected tidal power system in the Bay of Fundy.
Today	Between 5–10 percent of U.S. electricity comes from hydropower, depending on water supply. In total, the U.S. has about 79,000 MW of conventional capacity and 22,000 MW of pumped storage capacity. Hydropower provides 17% of the world's electricity.

Careers in the Hydropower Industry

Energy Industry Analysts assess the significance of developments and trends in the energy industry and use this information for current and future regulatory policies. Energy industry analysts require a degree in finance, management, or other business, industrial, mechanical, or other engineering field.

Accountants establish accounting policies, providing guidance to energy companies for reporting issues.

Auditors review financial information about energy companies to ensure they are in compliance with government regulations. Accountants and auditors require a bachelor's degree in accounting.

Administrators provide general office clerical support to professional, program, or technical staff members utilizing typing skills and a knowledge of office automation hardware and software systems. Administrative support staff may be responsible for timekeeping, government procedures, and other personnel matters.

Communications Professionals must possess excellent writing and speaking skills, a customer service attitude, and the ability to respond quickly in a dynamic environment. Communications professionals require a bachelor's degree in communications or English.

Economists closely follow and analyze trends in the various energy industries to make sure a healthy competitive market is in place. They consult with experts in energy economics, market design, anti-trust and other issues, and use economic theory on real-world problems and situations. Economists require a bachelor's degree in economics.

Hydrologists research the distribution, circulation, and physical properties of underground and surface waters, and study the form and intensity of precipitation, its rate of infiltration into the soil, movement through the earth, and its return to the oceans and atmosphere.

Hydrologists apply scientific knowledge and mathematical principles to solve water-related problems in society—problems of quantity, quality, and availability. They may be concerned with finding water supplies for cities and irrigated farms, or controlling river flooding and soil erosion. They may also work in environmental protection—preventing or cleaning up pollution and locating sites for safe disposal of hazardous wastes. The work of hydrologists is as varied as the uses of water and may range from planning multimillion dollar interstate water projects to advising homeowners about backyard drainage problems.

A bachelor's degree is adequate for entry-level positions. Students who plan to become hydrologists should take courses in the physical sciences, geophysics, chemistry, engineering science, soil science, mathematics, computer science, aquatic biology, atmospheric science, geology, oceanography, hydrogeology, and the management or conservation of water resources. In addition, some background in economics, public finance, environmental law, and government policy is needed to communicate with experts in these fields.

Information Technology Specialists do systems programming, off-the-shelf software management, database administration, network and telecommunications operations/administration, security implementation, disaster recovery, electronic filing, and customer service support. Information technology specialists require a bachelor's degree in information technology.

Power Plant Operators control machinery that makes electric power. They control and monitor boilers, turbines, and generators and adjust controls to distribute power demands among the generators. They also monitor the instruments that regulate the flow of electricity from the plant. When power needs change, they start or stop the generators and connect or disconnect them from the circuits. Many operators use computers to keep records of switching operations, to track the loads on generators and lines, and to prepare reports of unusual incidents, malfunctions, or repairs that occur during their shift.

Power Distributors and Dispatchers operate equipment that controls the flow of electricity from a power plant through transmission lines to substations that supply customers' needs. They operate converters, transformers, and circuit breakers. Dispatchers monitor the equipment and record readings at a pilot board—a map of the transmission grid system. It shows the status of circuits and connections with substations and industrial plants.

Dispatchers also anticipate power needs, such as those caused by changes in the weather. They call control room operators to start or stop boilers and generators. They also handle emergencies such as line failures and route electricity around the affected areas. In addition, dispatchers operate and monitor the equipment in substations. They step up or step down voltage and operate switchboard levers, which control the flow of power in and out of the substations.

Civil Engineers make site visits, prepare engineering studies, and design or evaluate various types of hydroelectric dams, powerhouses, and other project structures. They develop graphs, charts, tables, and statistical curves relating to these studies for inclusion in environmental impact statements and assessments and dam safety reports. Civil engineers require a bachelor's degree in engineering.

Environmental Engineers of proposed hydroelectric projects review environmental reports and exhibits. A main component of the job is to study aspects of environmental impact issues, determine the scope of the problem, and propose recommendations to protect the environment. They perform studies to determine the potential impact of changes on the environment. Environmental engineers require a bachelor's degree in engineering.

Electrical Engineers design and develop electrical systems and equipment, evaluate electrical systems, and ensure stability and reliability. Electrical engineers require a bachelor's degree in engineering.

Hydropower Engineers work with teams of environmental scientists and engineers to review, analyze, and resolve engineering and environmental issues associated with proposals to construct and operate hydroelectric projects, including major dams, reservoirs, and power plants. Hydropower engineers require a bachelor's degree in engineering.

Hydropower Resources and Career Information

U.S. Department of the Interior, Bureau of Reclamation

Explore the Hoover Dam. Learn how the dam was built, view construction era photographs, and learn how the dam operates as one of the largest hydroelectric power plants in the country. The site includes educational resources for teachers.
www.usbr.gov/lc/hooverdam/

CareerOneStop

Use this site to explore green careers, find resume templates, compare various occupations, and learn what's hot in different industries.
www.careeronestop.org

U.S. Department of Energy, Federal Energy Regulatory Commission

Visit the Students' Corner to learn more about hydropower. This website includes games and photos of dams and hydropower plants.
www.ferc.gov/students/index.asp

Foundation for Water and Energy Education

Watch a video of hydroelectric power production, take a virtual tour of a hydroelectric plant and a generator, and learn how a hydroelectric project can affect a river.
www.fwee.org

Hydro Research Foundation

An excellent resource that explores all aspects of hydropower using real life photos.
www.hydrofoundation.org

National Hydropower Association

Covers basic information about hydropower in all of its forms, both conventional and new technologies as well as hydropower issues as they relate to legislative and regulatory issues. The website also includes many links to other hydropower resources and is a great place to start for everything that is hydro.
www.hydro.org

PBS: Building Big

After learning about the different types of dams, take the dam challenge. As a consulting dam engineer, you decide whether to repair, take down, or leave alone several different dams.
www.pbs.org/wgbh/buildingbig/dam/index.html

Energy Information Administration

Up-to-date data and information on all energy sources, including hydropower.
www.eia.gov

EIA Kids

The Energy Information Administration's kids page has excellent energy-related information and games for students.
www.eia.gov/kids

Dams Contribute to Other Employment

When Hoover Dam (near Boulder City, Nevada) was built on the Colorado River, it created two huge lakes—Lake Mead and Lake Mohave. Together, they form the Lake Mead Reservoir, which offers almost unlimited water-based recreation on a year-round basis, catering to boaters, swimmers, sunbathers, and fishermen. National Park Rangers working at Lake Mead National Recreation Area (NRA), part of the National Park Service, are responsible for visitors' safety. The National Park Service employs over 20,000 people in both seasonal and permanent positions. For more information on working as a National Park Ranger, visit www.usajobs.gov.

The Army Corps of Engineers operates Summersville Dam as a flood control project on the Gauley River in West Virginia. The Summersville Reservoir is a center for powerboat recreation during the summer, but at the end of the season the Corps must lower the lake 75 feet to make room for the next spring's floods.

In addition to the people who work directly with the power plant, dam, and reservoir, the Gauley River provides jobs for the local economy. Small business owners run specialty sporting goods stores and white water rafting and kayaking expeditions. Store managers and salespeople run these businesses. Raft guides lead groups of rafters and kayakers down the river, and shuttle bus/van drivers transport customers to drop-off and pick-up points.

Image courtesy of National Park Service

National Park Service rangers care for and protect some of America's favorite places. They help visitors enjoy and appreciate the nearly 400 national parks, monuments, memorials, seashores, and historic sites across the country.

Presentation Topic Organizer

Important Information

Additional Information Needed

Topic

Graphics Needed

Design of Presentation

Forms and Sources of Energy

In the United States we use a variety of resources to meet our energy needs. Use the information below to analyze how each energy source is stored and delivered.

1 Using the graphic below, determine how energy is stored or delivered in each of the sources of energy. Remember, if the source of energy must be burned, the energy is stored as chemical energy.

NONRENEWABLE

Petroleum ____________________

Natural Gas ____________________

Coal ____________________

Uranium ____________________

Propane ____________________

RENEWABLE

Biomass ____________________

Hydropower ____________________

Wind ____________________

Solar ____________________

Geothermal ____________________

2 Look at the U.S. Energy Consumption by Source graphic below and calculate the percentage of the nation's energy use that each form of energy provides.

What percentage of the nation's energy is provided by each form of energy?

Chemical _____

Nuclear _____

Motion _____

Radiant _____

Thermal _____

What percentage of the nation's energy is provided by nonrenewables? ______

By renewables? ______

U.S. Energy Consumption by Source, 2015

NONRENEWABLE

PETROLEUM 36.57% *
Uses: transportation, manufacturing - includes propane

NATURAL GAS 28.97% *
Uses: heating, manufacturing, electricity - includes propane

COAL 15.97%
Uses: electricity, manufacturing

URANIUM 8.56%
Uses: electricity

PROPANE
Uses: heating, manufacturing

*Propane consumption figures are reported as part of petroleum and natural gas totals.

RENEWABLE

BIOMASS 4.86%
Uses: heating, electricity, transportation

HYDROPOWER 2.38%
Uses: electricity

WIND 1.83%
Uses: electricity

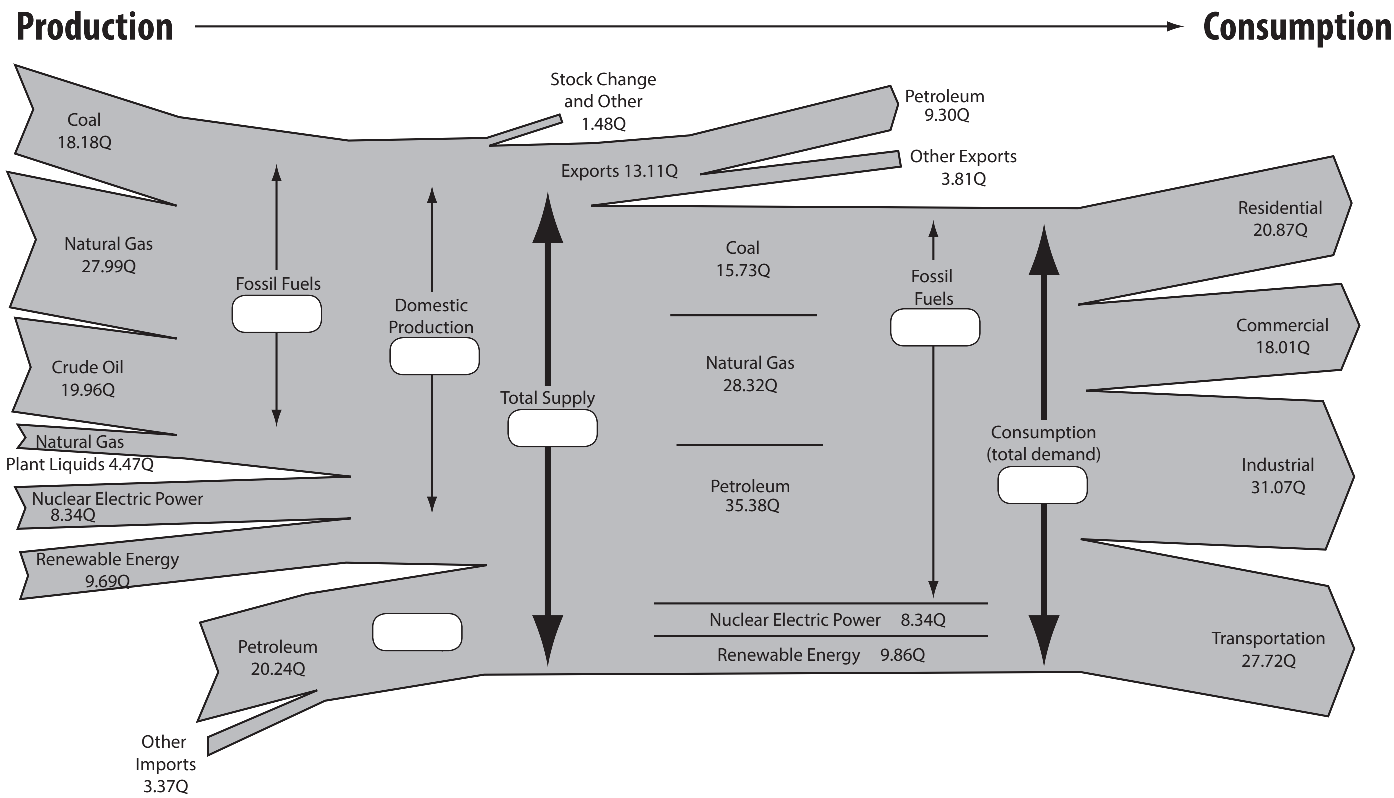
SOLAR 0.44%
Uses: heating, electricity

GEOTHERMAL 0.22%
Uses: heating, electricity

**Total does not add up to 100% due to independent rounding.
Data: Energy Information Administration

U.S. Energy Flow, 2015

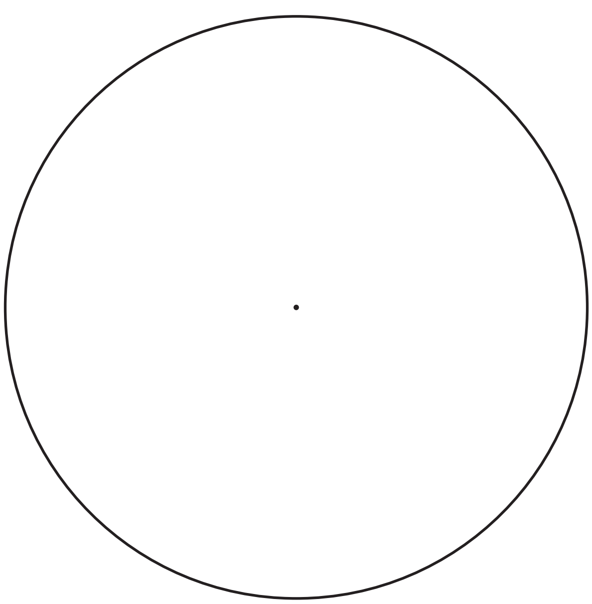
1. Fill in the blank boxes on the 2015 Energy Flow diagram.
2. Draw and label a pie chart of Domestic Energy Production by Source.
3. Draw and label a pie chart of U.S. Energy Consumption by Sector of the Economy.



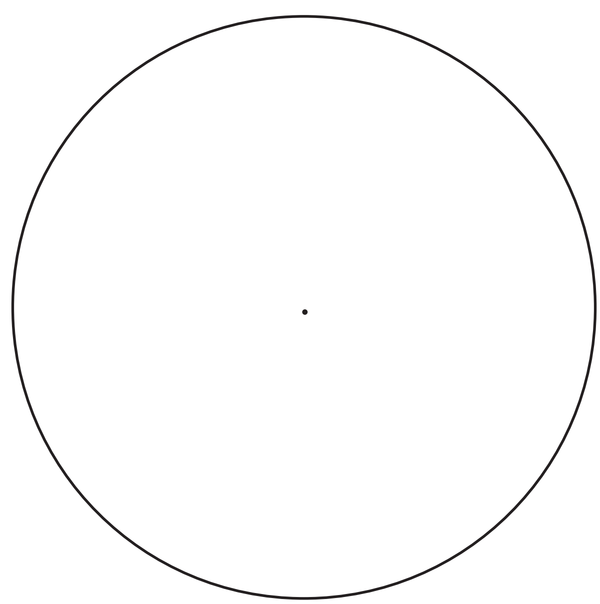
Data: U.S. Energy Information Administration

*Data incorporates electricity generation.

Domestic Energy Production by Source, 2015

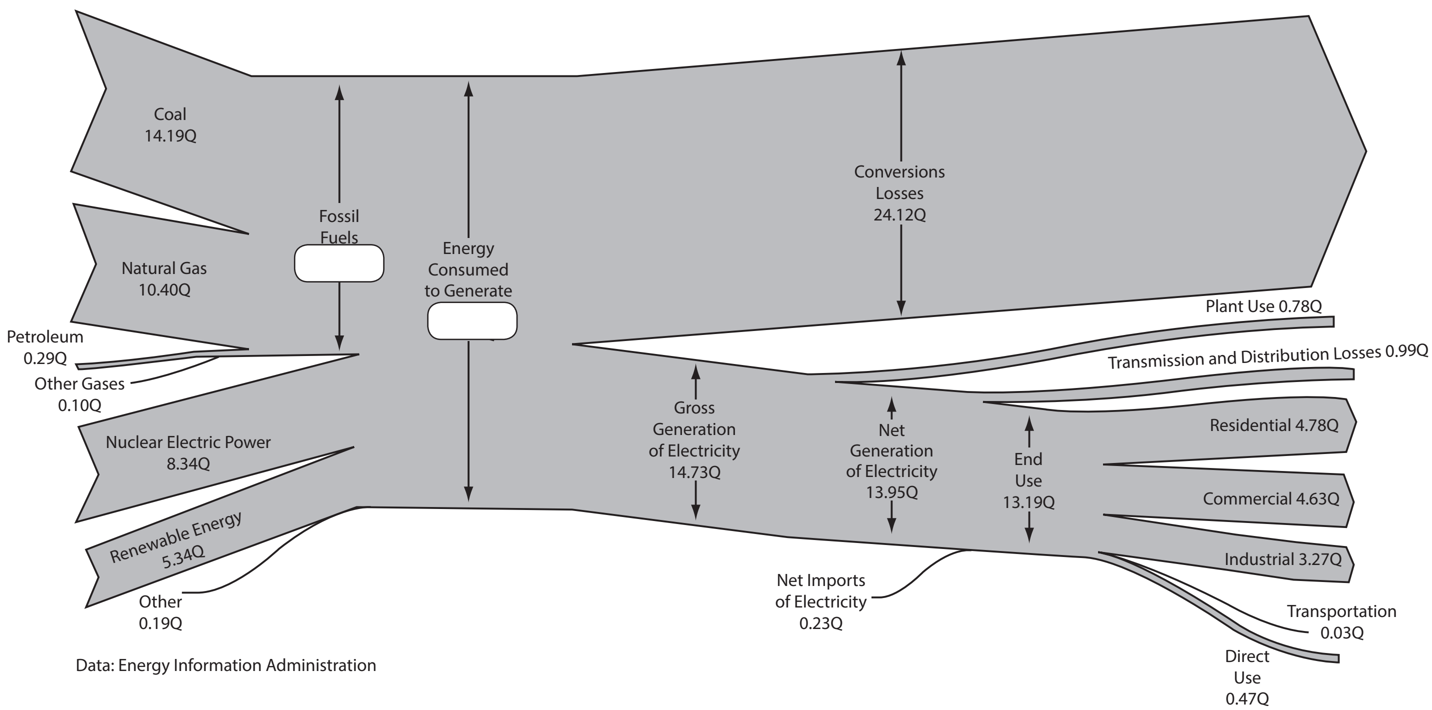


U.S. Energy Consumption by Sector of the Economy, 2015



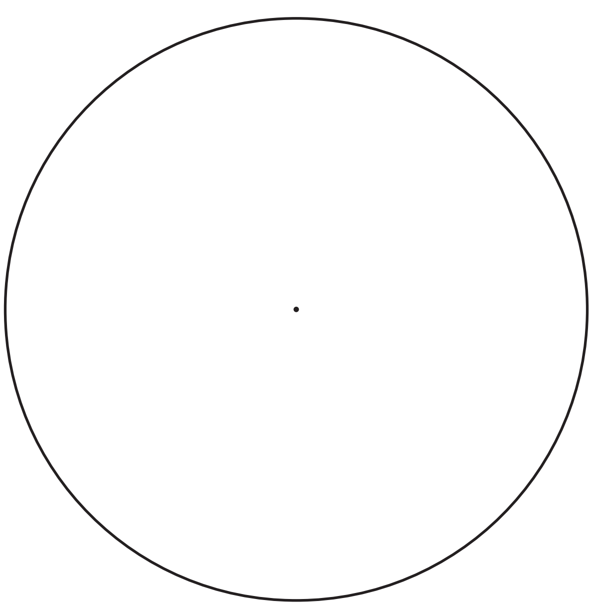
U.S. Electricity Flow, 2015

1. Fill in the blank boxes on the 2015 Electricity Flow diagram.
2. Draw and label a pie chart of U.S. Electricity Production by Source.
3. Draw and label a pie chart of U.S. Electricity Consumption by End Use.
4. On a separate piece of paper, write a paragraph explaining conversion losses.

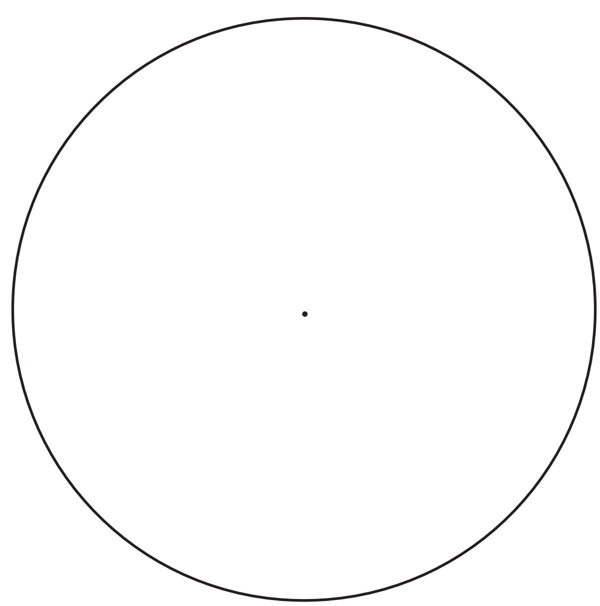


Data: Energy Information Administration

U.S. Electricity Production by Source, 2015



U.S. Electricity Consumption by End Use, 2015



Measuring Electricity: Sample Calculations

Example 1: Calculating Voltage

If household current is 6 amps and the resistance of an appliance is 20 ohms, calculate the voltage.
To solve for voltage, use the following equation: voltage = current x resistance (V = I x R).

Voltage = A x Ω

V = 6 A x 20 Ω = 120 V

Example 2: Calculating Current

The voltage of most residential circuits is 120 volts. If we turn on a lamp with a resistance of 60 ohms, what current would be required?
To solve for current, use the following equation: current = voltage / resistance (I = V / R).

Current = V / Ω

I = 120 V / 60 Ω = 2 A

Example 3: Calculating Resistance

A car has a 12-volt battery. If the car radio requires 0.5 amps of current, what is the resistance of the radio?
To solve for resistance, use the following equation: resistance = voltage / current (R = V / I).

Resistance = V / A

R = 12 V / 0.5 A = 24 Ω

Example 4: Calculating Power

If a 6-volt battery pushes 2 amps of current through a light bulb, how much power does the light bulb require?
To solve for power, use the following equation: power = voltage x current (P = V x I).

Power = V x A

P = 6 V x 2 A = 12 W

Example 5: Calculating Voltage

If a 3-amp blender uses 360 watts of power, what is the voltage from the outlet?
To solve for voltage, use the following equation: voltage = power / current (V = P / I).

Voltage = W / A

V = 360 W / 3 A = 120 V

Example 6: Calculating Current

If a refrigerator uses power at a rate of 600 watts when connected to a 120-volt outlet, how much current is required to operate the refrigerator?
To solve for current, use the following equation: current = power / voltage (I = P / V).

Current = W / V

I = 600 W / 120 V = 5 A

Example 7: Calculating Electrical Energy and Cost

If a refrigerator uses power at a rate of 600 watts for 24 hours, how much electrical energy does it use?
To solve for electrical energy, use the following equation: energy = power x time (E = P x t).

Electrical Energy = W x h

E = 600 W x 24 h = 14,400 Wh x (1 kW/1,000 W) = 14.4 kWh

If the utility charges $0.127 a kilowatt-hour, how much does it cost to run the refrigerator for 24 hours?
To calculate cost, use the following equation: cost = energy x price.

Cost = 14.4 kWh x $0.127/kWh = $1.83

Measuring Electricity

TABLE 1

VOLTAGE	=	CURRENT	X	RESISTANCE
1.5 V	=	_______ A	x	3 Ω
_______ V	=	3 A	x	4 Ω
120 V	=	4 A	x	_______ Ω
240 V	=	_______ A	x	12 Ω

TABLE 2

POWER	=	VOLTAGE	X	CURRENT
27 W	=	9 V	x	_______ A
_______ W	=	120 V	x	1.5 A
45 W	=	_______ V	x	3 A
_______ W	=	120 V	x	2 A

TABLE 3

APPLIANCE		POWER	=	VOLTAGE	X	CURRENT
TV		180 W	=	120 V	x	_______ A
COMPUTER		40 W	=	120 V	x	_______ A
PRINTER		120 W	=	120 V	x	_______ A
HAIR DRYER		1,000 W	=	120 V	x	_______ A

TABLE 4

POWER	X	TIME	=	ELECTRICAL ENERGY (kWh)	X	PRICE	=	COST
5 kW	x	100 h	=	______________	x	$0.127	=	$ _______
25 kW	x	4 h	=	______________	x	$0.127	=	$ _______
1,000 W	x	1 h	=	______________	x	$0.127	=	$ _______

Science of Electricity Model

Observe the science of electricity model. Draw and label the parts of the apparatus.

Explain how electricity is generated using appropriate vocabulary.

Turbine Component Assembly Instructions

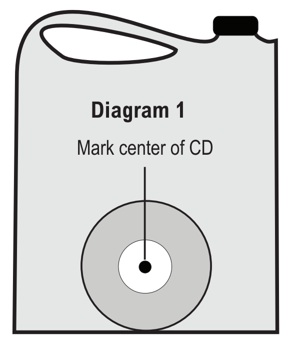
Materials

- 1 Rectangular jug
- 2 Compact discs
- 4 Disc magnets
- 1 Styrofoam hub (4 cm length)
- 8 Wooden spoons
- 1 Wooden dowel
- 1 Spool of magnet wire
- Templates for coils of wire and magnets
- 1 Glue gun with glue sticks
- 1 Roll of masking tape
- 4 Rubber stoppers with holes
- 1 Pair sharp scissors
- 1 Permanent marker
- 1 Nail
- 1 Cardboard tube (4 cm diameter)
- Sandpaper
- Double-sided tape
- Transparent tape
- Graphite pencil
- Ruler

✔ Procedure

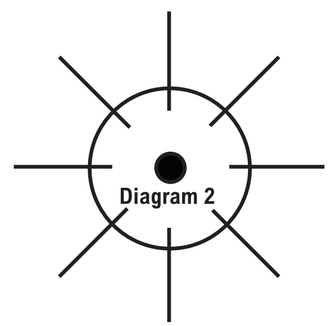
Jug Assembly

1. Cut the bottom off of the jug.
2. Stand the jug on the cut bottom. Place a CD in the exact middle of the long sides of the jug and mark the CD hole as shown in Diagram 1. Make the same mark on the other side of the jug.
3. Cut holes for the dowel with the scissors where you have marked. Make sure the dowel can rotate freely in the holes.



Hub Assembly *(see Hub Marking Guide on page 42)*

1. Make a hole in the exact center of the foam hub with the nail.
2. Use the *Hub Marking Guide* to mark the hub for the placement of 8 blades (spoons) as shown in Diagram 2.
3. Attach 4 blades equally spaced around the hub. You will add the other 4 later.
4. Make sure the hub will fit inside the jug. Glue the 4 blades in place to reinforce.

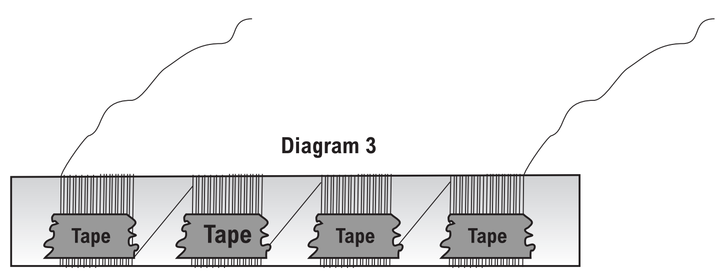


CD/Magnet Assembly *(see Magnet CD Template on page 42)*

1. Stack the 4 magnets.
2. On the top face of the top magnet, mark an N to indicate the north pole of the magnet.
3. Remove the top magnet and mark the top face of each remaining magnet with an N.
4. The blank faces of the magnets will indicate the south poles.
5. **Caution:** The magnets are very strong. Slide them apart rather than pulling them apart.
6. Place the magnets far apart from each other so they do not snap back together.
7. Cut out the *Magnet CD Template* and glue it to one CD. Allow time to dry.
8. Using double-sided tape, tape the magnets one at a time to the CD as indicated on the template.

CD/Wire Assembly *(see Coils of Wire CD Template on page 42)*

1. Cut out the template for the wire and glue it to the second CD. Allow time to dry.
2. Leaving 15 cm of wire at the beginning, loosely wind 50 wraps of wire around the cardboard tube as shown in Diagram 3. DO NOT CUT THE WIRE. Tape the coil of wire in place with masking tape.
3. Move 2 cm down the tube and wind another 50 wraps of wire. Tape this coil in place (see diagram).
4. Repeat this process two more times for a total of 4 coils.
5. Leave 15 cm of wire at the end of the fourth coil and cut the wire.
6. Carefully slide the coils off of the tube and re-tape each coil together.
7. Put a ring of glue on each coil and place it on the template, rotating each coil to match the direction of the coil as indicated on the template. Allow time to dry.

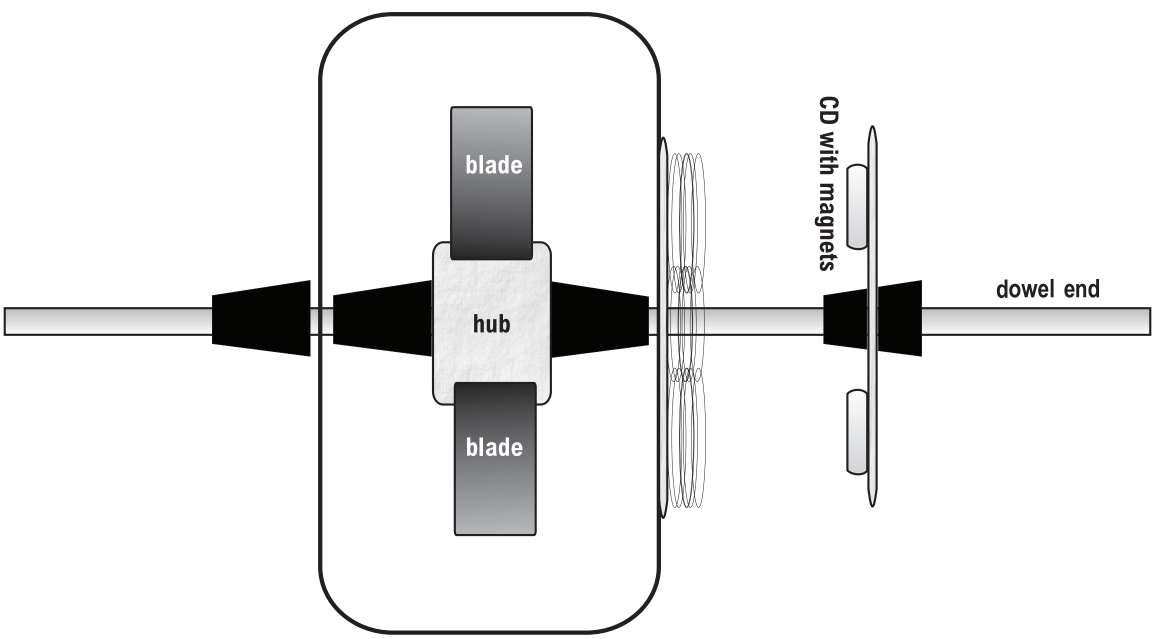


CONTINUED ON NEXT PAGE

Turbine Assembly Instructions

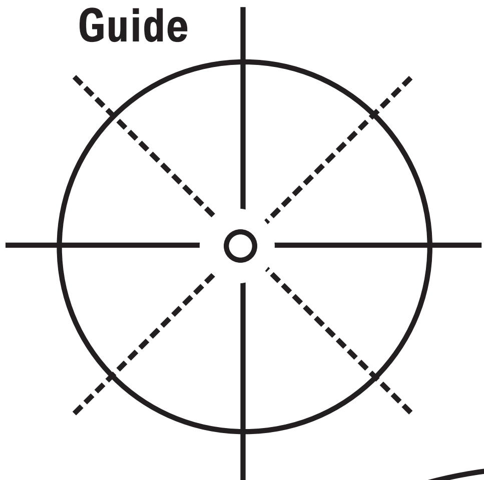
Turbine Assembly Instructions

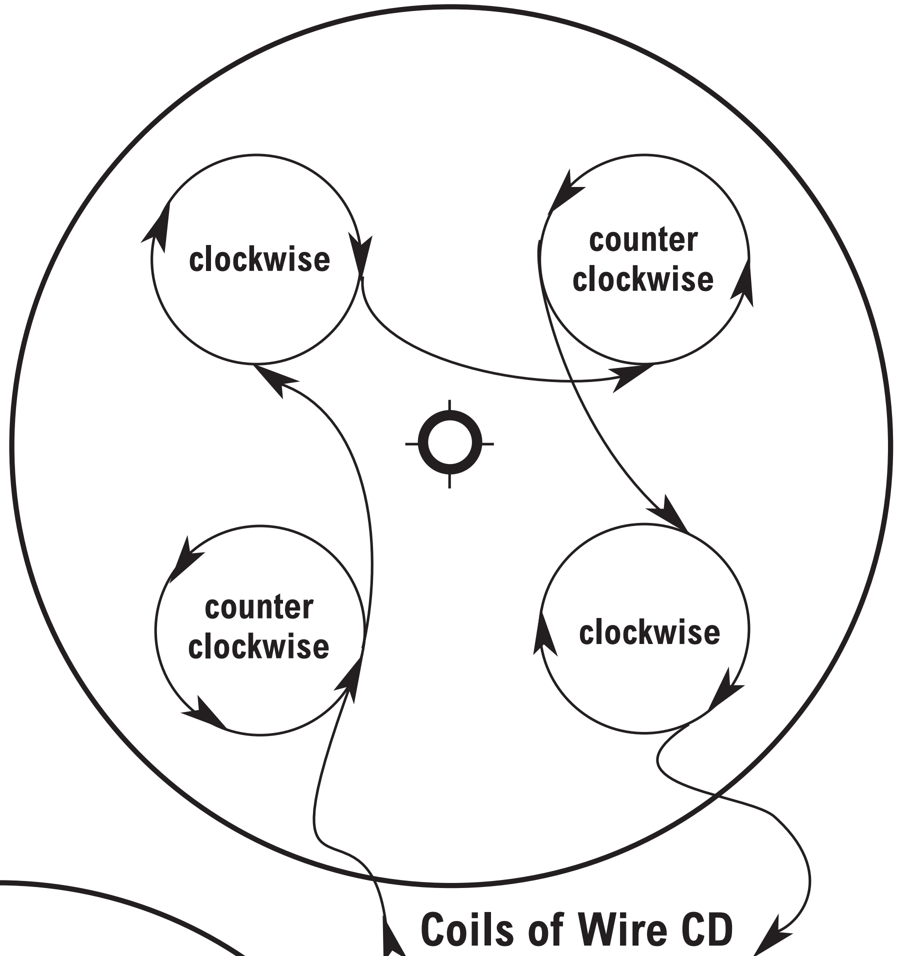
1. Slide the dowel through the holes in the container. Determine where the dowel will pass through the jug and mark these areas on the dowel. Remove the dowel and put one strip of transparent tape over these marked locations. Make sure the tape is smooth. Color over the tape with a graphite pencil, as it will help the dowel rotate smoothly.
2. Attach the CD with the coils of wire to the outside of the jug with three 6 cm pieces of double-sided tape. The holes in the CD and the jug should be aligned for the dowel. Put aside.
3. Take one rubber stopper and score around the stopper ¼" from the small end using the sharp scissors. Score twice, and break apart.
4. Push the ¾" end of the stopper you just cut 4 cm onto the dowel. The 4 cm end of the dowel with the stopper is the "dowel end." Everything else will slide onto the dowel from the longer side.
5. Slide the CD with the magnets onto the dowel so the blank side of the CD is flat against the stopper.
6. Slide the ¼" rubber stopper piece onto the dowel and up against the CD with magnets.
7. Slide the dowel through the CD with the coils and into the jug.
8. Slide a rubber stopper smaller side first onto the dowel.
9. Slide the hub onto the dowel, then slide another stopper onto the dowel with the larger side against the hub to hold it in place.
10. Slide the dowel through the other hole in the jug.
11. Slide another stopper onto the dowel on the outside of the jug. (Refer to the diagram below.)
12. Adjust the parts until the dowel spins freely. Make sure the stoppers inside the jug hold the hub securely, so it does not turn on the dowel.
13. Use the sandpaper to remove the enamel and oxidation from the ends of the wire to a length of 1 cm.



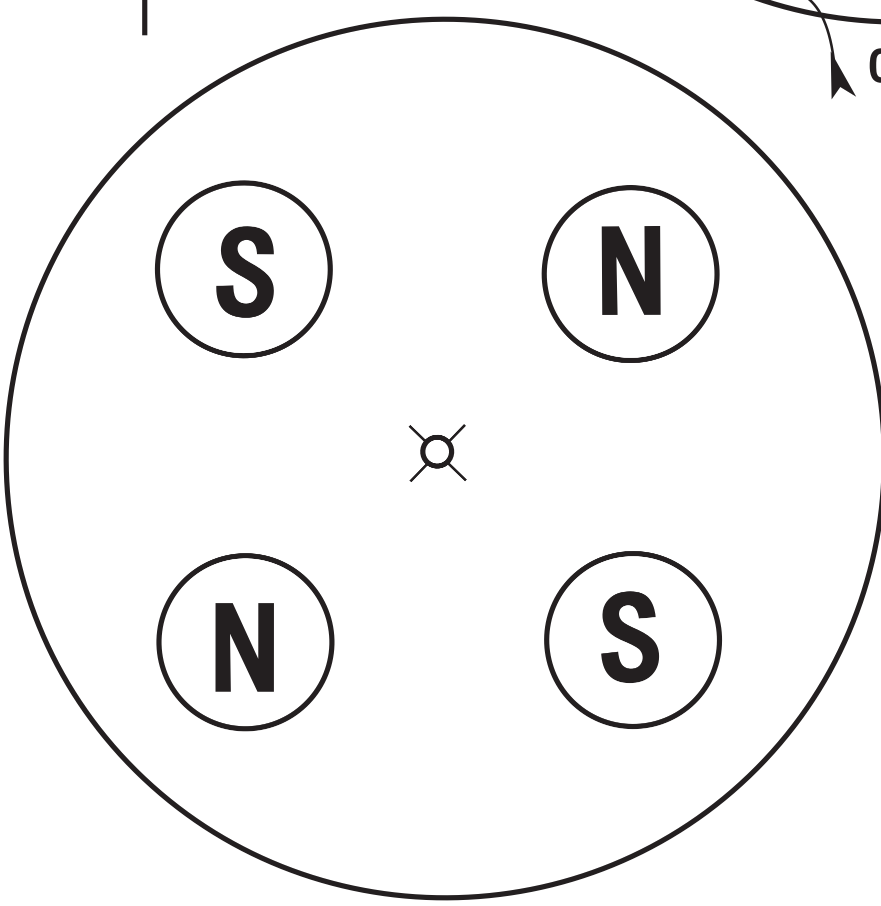
Turbine Component Template

Hub Marking Guide





Coils of Wire CD Template



Magnet CD Template

Reservoir Unit Instructions

1. Examine the water reservoir unit. Place one end of the tubing onto the end of the screwtop dispenser.
2. To fill the unit with water, place the unit with the opening on top and the spout lifted. Fill the unit completely with water. Screw the top securely on and make sure the valve is closed on the dispenser.
3. Lift the hose above the reservoir unit, slightly open the valve and put pressure on the unit to remove any air pockets at the top of the unit. Close the valve.
4. Place the unit on its side with the spout near the bottom when conducting all experiments, as shown in Diagram 1. Make sure there are no air pockets in the unit when you place it on its side to conduct the experiments.
5. Make sure there are no kinks in the hose when conducting experiments.
6. When conducting the experiments, rotate the valve to open and close and to ensure a constant rate of flow. Unscrew the dispenser to refill the unit.
7. Make sure the water from the hose hits the blades of the hub as shown in Diagram 2.
8. After each trial, use the funnel to pour the water from the bucket back into the unit. If necessary, add more water so that the unit is completely full.

Diagram 1

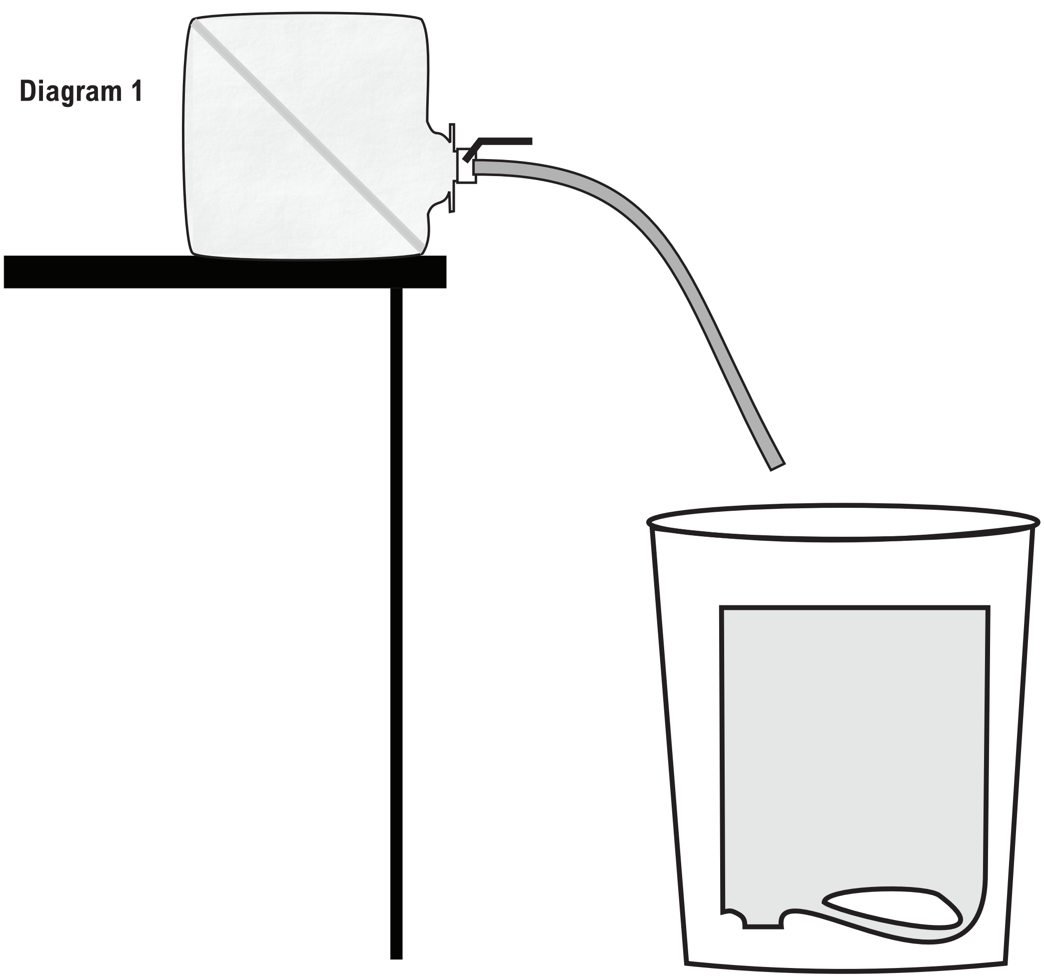
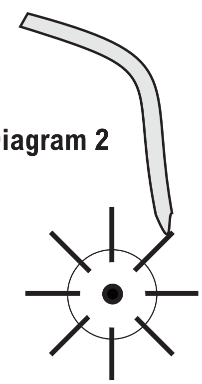
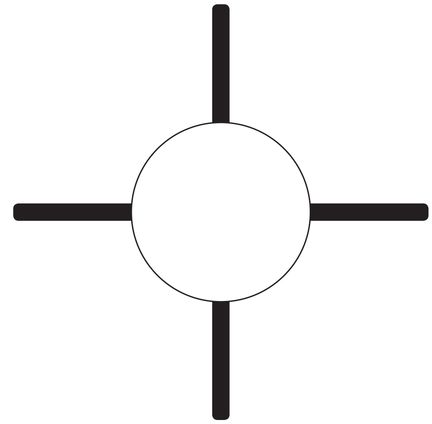


Diagram 2



Exploring Turbine Blades



Question

How do the number of blades affect the electrical output of a model hydropower turbine?

Hypothesis

Develop a hypothesis to address the question, using this format:

If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent—the variable that changes): ____________________.

Responding Variable (dependent—the variable that is measured): ____________________.

Controlled Variable (variable that is constant): ____________________________.

Materials

- Turbine
- Water
- Hub
- Glue
- Spoons

AT THE TESTING STATION:

- Reservoir unit
- Bucket
- Multimeter or voltmeter
- Alligator clips
- Funnel
- Stopwatch
- Meter stick

✔ Procedure

1. Attach the multimeter to the ends of the turbine wires with the alligator clips. Set it to the 20 DCV setting.
2. Place the turbine in the water collection bucket with the wide opening at the top. Fill the water reservoir unit and place it on a table about 50 cm higher than the top of the bucket. Pinch the hose together and open the valve.
3. Holding the end of the hose at the level of the top of the turbine assembly, allow the water to flow, pointing the hose so that the water flows on the blades for 10 seconds. Record the most consistent output reading in the table below.
4. Empty the bucket back into the water reservoir using the funnel.
5. Measure and record the electrical output two more times in the data table below. Calculate the average output.
6. Repeat Steps 2-5 with 8 blades. Make sure the position of the hose remains constant for all trials.

Observations and Data

NUMBER OF BLADES	OUTPUT 1	OUTPUT 2	OUTPUT 3	AVERAGE OUTPUT
4				
8				

Graphing

Make a graph of your data with the manipulated variable data on the X-axis (horizontal axis).

Conclusion

Explain why you think the number of blades affects the output of the turbine, using data to support your reasoning.

Note

The hub containing the number of blades that produced the best electrical output will become your "benchmark hub" to use in the rest of the investigations.

Exploring Reservoir Height

Question

How does the height of a reservoir affect the electrical output of a model hydropower turbine?

Hypothesis

Develop a hypothesis to address the question, using this format:

If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent—the variable that changes): ____________________________.

Responding Variable (dependent—the variable that is measured): ____________________________.

Controlled Variable (variable that is constant): ____________________________.

Materials

- Turbine unit with benchmark hub
- Reservoir unit
- Bucket
- Multimeter or voltmeter
- Alligator clips
- Water
- Funnel
- Meter stick
- Stopwatch

✔ Procedure

1. Use the benchmark hub from *Exploring Turbine Blades* that had the best electrical output.
2. Place the turbine unit into the water collection bucket.
3. Fill the reservoir unit and position the bottom of the unit 30 centimeters above the top of the bucket.
4. Position the hose at the top of the bucket so that the water will flow onto the blades.
5. Allow the water to flow for 10 seconds and record the most consistent output reading on the table below.
6. Refill the reservoir unit with water from the bucket. Make sure the reservoir unit is completely filled or filled with the same amount of water as in step 3.
7. Repeat Steps 2–6 two more times. Calculate the average output.
8. Repeat Steps 2–7 at reservoir heights of 65 and 100 centimeters.

Observations and Data

HEIGHT OF RESERVOIR	OUTPUT 1	OUTPUT 2	OUTPUT 3	AVERAGE OUTPUT
30 cm				
65 cm				
100 cm				

Graphing

Make a graph of your data with the manipulated data on the X-axis (horizontal axis).

Conclusion

Explain which height is most effective in converting the energy in flowing water into electricity and why, using data to support your reasoning.

Extension

Design an experiment to answer the following question: As the height of the water reservoir changes, should the number of blades on the turbine assembly change to deliver maximum output?

Exploring Copper Wire Wraps

Question

How does the number of copper wire wraps affect the electrical output of a model hydropower turbine?

Hypothesis

Develop a hypothesis to address the question, using this format:

If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent—the variable that changes): ____________________________.

Responding Variable (dependent—the variable that is measured): ____________________________.

Controlled Variable (variable that is constant): ____________________________.

Materials

List the materials you will need.

✔ Procedure

1. Decide how many wraps of wire to use on your stator (CD).
2. Use the benchmark hub from *Exploring Turbine Blades* that had the best electrical output.
3. Place the turbine unit model into the water collection bucket.
4. Fill the reservoir unit with one gallon of water.
5. Place the bottom of your water reservoir unit at the optimum height as determined in *Exploring Reservoir Height*.
6. Place the hose in the mouth of the unit model and let the water flow.
7. Record the electrical output as soon as possible to control the loss of water variable.
8. Empty the water collection bucket back into the reservoir, making sure there is one gallon of water in the reservoir.
9. Repeat steps 3–8 two more times for a total of three trials.
10. Repeat steps 1–9 with different numbers of copper wire wraps.

Observations and Data

Fill in your data below.

Graphing

Make a graph of your data with the manipulated data on the X-axis (horizontal axis).

Conclusion

Using results from your data table to support your reasoning, explain how many copper wire wraps are most effective in producing electricity. Include why you think this is the case.

Independent Turbine Investigation

Question

How does ______________________________________ affect the electrical output of a turbine?

Hypothesis

Develop a hypothesis to address the question, using this format:

If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent—the variable that changes): ______________________.

Responding Variable (dependent—the variable that is measured): ______________________.

Controlled Variable (variable that is constant): ______________________.

Materials

Procedure

1.
2.
3.
4.
5.

Observations and Data

Graphing

The manipulated variable is written on the X-axis (horizontal) and the responding variable is written on the Y-axis (vertical).

Conclusion

Using results from your data table to support your reasoning, explain how your revised design was or was not more effective in generating electricity.

Issue Organizer

Advantages of Actions	Disadvantages of Actions

Scenario: ______________________________

Stakeholder: ____________________________

Position and Three Reasons	Facts to Support Reasons

Glossary

ampere (amp)	a measurement of electric current
arch dam	a concrete, masonry, or timber dam with the alignment curved upstream
atom	the most basic unit of matter
atomic mass	the average mass of one atom of an element
atomic number	the number of protons in one atom of an element
baseload power	the minimum amount of power a utility company must make available to its customers
buttress dam	a dam consisting of a watertight part supported at intervals on the downstream side by a series of buttresses
cofferdam	a temporary dam structure enclosing all or part of a construction area so that construction can be performed; a diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse
conventional hydropower plant	a facility that uses available water from rivers, streams, canals, and reservoirs to produce electricity
crest	the highest point of a wave
current	the flow of electricity through a circuit; electric current
dam	a barrier constructed across a waterway to control the flow or raise the level of water
diversion project	a hydropower facility that does not require a dam but instead diverts river water from its course
efficiency	a percentage obtained by dividing the actual power or energy by the theoretical power or energy; it represents how well a hydropower plant converts the energy of the moving water into electrical energy
electromagnet	a magnet produced by electric current
electromagnetism	the relationship between electrical energy and magnetism
electron	the particle in an atom that carries a negative electrical charge
element	purest form of matter; all matter is made of elements or combinations of elements
embankment dam	any dam constructed of excavated natural materials, such as dirt and rock, or of industrial waste materials
energy	the ability to do work or make a change
energy level	area where electrons can be found; describes the probable amount of energy in an atom
estuary	the area of water at the mouth of a river
Federal Energy Regulatory Commission (FERC)	the federal agency that licenses non-federal hydropower projects
fish ladder	a series of small pools arranged like stairsteps that allow adult fish to bypass a dam
fixed device	a device that is anchored in one place
flow	volume of water, expressed as cubic feet or cubic meters per second, passing a point in a given amount of time; the amount and speed of water entering a water wheel or turbine
generator	a device that converts motion energy into electrical energy
gravity dam	a dam constructed of concrete and/or masonry that relies on its weight and internal strength for stability
head	vertical change in elevation, expressed in either feet or meters, between the headwater level and the tailwater level
hydrokinetic projects	projects that generate electricity from waves or directly from the flow of water in ocean currents, tides, or inland waterways
hydrologic cycle	the water cycle; the complete cycle of water evaporating from the oceans, rivers, and lakes through the atmosphere to the land (precipitation) and back to bodies of water
hydropower	the use of water to generate electricity

impoundment facility	typically a large hydropower system that uses a dam to store water in a reservoir
kilowatt	a unit of electric power equal to 1,000 watts
kilowatt-hour	a measure of electricity defined as a unit of work or energy, measured as 1 kilowatt of power expended for 1 hour
kinetic energy	the energy of motion
load	the part of an electrical circuit that uses electricity to do work (a light bulb, for example)
magnetic field	the area of force around a magnet
navigation dam	a dam built to ensure water depth; allows for commercial barge and ship travel
neutron	a particle in the nucleus of an atom that has no charge
non-overflow dam	a dam that diverts water to spillways to control the pressure and potential energy of the dam
nonrenewable energy source	an energy source with a long term replenish rate and reserves that are limited, including petroleum, coal, natural gas, uranium, and propane
nucleus	center of the atom
ohm	a measurement of resistance in an electrical circuit
Ohm's Law	the law that explains the relationship between current, voltage, and resistance in an electrical circuit; in all electrical circuits, the current (I) of that circuit is directly proportional to the voltage (V) applied to that circuit and inversely proportional to the resistance (R) of that same circuit
oscillating water column	a facility built into a cliff that captures wave energy
osmotic power	the spinning of a turbine using osmosis pressure differences of sea and fresh water
overflow dam	a dam that allows excess water to spill over its rim
penstock	a closed conduit or pipe for conducting water to a water wheel, turbine, or powerhouse
period	the time it takes for the crests of two concurrent waves to pass a stationary point
potential energy	stored energy; potential energy includes stored chemical and stored gravitational potential energy
power	the rate at which electrical energy is produced or consumed
power plant	the equipment attached to a dam that generates electricity, including the turbines and generators
proton	a particle in the nucleus of an atom that carries a positive electrical charge
pumped storage plant	a hydropower facility with two reservoirs (one higher than the other) used for peak generation; water from the lower reservoir is pumped into the higher reservoir to be stored until demand is high
renewable energy source	an energy source with a short term replenish rate, including biomass, geothermal, hydropower, solar, and wind
reservoir	a natural or artificial pond or lake for storing and regulating water
resistance	the force that resists the flow of electricity in an electrical circuit
resistor	a device with a set resistance that can be placed in circuits to reduce or control the current flow
revolutions per minute (RPM)	the number of rotations made by a device in one minute
run-of-river project	a hydropower facility with turbines placed in fast flowing sections of rivers to generate power without impeding the river's natural flow
Salter Duck	a machine that can capture the energy in the movement of ocean waves
secondary source of energy	often called an energy carrier; requires another source, like coal, to be converted for generation; electricity and hydrogen are examples
spillway	a channel for overflow of water from a reservoir
static electricity	a stationary electric charge on a surface
TAPCHAN system	a tapered channel facility built into a cliff that generates electricity from energy in the waves
tidal barrage	a facility built like a dam that allows the tides to power turbines and generate electricity

tidal bulge	the area of the Earth where the moon's gravitational force creates high tides
tidal fence	an open structure with vertical-axis turbines mounted across a channel
tidal power	hydropower derived from the rise and fall of the tides
tidal turbine	underwater turbine driven by ocean currents
transformer	a device that changes the voltage of electricity
tributary	a stream or river that flows into another stream, river, or lake
trough	the lowest point of a wave
turbine	a machine of curved blades or buckets that converts the kinetic energy of a moving fluid to mechanical power
valence electron	an electron in the outer shell of an atom that can be pushed from its shell by a force
valence energy level	the outer energy level of an atom that contains valence electrons
volt	measure of electric potential or force
voltage	a measure of the pressure (or potential difference) under which electricity flows through a circuit
watt	unit of measurement of electric power
wicket gate	adjustable elements that control the flow of water to the turbine

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