2021-2022

Energy of Moving Water

Student Guide

National Energy Education Development Project

INTERMEDIATE

What Is Energy?

Energy makes change; it does things for us. It moves cars along the road and boats on the water. We use it to bake cakes in the oven and keep 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. Scientists define **energy** as the ability to do work or the ability to make a 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. Forms of potential energy include:

- **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 can be released when nuclei are combined (fusion) or split apart (fission). In both fission and fusion, the mass is converted into energy.
- **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**. A rock 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.

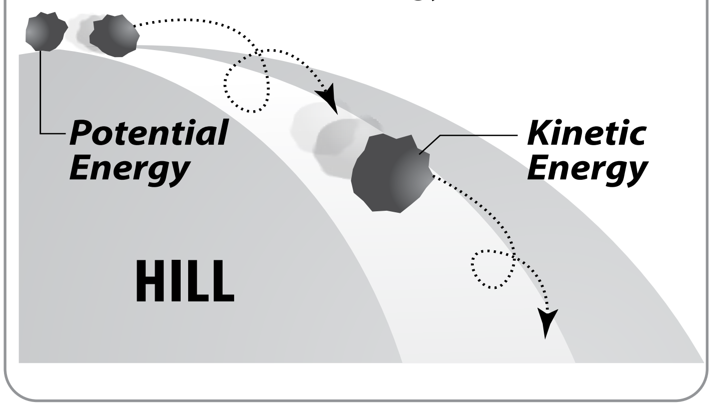
  The water in a reservoir behind a hydropower dam is another example of gravitational potential energy. The stored energy in the reservoir is converted into kinetic energy (motion) as the water flows down a large pipe called a penstock and spins a turbine. The turbine spins a shaft inside the generator,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

Kinetic Energy

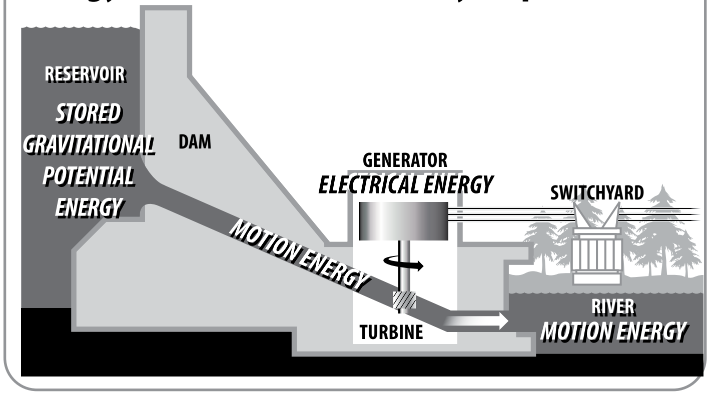
Kinetic energy is energy in motion; it is the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- **Electrical energy** is the movement of electrons. The movement of electrons in a wire is called electricity. Lightning and static electricity are other examples of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Energy from the sun (solar energy) is an example of radiant energy.

Potential and Kinetic Energy



Energy Transformations in a Hydropower Dam



- **Thermal energy** is the internal energy of substances; it is the vibration and movement of the atoms and molecules within substances. The faster the atoms and molecules move around, the more thermal energy in a substance, and the hotter it gets. Geothermal energy is an example of thermal energy. Thermal energy is sometimes called heat.
- **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 is acting on them according to Newton's Laws of Motion. A river flowing or breeze blowing are examples of motion energy.

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 is not about saving energy. The law 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.

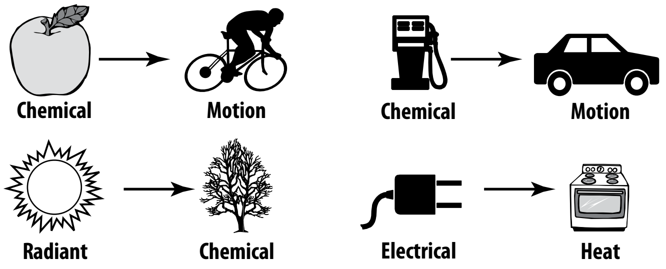
Energy Efficiency

Energy **efficiency** is the amount of useful energy produced by a system compared to the amount of energy put in. A perfect energy-efficient machine would convert all of the input energy into useful work. This is nearly impossible to do! Converting one form of energy into another form always involves a loss of usable energy. This is called a conversion loss. These losses are usually in the form of heat, or thermal energy. This 'waste heat' spreads out quickly into the surroundings and is very difficult to recapture.

A typical coal-fired power plant converts about 35 percent of the energy in the coal into electricity. In fact, all thermal power plants have a similar conversion loss. The rest of the energy is lost as heat. A hydropower plant, on the other hand, converts about 90 percent of the energy in the water flowing through the system into electricity.

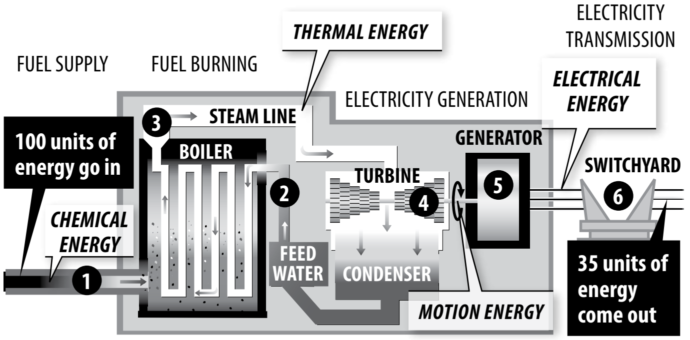
Most transformations are not very efficient. The human body is a good example of an inefficient machine. The fuel for your machine is food. The typical body is about fifteen percent efficient when converting food into useful work such as moving, thinking, and controlling body processes. The rest is lost as heat. The efficiency of a typical gasoline powered car is about 15-25 percent.

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.



How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned (except for uranium which is fissioned) 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

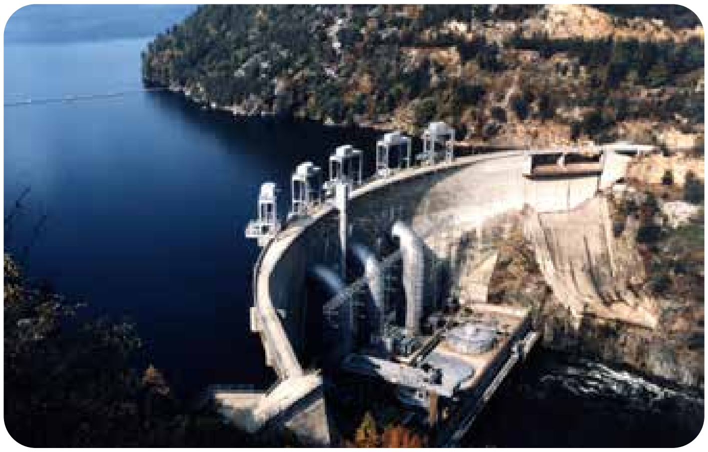
We use many different sources to meet our energy needs. All sources have advantages and disadvantages. Some are cheap; others are expensive. Some contribute to global warming; others are pollution-free. Some are limited in their supplies; others are abundant. Some are always available; others are only available some of the time.

Energy sources are 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 make electricity, heat homes, move cars, and manufacture all kinds of products from candy bars to smart phones.

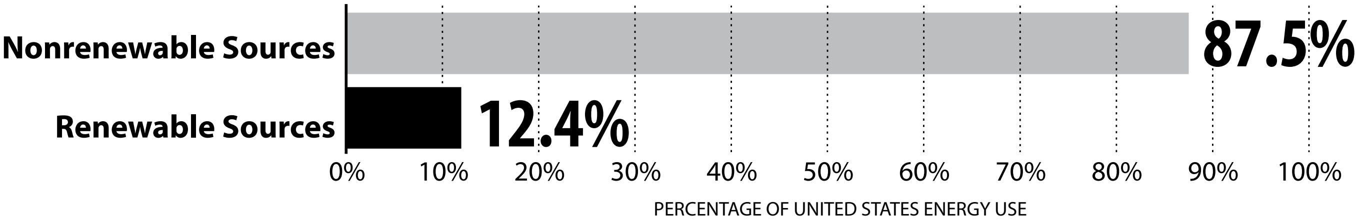
They are called nonrenewable because the supplies of the fuels are limited. Petroleum, for example, was formed hundreds of millions of years ago, before dinosaurs lived, from the remains of ancient sea plants and animals. We cannot make more petroleum in a short time.

Renewable energy sources include biomass, geothermal energy, hydropower, solar energy, and wind energy. They are called renewable because they are replenished in a short time. Day after day, the sun shines, the wind blows, the rivers flow, and plants grow. Heat from inside the Earth—geothermal energy—is continuously made by the radioactive decay of elements in the Earth's core.

We can harness this renewable energy to do work for us. We use renewable energy sources mainly to make electricity.



U.S. Consumption of Energy by Source, 2020



Nonrenewable Energy Sources and Percentage of Total Energy Consumption

PETROLEUM 34.7%
Uses: transportation, manufacturing
- Includes propane

NATURAL GAS 34.0%
Uses: heating, manufacturing, electricity
- Includes propane

COAL 9.9%
Uses: electricity, manufacturing

URANIUM 8.9%
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 4.9%
Uses: heating, electricity, transportation

WIND 3.2%
Uses: electricity

HYDROPOWER 2.8%
Uses: electricity

SOLAR 1.3%
Uses: heating, electricity

GEOTHERMAL 0.2%
Uses: heating, electricity

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

The Science of Electricity

Electricity is different from energy sources; it is a **secondary source of energy**, which 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.

A Mysterious Force

What exactly is the force we call electricity? It is moving **electrons**. And what exactly 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

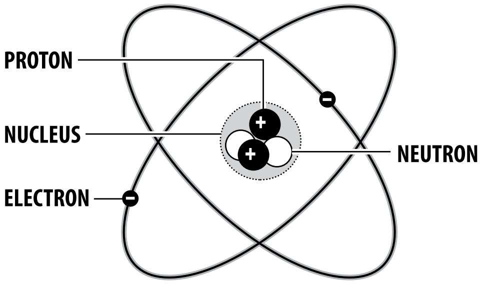
Atoms are made of smaller particles. The center of an atom is called the nucleus. It is made of particles called **protons** and **neutrons** that are approximately the same size. The mass of a single proton is 1.67×10^{-24} grams.

Protons and neutrons are very small, but electrons are much, much smaller—1,835 times smaller, to be precise. Electrons move around the nucleus in orbits a relatively great distance from the nucleus. If the nucleus were the size of a tennis ball, the atom with its electrons would be several kilometers.

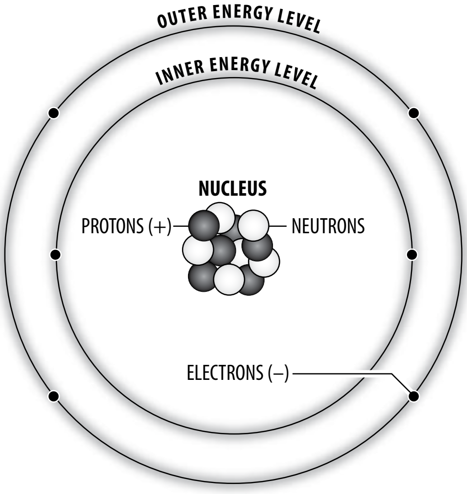
If you could see an atom, it might look a little like a tiny center of spheres surrounded by giant clouds (or **energy levels**). Electrons are held in their levels by an electrical force. The protons and electrons of an atom are attracted to each other. They both carry an electrical charge.

Protons have a positive charge (+) and electrons have a negative 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 neutral, it has an equal number of protons and electrons. The neutrons carry no charge and their number 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 composed of atoms that have a specific number of protons. The number of protons is an element's **atomic number** and determines the element's identity.

Every atom of hydrogen, for example, has one proton and one electron. Every atom of carbon has six protons and six electrons. The **atomic mass** of an element is the combined mass of its protons, neutrons, and electrons. Atoms of the same element may have different numbers of neutrons, but they will all have the same number of protons. Atoms of the same element that have different numbers of neutrons are called **isotopes** of that element.

Electrons

The electrons usually remain within a region a relatively constant distance from the nucleus. These regions are called energy levels. Within energy levels, there are areas of different shapes, called orbitals, where the electrons will be found. The energy level closest to the nucleus can hold a maximum of two electrons. The next level can hold up to eight. The outer levels can hold more.

The electrons in the energy levels closest to the nucleus have a strong force of attraction to the protons in the nucleus—they are stable. Sometimes, the electrons in the outermost energy level are not strongly held. These electrons—**valence electrons**—can be pushed or pulled from their energy level by a force. These are the electrons that are typically involved when chemical reactions occur, or electricty is produced.

Magnets

In most objects, molecules that make up the substance have randomly arranged electrons that are scattered evenly throughout the object. **Magnets** are different—they are made of molecules that have north- and south-seeking poles. Most of their electrons are arranged so that they spin in the same direction. Each molecule in an item is really a tiny magnet. 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 direction. Non-magnets have electrons spinning randomly, cancelling out their magnetic properties.

A magnet's molecules spin the same way at one pole, and the other way at the other pole. This creates a **magnetic field** around a magnet—an imbalance in the forces between the ends of a magnet. A magnet is labeled with north (N) and south (S) poles. The magnetic field in a magnet flows from the north pole to the south pole.

Electromagnetism

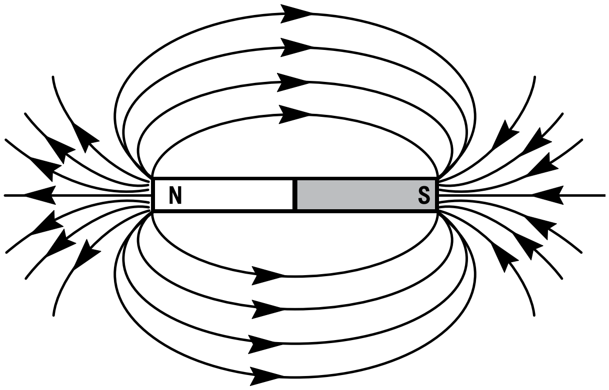
A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable concepts called **electromagnetism**. Every time there is a change in a magnetic field, an electric field is produced. Every time there is a change in an electric field, a magnetic field is produced.

We can use this relationship to create electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their energy levels by the application of a magnetic field. If a coil of copper wire is moved in a magnetic field, or if magnets are moved around a coil of copper wire, an **electric current** is generated in the wire.

Several Common Elements

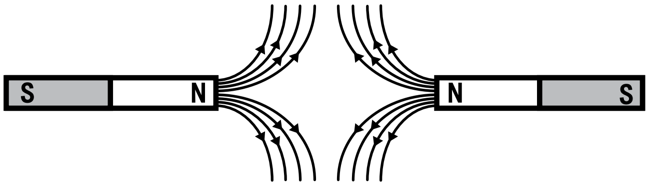
ELEMENT	SYMBOL	PROTONS	ELECTRONS	NEUTRONS
Hydrogen	H	1	1	0
Lithium	Li	3	3	4
Carbon	C	6	6	6
Nitrogen	N	7	7	7
Oxygen	O	8	8	8
Magnesium	Mg	12	12	12
Iron	Fe	26	26	30
Copper	Cu	29	29	34
Gold	Au	79	79	118
Uranium	U	92	92	146

Bar Magnets



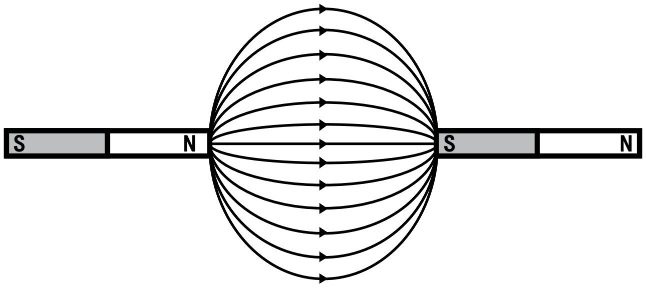
Like Poles

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



Opposite Poles

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



Generating Electricity

A **generator** is an engine that converts motion energy into electrical energy using electromagnetism. A **turbine** is a device that converts the flow of air, steam, or water into motion energy to power a generator.

Power plants use huge turbine generators to make the electricity we use in our homes and businesses. Power plants use many fuels to spin a turbine. They can burn coal, oil, or natural gas to make steam to spin a turbine. They can split atoms of uranium to heat water into steam. They can also use the power of rushing water from a dam or the energy in the wind to spin the turbine.

The turbine is attached to a shaft in the generator. Inside the generator are magnets and coils of copper wire. The generator can be designed in two ways. The turbine can spin coils of wire inside magnets, or can spin magnets inside coils of wire. In either design, the electrons are pushed very quickly from one copper atom to another inside the wire by the moving magnetic field created as the magnets and wire spin around each other.

The electrons in the copper wire then flow into transmission lines. These moving electrons are the electricity that flows to our houses.

Other Ways to Produce Electricity

Electricity can also be produced in other ways. A solar cell turns radiant energy into electricity. A battery turns chemical energy into electricity.

A battery produces electricity using two different metals in a chemical solution. A chemical reaction between the metals and the chemicals frees more electrons in one metal than in the other. One end of the battery is attached to one of the metals; the other end is attached to the other metal. The end that frees electrons develops a positive charge and the other end develops a negative charge. If a wire is attached from one end of the battery to the other, electrons flow through the wire to balance the electrical charge.

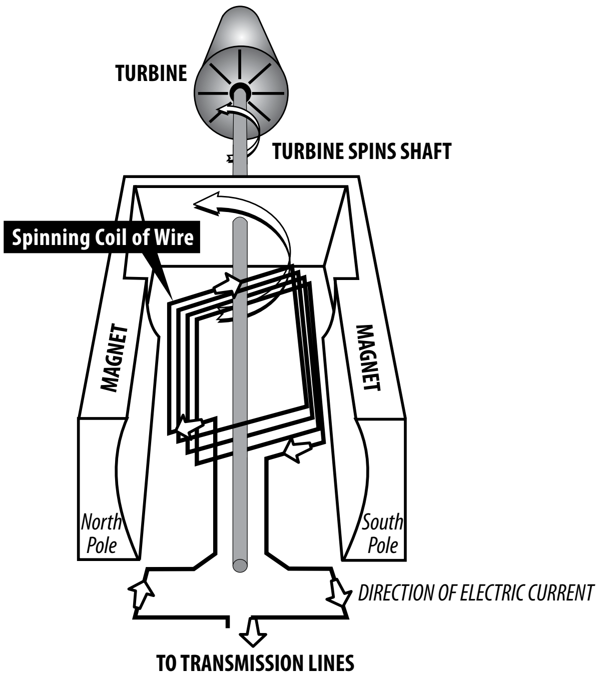
A **load** is a device that does work or performs a job. If a load—such as a light bulb—is placed along the wire, the electricity can do work as it flows through the wire. In the picture to the right, electrons flow from the end of the battery, through the wire to the light bulb. The electricity flows through the wire in the light bulb and back to the battery.

Circuits

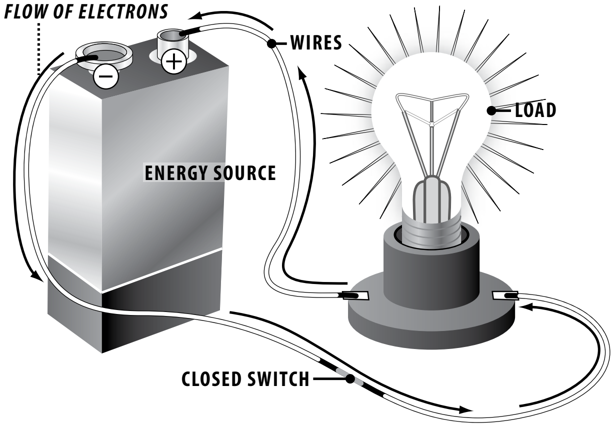
Electricity travels in closed loops, or **circuits**. It must have a complete path before the electrons can move. If a circuit is open, the electrons cannot flow. When we flip on a light switch, we close a circuit. The electricity flows from the electric wire through the light and back into the wire. When we flip the switch off, we open the circuit. No electricity flows to the light. If the bulb burns out, the path through the bulb is gone, and the circuit is also opened.

When we turn on the TV, electricity flows through wires and bulbs inside the set, producing pictures and sound. Sometimes electricity runs motors in items such as washers or mixers. Electricity does a lot of work for us. We use it many times each day.

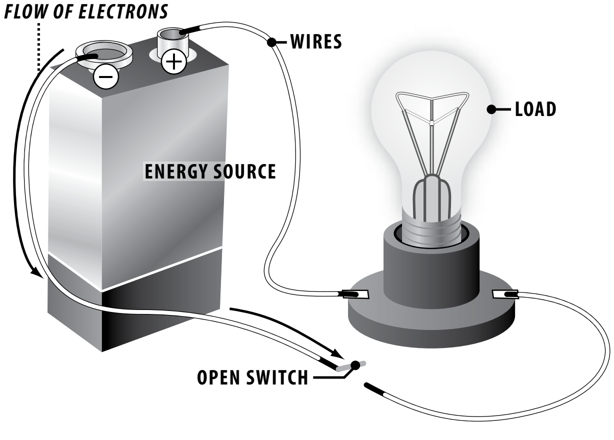
Turbine Generator



Electric Circuits



A closed circuit is a complete path allowing electricity to flow from the energy source to the load.



An open circuit has a break in the path. There is no flow of electricity because the electrons cannot complete the circuit.

Measuring Electricity

Measuring electricity is confusing because we cannot see it. We are familiar with terms such as watt, volt, and amp, but we may not have a clear understanding of these terms. We buy a 13-watt light bulb, a tool that needs 120 volts, or a vacuum cleaner that uses 8.8 amps, and we do not 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 moving 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 electrical pressure pushing the electrons and on the cross-sectional area of the wire.

Voltage

The 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 high tank applies greater pressure than the one-meter high tank, a 10-volt power supply (such as a battery) would apply greater pressure than a one-volt power supply.

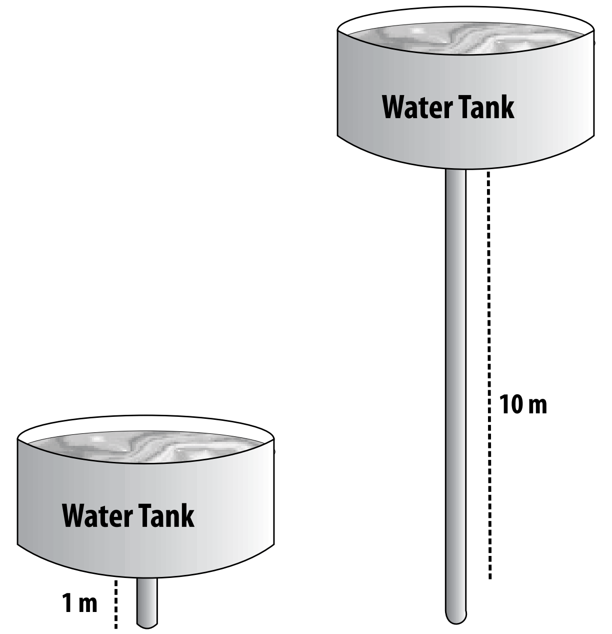
AA batteries are 1.5 volts; they apply a small amount of voltage or pressure for lighting small flashlight bulbs. A car usually has a 12-volt battery; it applies more voltage to push current through circuits to operate the radio or defroster. The standard voltage of wall outlets is 120 volts—a dangerous amount of voltage.

Electric Current

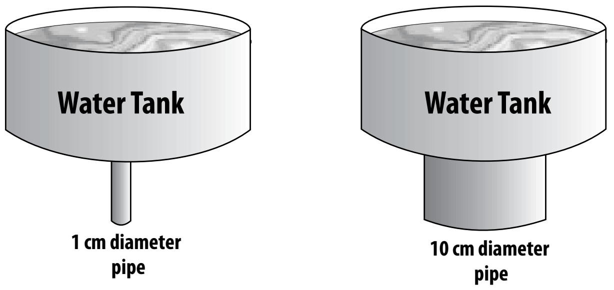
The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point. Electric current is the number of electrons flowing past a fixed point. Electric current (I) is defined as electrons flowing between two points having a difference in voltage.

Current is measured in **amperes** or amps (A). One ampere is 6.25×10^{18} electrons per second passing through a circuit. With water, as the diameter of the pipe increases, so does the amount of water that can flow through it. 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. Power lines are much thicker than a wire you might have in your house, because power lines must carry electricity to multiple homes and devices.

Voltage



Current



GENERATORS

Generators at a hydropower plant.

Resistance

Resistance (R) is a property that slows the flow of electrons (the current). Using the water analogy, resistance is something that slows water flow—a smaller pipe or fins on the inside of the pipe. In electrical terms, the resistance of a conducting wire depends on which metal the wire is made of and its diameter. Copper, aluminum, and silver—metals used in conducting wires—all have different resistances.

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.

Ohm's Law

George Ohm, a German physicist, discovered that in many materials, especially metals, the current that flows through a material is proportional to the voltage. In the substances he tested, 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 written in three simple formulas. If you know any two of the measurements, you can calculate the third using the formulas to the right.

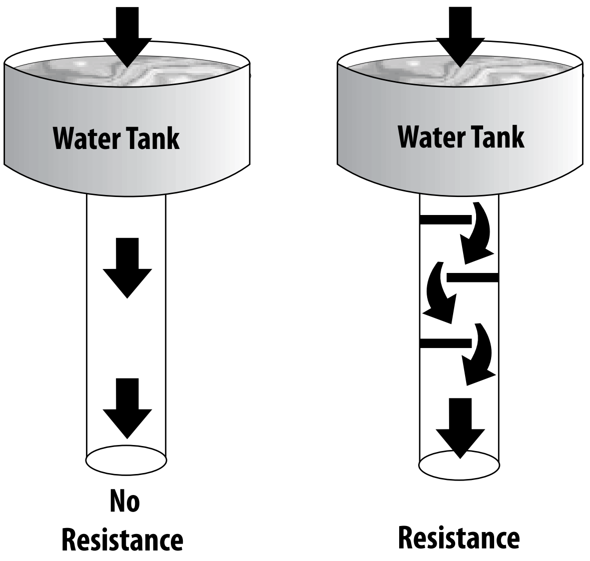
Electric Power

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 electricity required to start or operate a load for one second. Electric power is measured in **watts** (W).

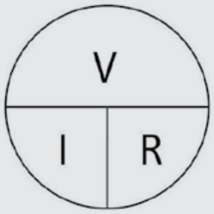
Resistance



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

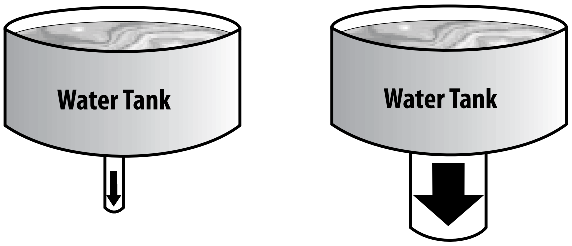
Formulas for Measuring Efficiency



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

Electrical Energy

Electrical energy introduces time to electric power. In the water analogy, it would be the amount of water falling through the pipe over a period of time, such as an hour. 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 an appliance consumes can only be determined if you know how long (time) it consumes electricity 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)
or
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, you would multiply the rate of travel by the amount of time you 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 h = 40 miles

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

Distance = 40 mph x 3 h = 120 miles

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 can be compared to the distance traveled or the work done by the car.

A person would not say he took a 40-mile per hour trip because that is the rate. He would say he took a 40-mile trip or a 120-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance is the work done.

The same applies with electrical energy. You would not say you used 100 watts of light energy to read your book, because watts represents the rate you used 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-W bulb, for example, you would use the formula as follows:

Energy = Power x Time or E = P x t

Energy = 100 W x 5 h = 500 Wh

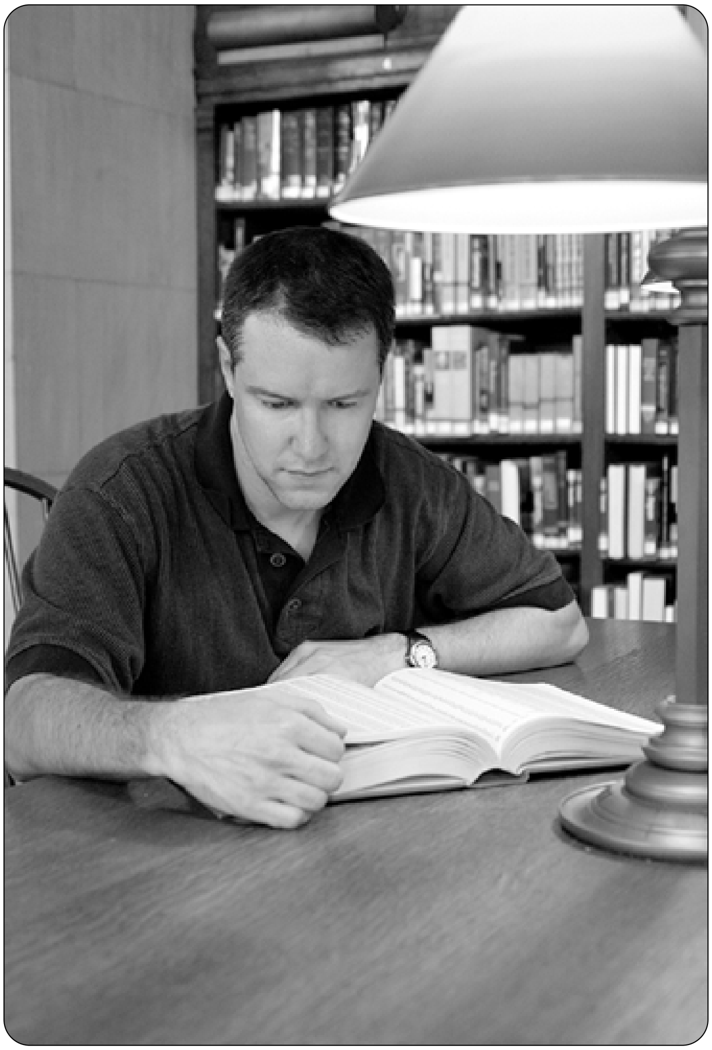
One watt-hour is a very small amount of electrical energy. Usually, we measure electric power in larger units called **kilowatt-hours** (kWh) or 1,000 watt-hours (kilo = thousand). A kilowatt-hour is the unit that utilities use when billing most customers.

The average cost of a kilowatt-hour of electricity for residential customers is about $0.129. To calculate the cost of reading with a 100-watt 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.

$$500\text{ Wh} \times \frac{1\text{kW}}{1{,}000\text{ W}} = 0.5\text{ kWh}$$

0.5 kWh x $0.13/kWh = $0.065

It would cost about seven cents to read for five hours using a 100-watt bulb.



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

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

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.

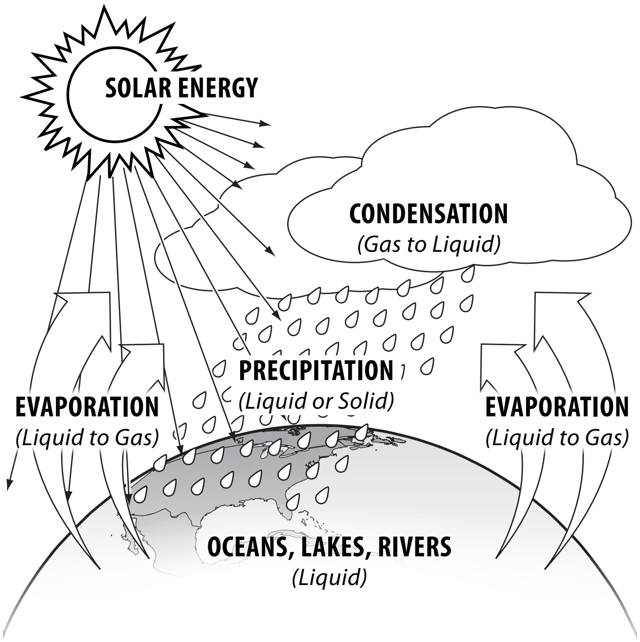
The water vapor cools and condenses into a liquid state in the atmosphere where it forms clouds.

Inside a cloud, water droplets join together to form bigger and bigger drops. As the drops become heavy, they start to fall. Clouds release precipitation as rain or snow. Liquid water is pulled by gravitational forces back to the oceans and rivers and the cycle starts again. This continuous cycle is called the water cycle or **hydrologic cycle**.

Image courtesy of NASA

Water covers most of the Earth's surface.

The Water Cycle



Water as an Energy Source—Hydropower

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, 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 enclosed water wheel so that water flowed through the wheel instead of around it. This idea became the basis of the modern American water turbine.

In the mid-1800s, James Francis, Chief Engineer of the Locks and Canal Company in Lowell, MA, improved the enclosed water turbine by reshaping the blades. Known as the Francis turbine, modern variations of this turbine are still in use today in hydropower plants.

Generating electricity using moving water, or **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, NY.

Dams Yesterday and Today

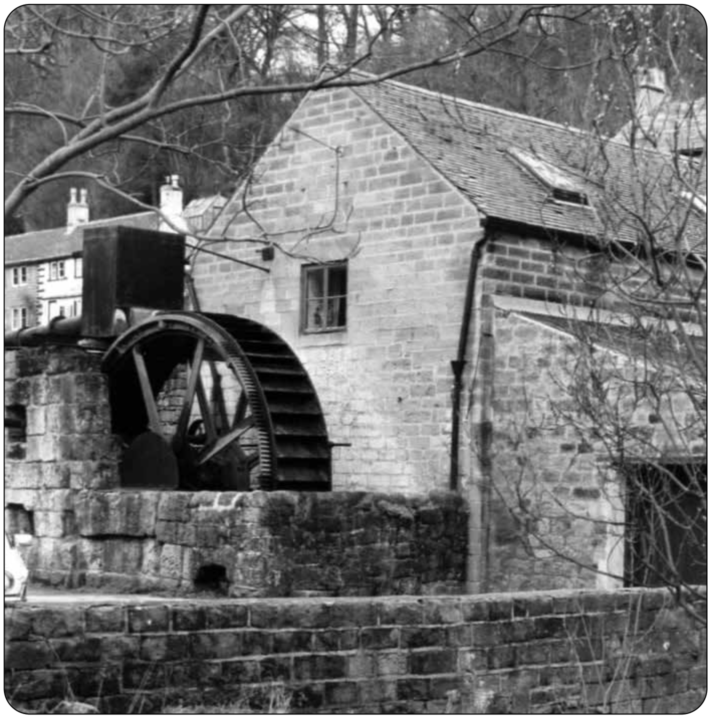
The oldest known man-made dams were small structures built over 5,000 years ago to divert river water to irrigate crops in Mesopotamia. Around 2900 BCE, Egyptians in the city of Memphis built a dam around the city. The dam stopped periodic flooding of the Nile River and created a reservoir for irrigation 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 projects until the end of the 19th century when the need for large dams lined up with the ability to build them.

Today, about half of all dams in the world are used for irrigation. Only 18 percent of these are used to generate electricity.

There are over 90,000 dams in the United States, but about three percent (2,000) 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. Power plants with turbines and generators could be added to some of these dams to produce electricity.

WATER WHEEL



A mid-nineteenth century water wheel.

TURBINE

Image courtesy of U.S. Bureau of Reclamation

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

Types of Dams

A **dam** is either an overflow or non-overflow dam. An **overflow dam** allows water to spill over its rim. A **non-overflow dam** uses **spillways**—channels going through or around the dam—to control the amount of water behind the dam. This also allows a dam operator to channel water to a hydropower plant 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, 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 cancel out 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 rocks and dirt, with a dense, water-resistant center that prevents water from seeping through the dam. 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 on 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 tremendous 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 U.S. It is 216 meters (710 feet) high. It was opened in 1966 to provide water storage for the dry 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 (triangle-shaped supports) 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

A Hydropower Plant

There are three main parts of a typical hydropower plant: the reservoir, the dam, and the power plant (turbines and generators), but not all facilities need to include all three. The **reservoir** stores the water (potential energy). The dam holds back the water, with openings in the dam controlling the water's flow (kinetic energy). The **power plant** (turbine and generator) converts the motion energy in the moving water into electricity.

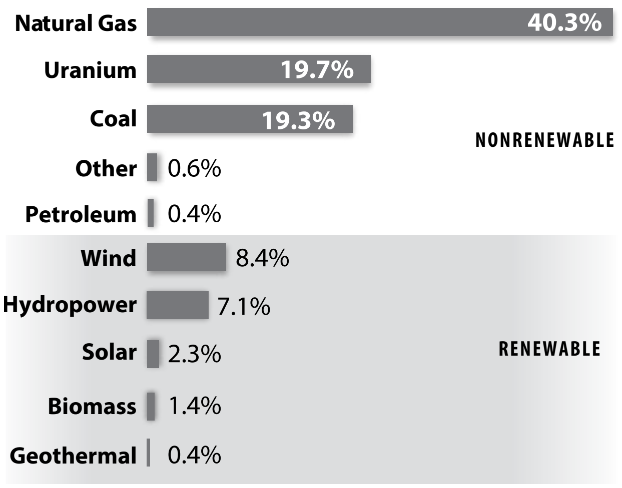
A reservoir holds water behind the dam to create a greater distance between the water in the reservoir and the river below. The distance the water drops from the reservoir to the turbine is the **head**; the higher the drop, the greater the head. The amount of moving water is called the **flow**; more flow equals more force. The mass of the water in the reservoir exerts pressure to move the water; the greater the mass, the greater the pressure.

The generation of electricity begins with water flowing from the reservoir into openings on the upstream side of the dam to **penstocks**, which are very large pipes. The water flows down the penstocks to turbines at the bottom, spinning the turbines to power the generators. The generators produce electricity, which is sent to transmission 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

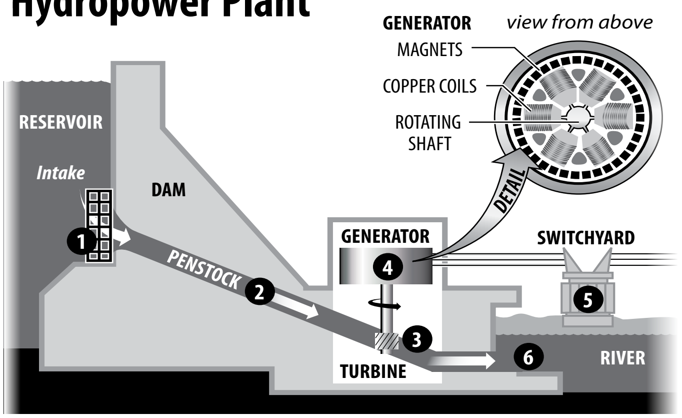
16 percent of the world's electricity is produced by hydropower. Some countries like Canada, China, Norway, and Brazil produce large amounts of electricity from hydropower, and others produce much less. In the United States, 5-10 percent of electricity comes from hydropower, depending on the supply of water. In 2020, it was enough to power more than 27 million households.

U.S. Electricity Net Generation, 2020



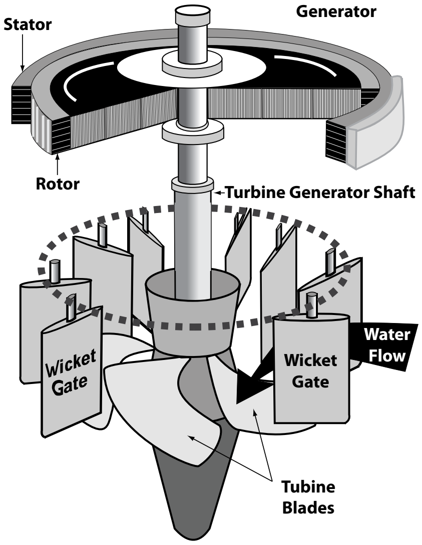
Data: Energy Information Administration
*Total does not equal to 100% due to independent rounding.

Hydropower Plant

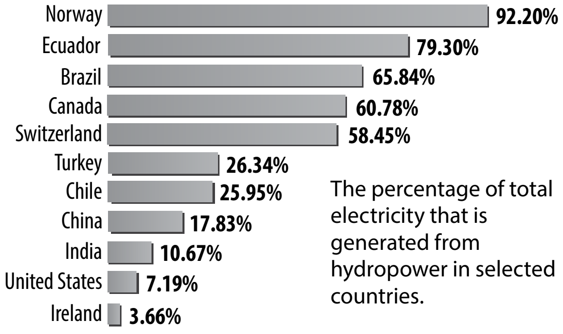


1. Water in a reservoir behind a hydropower dam flows through an intake screen, which filters out large debris, but allows smaller fish to pass through.
2. The water travels through a large pipe, called a penstock.
3. The force of the water spins a turbine at a low speed, allowing fish to pass through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

Hydro Turbine Generator



Hydropower Around the World, 2019



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

Data: EIA, 2019
2019 data used, as international data for 2020 was unavailable at the time of print. Countries depicted are only a selection of Hydropower generators.

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.

Types of Hydropower

Hydropower facilities can be categorized into two main types: conventional and pumped storage. Conventional projects account for nearly 80 percent of hydropower generating capacity in the U.S. **Conventional hydropower plants** use the available water from rivers, streams, canal systems, or reservoirs to produce electrical energy.

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. Electricity from Niagara Falls is generated through diversion facilities.

Run-of-river projects have turbines installed in fast-flowing sections of the rivers, but they do not significantly slow down 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.

Another type of hydropower plant is known as a pumped storage plant. A **pumped storage plant** circulates water between two reservoirs—one higher than the other. When the demand for electricity is low, the plant uses electricity to pump water to the upper reservoir and stores the water there until it is needed.

When there is a high demand for electricity, the water is released from the upper reservoir to flow through turbines and back into the lower reservoir to quickly generate electricity.

A pumped storage plant 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 very quickly by releasing the water.

RUN-OF-RIVER PROJECT

Image courtesy of U.S. Army Corps of Engineers

Chief Joseph Dam on the Columbia River in Washington.

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. An agreement between Canada and the United States allows both countries to draw water upstream from the falls to generate electricity. But each country is limited to specific amounts. How much water each country can draw is based on tourism. Less water can be used by the power plants during the day for the months of tourist season, making sure visitors get a great view of the falls. More water can be drawn at night and during the off-season.

NIAGARA FALLS

Maneuvering Around a Dam

The impact of dams on the migration of fish, especially spawning salmon and steelhead in the Northwest, is an important 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 pool higher than the one before, eventually bypassing the dam. Some dams use an elevator or lift in place of the ladder or transport fish back over the dam to spawn upstream.

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 spillways.

Navigation Dams

Dams that produce electricity are not the only dams built across rivers. **Navigation dams** are built to make sure there is enough water for boats and barges as they travel up and down rivers.

When a dam is built across a river that is used by boats and barges, a canal is dug next to the dam for the boats to use. The boats bypass the dam through locks in the canal. Each lock has large upstream and downstream doors that can be opened and closed.

A boat traveling upstream is moving from a lower water level to a higher water level. When the boat enters a lock, the doors are closed and water is let in so that the water level in the lock rises. The boat rises with the water until it is level with the upstream water level. The upstream door opens, and the boat moves on to the next lock. A boat may need to go through several locks before it reaches the river on the other side of the dam.

Hydroelectric Power Plant Safety

The purpose of a dam is to contain a large amount of water that could cause major destruction downstream if the dam fails, so 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, and to withstand 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.

Federal Regulation

The **Federal Energy Regulatory Commission (FERC)** is the federal agency that oversees all non-federal hydropower plants on navigable waterways and federal lands. FERC is in charge of licensing new plants and relicensing older plants when their licenses expire.

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

FISH LADDER

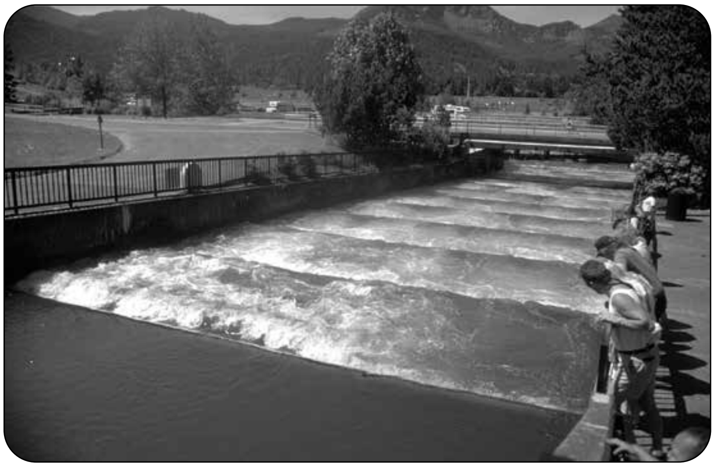


Image courtesy of Bonneville Power Administration

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.

The down river side of a hydropower plant on the Susquehanna River in southern Pennsylvania.

Advantages and Disadvantages

Using hydropower as an energy source has many advantages over other energy sources, but hydropower has significant disadvantages too because of its impact on the environment.

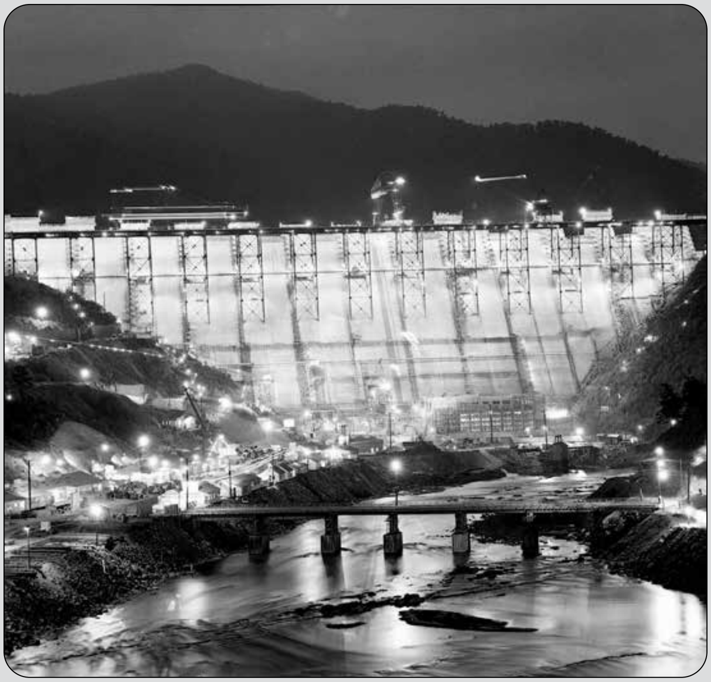
Advantages of Hydropower

- Hydropower is a clean energy source. It is fueled only by moving water, so it does not produce emissions. Hydropower does not increase the level of greenhouse gases in the atmosphere.
- Hydropower is a renewable energy source. The total amount of water in a hydropower system does not change; the moving water is used to generate electricity and is returned to the source from which it came.
- Hydropower is usually available when it is needed. Engineers can manage the flow of water through the turbines to 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 about 90 percent efficient at converting the energy in the moving water into electricity.
- Dams 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 manage the water supply, providing flood control and a reliable supply of drinking water during drought. Many dams were built for flood control. The power plants were an additional benefit.
- 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**.
- Currently, 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, enough electricity for almost five million households.

Disadvantages of Hydropower

- Hydropower plants are dependent on water supply. When there is a drought, for example, hydropower plants cannot produce as much electricity.
- Hydropower dams on rivers permanently change the natural ecology of large areas of land, upstream and downstream. When a dam is built, the resultant reservoir floods large areas 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 dams can impact water quality and flow. Reservoirs can have low dissolved oxygen levels in the water, a problem that can be harmful to fish and downstream riverbank habitats. Maintaining water flow downstream of a dam is also critical for the survival of habitats.
- Some fish populations, such as salmon, migrate upstream to reach spawning grounds before returning downstream. Dams can block fish from completing this natural migration process. Fish ladders or elevators may be built to help fish swim upstream. Fish traveling downstream can be helped with a diversion or even lights or sounds.
- Development of new hydropower resources can be very expensive because dams have 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;
- 5 fossil plants (coal);
- 3 nuclear plants;
- 8 natural gas plants;
- 1 diesel generator site;
- 14 solar energy sites; and
- 1 wind energy site.

Images courtesy of Tennessee Valley Authority

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

TVA operates a system of 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 (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 Interior, 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 develops and tests new technologies that generate electricity from water. The focus is on increasing cost efficiency and improving environmental responsibility.

For conventional hydropower, the Water Power Program looks to increase generating capacity and efficiency at existing hydropower facilities, add electricity generating capacity at non-powered dams, and reduce environmental effects at existing dams.

In 2009, 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 hydropower 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 projects are in various stages of completion and include:

- upgrading turbines to high-efficiency, fish-friendly units;
- replacing generators, transformers, and wiring to increase efficiency;
- removing health and environmental hazards such as lead and asbestos from buildings;
- installing automated maintenance devices to clear debris from water intakes;
- reintroduction of native fish species; and
- improving downstream water conditions and habitats.

These projects were all funded in 2009-2014. Over 50% of the funded projects are centered around capacity and efficiency upgrades.

New Turbine Systems

The Department of Energy supports research into new technologies. Hydropower plants can cause injuries or death to fish and impact water quality. New hydropower turbine technologies could minimize these effects. Benefits of new turbine technologies include:

- reduced fish mortality;
- improved water quality; and
- reduction in carbon dioxide (CO_2) emissions.

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

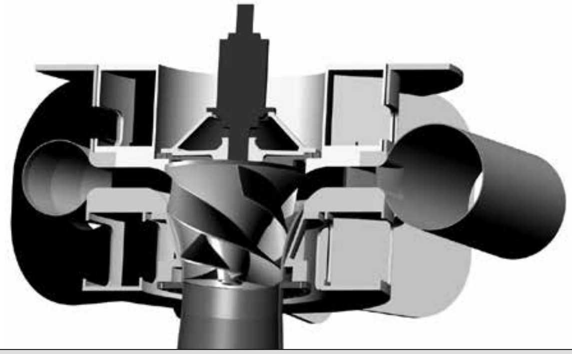
A fish-friendly turbine bypass at the Wanapum Dam on the Columbia River. The bypass is designed to help salmon smolts pass through the dam without injury, or exposure to turbines.

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 program. Results of pilot-scale tests indicate that fish survival through the turbine would be 94-100 percent. Studies are being planned for a hydropower site.

Image courtesy of Alden Lab

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



Energy from the Tides

Near shore, the ocean rises and falls with the tides. Tides contain an enormous amount of energy. Some power plants harness the energy in the changing tides to generate electricity.

Tides are caused by the gravitational forces between the Earth and moon. 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. Between the tidal bulges is lower water that produces low tides.

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 is like a dam with gates and turbines held in a **caisson**, a supporting structure. 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 and out of the estuary.

Tidal Stream Power

Another source of tidal power relies on strong, steady ocean currents. This technology is known as **tidal stream power**. Underwater turbines can be installed in the ocean in places with strong tidal currents or steady ocean currents.

Marine Current Turbines Ltd, based in Bristol, England, developed the world's largest grid-connected tidal stream system, known as SeaGen S. A SeaGen S device is operating in Strangford Lough (a shallow bay situated on the east coast of Northern Ireland). The system regularly delivers enough power to the Northern Ireland grid for 1,500 homes.

The SeaGen S consists of two large rotors, each driving a generator. The twin rotors are mounted on wing-like extensions on either side of a steel tower that is set into a hole drilled in the sea floor.

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

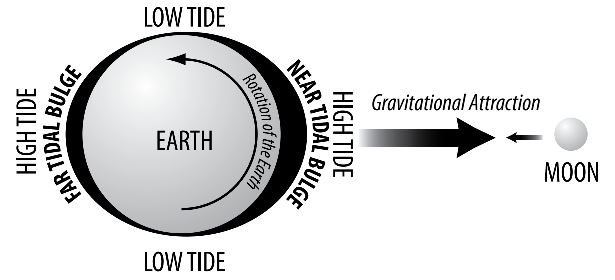
New York City's East River Project

The city and state of New York have partnered with Verdant Power to harness the energy in the tides in Manhattan's East River. The Roosevelt Island Tidal Energy (RITE) Project is the first grid-connected, non-commercial array of underwater turbines using tidal stream power in the world. Monitoring of the six initial turbines was completed in 2008. Evaluated for performance and for environmental impact, the first stage was deemed a success. Verdant Power installed three 35-kilowatt generators in 2020 with hope to expand with future funding.

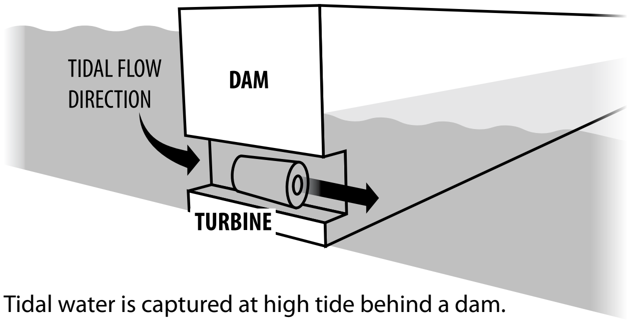
Image courtesy of Verdant Power

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

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 STREAM POWER

Image courtesy of Marine Current Turbines

An artist's rendering of the SeaGen S tidal stream system.

Waves

Ocean waves are caused mainly by wind. The size of waves depends on the speed of the wind, wind duration, and the distance of water over which the wind blows. 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 cause 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 it is pulled back down by the force of gravity. The falling water's momentum moves it below the surface, and water pressure from below pushes it 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. 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.

Harnessing Wave Energy

The energy in waves can be harnessed to generate electricity. While wave power varies around the world, the waves off the northwest coast of the U.S. have good potential for generating electricity.

There are two main types of wave energy generation devices, fixed and floating. **Fixed 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 device is a **tapered channel (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.

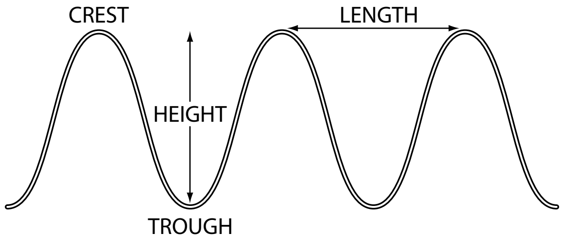
When the waves are high enough, they spill over the top of the channel into the reservoir. The stored water flows out of the reservoir through a turbine, generating electricity.

The TAPCHAN system is not useable in all coastal areas. Ideal locations have consistent waves, good wave energy, and a tidal range (the difference between low tide and high tide) of less than one meter.

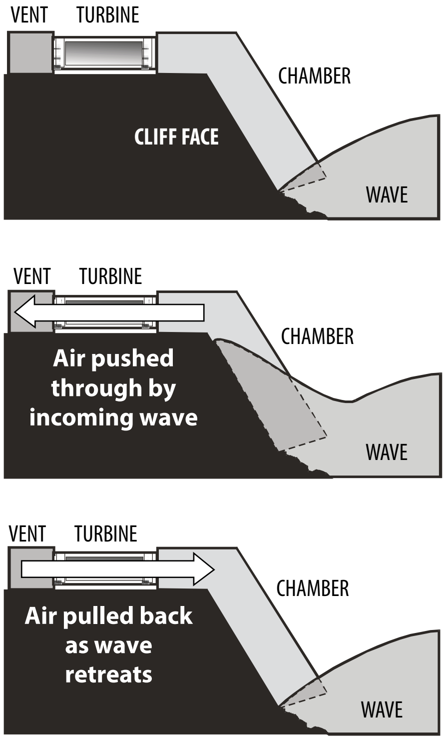
Several floating wave devices are under development. They generate electricity as they are moved by the motion of waves.

One such device, called an attenuator, is a series of tubes that are linked together with hinged joints. Passing waves cause each tube to rise and fall like a giant sea snake. The motion tugs at the joints linking the tubes. The joints act as a pumping system, pushing high pressure oil through a series of motors that drive the generators to

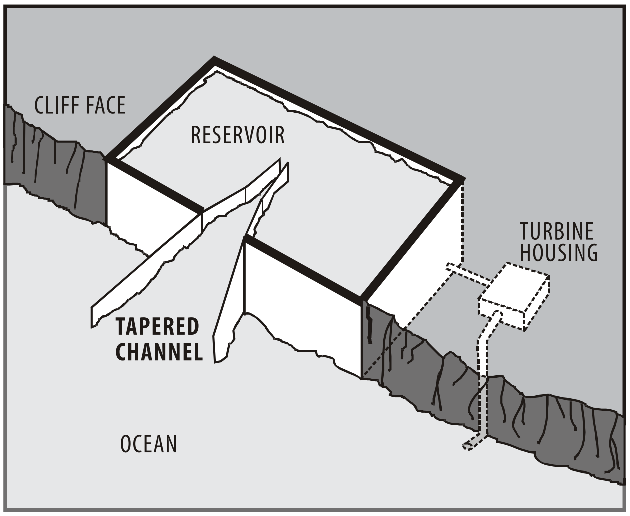
Wave Measurements



Oscillating Water Column



TAPCHAN System



produce electricity. The wave energy devices are anchored to the seafloor by moorings and then connected to the electric grid with subsea power cables. Other wave energy devices can be shaped and designed differently, such as single, pherical buoys.

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.

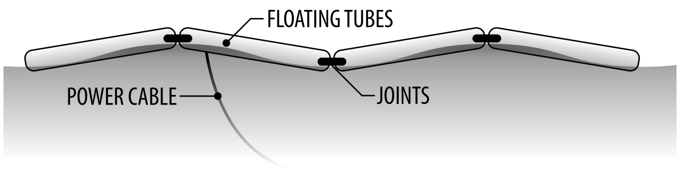
Future of Hydropower

The future of hydropower includes both challenges and opportunities, and it 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 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.

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. The U.S. Department of Energy has recently committed funding to further research wave power off the coast of Oregon.

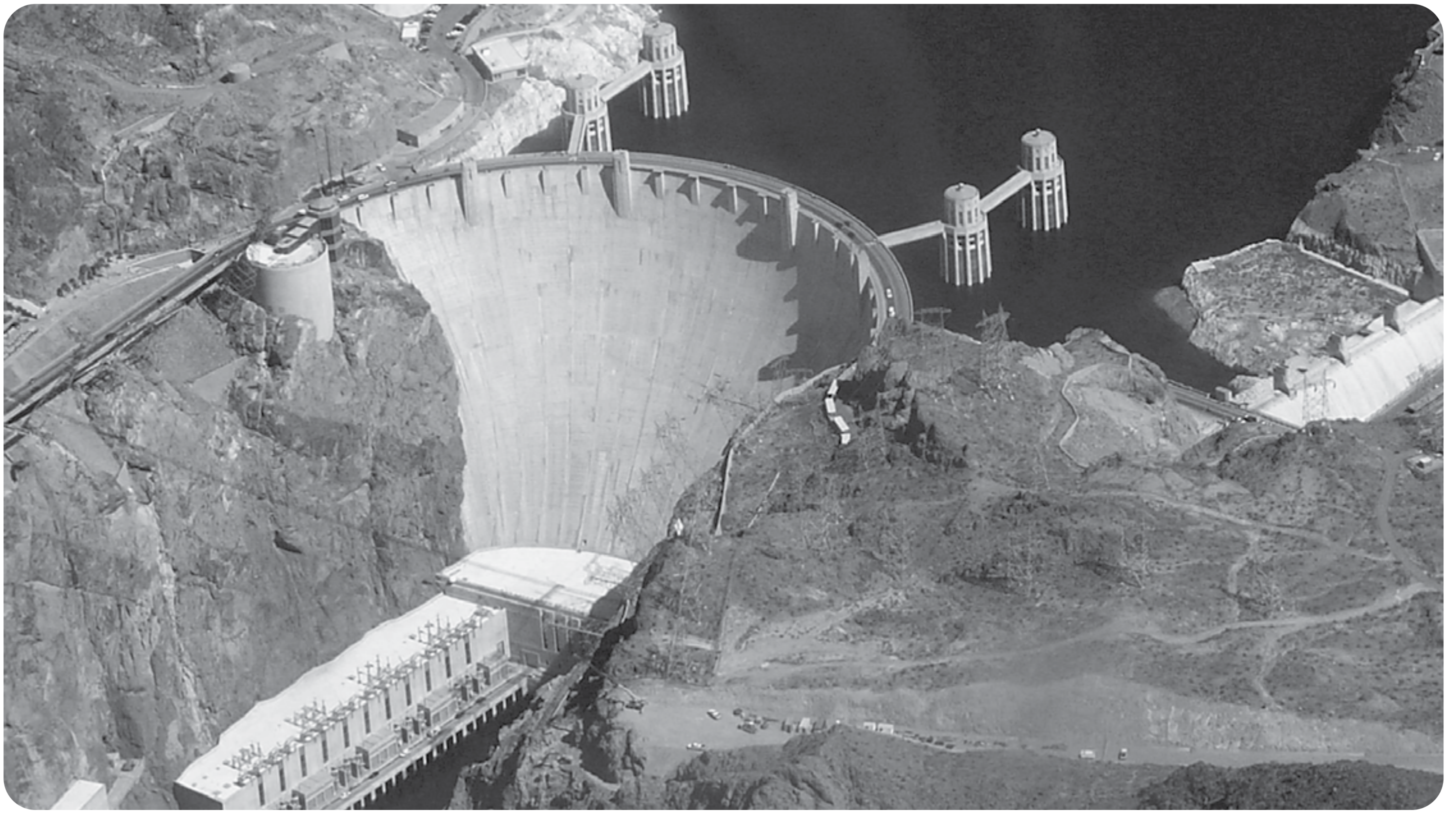
Wave Energy Converter



PELAMIS FLOATING WAVE DEVICE

Image courtesy of Pelamis

An artist's rendering of the Pelamis wave energy devices.



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, Maine.
Today	Between 5–10 percent of U.S. electricity comes from hydropower, depending on water supply. In total, the U.S. has almost 80,000 MW of conventional capacity and over 22,000 MW of pumped storage capacity. Hydropower provides almost 16% 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 policy, 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

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

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

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.
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

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/

U.S Department of Energy, OpenEI
An open source data platform for energy and energy efficiency, Check out their career profiles.
openei.org/wiki/hydropower/STEM/Resources/Career_Pathways

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.

KWL Organizer for Energy

What I Think I Know	What I Want to Know	What I Learned

KWL Organizer for Electricity

What I Think I Know	What I Want to Know	What I Learned

KWL Organizer for Water

What I Think I Know	What I Want to Know	What I Learned

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		RENEWABLE	
Petroleum	________________________	Biomass	________________________
Coal	________________________	Wind	________________________
Natural Gas	________________________	Hydropower	________________________
Uranium	________________________	Solar	________________________
Propane	________________________	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, 2020

NONRENEWABLE

PETROLEUM **34.7%** *
Uses: transportation, manufacturing - includes propane

NATURAL GAS **34.0%** *
Uses: heating, manufacturing, electricity - includes propane

COAL **9.9%**
Uses: electricity, manufacturing

URANIUM **8.9%**
Uses: electricity

PROPANE
Uses: heating, manufacturing

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

RENEWABLE

BIOMASS **4.9%**
Uses: heating, electricity, transportation

WIND **3.2%**
Uses: electricity

HYDROPOWER **2.8%**
Uses: electricity

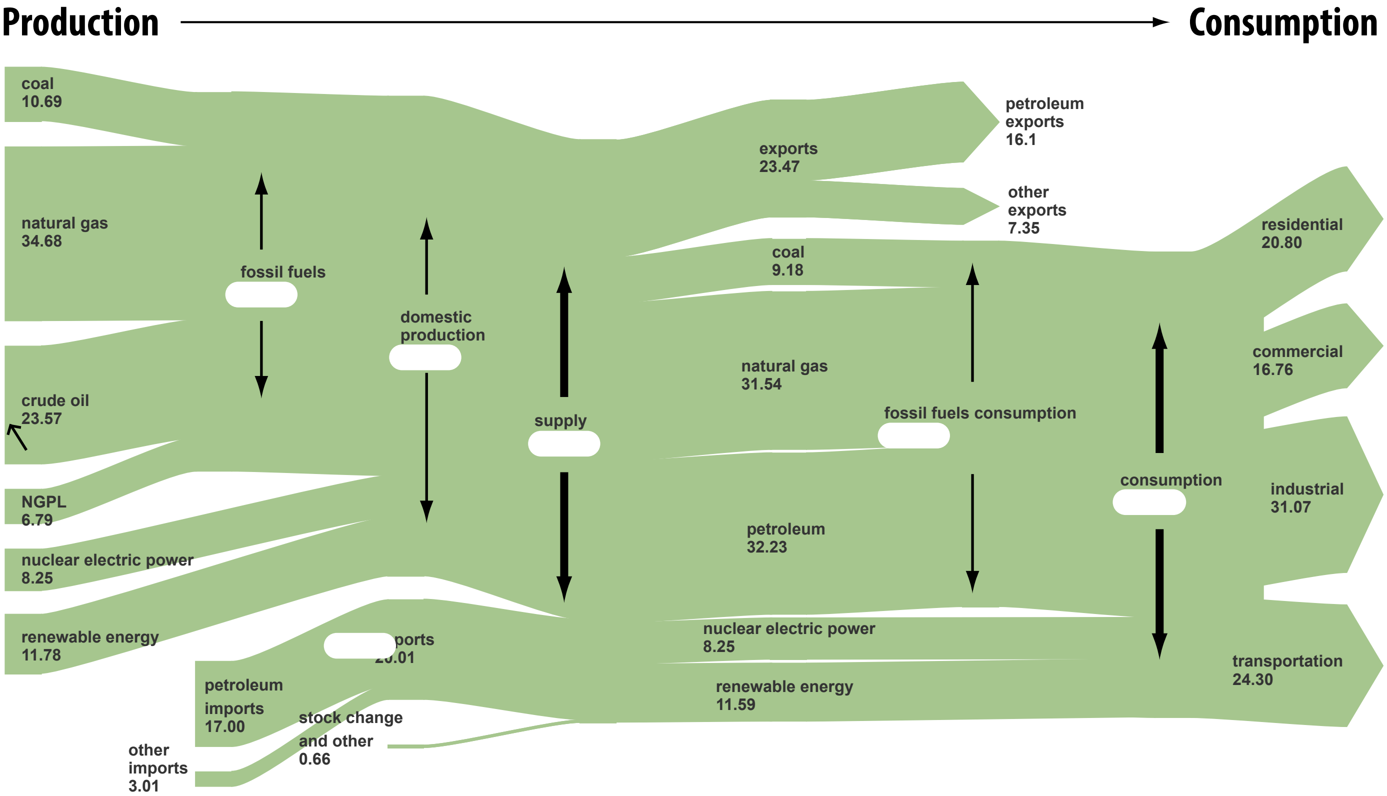
SOLAR **1.3%**
Uses: heating, electricity

GEOTHERMAL **0.2%**
Uses: heating, electricity

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

U.S. Energy Flow, 2020

1. Fill in the blank boxes on the 2020 Energy Flow diagram.
2. Draw and label a pie chart of 2020 Domestic Energy Production by Source.
3. Draw and label a pie chart of 2020 Energy Consumption by Sector.



Data: U.S. Energy Information Administration

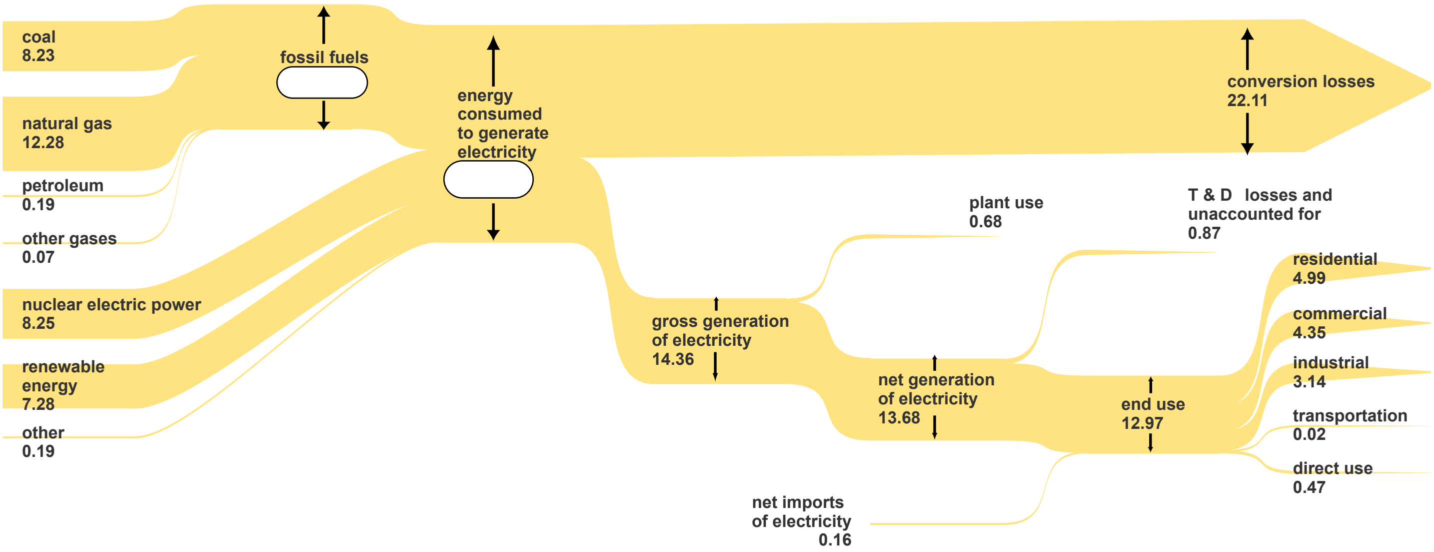
*Data incorporates electricity generation.

2020 Domestic Energy Production By Source

2020 Energy Consumption By Sector

U.S. Electricity Flow, 2020

1. Fill in the blank boxes on the 2020 Electricity Flow diagram.
2. Draw and label a pie chart of 2020 Electricity Production by Source.
3. Draw and label a pie chart of 2020 Electricity Consumption by End Use.
4. On a separate piece of paper, write a paragraph explaining conversion losses.



2020 Electricity Production By Source

2020 Electricity Consumption By End Use

Atomic Structure

Below is an atom of magnesium (Mg). Magnesium is a silvery white metal that has 12 protons, 12 electrons, and 12 neutrons. Number the words on the left with the correct part of the atom in the diagram.

proton ____

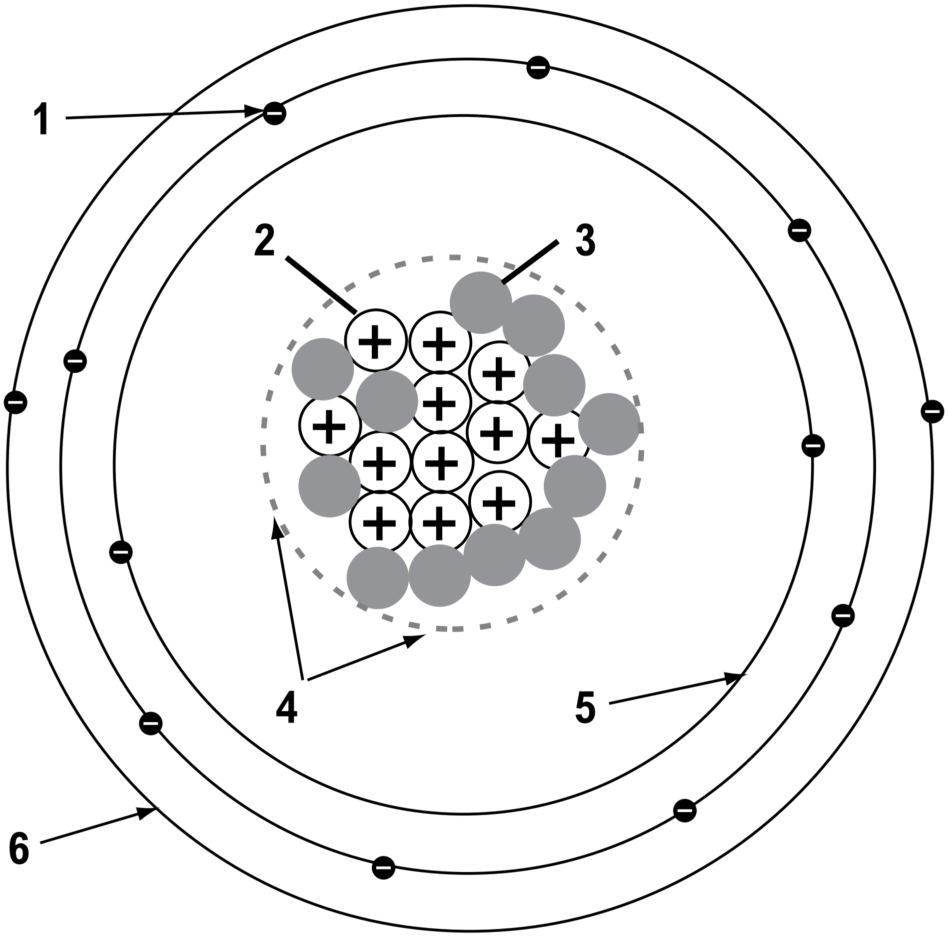
electron ____

neutron ____

inside energy level ____

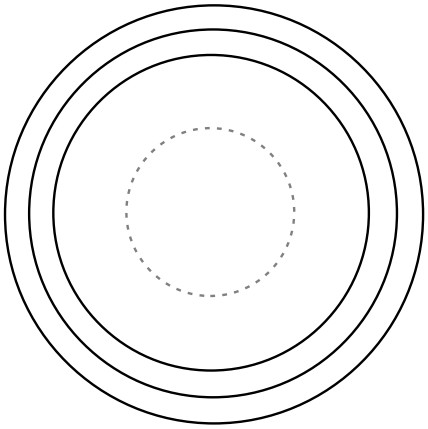
nucleus ____

outside energy level ____

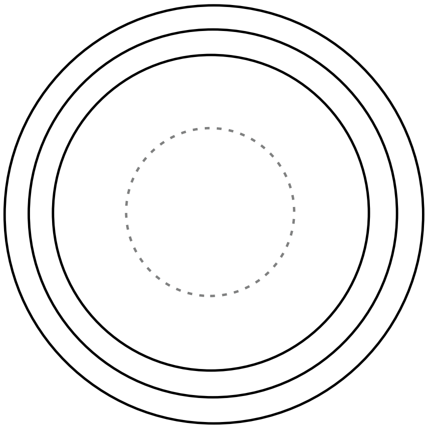


Magnesium-24

Draw the protons, neutrons, and electrons on the atoms below. Be sure to put the electrons in the correct energy levels. Lithium has three protons and four neutrons. Nitrogen has seven protons and seven neutrons.



Lithium-7



Nitrogen-14

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 in kWh?
To solve for electrical energy, use the following equation: energy = power x time (E = P x t).

Electrical Energy = W x h

$$\mathbf{E = 600\ W \times 24\ h = 14{,}400\ Wh \times \frac{1\ kW}{1{,}000\ W} = 14.4\ kWh}$$

If the utility charges $0.13 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 $0.13/kWh = $1.87

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	$ 0.13	=	$ _______
25 kW	x	4 h	=	_____________	x	$ 0.13	=	$ _______
1,000 W	x	1 h	=	_____________	x	$ 0.13	=	$ _______

The Water Cycle

Draw a diagram of the water cycle. Include arrows and labels to identify each step of the cycle. On the lines below, write a paragraph describing how the water cycle works. You may use the words in the word bank as labels and in your written explanation.

Word Bank

- condensation
- liquid
- evaporation
- ocean
- lake
- cloud
- river
- gravity
- solar energy
- atmosphere
- gas
- precipitation
- water vapor
- water

Magnets and Compasses

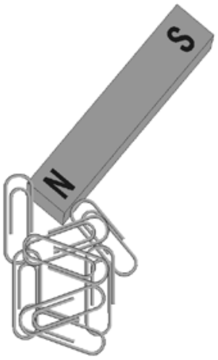
Did you know the Earth is a giant magnet? The North Pole of the Earth is like the north pole of a magnet, and the South Pole of the Earth is like the south pole of a magnet. The whole Earth has a magnetic field around it. The needle of a compass always points to the north because the needle is a magnet, too. You can turn an ordinary needle into a magnet by stroking it with a magnet—rearranging the molecules in the needle. You can demagnetize the needle by dropping or striking it several times.

Question

What are the properties of magnets?

Hypothesis

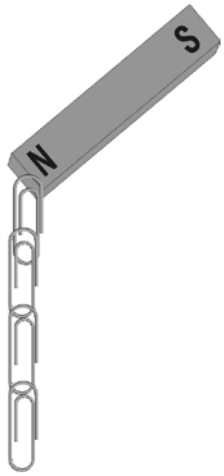
Materials



- 2 Bar magnets
- Needle
- Wood disk
- Small dish with water
- Compass
- Paper clips
- Tape

✔ Procedure

1. Hold the needle firmly on the end with the eye. Hold one end of a bar magnet with your other hand. Stroke the needle from the eye to the pointed end—in one direction only—about 25 times.
2. Tape the needle to the wood disk, and float it in the water in your dish with the needle on top. Observe the direction that the needle points. Compare it to the direction of the needle of the compass. The compass needle will always point north.
3. Examine the two bar magnets. Try to push the north (N) poles of the bar magnets together, then the two south (S) poles. Now place the N pole of one magnet next to the S pole of the other. Observe how the magnets attract and repel each other.
4. Put the paper clips in a pile. See how many paper clips the N pole of one bar magnet can lift. Now try the S pole. Try the other bar magnet to determine if it has the same force as the first. See if a magnet can lift as many paper clips end to end as it can if the paper clips are bunched together.
5. Place both bar magnets in a stack, N pole to S pole. See how many paper clips the magnets together can lift.



Observations and Data

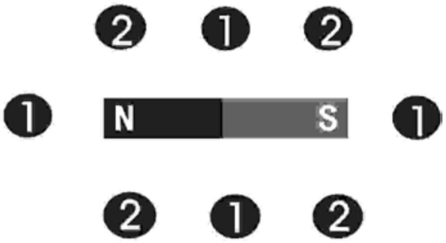
Record observations and data in your science notebook.

Conclusion

1. What are the properties of magnets?
2. Which end of the needle in your dish is the N pole? How do you know? What would happen if you stroked the needle in the other direction? Why do you think this?
3. Do you think the paper clips became magnetized to lift other paper clips? Why or why not?

Magnetic Fields

Every magnet produces a field of force around it. This magnetic field attracts certain materials, such as some metals. It can also affect the direction of a compass needle. The magnetic field demonstrator holds small pieces of iron—a metal that is attracted to a magnet—suspended in liquid.



Question

Are all magnetic fields arranged the same way?

Hypothesis

Materials

- 2 Bar magnets
- 1 Horseshoe magnet
- 1 Ring magnet
- 4 Compasses
- 1 Magnetic field demonstrator
- White paper

✔ Procedure

1. Arrange four compasses around a bar magnet. Using the diagram above, place the compasses at the positions marked as 1. Each compass should be far enough away from the magnet so that the compasses do not move toward the magnet. Make a diagram of the magnet and compasses, showing the N and S poles of the magnet and the direction that each compass needle points. Do the same placing the compasses at the 2 positions.
2. Arrange compasses in similar ways around the horseshoe magnet, then around the ring magnet, and make diagrams of these too.
3. Shake the magnetic field demonstrator (MFD). Place a bar magnet on white paper and place the MFD on top of it. Observe the pattern of the iron filings. Make a diagram of the magnetic field of the magnet, as shown by the iron filings.
4. Shake the MFD. Place both bar magnets together on white paper with N and S poles together. Place the MFD on top of the magnets. Make a diagram of the magnetic field produced by the two magnets.
5. Shake the MFD and place it on the horseshoe magnet. Make a diagram of its magnetic field.
6. Shake the MFD and place it on the ring magnet. See if the magnetic field changes if you turn the ring magnet over. Draw a diagram of the magnetic field of the ring magnet.

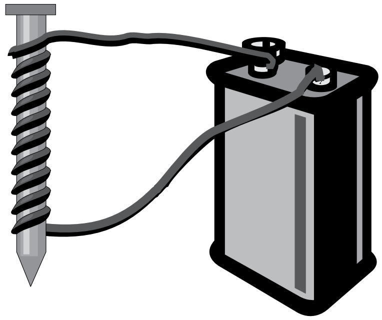
Observations and Data

Record diagrams of the magnetic fields you observe in your science notebook. Be sure to label the north and south poles of each magnet.

Conclusion

1. Do your diagrams of the compasses and the iron filings for each of the magnets give you the same information? Compare them and see what you discover.
2. Which magnet has a magnetic field most like that of the Earth? Draw a diagram showing what the magnetic field of the Earth might look like.

Electromagnets 1



Question

What happens when you wrap a wire around a nail and connect the wire to a battery?

Hypothesis

Preparation

Check to see if the nail is magnetized by moving it over the compass. Does the needle of the compass move? If it moves, tap or drop the nail on the floor several times and recheck.

Materials

- 1 Piece of coated copper wire (1 meter long)
- 1 Large iron nail
- 1 9-volt Battery
- 1 Compass
- Paper clips

Safety

If the wire begins to feel hot during the experiments, detach it from the battery and allow it to cool before resuming the experiments.

✔Procedure

1. Move the wire over the compass. Observe any movement of the compass needle. Does the compass detect a magnetic field around the wire? Record your observations in your science notebook.
2. Wrap the middle of the wire around the nail 10 times, as shown in the picture above. Do not let the wires cross or touch each other; wrap the wire as if it were a spring.
3. Wrap the ends of the wire around the metal contacts on top of the battery to make a closed circuit, as shown in the picture at the top of the page.
4. Move the compass near the wire wrapped nail. Observe any movement of the compass needle. Does the wrapped nail act like a magnet? Has the nail wrapped with wire become an electromagnet? Record your observations.
5. Place a pile of paper clips on the table. Touch the nail to the paper clips and lift. See how many paper clips the nail can lift. Record the data.
6. Carefully remove the nail from the coil of wire. See if the coil of wire can lift paper clips without the nail inside. Is the coil of wire an electromagnet? Record the data and observations.
7. Move the compass over the nail. Did the nail become magnetized?

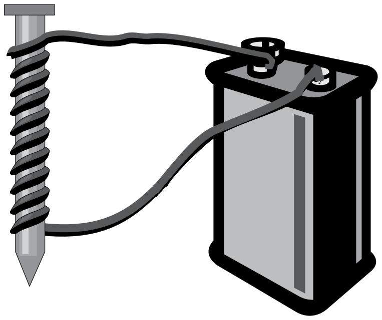
Observations and Data

Record your observations in your science notebook.

Conclusion

1. When you wrapped the wire around the nail, you organized the magnetic field of the electrons flowing through the wire. Did the nail also become a magnet while it was in the wire? Why or why not?
2. Is the coiled wire connected to a battery an electromagnet without the nail inside? How do you know?

Electromagnets 2



Question

What variables affect the force of an electromagnet?

Hypothesis

Materials

- 1 Piece of copper wire
- 1 Large iron nail
- 1 Small iron nail
- 1 9-volt Battery
- 1 1.5-volt D-battery
- Paper clips

Safety

If the wire begins to feel hot, detach it from the battery and allow it to cool before resuming the experiments.

✔ Procedure

1. Wrap the middle of the wire around the large nail 10 times, like a spring. Do not allow the wire coils to cross or touch each other.
2. Attach the wire to the 9-volt battery terminals by wrapping each end around a metal contact, as shown in the picture.
3. Place a pile of paper clips on the table. Touch the nail to the paper clips and lift. Record the data and your observations in your science notebook, or in the charts below.
4. Remove the ends of the wire from the battery. Wrap the wire around the large nail 10 more times, for a total of 20 coils, ensuring each coil does not touch or cross another. Reattach the wire to the 9-volt battery. Repeat step 3.
5. Remove the ends of the wire from the 9-volt battery. Have someone hold each end of the wire to a terminal (end) of the 1.5-volt battery. Repeat step 3.
6. Remove 10 coils from the large nail and hold the wire ends to the 1.5-volt battery terminals. Repeat step 3.
7. Remove the large nail from the coil of wire and insert the small nail, tightening the coils, as needed. Hold the wire ends to the 1.5-volt battery terminals. Repeat step 3.
8. Wrap 10 more coils of wire around the small nail. Check to make sure they are not touching or crossing each other. Hold the wire ends to the 1.5-volt battery terminals. Repeat step 3.

Observations and Data

Create these data tables in your science notebook.

Large iron nail, 9-volt battery	
NUMBER OF WIRE WRAPS	# OF PAPER CLIPS
10	
20	

Large iron nail, 1.5-volt battery	
NUMBER OF WIRE WRAPS	# OF PAPER CLIPS
10	
20	

Small iron nail, 1.5-volt battery	
NUMBER OF WIRE WRAPS	# OF PAPER CLIPS
10	
20	

⁂ Conclusion

1. Which combination of variables allowed you to pick up the most paper clips?
2. How does the number of coils affect the strength of an electromagnet?
3. How does the voltage of the battery affect the strength of an electromagnet?
4. How does the size of the nail in the coil affect the strength of the electromagnet?
5. What would you do to build a very strong electromagnet?

Science of Electricity Model

Observe the science of electricity model. Draw and label the parts of this model. On the lines below, explain how electricity is generated.

History of Hydropower

What do you consider the three most important milestones in the history of hydropower and why? Explain in short paragraphs.

1.

2.

3.

Dams and Their Uses

Explain in complete sentences the major reasons that dams are built.

1.

2.

3.

4.

5.

Describe in complete sentences the major types of dams.

1.

2.

3.

4.

Explain the difference between a dam and a hydropower plant.

Explain how a hydropower plant generates electricity.

Research assignment: Research and write a paragraph about dams in your state.

Effect of Volume on the Force of Water

Question

What effect does the volume of water have on the water's force?

Materials

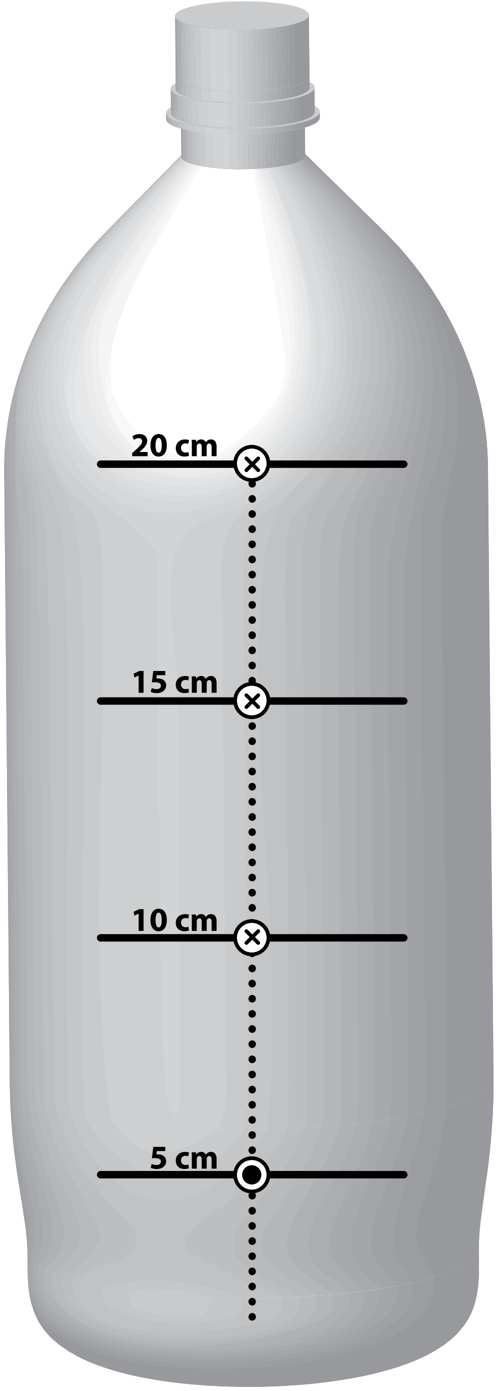
- 1 2-Liter soda bottle
- 1 Ruler
- 1 Push pin
- 1 Wallpaper pan
- Towel or paper towels
- Permanent marker
- Water supply
- Duct tape

Preparation

- Use the ruler to measure from the bottom of the bottle to 5 cm. Mark this spot with a dot, and also mark a line horizontally across the bottle at this height. Continue marking straight up every 5 cm, and horizontally at each mark until you reach 20 cm.
- Use the push pin to make a hole at the 5 cm mark only. Put a piece of duct tape over the hole.
- Read the procedure. Record your hypothesis on the next page, or in your scienec notebook before completing your investigations.
- Decide if you will need to remove the cap, loosen the cap, or keep the cap in place.

✔ Procedure

1. Fill the bottle with water to the 20 cm mark.
2. Place the bottle in the wallpaper pan with the hole pointing into the pan. Place the ruler at the base of the bottle and make marks on the bottom of the pan at each 2 cm increment until you reach the end of the pan.
3. Remove the duct tape and immediately measure the distance the water projects out from the hole. Cover the hole with your finger.
4. Record the distance in your table.
5. Repeat steps 1-4 two more times for a total of three trials.
6. Repeat steps 1-4 three times filling the bottle to 15 cm. Record your data with each trial.
7. Repeat steps 1-4 three times filling the bottle to 10 cm. Record your data with each trial.
8. Repeat steps 1-4 three times filling the bottle to 5 cm. Record your data with each trial.



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Effect of Volume on the Force of Water

Question

What effect does the volume of water have on the water's force?

Hypothesis

Observations and Data

Record your data in the table below.

VOLUME	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Conclusion

Was your hypothesis correct? Why or why not? What is the effect of the volume of water on the water's force? Use data to support your answer.

Effect of Penstock Height on the Force of Water

Question

What is the relationship between the penstock height and the force of water?

Materials

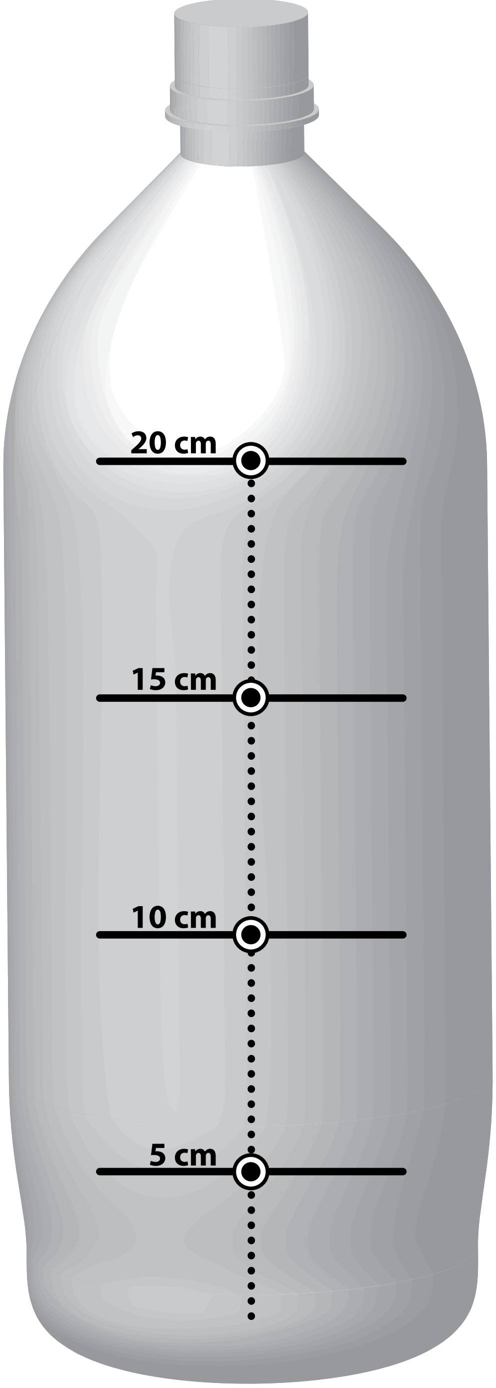
- 1 2-Liter soda bottle from previous investigation
- 1 Ruler
- 1 Push pin
- 1 Wallpaper pan
- Towel or paper towels
- Water supply
- Duct tape

Preparation

- Make sure the outside of the bottle is dry.
- Using the push pin, make holes at the 10 cm, 15 cm, and 20 cm marks. Cover each hole with a piece of duct tape.
- Read the procedure. Write your hypothesis on the next page or in your science notebook before completing your investigation.
- Decide if you will need to remove the cap, loosen the cap, or keep the cap in place.

✔Procedure

1. Fill the bottle with water to the 20 cm line.
2. Place the bottle at one end of the wallpaper pan with the holes pointing into the pan.
3. Remove the duct tape from the 5 cm hole and immediately measure the distance the water projects from the hole. Record the results on your data table.
4. Cover the hole with your finger, refill the bottle with water to the 20 cm line and place back in the pan. Uncover the hole and measure the distance the water projects again. Record your results. Repeat once more for a total of three trials.
5. Dry the outside of the bottle. Tape the hole closed.
6. Follow steps 1-5 again for the 10 cm, 15 cm, and 20 cm holes.



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Effect of Penstock Height on the Force of Water

Question

What is the relationship between the penstock height and the force of water?

Hypothesis

Observations and Data

Record your data in the table below.

Penstock Height	Trial 1	Trial 2	Trial 3	Average

Conclusion

Was your hypothesis correct? Why or why not? What is the relationship between penstock height and the force of water? Use data to support your answer.

Reflection

Think about what you learned from your two investigations about the force of water. How does what you learned help you understand how hydroelectric power plants work? What would the ideal conditions be to get the most energy out of the water when designing a dam? Use words and diagrams to explain your thinking.

Turbine Assembly Instructions

Materials

- 1 Rectangular plastic jug
- 1 Motor
- 3 Pieces double-sided tape
- 1 Hub
- 1 Pair scissors
- 1 Nail
- Safety glasses
- 12 Wooden dowels
- 12 Wooden spoons
- Glue

Safety

- Be careful when using sharp scissors to cut through plastic.
- Use safety glasses.
- Follow all safety rules.

✔ Procedure

1. Use the nail to make a hole in the center of one side of the jug as shown in Diagram 1.
2. Carefully cut the bottom off the jug with the scissors (Diagram 1).
3. From the outside of the jug, insert the shaft of the motor through the hole. Make sure the shaft can rotate freely. Use the nail to widen the hole if necessary.
4. Inside the jug, insert the shaft of the motor into the hub. Make sure the hub can rotate freely. Remove the hub and motor.
5. Place the jug on its side with the hole facing upward. Place the double-sided tape around the hole as shown in Diagram 2. Insert the shaft of the motor into the hole in the jug, holding the motor firmly against the jug so the motor sticks firmly to the jug.
6. Place 4 dowels evenly spaced in the hub. Cut a spoon so that it fits in the jug and does not hit the sides as the hub rotates. Glue the spoon to the dowel and allow to dry. Repeat this process to make 12 identical blades. Only four will be used in the first activity to start.

Diagram 2

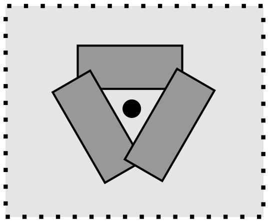
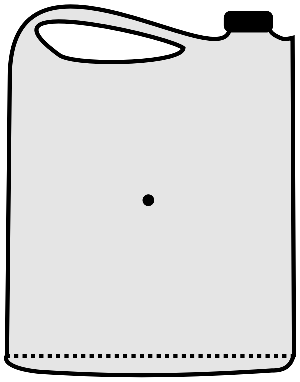
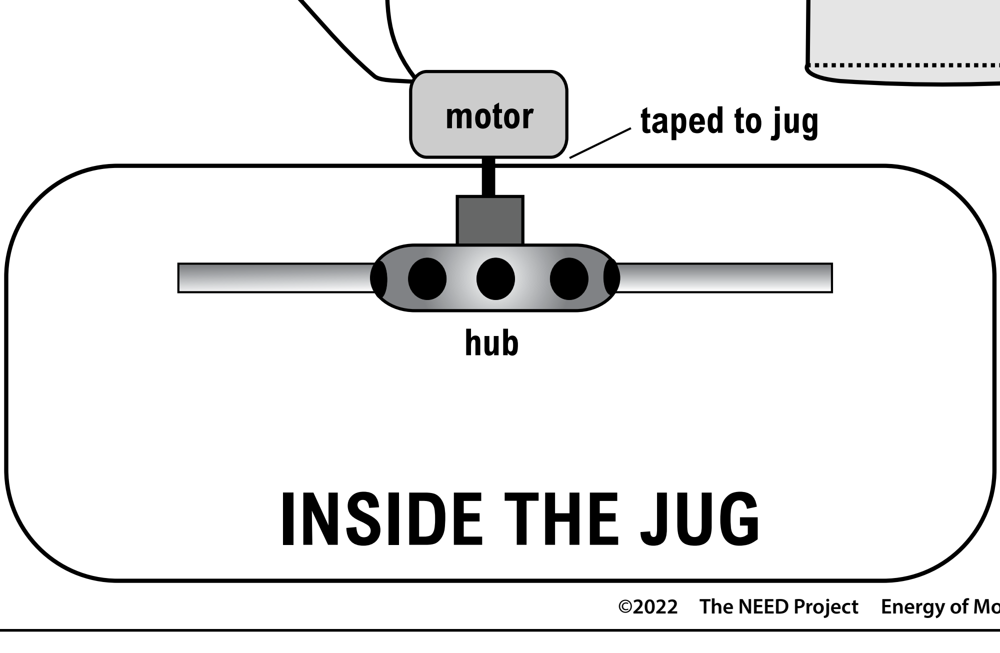


Diagram 1





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

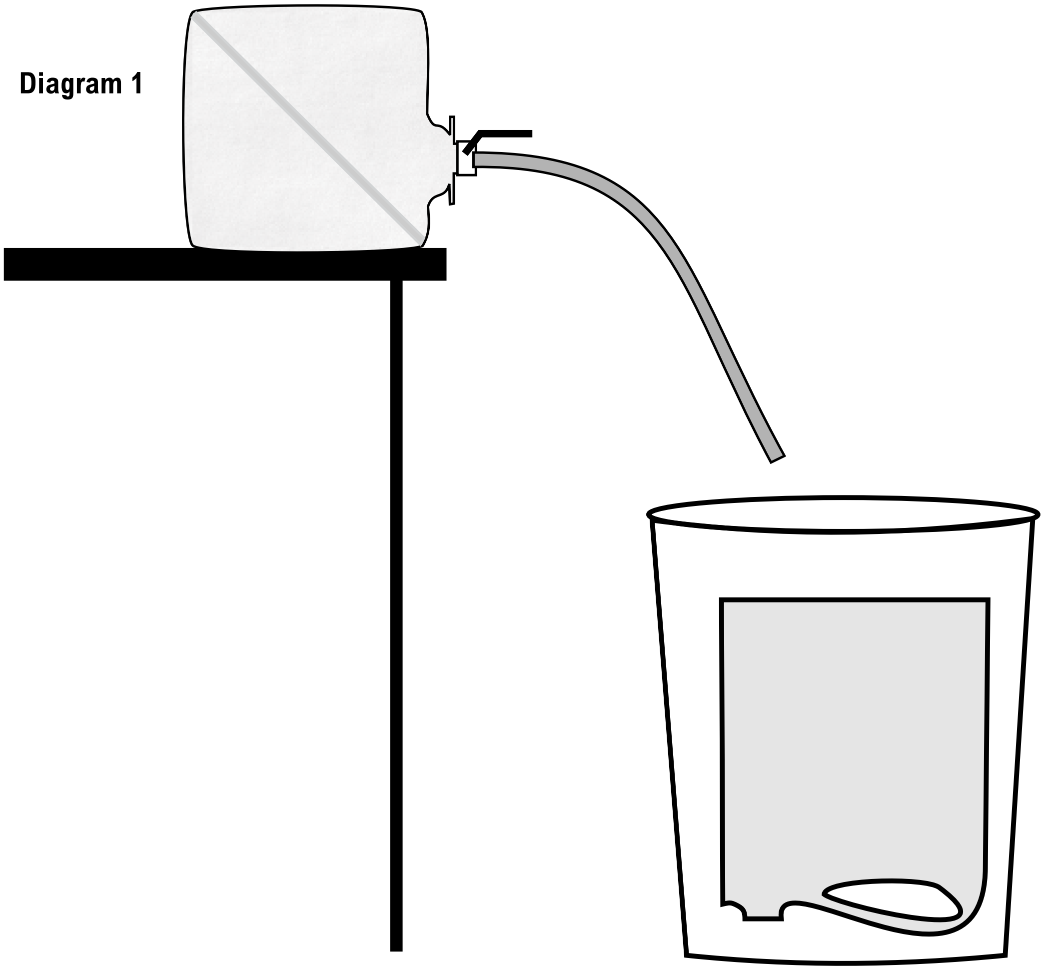
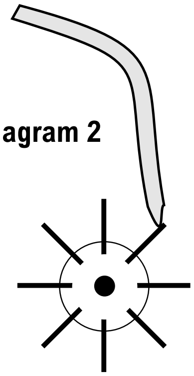


Diagram 2



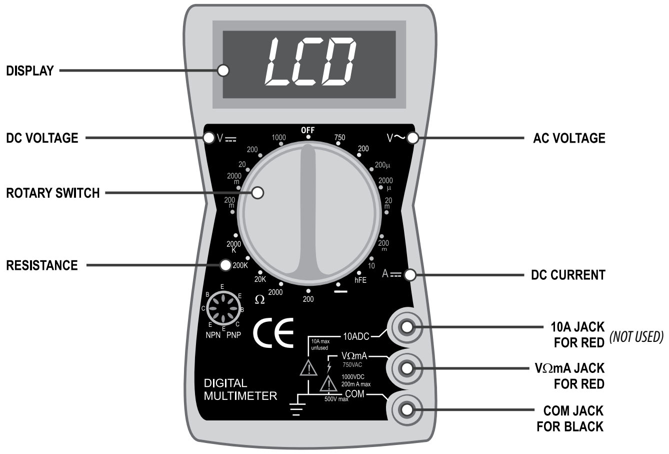
Measuring Electricity

Multimeters are tools used to measure electricity. The multimeter allows you to measure current, resistance, and voltage, and displays the reading numerically.

When using a multimeter it should be noted that some measurements will never "stay still" at a single repeatable value. This is the nature of the variables being monitored in some circumstances. For example, if you were to measure the resistance between your two hands with the ohmmeter setting on the multimeter (megohm range—millions of ohms), you would find that the values would continuously change. How tightly you squeeze the metal probes and how "wet" or "dry" your skin is can have a sizable effect on the reading that you obtain. In this situation you need a protocol or standardized method to allow you to record data.

We recommend that you discuss with your class the variability of measurement and let them come up with a standard for collecting data. They may decide to go with the lowest reading, the highest reading, or the reading that appears most frequently in a certain time period.

Digital Multimeter



Directions:

DC VOLTAGE

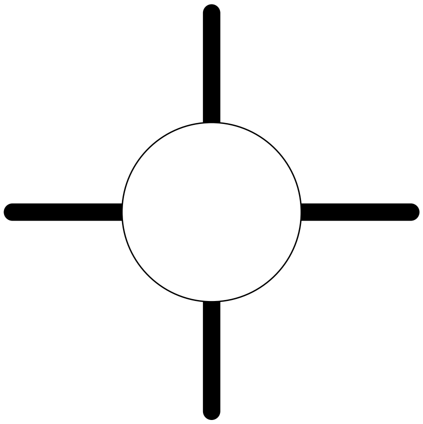
1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to highest setting on DC VOLTAGE scale (1000).
3. Connect leads to the device to be tested using the alligator clips provided.
4. Adjust ROTARY SWITCH to lower settings until a satisfactory reading is obtained.
5. With the hydropower turbine, usually the 20 DCV setting provides the best reading.

DC CURRENT *(must include a load in the circuit)* NOT NECESSARY FOR THESE ACTIVITIES

1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to 10 ADC setting.
3. Connect leads to the device to be tested using the alligator clips provided.
   Note: The reading indicates DC AMPS; a reading of 0.25 amps equals 250 mA (milliamps).

YOUR MULTIMETER MIGHT BE SLIGHTLY DIFFERENT FROM THE ONE SHOWN. BEFORE USING THE MULTIMETER, READ THE OPERATOR'S INSTRUCTION MANUAL INCLUDED IN THE BOX FOR SAFETY INFORMATION AND COMPLETE OPERATING INSTRUCTIONS.

Exploring Turbine Blades



Question

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

Hypothesis

Record your hypothesis in your science notebook.

Materials

- Assembled turbine
- Meter stick
- Water
- Hub
- 12 Blades

At the Testing Station:

- Reservoir unit
- Bucket
- Multimeter
- Alligator clips
- Funnel
- Stopwatch or watch with second hand
- Meter stick

✔ Procedure

1. Attach the hub with four blades to the motor. Attach the multimeter leads to the ends of the motor wires with the alligator clips. Set the meter to 200 mV.
2. Place the turbine in the 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 bucket. Pinch the hose together and open the valve.
3. Holding the end of the hose at the top of the turbine jug, allow the water to flow. Point the hose so that the water flows on the blades for 10 seconds and record the most consistent output reading. Empty the bucket back into the water reservoir unit using the funnel.
4. Measure and record the electrical output two more times in the data table. Calculate the average output.
5. Repeat steps 2-4 with 6 and 12 blades. Make sure the position of the hose remains constant.

Observations and Data

NUMBER OF BLADES	OUTPUT 1	OUTPUT 2	OUTPUT 3	AVERAGE OUTPUT
4				
6				
12				

Conclusion

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

Benchmark

Use the hub containing the number of blades with the highest electrical output as your benchmark hub for the next exploration. Be sure to set up the blades exactly as you had done above.

Extension

Design different shaped blades or blades with different materials. Test how the new blades affect electricity output.

Exploring Reservoir Height

Question

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

Hypothesis

Record your hypothesis in your science notebook.

Materials

- Turbine with benchmark hub (from previous exploration)
- Reservoir unit
- Bucket
- Multimeter
- Alligator clips
- Water supply
- Funnel
- Meter stick
- Stopwatch or watch with second hand

Preparation

Attach the benchmark hub to the motor. Attach the multimeter to the ends of the motor wires with alligator clips. Set meter to 200 mV.

Procedure

1. Place the turbine into the water collection bucket.
2. Fill the water reservoir unit and position the bottom of the unit 30 cm above the top of the bucket.
3. Position the hose at the top of the jug so that the water will flow onto the blades.
4. Allow the water to flow for 10 seconds and record the most consistent output reading.
5. Refill the reservoir unit with water from the bucket. Make sure the reservoir unit is completely filled.
6. Repeat steps 1-5 two more times. Calculate the average output and record it in the table.
7. Repeat steps 1-6 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				

Graph your results with your manipulated variable (height of the reservoir) on the X-axis (horizontal).

Conclusion

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

Teaching About Your Turbine

1. Explain how the turbine unit generated electricity, and how energy flows through the system.

2. List five ways you could change the design of the turbine unit to increase its efficiency.

    1.

    2.

    3.

    4.

    5.

3. What characteristics of a river would be most important in determining whether it is suitable for a hydropower dam?

The Future of Hydropower

1. Which new hydropower technology do you think will generate the most electricity in the future?

2. Explain how the technology generates electricity using words and diagrams.

3. Explain why you think it is the most promising new technology.

Résumé

NAME:

CONTACT INFORMATION:

EDUCATION:

TRAINING:

RELATED EXPERIENCE:

SKILLS:

INTERESTS:

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
caisson	a watertight support structure for an underwater turbine array designed to capture the energy in the tides
circuit	the path of electric current
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
condensation	physical phase change when a gas becomes a liquid
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
dam	a barrier constructed across a waterway to control the flow or raise the level of water
deposition	physical phase change when a gas becomes a solid
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
electric current	the flow of electricity through a circuit
electromagnetism	the relationship between electrical energy and magnetism
electron	the particle in an atom that carries a negative electrical charge
element	most pure form of all 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
evaporation	physical phase change when a liquid becomes a gas
Federal Energy Regulatory Commission (FERC)	the federal agency that licenses non-federal hydropower projects
fish ladder	a series of small pools arranged like stair steps 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
freezing	physical phase change when a liquid becomes a solid
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 head water level and the tail water level
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	a body of water formed by a dam, dike, floodgate, or other structure
isotope	atoms of the same element (same number of protons), but with differing numbers of neutrons
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 electric circuit that uses electricity to do work (a light bulb, for example)
magnet	material with pairs of non-canceling, spinning electrons that line up to form a magnetic field; magnetic materials are attracted to each other
magnetic field	the area of force around a magnet
melting	physical phase change when a solid becomes a liquid
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
ohm	a measurement of resistance in an electric circuit
Ohm's Law	the law that explains the relationship between current, voltage, and resistance in an electric circuit; in all electric 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
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 examples include chemical and 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 replenishment 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 electric circuit
resistor	a device with a set resistance that can be placed in circuits to reduce or control the current flow
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
secondary source of energy	often called an energy carrier, secondary sources of energy require another source, like coal, to be converted for creation; electricity and hydrogen are examples

spillway	a channel for overflow of water from a reservoir
sublimation	physical phase change when a solid becomes a gas
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 stream power	hydropower derived from swift, steady ocean currents
tributary	a stream or river that flows into another stream, river, or lake
trough	the lowest point of a wave
turbine	a machine with a series 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
volt	measure of electric potential or force
voltage	a measure of the pressure under which electricity flows through a circuit, measured in volts (V)
watt	unit of measurement of electric power

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