# EXPLORING HYDROELECTRICITY

## Student Guide

NEED

2009-2010

Putting Energy into Education

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**MEASURING ENERGY**

One **Btu** (British Thermal Unit) is the amount of energy needed to raise the temperature of one pound of water one degree Fahrenheit. One Btu is a small amount of energy. A wooden kitchen match, if allowed to burn completely, would give off about one Btu of energy. One ounce of gasoline contains almost 1,000 Btus of energy.

The term **quad** is used to measure large quantities of energy. A quad is one quadrillion (1,000,000,000,000,000) Btus. The United States uses about one quad of energy every 3.7 days. In 2006, the U.S. consumed 99.9 quads of energy.

## What Is Energy?

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

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.

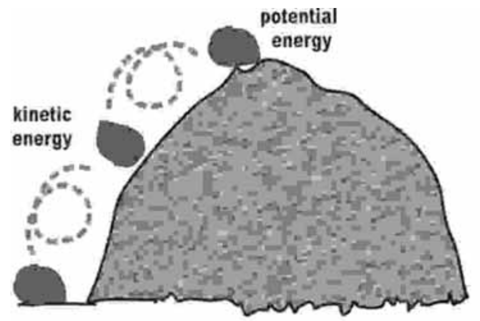
### Potential and Kinetic Energy

**Potential energy** is stored energy and the energy of position. Potential energy includes:

***Chemical energy*** stored in molecular bonds. Fossil fuels such as coal, oil, and natural gas contain chemical energy that was stored in the organic material from which they were formed millions of years ago. Biomass, which is any organic material that can be used as a fuel, contains stored chemical energy, produced from the sun through the process of photosynthesis.

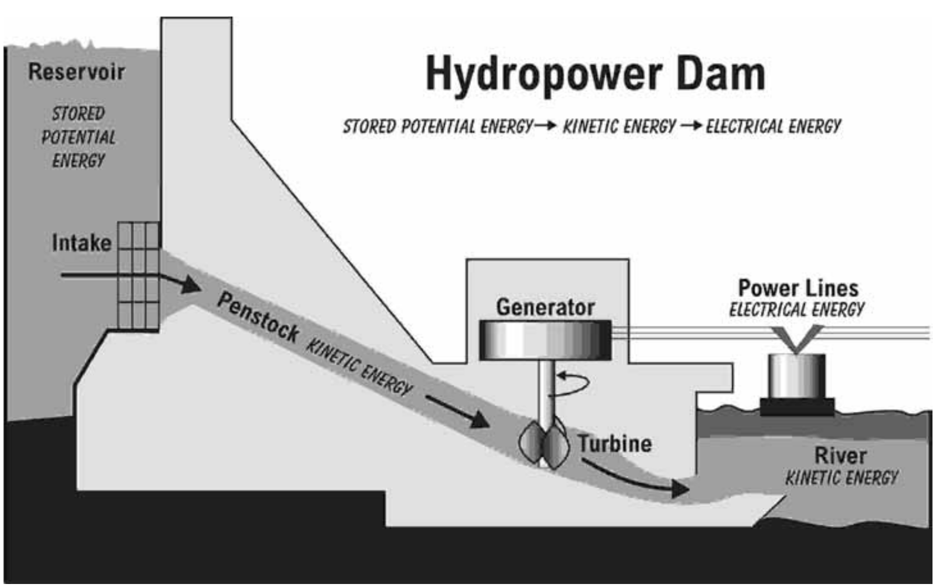
***Stored gravitational energy***. A rock on top of a hill contains potential energy because of its position. If a force pushes the rock, it rolls down the hill because of the force of gravity. The potential energy is converted into kinetic energy until it reaches the bottom of the hill and stops.

The water in a reservoir behind a hydropower dam is another form of potential or stored gravitational energy. The stored energy in the reservoir is converted into kinetic energy as the water flows down a pipe called a penstock and spins a turbine.




**POTENTIAL TO KINETIC ENERGY**

The turbine spins a shaft inside a generator, where magnets and coils of wire convert the kinetic energy into electrical energy. This electricity is transmitted over power lines to consumers who use it to accomplish many tasks.




***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. Everything is made of tiny particles called atoms. Atoms are made of even smaller particles—electrons, protons, and neutrons. The movement of electrons in a wire is called current electricity. Lightning is another example 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. Solar energy is an example of radiant energy.

***Thermal energy*** is the internal energy in substances; it is the vibration and movement of the atoms and molecules within substances. The more thermal energy in a substance, the faster the atoms and molecules vibrate and move. Geothermal energy is an example of thermal energy.

***Sound*** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate; the energy is transferred through the substance in a longitudinal wave.

***Motion*** is the movement of objects and substances from one place to another. Objects and substances move when a force is applied according to Newton's Laws of Motion. Wind is an example of motion energy.

## *Law of Conservation of Energy*

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.

A car engine, for example, burns gasoline, converting the chemical energy in the gasoline into useful mechanical energy or motion; some of the energy is also converted into light, sound and heat. Solar cells convert radiant energy into electrical energy. Energy changes form, but the total amount of matter and energy in the universe remains the same.

## *Energy Efficiency*

Energy efficiency is the amount of useful energy produced by a system compared to the energy input. A perfect energy-efficient machine would convert all of the input energy into useful work, which is technologically impossible at this time. Converting one form of energy into another form always involves a loss of usable energy—usually in the form of heat—from friction and other processes. This 'waste heat' dissipates and is very difficult to recapture.

A typical coal-fired plant converts about 35 percent of the chemical energy in the coal into electricity. A hydropower plant, on the other hand, converts about 95 percent of the kinetic energy of the water flowing through the system into electricity.

Most energy transformations are not very efficient. The human body is a good example. Your body is like a machine, and the fuel for your machine is food. Food gives you the energy to move, breathe, and think. Your body is less than five percent efficient at converting food into useful work. The rest of the energy is lost as heat.

## *Sources of Energy*

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

In the United States, most of our energy comes from nonrenewable energy sources. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to make electricity, heat our homes, move our cars, and manufacture all kinds of products. They are called ***nonrenewable*** because their supplies are limited. Petroleum, for example, was formed millions of years ago from the remains of ancient sea plants and animals. We can't make more oil 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, and the rivers flow. We use renewable energy sources mainly to make electricity. *(See the **Secondary Energy Infobook** for detailed information about energy sources.)*

### U.S. Energy Consumption by Source 2008

| | | | | | |
|---|---|---|---|---|---|
| PETROLEUM | 37.0% | nonrenewable<br>transportation, manufacturing | BIOMASS | 3.9% | renewable<br>heating, electricity, transportation |
| COAL | 22.6% | nonrenewable<br>electricity, manufacturing | HYDROPOWER | 2.5% | renewable<br>electricity |
| NATURAL GAS | 23.5% | nonrenewable<br>heating, manufacturing, electricity | GEOTHERMAL | 0.4% | renewable<br>heating, electricity |
| URANIUM | 8.5% | nonrenewable<br>electricity | WIND | 0.5% | renewable<br>electricity |
| PROPANE | 1.0% | nonrenewable<br>manufacturing, heating | SOLAR | 0.1% | renewable<br>light, heating, electricity |

## *Electricity*

Electricity is different from primary energy sources; it is a secondary source of energy. That means we must use another energy source to produce electricity. Electricity is sometimes called an ***energy carrier*** because it is an efficient and safe way to move energy from one place to another, and it can be used for so many tasks.

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

As we use more technology, the demand for electricity continues to grow. In the U.S. today, 40 percent of the energy we consume is in the form of electricity. This percentage is expected to increase and poses many challenges for the nation, with no easy answers.

Global climate change is one important issue, since most U.S. electricity is produced by fossil fuels today. Should fossil plants be required to minimize carbon dioxide emissions? Should we build more nuclear power plants? Can we reduce demand with conservation and efficiency measures? Can renewable energy sources meet the increasing demand?

How much are consumers willing to pay for a reliable supply of electricity, for a cleaner environment, for efficient technologies? These questions will only become more important.

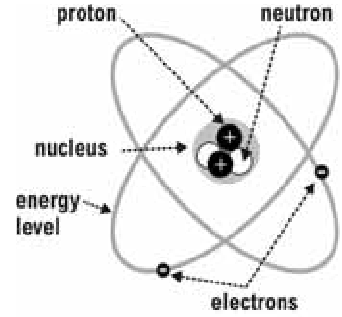
### *A Mysterious Force*

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

### *Atomic Structure*

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

Protons and neutrons are very small, but electrons are much smaller—1836 times smaller, to be precise. ***Electrons*** move around the nucleus in orbits a great distance from the nucleus. If the nucleus were the size of a tennis ball, the diameter of the atom with its electrons would be the size of the Empire State Building.




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

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 in balance, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons act as a glue to hold the nucleus together.

### *Elements*

An ***element*** is a substance in which all of the atoms are identical. The number of protons in an atom determines the kind of element it is. The number of protons is an element's ***atomic number***. Every atom of hydrogen, for example, has one proton and one electron, with no neutrons. Every atom of carbon has six protons, six electrons, and six neutrons. The ***atomic mass*** of an element is the combined mass of all the particles in one atom of the element.

**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 |
| COPPER | Cu | 29 | 29 | 34 |
| SILVER | Ag | 47 | 47 | 51 |
| GOLD | Au | 79 | 79 | 118 |
| URANIUM | U | 92 | 92 | 146 |

### *Electrons*

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

The electrons in the levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost level—the ***valence level***—do not. These electrons—***valence electrons***—can be pushed from their energy levels.

Applying a force (***voltage***) can make the electrons move from one atom to another; the force that opposes this movement of electrons is known as ***resistance***. The moving electrons (***current***) are called current electricity. Voltage, current and resistance exist in all electrical circuits. Each has a unit of measurement: voltage (V)—volts, current (I)—amps, resistance (R)—ohms.

The relationship between voltage, current, and resistance is defined in ***Ohm's Law***, which states that in an electrical circuit, the current passing through a conductor between two points is directly proportional to the potential difference (voltage) across two points, and inversely proportional to the resistance between them. Ohm's Law is expressed by the equation: $V = I \times R$. *(See the **Measuring Electricity** factsheet in the **Secondary Energy Infobook** for detailed information.)*

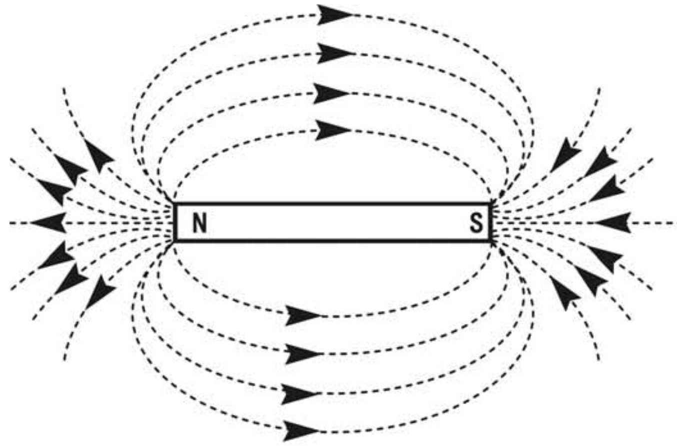
### *Electrical Energy*

Electrical energy has been moving in the world forever. Lightning is a type of electrical energy. It is electrons moving from one cloud to another or jumping from a cloud to the ground. Have you ever felt a shock when you touched an object after walking across a carpet? A stream of electrons jumped to you from that object. This is called ***static electricity***.

Have you ever electrified your hair by rubbing a balloon on it? If so, you rubbed some electrons off the balloon. The electrons moved into your hair from the balloon. They tried to get far away from each other. They pushed against each other and made your hair move—they repelled each other. While opposite charges attract each other, like charges repel each other.

### *Magnets*

In most objects, the molecules are arranged randomly. They are scattered evenly throughout the object. Magnets are different—they are made of molecules that have North- and South-seeking poles. Each molecule 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. 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.




BAR MAGNET

### *Electromagnetism*

A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called ***electromagnetism***. Every time there is a change in a magnetic field, an electric field is produced. this relationship to produce electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their valence shells 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.

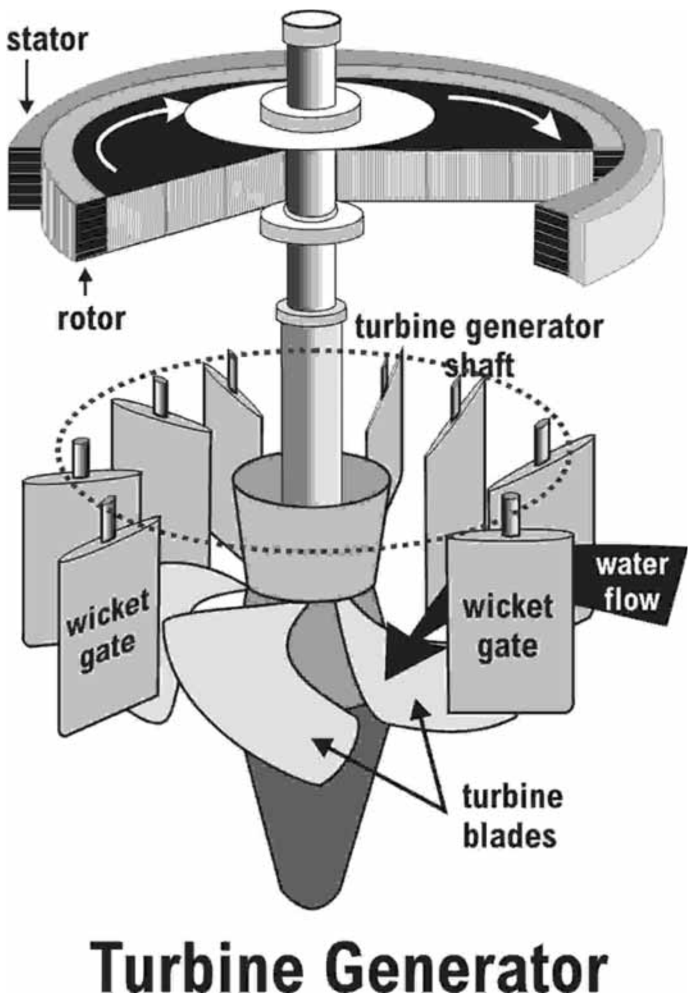
Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire.

### *Producing Electricity*

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

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

Geothermal power plants harness hot water and steam from underground reservoirs to spin turbines. We can also harness the energy in flowing water and the energy in the wind to spin turbines. Photovoltaic (solar) cells are made with chemically infused silicon that allow them to convert radiant energy from the sun directly into electricity.




## *Measuring Electricity*

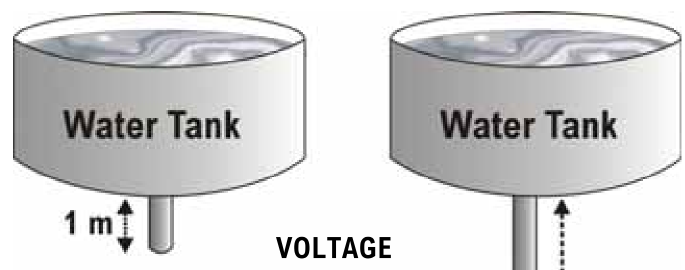
We are familiar with terms such as watt, volt, and amp, but we do not always have a clear understanding of these terms. We buy a 60-watt light bulb, a tool that requires 120 volts, or an appliance that uses 8.8 amps, but we don't think about what those units mean.

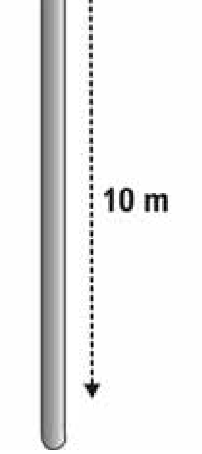
Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second.

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



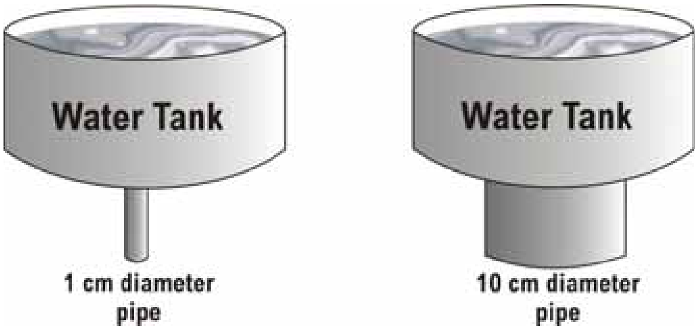

***Voltage (V)*** is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in ***volts (V)***. Just as the 10-meter tank applies greater pressure than the 1-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply.

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

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

### *Current*

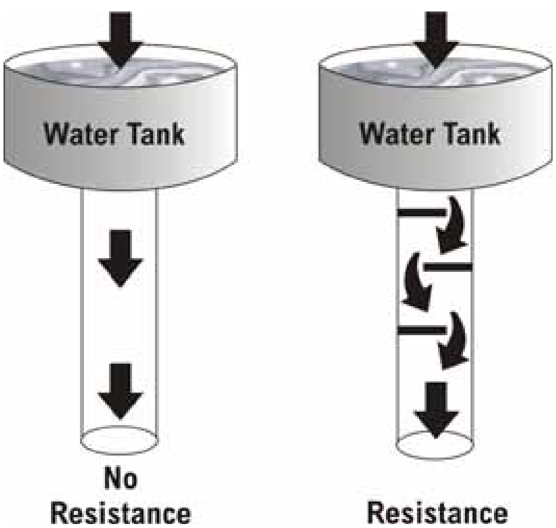
The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point; electrical current is the number of electrons flowing past a fixed point.




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

### *Resistance*

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




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

## *Ohm's Law*

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

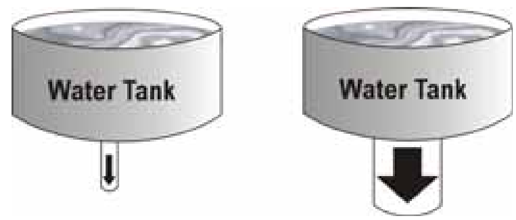
**voltage = current x resistance**
**V = I x R or V = A x W**

## *Electrical Power*

**Power (P)** is a measure of the rate of doing work or the rate at which energy is converted. Electrical 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 1-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

**Electrical 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. Electrical power is measured in **watts (W)**. The




formula is:

**power = voltage x current**
**P = V x I or W = V x A**

## *Electrical Energy*

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

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

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

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, one would multiply the rate of travel by the amount of time traveled at that rate. If a car travels for 1 hour at 40 miles per hour, it would travel 40 miles:

**distance = 40 mph x 1 hour = 40 miles**

If a car travels for 3 hours at 40 miles per hour, it would travel 120 miles:

**distance = 40 mph x 3 hours = 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 is analogous to the distance traveled or the work done by the car.

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

If you read for five hours with a 100-W lightbulb, for example, you would use the formula as follows:

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

One watt-hour is a very small amount of electrical energy. Usually, we measure electrical 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 $0.11.

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

**500 Wh divided by 1,000 = 0.5 kWh**
**0.5 kWh x $0.11/kWh = $0.055**

Therefore, it would cost about four and a half cents to read for five hours with a 100-W lightbulb.

## *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 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 ice.

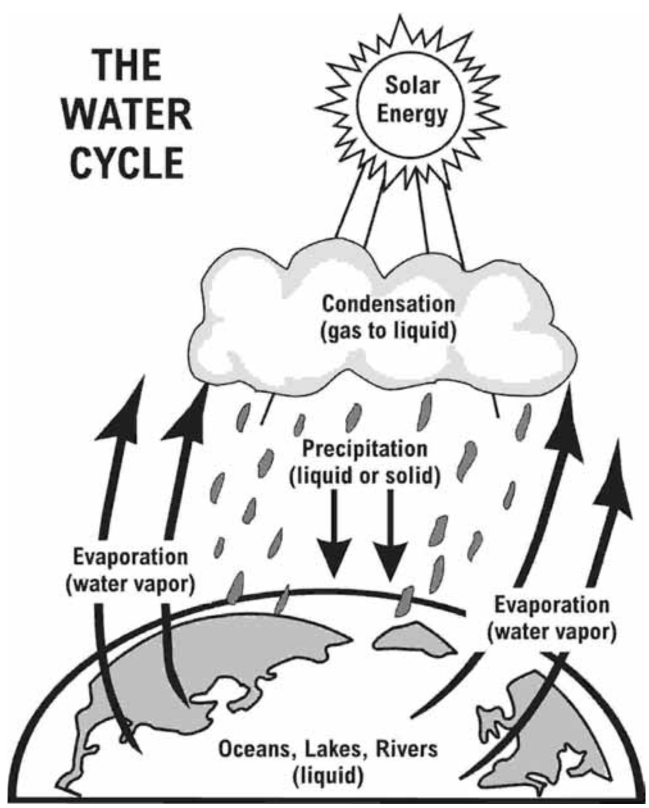
***Melting*** changes ice into liquid water.

***Evaporation*** changes liquid water into water vapor.

**Condensation** changes water vapor into liquid water. For example, morning dew on the grass comes from water vapor.

***Sublimation*** changes ice or snow into water vapor without passing through the liquid state. The ice or snow seems to disappear without melting first.

***Deposition*** changes water vapor into ice without the vapor becoming a liquid first. Water vapor falls to the ground as snow.



### *The Hydrologic or Water Cycle*

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

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

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

### *Water as an Energy Source*

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

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

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

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

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

## *Harnessing Water Power*

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

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

Early waterwheels 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.

*Early English waterwheel*

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 waterwheels being the main power source for sawmills, textile mills, and forges through the nineteenth century.

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

### *Niagara Falls: A Natural Wonder and Wonderful Energy Source*

***Niagara Falls produces one-quarter of Ontario's electricity, but the power does not come directly from the falls. Rushing water is diverted from the Niagara River, upstream from the falls, to a powerhouse.***

***There the water drops 120 feet through large pipes, called penstocks. The rushing water provides energy to turbines at the bottom, spinning three-foot diameter shafts attached to the generators, which rotate 250 times a minute to produce electricity. After the water flows past the turbines, it runs through a discharge tunnel and empties back into the Niagara River half a mile downriver from the Canadian Falls.***

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

## *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. In 2,900 BC, Egyptians in the city of Memphis built a dam across the Nile River. The dam stopped periodic flooding and created a reservoir for irrigation and drinking water.

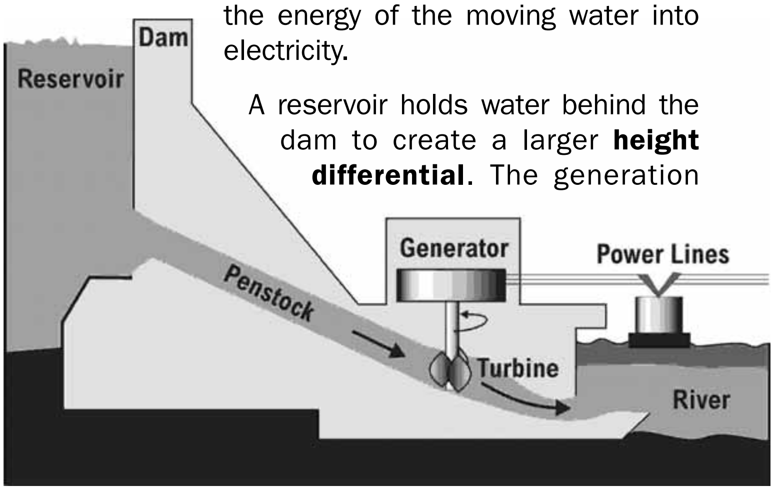
The Romans also built many dams in the first millennium, but most of their technical knowledge and engineering skills were lost during the fall of the Roman Empire. Dams did not become major civil projects until the end of the nineteenth century when the need for large dams coincided with the ability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

Today, there are more than 500,000 dams worldwide. Most dams are small—less than three meters high. There are about 40,000 large dams higher than 15 meters.

There are approximately 80,000 dams in the United States, but less than three percent (2,400) are used to generate electricity. The rest were built for recreation, fishing, flood control, crop irrigation, to support the public water supply, or to make inland waterways accessible to ships and barges. Some of these dams could be retrofitted with turbines and generators to produce electricity.

## *A Hydropower Plant*

There are three main parts of a typical hydropower plant: the reservoir, dam, and power plant (turbines and generators). The **reservoir** stores the water until it is needed. The **dam** contains the water; there are openings in the dam to control its flow. The **power plant** converts the energy of the moving water into electricity.



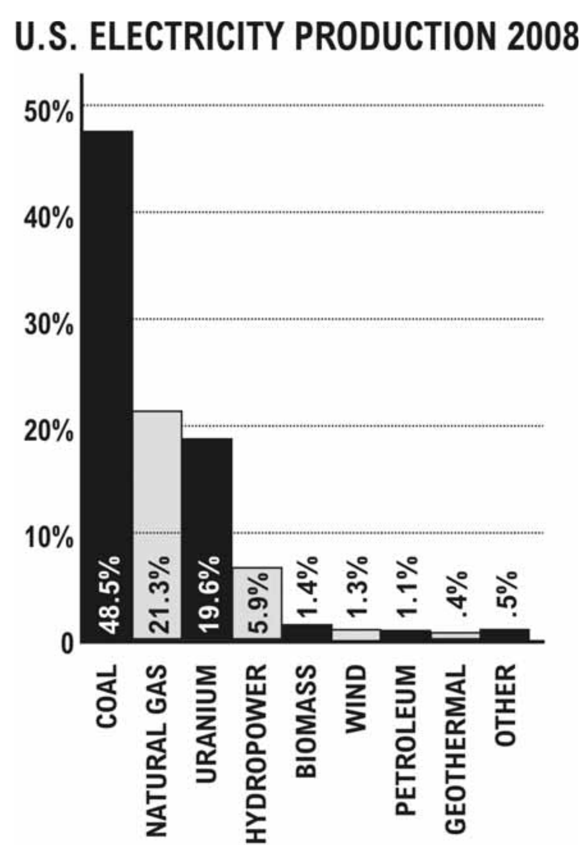

A reservoir holds water behind the dam to create a larger **height differential**. The generation process begins with water flowing from the reservoir into openings on the upstream side of the dam, called **penstocks**, which are very large pipes. The water flows down the penstocks to turbines at the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

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

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

## *Electricity from Hydropower*

Most electricity from water in the United States and the world is produced by conventional hydropower using gravitational energy. Almost 17 percent of the world's electricity is produced by hydropower, and 7–10 percent of U.S. electricity, depending on the supply of water. That's enough power to supply 28 million households with electricity, or the equivalent of nearly 500 million barrels of oil. The total U.S. hydropower capacity is about 95,000 megawatts. In 2008, 5.9 percent of U.S. electricity was produced by conventional hydropower.



## *Types of Dams*

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

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

A ***gravity dam*** uses only the force of gravity to resist water pressure. It holds back the water by the sheer force of its mass pressing downward. A gravity dam is built wider at its base to offset the greater water pressure at the bottom of the reservoir. Most gravity dams are made of concrete. The Hoover Dam is an example of a concrete gravity dam. *(See page 13 for the story of how Hoover Dam was built.)*

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

*Embankment Dam.*
*Credit: Bureau of Reclamation.*

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

An ***arch dam*** can only be built in a narrow river canyon with solid rock walls. It is built from one wall of a river canyon to the other and curves upstream toward the body of a reservoir. The curved shape diverts some of the immense force of the water toward the canyon walls.

*Glen Canyon Dam*

An arch dam is built of stone masonry or concrete and requires less material than a gravity dam. It is usually less expensive to build.

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

*Buttress dam in Canada*

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

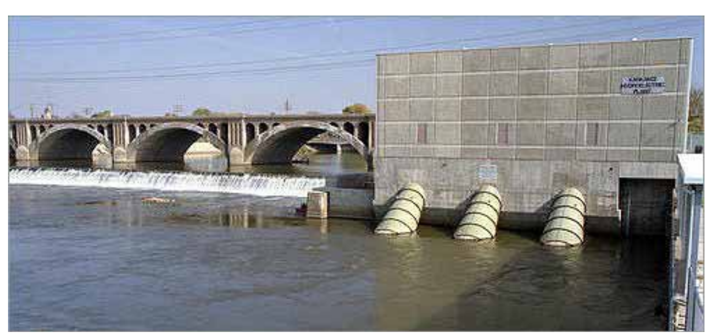
Thick buttresses help the dam withstand the pressure of water behind it. While buttress dams use less material than gravity dams, they are not necessarily cheaper to build. The complex work of forming the buttresses may offset the savings on construction materials. A buttress dam is desirable in a location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

## *Conventional Hydropower*

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

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

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



*Run-of-river project in Kankakee, IL. Credit: U.S. DOE.*

## *Building Hoover Dam: Transforming the Desert Southwest*

*Hoover Dam. Credit: U.S. Bureau of Reclamation.*

*Hoover Dam is located in Black Canyon on the Colorado River, about 30 miles southeast of Las Vegas, Nevada. 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 type dam, in which the water load is carried by both gravity action and horizontal arch action. It is 726.4 feet tall from foundation rock to the roadway on the crest of the dam. The towers and ornaments on the parapet rise 40 feet above the crest, and weigh more than 6,600,000 tons. The maximum water pressure at the base of the dam is 45,000 pounds per square foot.*

*Before construction of the dam itself could begin, the Colorado River had to be diverted around the construction site. Four concrete-lined diversion 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 the diversion tunnels were no longer needed, the upstream entrances were closed by huge steel gates and concrete plugs were inserted near the midpoints. Downstream sections of the tunnels are used as spillways for the dam. 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 appurtenant works (additional structures necessary to the operation of the dam). This much concrete would build a monument 100 feet square and 2-1/2 miles high or pave a standard highway 16 feet wide, from San Francisco to New York City.*

*Setting the concrete produced an enormous amount of heat. The heat was dissipated by embedding more than 582 miles of 1-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. Cooling was completed in March 1935.*

*The most unusual feature of the dam is that it was built in blocks or vertical columns varying in size from about 60 feet square at the upstream face of the dam to about 25 feet square at the downstream face. Adjacent columns were locked together by a system of vertical keys on the radial joints and horizontal keys on the circumferential joints (like a giant Lego set).*

*Concrete placement in any one block was limited to five feet in 72 hours. After the concrete cooled, grout was forced into the spaces between the columns––created by the contraction of the concrete as it cooled––to form a monolithic (one-piece) structure.*

*The principal materials, all of which were purchased by the government, were reinforcement steel—45,000,000 pounds; gates and valves—21,670,000 pounds; plate steel and outlet pipes—88,000,000 pounds; pipe and fittings—6,700,000 pounds or 840 miles; structural steel—18,000,000 pounds; miscellaneous metal work—5,300,000 pounds.*

*It took five years to build the dam, power plant, and appurtenant works. The contractors were allowed seven years from April 20, 1931, but concrete placement in the dam was completed May 29, 1935, and all features were completed by March 1, 1936.*

*During construction, a total of 21,000 men worked on the dam with an average of 3,500 men daily. A total of 114 men died during construction of the dam, but none 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 both government and contractor employees;*
- *the construction of seven miles of 22-foot wide, asphalt-surfaced highway from Boulder City to the dam site;*
- *the construction of 22.7 miles of standard-gauge railroad from the Union Pacific main line in 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 San Bernardino, California, to the dam site to supply energy for construction.*

*Once the dam was completed, the diversion tunnels were closed and the cofferdams were removed, and a reservoir formed named Lake Mead that holds more than 28 million acre-feet of total water storage capacity.*

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

## Pumped Storage

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

*Pumped storage facility in Warren, PA. Credit: FirstEnergy Corp.*

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

## Hydropower Plant Capacity

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

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

## Maneuvering Around Dams

The impact of dams on the migration of fish is an important ecological issue today. Some dams have fish ladders built in to allow fish to migrate upstream to spawn. Fish ladders are a series of small pools arranged like stair steps. The fish jump from pool to pool, each higher than the previous one, eventually bypassing the dam.

*Fish ladder on Ice Harbor Dam, WA*

When the fish swim downstream, to return to the ocean, they need to bypass the dam again. Headed downstream, fish are diverted around dams through special spillways.

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

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

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

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

## Hydropower Plant Safety

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

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

## Federal Regulation

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

- the Commission relicenses the project
- the federal government takes over the project
- the project is decommissioned

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

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

Many hydropower projects built in the 1960s and 1970s are now applying for relicensing. It is the job of FERC to weigh all of the economic, environmental, and societal issues and grant or reject the relicensing applications.

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

## *Relicensing Issues*

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

Each group has its own set of issues concerning hydropower; those in favor of hydropower encounter difficulties with relicensing authorities, while those who oppose hydropower fight for dam removal where dams don't make sense to them. Local, state, and federal regulations protect rare, threatened and endangered species. Local groups may advocate for such species, as well as other region–specific issues.

FERC has licensing authority over all non-federal facilities. In May of 1994, arguments over environmental considerations resulted in a Supreme Court decision—the Tacoma decision—that raised questions about which agencies have the authority to relicense hydropower plants.

In the past, FERC was responsible for considering and setting the environmental, energy and water supply conditions that are factors in whether or not a hydropower plant project should continue. The Tacoma decision gave states the authority to set license conditions under Section 401 of the Clean Water Act and prevented FERC from limiting the continuation of the project.

Another issue facing the hydroelectric power industry involves the Endangered Species Act. Under the Act, federal agencies are required not to jeopardize any protected species or habitat, a requirement that applies to all federal hydropower facilities. The Columbia River, one of the largest water systems, stretches through four states and provides 36.6 percent of the nation's federal hydroelectric energy.

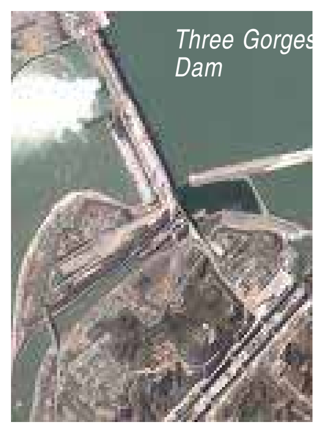
The Columbia River is also home to the endangered salmon population. More than four billion dollars have been spent to improve salmon migration around these important dams on the river.

*Endangered Pacific Salmon.*

*Credit: Robert Hines, U.S. Fish & Wildlife Service.*

## *Three Gorges Dam*

***The Three Gorges Dam on the Yangtze River in China is one of the world's largest engineering projects. The dam is more than 200 meters high and 1.6 kilometers long. The hydropower plant can generate over 18,000 megawatts of much needed electricity for China's growing industries. The dam will also provide flood prevention. Massive flooding has killed thousands of people and left millions homeless. Finally, the dam will provide clean electricity. Currently, 75 percent of China's electricity is produced by coal-fired plants.***




***However, there are several disadvantages to the project. The reservoir will flood 650 square kilometers (400 square miles) of land, which includes two cities. More than one million people will be relocated. The dam and reservoir will also alter the area's ecological system. The Yangtze River's natural course is being diverted and hundreds of acres of land will be flooded. Finally, large quantities of silt will be dumped into the reservoir. Normally the silt flows down river to create fertile flood plains.***

## *Advantages & Disadvantages of Hydropower*

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

### *Advantages of Hydropower*

Hydropower is a clean energy source. It is fueled only by moving water, so it doesn't produce emissions. Hydropower does not increase the level of greenhouse gases in the atmosphere.

Hydropower is a renewable energy source. It relies on the water cycle, which is driven by the sun. The total amount of water in a hydropower system does not change; the moving water is used to generate electricity and returned to the source from which it came.

Hydropower is usually available when it is needed; engineers can produce electricity on demand and control the amount of electricity generated.

Hydropower is an established, proven, and domestic source of energy, produced in the United States.

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 95-97 percent efficient at converting the energy in the moving water into electricity.

Impoundment facilities create reservoirs that offer a wide variety of non–energy benefits to communities, such as recreational fishing, swimming, and boating. The reservoirs can also increase the property value of the adjacent land.

Hydropower facilities can help regulate the water supply, providing drought and flood control. Many dams were designed primarily as flood control projects; the generating equipment was an additional benefit. During drought, the reservoirs provide a more reliable source of drinking water, as well as water for fragile downstream habitats.

Hydropower dams are very safe and durable—built to last for hundreds of years.

Hydropower is a flexible energy source in meeting electricity generating needs quickly; hydropower plants can begin generating electricity within minutes of increased demand. Most hydropower plants can also provide reliable and dependable baseload power.

Only three percent of existing dams in the U.S. contain generators. Without building any new dams, existing dams have the potential to generate 23,000 MW of power.

### *Disadvantages of Hydropower*

Hydropower plants are dependent on water supply. When there is a drought, for example, hydropower plants cannot produce as much electricity.

A dam on a river can permanently change the ecology of a large land area, upstream and downstream, creating a different environment. When a dam is built, the resultant reservoir floods a large area of land upstream from the dam. The natural ecology of the river and adjacent land downstream is changed by a reduction in soil deposition.

Hydropower facilities can impact water quality and flow. Reservoirs can experience low dissolved oxygen levels in the water, a problem that can be harmful to fish populations and downstream ***riparian*** (riverbank) habitats. Maintaining minimum flows of water downstream of a reservoir is also critical for the survival of riparian habitats.

Some fish populations, such as salmon, migrate upstream to reach spawning grounds and then return to the ocean. Impoundment facilities block fish from completing this natural migration process. Fish ladders or elevators may be built to aid upstream fish passage. Downstream fish passage can be aided by diverting fish around the turbine intakes by maintaining a minimum spill flow past the turbines, using screens or racks, and even underwater lights and sounds.

Development of new hydropower reservoirs can be very expensive because dams have already been built at many of the more economical locations. New sites must compete with other potential uses of the land.

## *A Case Study in Improving Ecology Downstream of an Existing Dam*

***Observers in the Grand Canyon of the Colorado River have noticed a decline in the number and size of sandbars used as campsites—a decline attributed to Glen Canyon Dam, which controls the flow of the Colorado through the canyon. Most of the sand that used to be delivered yearly to the Grand Canyon by the Colorado River now gets trapped behind the dam.***

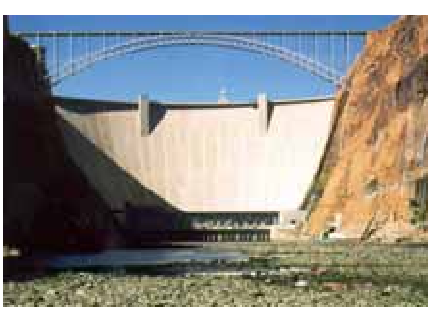
*High flow test. Credit: U.S. Bureau of Reclamation.*

***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 the tributaries during intense rainfall. Rapids form where the debris fans extend into the river and constrict its channel. Fresh debris fans used to be cleaned out yearly by large floods of water that flowed through the canyon during spring snowmelt in pre-dam years.***

***Glen Canyon Dam dramatically reduced flows through the canyon. This drop in water flow reduced the river's ability to move rock debris at tributary mouths. In the absence of floods, there will be a continuing buildup of boulders and smaller rocks on many rapids, which could become more dangerous to navigate. Elimination of yearly flooding in the Grand Canyon also allowed silt to build up in backwater channels used as habitats by native fish.***

***The United States 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.***

***A second experimental flow was released in November 2004, and a third, the largest yet, began in March 2008. The controlled flooding is one result of more than a decade's study of the effects of Glen Canyon Dam on the Grand Canyon ecosystem by a multidisciplinary team coordinated by the Bureau of Reclamation's Glen Canyon Environmental Studies. If the controlled flooding is judged successful, such short-duration, high-release flows will probably be incorporated into long-term plans for the operation of the dam.***



*Glen Canyon Dam on the Colorado River in the Grand Canyon. Credit: U.S. Bureau of Reclamation.*

## *A Case Study in Removing a Dam: When the Benefits No Longer Outweigh the Costs*


***In May 1999, Portland General Electric (PGE) announced plans to decommission its 95-year-old hydropower project on the Sandy River in Oregon. The project consists of dismantling the following:***

- ***the 47-foot-high Marmot Dam,***
- ***a concrete-lined canal that takes water from Marmot Dam to the Little Sandy River,***
- ***the 16-foot-high Little Sandy Dam,***
- ***a 15,000-foot-long wooden-box flume, and***
- ***a 22-megawatt powerhouse.***

***The final bits of concrete from Marmot Dam were removed September 30, 2007. The remaining earthen cofferdam, built to give crews a dry workspace, was breached on October 19, 2007, restoring the Sandy to a free-flowing river for the first time in nearly a century. A cofferdam is a temporary barrier used to keep water from an area that is normally submerged. The Little Sandy Dam was removed in 2008.***

***Within hours the Sandy River resumed the appearance of a natural river. Torrents of water carried hundreds of thousands of yards of sediment downstream, helping create natural bends, bars and logjams indicative of a free-flowing river.***

***The project will enable the river to flow unimpeded from glacier to gorge to the Pacific Ocean. The dam removals will help improve habitat for threatened fish and wildlife, and expand public recreation opportunities. It will also eliminate expensive maintenance costs to the 95-year-old power plant and avoid the costly upgrades necessary to bring fish protection up to today's standards.***

***PGE is giving about 1,500 acres of land and other nearby holdings to the Western Rivers Conservancy. This land will form the foundation of a natural resource and recreation area in the Sandy River Basin. Ultimately covering more than 9,000 acres, the area will be owned and managed by the U.S. Bureau of Land Management.***

***The hydro project removal plan was developed through a diverse collaboration of 23 environmental organizations, state and federal natural resource agencies, local governments and businesses. You can go to www.MarmotDam.com for more information.***

*Marmot Dam*

*Marmot Dam during demolition*

## *The Tennessee Valley Authority—A Public Utility—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 habitat 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, 12 hydroelectric 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 (1,050-kilometer) navigation channel the length of the Tennessee River and had become the nation's largest electricity supplier.*

*In the 1960s, TVA's electric rates were among the nation's lowest and TVA brought larger, more efficient generating units into service. Expecting the Valley's electric power needs to continue to grow, TVA began building nuclear plants. During the 1970s, significant changes occurred in the energy industry because of the oil embargo in 1973 and rising fuel costs. Electricity rates skyrocketed. With demand dropping and construction costs rising, TVA canceled several nuclear plants, as did other utilities in the nation. To become more competitive, TVA improved efficiency and productivity while cutting costs. By the late 1980s, TVA had stopped the rise in rates.*

*In the 1990s, as the electric-utility industry moved toward restructuring, TVA began preparing for competition. It cut operating expenses, reduced its workforce, increased the generating capacity of its plants, stopped building nuclear plants, and developed a plan to meet the energy needs of the Tennessee Valley through the year 2020. Conservation became an economic necessity, and TVA became a leader in promoting energy conservation.*

*Today, TVA's power system consists of a diverse mix of fuel sources, including:*

- *29 hydroelectric dams and 1 pumped storage plant*
- *11 coal-fired and 8 combustion-turbine power plants*
- *3 nuclear power plants*
- *16 solar power sites*
- *1 wind-power site*
- *1 methane gas site*

*Norris Dam: TVA's first hydro dam. Credit: TVA.*

*TVA operates a system of 49 dams and reservoirs on the 652-mile-long Tennessee River and its tributaries and manages 293,000 acres of public land. TVA's operates its 34 flood control dams as a system to prevent an estimated $230 million in flood damage a year. TVA manages the complete river system 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.*

*Spillways of TVA's Great Falls Dam. Credit: TVA.*

## *New Hydropower Initiatives*

The mission of the U.S. Department of Energy (DOE) Hydropower Program is to conduct research and development that will improve the technical, societal, and environmental benefits of hydropower and provide cost-competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity to the nation's energy supply.

One DOE initiative promotes both the upgrading of existing hydropower plants and the retrofitting of existing dams with generating facilities. The power provided under the initiative could replace approximately 9 GW (gigawatts) of fossil-fueled capacity, or approximately 18 large (500-MW) coal-fired power plants. It is estimated to reduce the sulfur dioxide emissions from coal fired generations by up to 1.3 percent by the year 2020.

Upgrades to existing facilities will increase their efficiency and capacity; upgrades will include replacing obsolete or worn turbines and generator parts with new, more efficient equipment; fine-tuning the performance of equipment; reducing friction losses; and automating operations.

Upgrades that involve only efficiency increases have little environmental impact and provide benefits such as reduced fish mortality and improved water quality. Upgrades that increase capacity by adding turbines or raising the elevation of the reservoir have greater potential to cause changes in the environment. Mitigation techniques are available to minimize or eliminate most impacts of upgrade projects.

Only three percent of existing dams in the U.S. are hydropower plants; the rest were built for other reasons, including flood control, irrigation, and navigation. The Department of Energy supports the installation of generating facilities at existing storage and flood control dams, navigation dams, other impoundments, and water works such as canals and pipelines.

Most of the impacts of hydropower development have already occurred at these facilities as a result of construction and operation. Additional negative impacts are expected to be minor and will depend on the kind of retrofit and the local environment. The installation of generating plants at existing dams may not be allowed to alter daily or seasonal flow release patterns and so may not be as useful in meeting peaks in demand.

### *Advanced Turbine Systems*

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

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

Potential benefits of advanced turbine technologies include:

- ***Reduced fish mortality:*** Advanced turbine technology could reduce fish mortality resulting from turbine passage to less than 2 percent, in comparison with turbine-passage mortalities of 5 to 10 percent for the best existing turbines and 30 percent or greater from other turbines.
- ***Improved water quality:*** Advanced turbine technology would maintain a downstream dissolved oxygen level of at least 6 mg/L, ensuring compliance with water quality standards.
- ***Reductions in $CO_2$ emissions:*** The use of environmentally friendly turbine technology would help reverse the decline in hydroelectric generation and reduce the amounts of $CO_2$ and other greenhouse gases emitted by consumption of fossil fuels.

### *Alden Lab*

***Founded in 1894, Alden Lab is the oldest continuously operating hydraulic laboratory in the United States and one of the oldest in the world.***

*Alden Lab's fish friendly turbine.*
*Photo Credit: Alden Lab*

***Alden has developed a new hydraulic turbine runner to reduce fish injury and mortality as part of the Advanced Hydropower Turbine Project sponsored by DOE. A pilot-scale turbine test facility was designed by Alden engineers and fisheries biologists.***

***Results of the pilot-scale tests indicate that fish survival through the full size prototype turbine would be 94-100 percent, depending on the fish length. Prototype studies are being planned for a hydroelectric site.***

## *Ocean Energy*

The ocean is in constant motion and contains energy that can be harnessed. Some devices harness the energy in the changing tides to generate electricity. Others harness the energy in the waves.

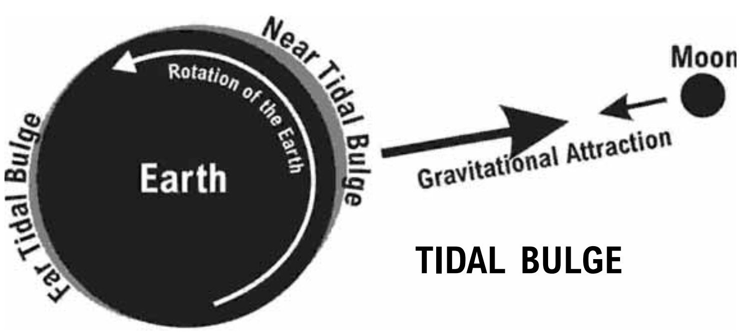
***Hydrokinetic energy conversion devices*** capture kinetic energy from the flow of water through turbines to power generators without impeding the flow of the water. These devices are used to capture the energy of the tides.

## *Tidal Barrage*

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


*Tidal power plant on the estuary of the Rance River in Bretagne, France.*

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



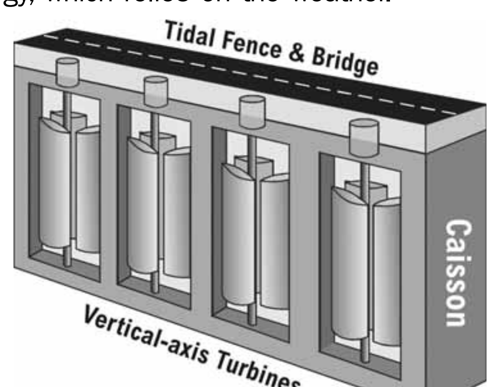

Between the tidal bulges are lower levels of water that produce low tides. The tidal bulges move slowly around the earth as the moon does. Halfway between each high tide is low tide. Most shore lines have two high and two low tides each day. The Gulf of Mexico only experiences one tide each day because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

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


The main challenge with using tidal power is geographical. There are few parts of the world with significant enough tides to support tidal power stations. Countries that currently use tidal power include Canada, China, France and Russia. Tidal systems are expensive to build, and their construction may harm local wildlife habitats.

## *Tidal Stream Power*

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



Research and development in tidal stream power is still underway. Marine Current Turbines Ltd, based in Bristol, England, is a world leader in the development of tidal turbines and has a significant global technical lead in this field. They developed and installed the world's first offshore tidal stream device, a 300kW experimental test system called SeaFlow, off the coast of Lynmouth Devon, England in 2003. It is still in operation.

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

*Artist's drawing of SeaGen project.*
*Credit: Marine Current Turbines*

SeaGen is able to generate clean and sustainable electricity equivalent to the average needs of approximately 1,000 homes. It is also a world first as the prototype for commercial technology to be replicated on a large scale over the next few years.

The SeaGen technology under development consists of two large rotors, each driving a generator with a gearbox. The twin rotors—each 15-20 meters in diameter—are mounted on wing-like extensions on either side of a three-meter wide tubular steel monopile that is set into a hole drilled in the sea floor.

SeaGen turbines are able to be installed and maintained without costly underwater operations. The turbines and power units can be raised above sea-level to allow maintenance from small service vessels. This is an important feature because underwater maintenance by divers or Remotely Operated Vehicles (ROVs) is impossible in locations with the strong currents needed for effective power generation.

*A 16-meter rotor of the SeaGen. Credit: Marine Current Turbines*

The plan is for the submerged turbines to be grouped in arrays under the sea in areas with high current, similar to a wind farm. Marine current turbines can be smaller and produce the same amount of power as wind farms since water is denser than air. The turbines can also be sited closer together because tidal streams are normally bi-directional, whereas wind tends to be multi-directional.

Environmental impact studies report that this technology does not offer a serious threat to fish or marine mammals. The rotors turn slowly, at 10 to 20 rotations per minute (rpm). A ship's propeller, by comparison, typically rotates ten times as fast. The risk of impact from the rotor blades is extremely small, considering that most marine creatures that swim in areas with strong currents have excellent perception and agility, giving them the ability to successfully avoid collisions with slow-moving underwater obstructions.

Marine Current Turbines and Canada's BC Tidal Energy Corporation plan to install at least three 1.2 MW turbines in Vancouver's Campbell River by 2011, a project that will generate power for 3,000 homes. It is estimated that the tidal energy potential in British Columbia is 4,000 MW, making it one of the best areas for tidal energy anywhere in the world.

## *New York City's East River Project*

***The city and state of New York have partnered with Verdant Power to harness the energy in the ebb and flow of the tides in Manhattan's East River. The Roosevelt Island Tidal Energy (RITE) Project is incorporating a kinetic hydropower system comprised of 35-kW tidal turbines anchored on the bottom of the river.***

***The project will progress from an initial demonstration array of six turbines to a complete arrangement of 100-300 turbines that could generate up to 10 MW to power nearly 8,000 New York homes.***

***Installation of the six initial turbines was completed in the spring of 2007 and they are being monitored.***

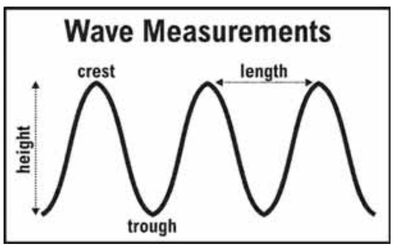
***Biologists will also monitor the movement of fish through and around the turbines for up to 18 months.***

*Credit: U.S. DOE.*

## *Ocean Waves*

The main cause of surface ocean waves is wind; although, they can also be affected by tides, weather conditions, and underwater events. The size of waves depends on the speed of the wind, wind duration, and the distance of water over which the wind blows. Usually, the longer the distance the wind travels over water, or the harder it blows, the higher the waves. Winds of 30 miles per hour can cause 15-foot waves. Very strong winds can cause waves 40-50 feet high.

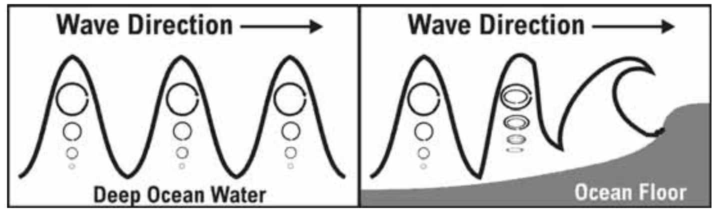
As the wind blows over the water, there is friction between the wind and the surface of the water. The wind pulls the surface water in the direction it is going. The water is much denser than the air and cannot move as fast, so it rises and then is pulled back down by the force of gravity. The descending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




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

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

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

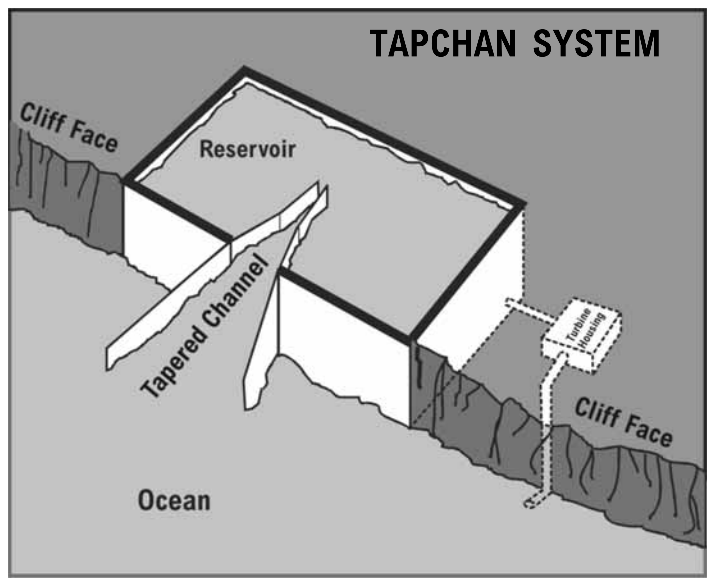



## *Harnessing Wave Energy*

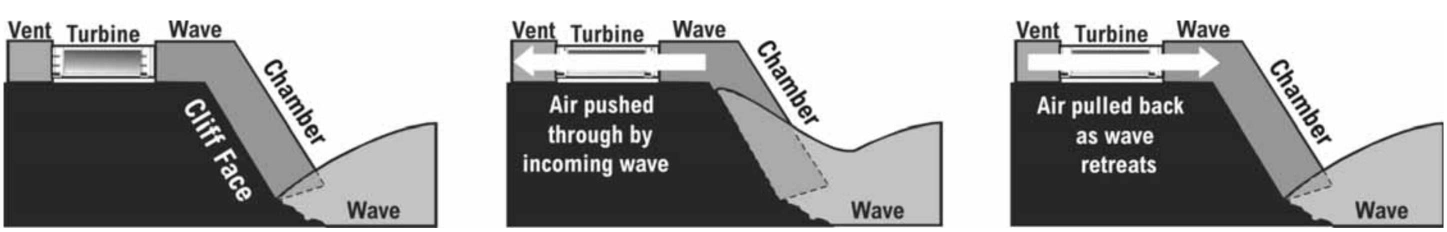
The energy in waves can be harnessed to generate electricity. There are two main types of wave energy generation devices, fixed and floating. Fixed generating devices are built into cliffs along a coast.

One fixed device is the **Oscillating Water Column** *(see diagram below)*. The column, or chamber, is partially submersed in the water. As the waves flow in and out of the chamber, the air inside the chamber is compressed and decompressed. The forced air spins a turbine. The generator attached to the turbine produces electricity.

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




## OSCILLATING WATER COLUMN



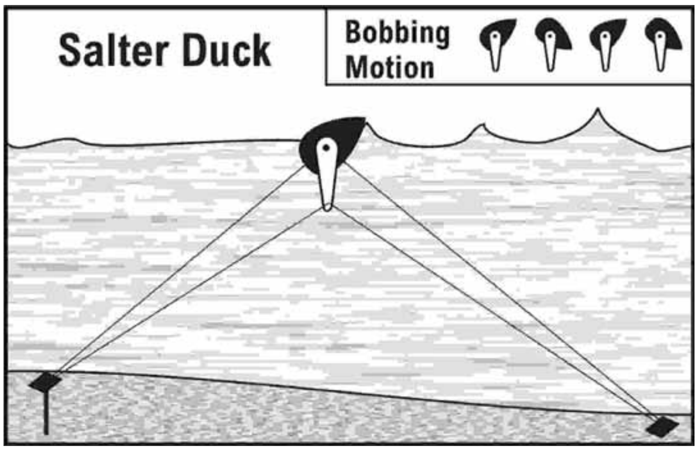

 

When the waves are high enough, they spill over the top of the channel into the reservoir. The stored water in the reservoir flows through a turbine, generating electricity.

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

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

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




A Scottish company, Pelamis Wave Power, has developed a floating wave energy converter known as Pelamis, named after the Latin word for sea snake. Building on technology developed for the offshore industry, the Pelamis has an output that is similar to a modern wind turbine.

*Pelamis Wave Energy Converter. Credit: Pelamis Wave Power.*

About three miles off the coast of Portugal, the world's first commercial wave farm plans to use the movement of the ocean to generate 2.25 megawatts of electricity—enough to meet the energy needs of more than 1,500 homes—from three 459-foot-long Pelamis Wave Energy Converters.

Each device is a series of four semi-submerged tubes that are linked to each other by hinged joints. Passing waves cause each tube to rise and fall like a giant sea snake. The motion tugs at the joints linking the segments. The joints act as a pumping system, pushing high pressure oil through a series of hydraulic motors, which in turn drive the electrical generators to produce electricity. The wave energy converters will be moored to the seafloor by transmission lines.

Although the owner of the wave farm, Portuguese renewable energy company Enersis, had planned to have the wave farm producing electricity by the end of 2007, bad weather caused installation delays. If the first three converters are successful, the company plans to expand to 30 additional converters.

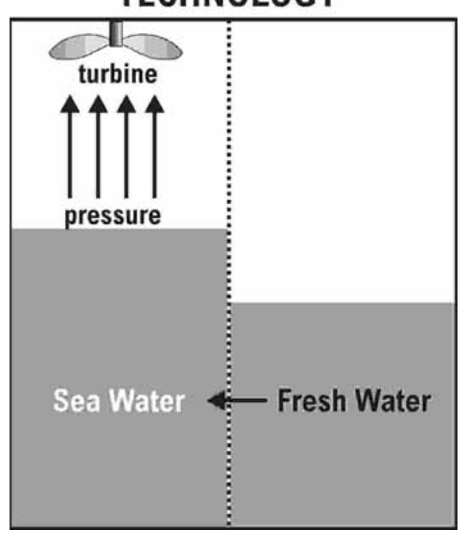
### *Osmotic Power Plant*

In 2007, a Norwegian energy group, Statkraft, announced plans to build the world's first **osmotic power plant**. Osmotic power is based on the natural process of osmosis—the diffusion of molecules through a semipermeable membrane from a place of higher concentration to a place of lower concentration. It is a clean, renewable energy source.

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

A prototype of the osmotic power plant is being built in Norway to generate two–four kilowatt hours of electricity. A full scale plant could be operating by 2015.

OSMOTIC POWER PLANT TECHNOLOGY



## Future of Hydropower

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

Advances in turbine design and other mitigation strategies will continue to reduce the impact of conventional hydropower facilities on fish populations, water quality, and the environment. New technologies will also allow facilities to become more efficient and generate more electricity.

### Wave Energy is Happening in the U.S.

***In December 2007, the Federal Energy Regulatory Commission (FERC) issued the first operating license in the United States for a wave energy project the —Makah Bay Offshore Wave Pilot Project in Washington State. The project is a partnership between the Makah Indian Nation and Finavera Renewables and will be located in the Pacific Ocean in Makah Bay near the city of Neah Bay.***

***The project is planned as a 1 MW demonstration project. It is expected to generate about 1500 MWh/year of electricity, enough to power about 150 homes.***

***Finavera recently completed a successful test of its AquaBuOY wave energy converter off the coast of Newport, Oregon. The AquaBuOY is a cylinder-shaped buoy that floats on the surface, with a long, hollow tube attached below it. The acceleration tube is open at both ends so that seawater can pass through it as the waves move up and down.***

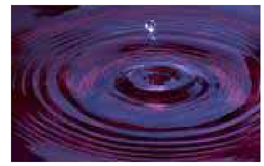
***In the middle of the tube is a piston—a broad buoyant disk–that is held in place by two hose pumps. The hose pumps are attached to either side of the piston and to the top and bottom of the tube respectively.***

***As the seawater moves up and down through the tube, it moves the piston, stretching and compressing the hose pumps. The hose pumps channel the seawater through a turbine that drives a generator, producing electricity. The electricity is transmitted to shore by an underwater cable.***

The addition of electricity generating facilities to existing dams could increase the overall capacity of the hydropower industry by one fourth.

The development and implementation of technologies that harness the power of moving water from free-flowing streams, the tides, ocean currents and waves will also contribute to the future of hydropower in the United States and the world. The waves off the coasts of Oregon and Washington, especially, are expected to have excellent potential for power generation.

### It's Raining Energy



Researchers have developed a technique that harvests energy from rain showers and converts it into electricity.

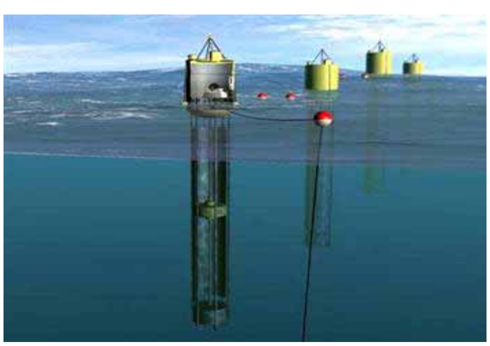
The technology could work in industrial air conditioning systems, where water condenses and drops like rain. It could also be used in combination with solar power to harness energy from the environment or to power tiny, wireless sensors designed to monitor environmental conditions.

The method relies on a plastic called PVDF (for polyvinylidene difluoride), which is used in a range of products from pipes, films, and wire insulators to high-end paints for metal. PVDF has the unusual property of piezoelectricity—it can produce a charge when it is mechanically deformed.

Guigon and his team embedded electrodes in a thin membrane of PVDF, just 25 micrometers thick. Then they bombarded the sheet with drops of water varying in diameter from 1 to 5 mm. As the drops hit the material, they created vibrations, which created a charge. The electrodes recovered the charge for use as power.

Not surprisingly, the largest drops caused the biggest vibrations. The researchers found the system could capture 12 milliwatts from the largest drops and generate at least 1 microwatt of continuous power.

*(Summarized from an article by Tracy Staedter in Discovery Channel News, February 7, 2008.)*



*On the left is an artist's rendering of the AquaBuOY wave energy converter system.*

*On the right is an AquaBuOY during testing.*

*Credit: Finavera.*

# HISTORY OF HYDROPOWER TIMELINE

| | |
|---|---|
| B.C. | 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. |
| 1879 | The first hydroelectric plant was built in the U.S. at Niagara Falls. |
| 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, Wisconsin. |
| 1886 | About 45 water-powered electric plants in the U.S. and Canada. |
| 1887 | San Bernardino, CA opens first hydroelectric plant in the west. |
| 1889 | Two hundred power plants in the U.S. use waterpower for some or all 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. electrical generation. |
| 1920 | Hydropower provided 25 percent of U.S. electrical generation. Federal Power Act establishes 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 Mississippi River in the Tennessee Valley. |
| 1935 | Federal Power Commission authority 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 40 percent of electrical 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. |
| Today | Between 7–10 percent of U.S. electricity comes from hydropower, depending on the supply of water.<br>The U.S. has about 80,000 MW of conventional capacity and 18,000 MW of pumped storage capacity. |

# CAREERS IN THE HYDROPOWER INDUSTRY

*Source: www.ferc.gov/industries/hydropower.asp*

**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 engineering, 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 that they are in compliance with government regulations. Accountants and Auditors require a bachelor's degree in accounting.

**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.

**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.

**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.

*Environmental Biologist, Brittany Schoenen, started working for the Federal Energy Regulatory Commission's Office of Energy Projects in 2003 after graduating with a bachelor's degree in Environmental Resource Management from Penn State University. Brittany says, "I ensure that hydropower project owners are meeting the requirements of their licenses in the areas of recreation and environmental compliance. This includes reviewing recreation plans and monitoring reports, as well as amendments to project licenses. Travel to projects is sometimes necessary. I've also been working on developing GIS maps of FERC hydropower projects in various states."*

**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.

**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.

**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.

**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.

***Hydrologists***

**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 ocean 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.

Entry-level hydrologists spend the majority of their time in the field, while more experienced workers generally devote more time to office or laboratory work. A hydrologist may spend considerable time doing field work in remote and rugged terrain. They often take field trips that involve physical activity, and work in all kinds of weather. In the field, they may collect basic data, oversee testing of water quality, direct field crews and work with equipment. They travel often to meet with prospective clients or investors.

As part of their work at the office, hydrologists interpret data and perform analyses to determine possible water supplies. Much of their work relies on computers for organizing, summarizing and analyzing masses of data, and for modeling studies to predict flooding, the consequences of reservoir releases or the effects of leaks from underground oil tanks.

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.

Hydrologists need excellent oral and written communication skills. They should work well with people, not only as part of a team with other scientists and engineers, but also in public relations, whether advising government leaders or informing the public on water issues.

***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 individuals. Ranger salaries begin at $20,908-$31,680, based on education and experience. *For more information on working as a National Park Ranger, visit www.nps.gov/personnel/index.htm.*

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 Mangers** 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.

# HYDROPOWER RESOURCES & CAREER INFORMATION

The U.S. Department of Energy's Idaho National Laboratory website has extensive information about hydropower and new technologies. Go to http://hydropower.id.doe.gov/.

The U.S. Department of Energy's Energy Information Administration website, www.eia.doe.gov, has up-to-date data and information on all energy sources, including hydropower.

The National Hydropower Association's website, www.hydro.org, covers basic information (see Fact Sheets under Hydro Facts) 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.

On The Hydro Research Foundation's website, www.hydrofoundation.org, learn about hydropower as a renewable energy resource, and take a Hydro Venture, an excellent resource that explores all aspects of hydropower using real life photos.

On the Federal Energy Regulatory Commission's website, visit the Students' Corner at www.ferc.gov/students/index, to learn more about hydropower. This website includes games, photos of dams and hydropower plants, and a resource section for teachers.

On the Foundation for Water and Energy Education website, www.fwee.org, 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.

At www.pbs.org/wgbh/buildingbig/dam/index.html, the PBS Building Big website, there is a section on dams. 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.

The Bureau of Land Reclamation's website, www.usbr.gov/lc/hooverdam/index, explores 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.

At www.careervoyages.gov, there are two resources about all careers:

Watch "In Demand Occupation Videos" at www.careervoyages.gov/careervideos-main.cfm. This website features short videos for occupations found in the Bureau of Labor Statistics' Occupational Outlook Handbook. This is an excellent place to see careers in action.

Click on "InDemand Magazine" to view or download several magazines with an introduction to the different career paths in construction, energy, advanced manufacturing, and health care and the young professionals who have chosen those careers.

# PRESENTATION TOPIC ORGANIZER

| IMPORTANT INFORMATION | ADDITIONAL INFORMATION NEEDED |
| --- | --- |
| | |

**TOPIC**

| GRAPHICS NEEDED | DESIGN OF PRESENTATION |
| --- | --- |
| | |

# FORMS & SOURCES OF ENERGY

1. Write the form in which the energy is stored or delivered for each source on the line to the right of the source.

| RENEWABLE | | NONRENEWABLE | |
|---|---|---|---|
| Biomass | ____________ | Petroleum | ____________ |
| Hydropower | ____________ | Natural Gas | ____________ |
| Geothermal | ____________ | Coal | ____________ |
| Wind | ____________ | Uranium | ____________ |
| Solar | ____________ | Propane | ____________ |

2. What percentage of the nation's energy is provided by each form of energy? By renewables? By nonrenewables?

| | | | |
|---|---|---|---|
| Chemical | ________ | Renewables | ________ |
| Nuclear | ________ | Nonrenewables | ________ |
| Motion | ________ | | |
| Thermal | ________ | | |
| Radiant | ________ | | |

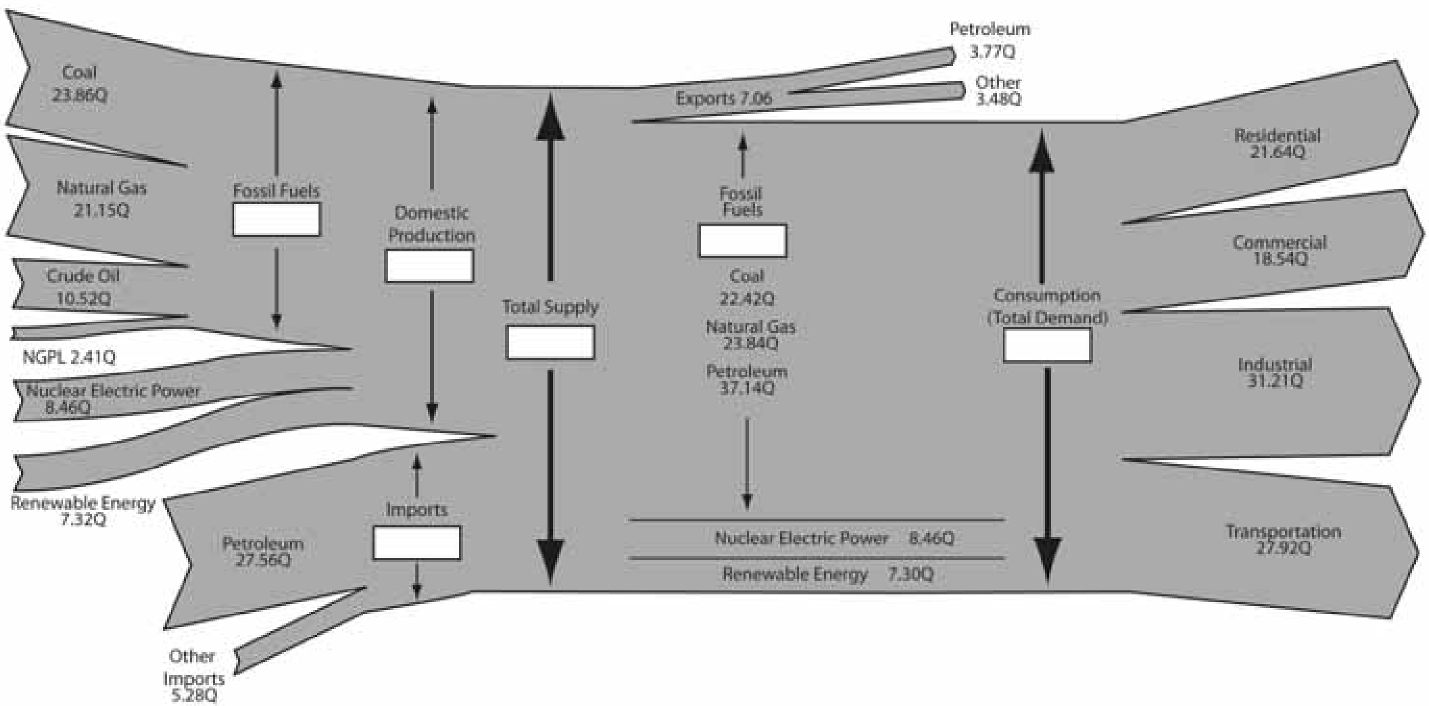
## U.S. Energy Consumption by Source 2008

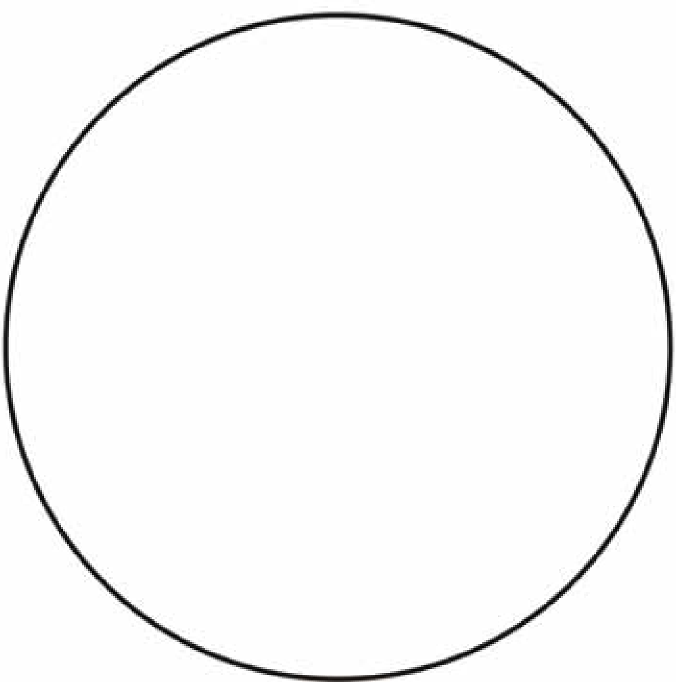
| | | | |
|---|---|---|---|
| **PETROLEUM** nonrenewable<br>transportation, manufacturing | **37.0%** | **BIOMASS** renewable<br>heating, electricity, transportation | **3.9%** |
| **COAL** nonrenewable<br>electricity, manufacturing | **22.6%** | **HYDROPOWER** renewable<br>electricity | **2.5%** |
| **NATURAL GAS** nonrenewable<br>heating, manufacturing, electricity | **23.5%** | **GEOTHERMAL** renewable<br>heating, electricity | **0.4%** |
| **URANIUM** nonrenewable<br>electricity | **8.5%** | **WIND** renewable<br>electricity | **0.5%** |
| **PROPANE** nonrenewable<br>manufacturing, heating | **1.0%** | **SOLAR** renewable<br>light, heating, electricity | **0.1%** |

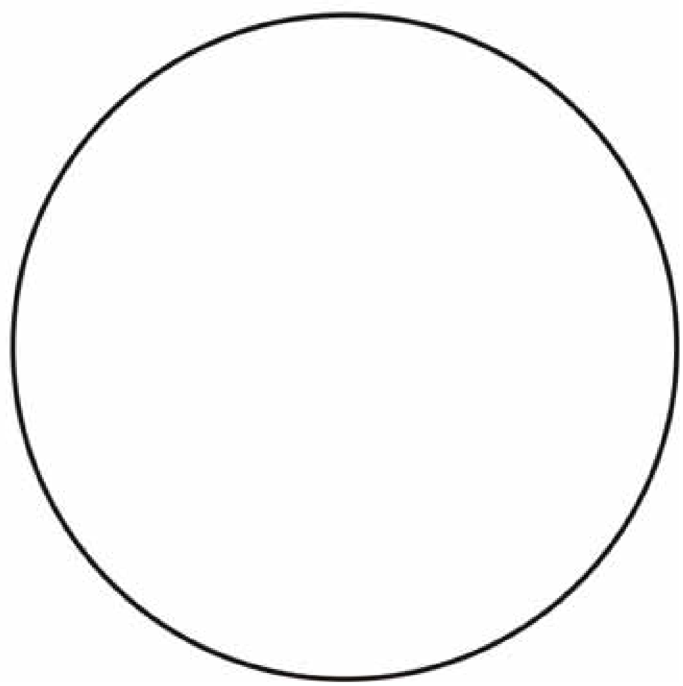
# U.S. ENERGY FLOW 2008

## PRODUCTION ⟶ CONSUMPTION

1. Fill in the blank boxes on the 2008 Energy Flow.
2. Draw and label a pie chart of 2008 Energy Production by Source.
3. Draw and label a pie chart of 2008 Energy Consumption by Sector of the Economy.



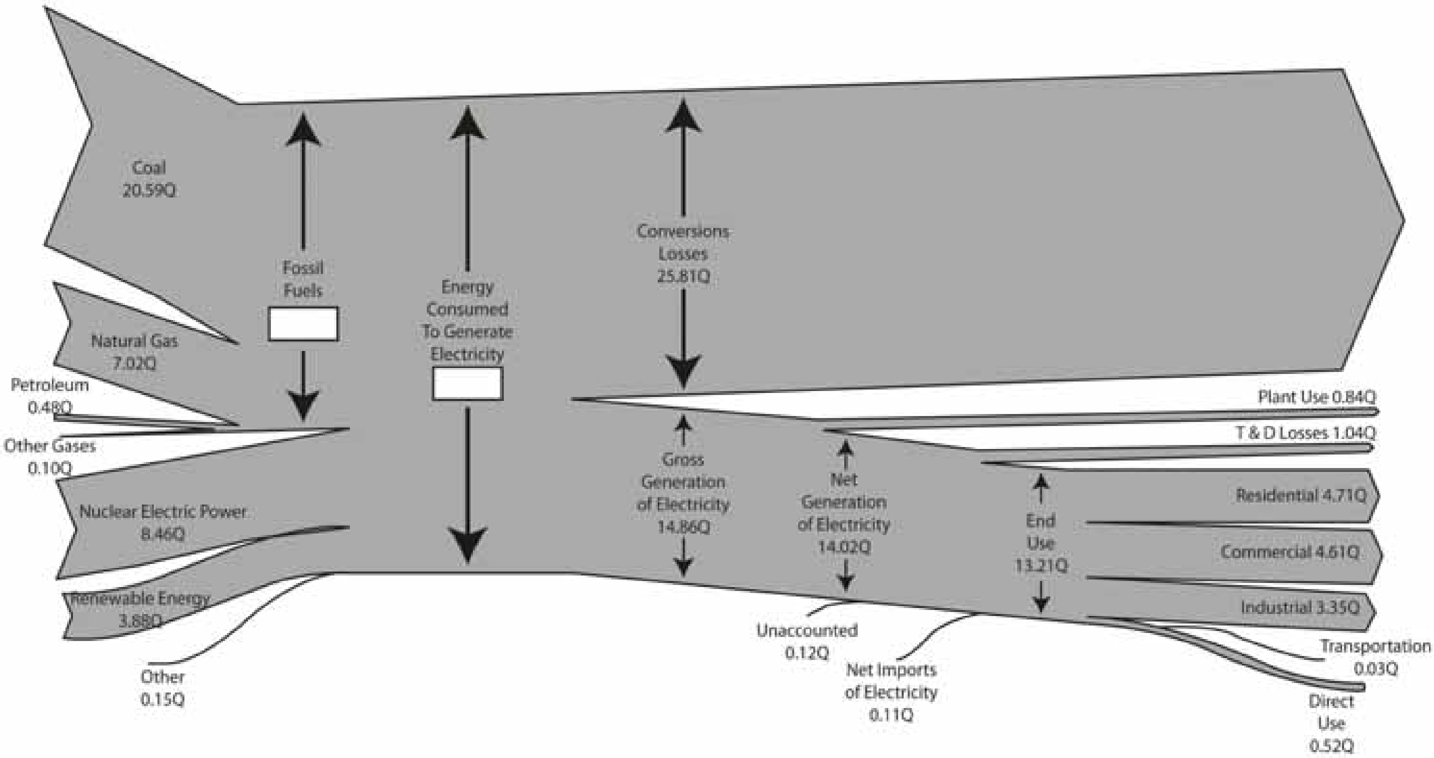



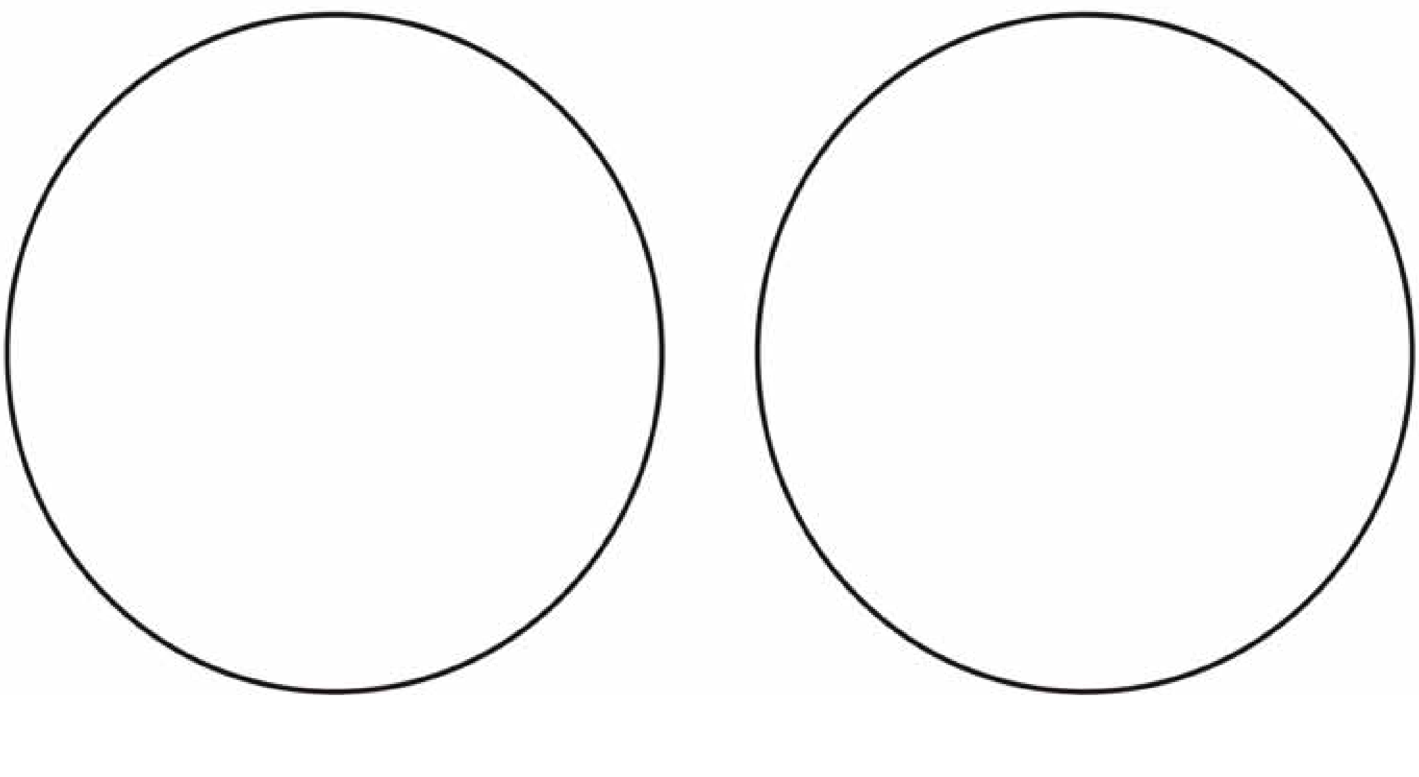


# U.S. ELECTRICITY FLOW 2008

GENERATION → CONSUMPTION

1. Fill in the blank boxes on the 2008 Electricity Flow.
2. Draw and label a pie chart of 2008 Electricity Generation by Source.
3. Draw and label a pie chart of 2008 Electricity Consumption by Gross Generation.
4. On a separate piece of paper write a paragraph explaining Conversion Losses.



# 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 = 6 A x 20 Ω**
**V = 6 A x 20 Ω = 120 V**

***Example 2: Calculating Current***

The voltage of most residential circuits is 120 V. 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 = 120 V / 60 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 V battery pushes 2 A 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 A blender uses 360 W 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 W when connected to a 120 V 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 W for 24 hours, how much electrical energy does it use?
To solve for electrical energy, use the following equation: energy = power x time (E = P x t).

**Electrical Energy = W x t**
**E = 600 W x 24 h = 14,400 Wh/1000 = 14.4 kWh**

If the utility charges $0.11 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 $0.11/kWh = $1.58**

# MEASURING ELECTRICITY

Directions: Fill in the blanks in the tables below.

**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 | |
| Computer | 40 W | = | 120 V | x | |
| Printer | 120 W | = | 120 V | x | |
| Hair Dryer | 1,000 W | = | 120 V | x | |

**Table 4**

| POWER | x | TIME | = | ELECTRICAL ENERGY | x | PRICE | = | COST |
|---|---|---|---|---|---|---|---|---|
| 5 kW | x | 100 h | = | | x | $0.11 | = | |
| 1000 W | x | 1 h | = | | x | $0.11 | = | |
| 25 kW | x | 4 h | = | | x | $0.11 | = | |

# SCIENCE OF ELECTRICITY DEMONSTRATION

After observing the science of electricity demonstration, draw and label a diagram of the apparatus.

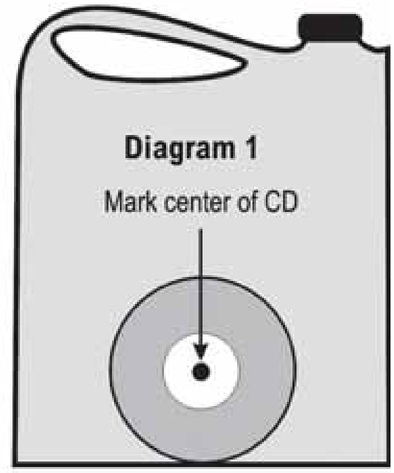
Explain how electricity is generated using appropriate vocabulary.

# TURBINE COMPONENT ASSEMBLY INSTRUCTIONS

MATERIALS:
- 1 Rectangular Jug
- 2 Compact Discs
- 4 Circular Magnets
- 1 Foam Hub (4 cm width)
- 8 Wooden Blades
- 1 Wooden Dowel (12" x 1/4")
- 1 Plastic Tubing (2 cm)
- 1 Spool of Coated Magnet Wire
- Templates for Coils of Wire & Magnets
- 1 Glue Gun with Glue Sticks
- 1 Roll of Masking Tape
- 4 Rubber Stoppers
- 1 Sharp-pointed Scissors
- 1 Permanent Marker
- 1 Nail
- 1 Form (4 cm diameter)
- 1 Sandpaper

Jug Assembly:

1. Cut the bottom off the jug.
2. Stand the jug on the cut bottom, place a CD in the exact middle of the long sides of the jug and mark the CD hole as shown in Diagram 1. Mark the same on the other side of the jug.
3. Use a pushpin to make the initial hole over the mark, then use a nail to widen the hole out. Finally, use a round pencil or pen barrel to widen the hole so the dowel can fit through easily. Try to keep the hole edges as smooth as possible.

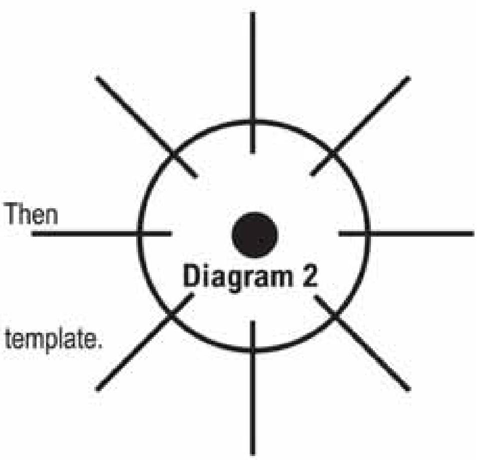



Hub Assembly:

1. Make a hole in the exact center of the foam hub with the nail.
2. Mark the hub for the placement of 8 blades as shown in Diagram 2.
3. Attach 4 blades equally spaced around the hub. You will add the other 4 later.
4. Make sure the hub will fit into the jug. Glue the 4 blades in place to reinforce.

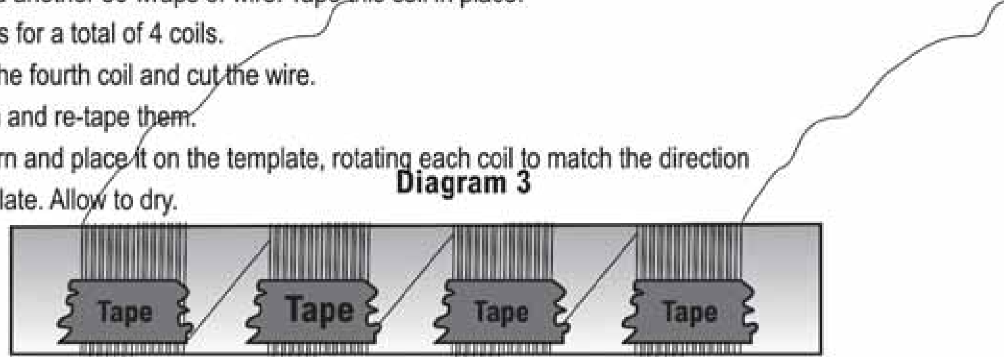
CD/Magnet Assembly (see CD Template on page 37):

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




CD/Wire Assembly (see Wire Template on page 37):

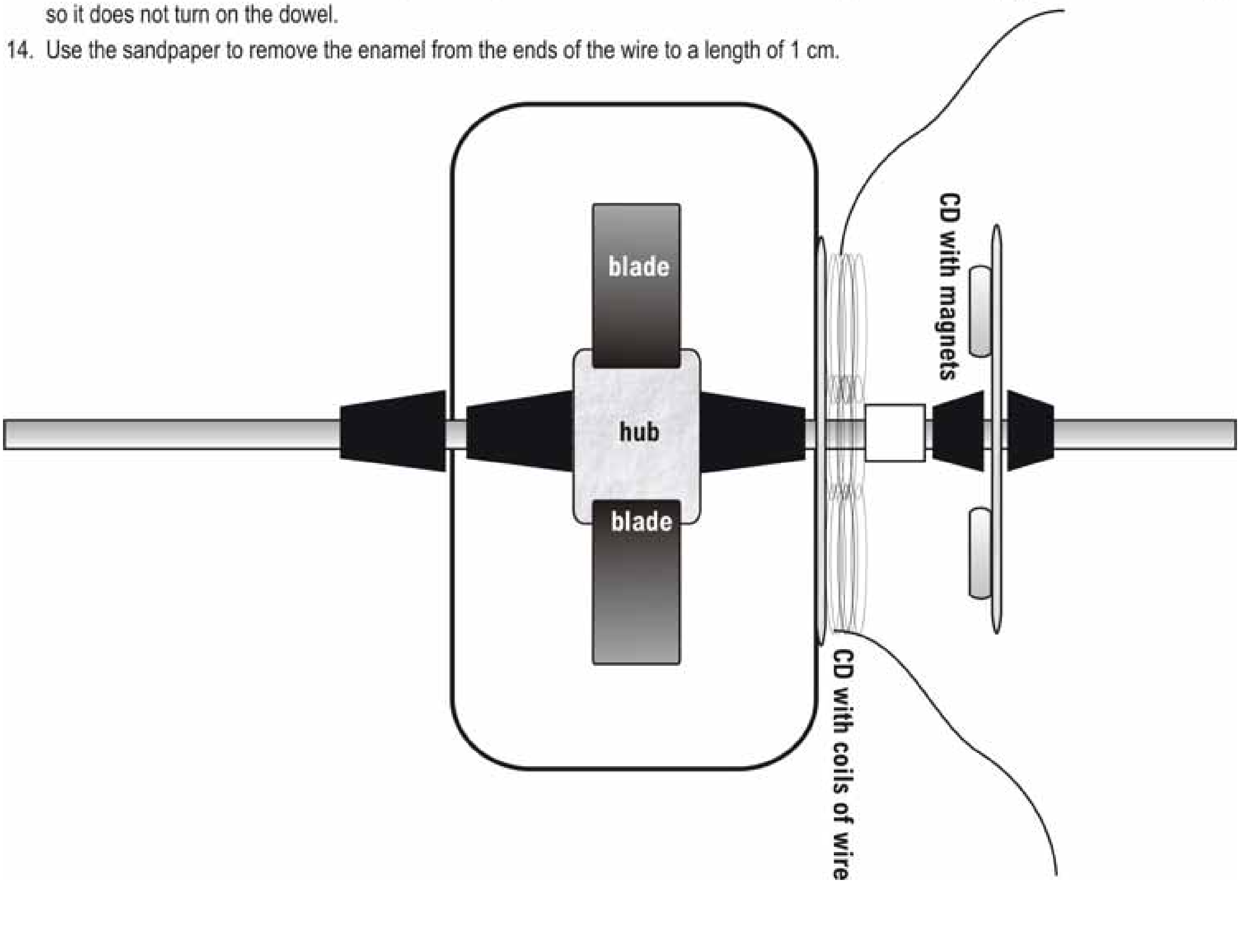
1. Cut out the template for the wire and glue to the second CD. Allow to dry.
2. Leaving 15 cm of wire at the beginning, loosely wind 50 wraps of wire around the 4 cm form as shown in Diagram 3. DO NOT CUT THE WIRE. Tape the coil of wire in place.
3. Drop 2 cm down the form, and wind another 50 wraps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



# TURBINE UNIT ASSEMBLY INSTRUCTIONS

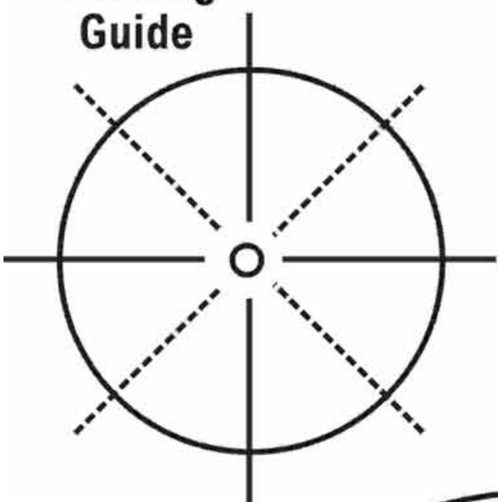
Turbine Unit Assembly:

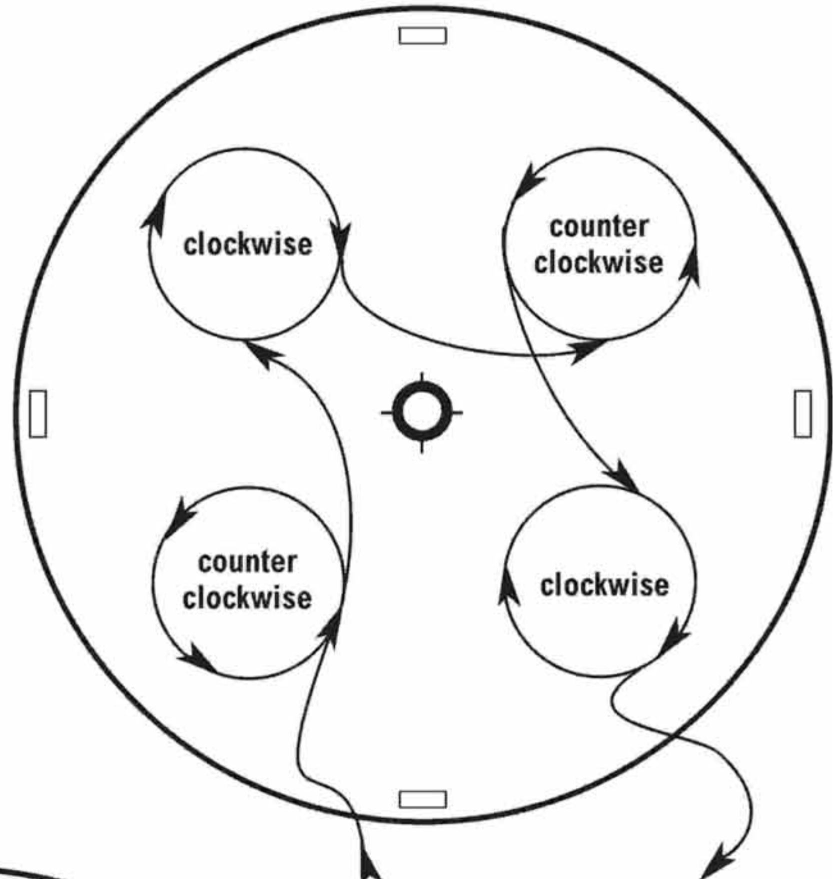
1. Slide the dowel through the holes in the container. Determine where the dowel will pass through the jug and make a mark these areas. Remove the dowel and put one strip of clear tape over these locations. Make sure the tape is smooth. Color over the tape with a graphite pencil, this will help the dowel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



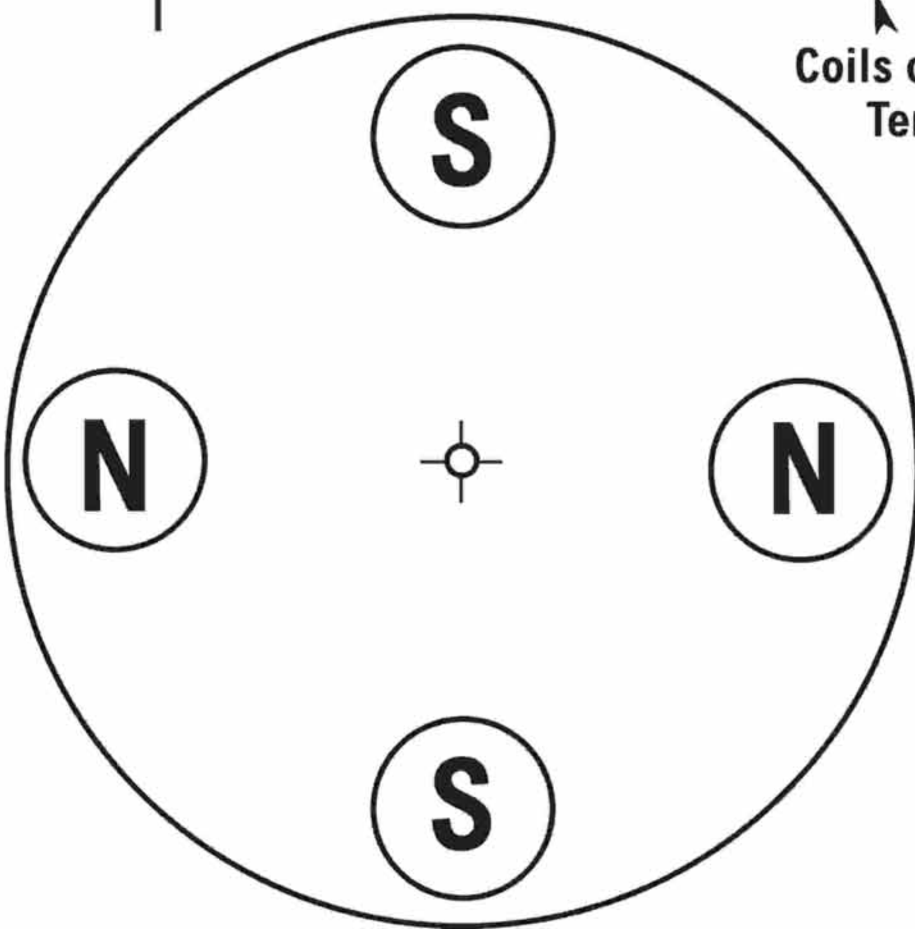
# TURBINE UNIT TEMPLATES

**Hub Marking Guide**






**Coils of Wire CD Template**




**Magnet CD Template**

# WATER RESERVOIR UNIT INSTRUCTIONS

1. Examine the water reservoir unit. Become familiar with the operation of the hose clamp.
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. Tighten the top securely and make sure the clamp on the hose is shut.
3. Lift the hose above the unit, slightly open the clamp and put pressure on the unit to remove any air pockets at the top of the unit. Close the clamp.
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 that there are no kinks in the hose when conducting experiments.
6. When conducting the experiments, pinch the hose closed and remove the clamp to ensure a constant rate of flow. Replace the clamp and close it to refill the unit.
7. Make sure the water from the hose hits the blades of the hub as shown in Diagram 2.
8. After each trial, use the funnel to pour the water from the bucket back into the unit. If necessary, add more water so that the unit is completely full.

**Diagram 1**

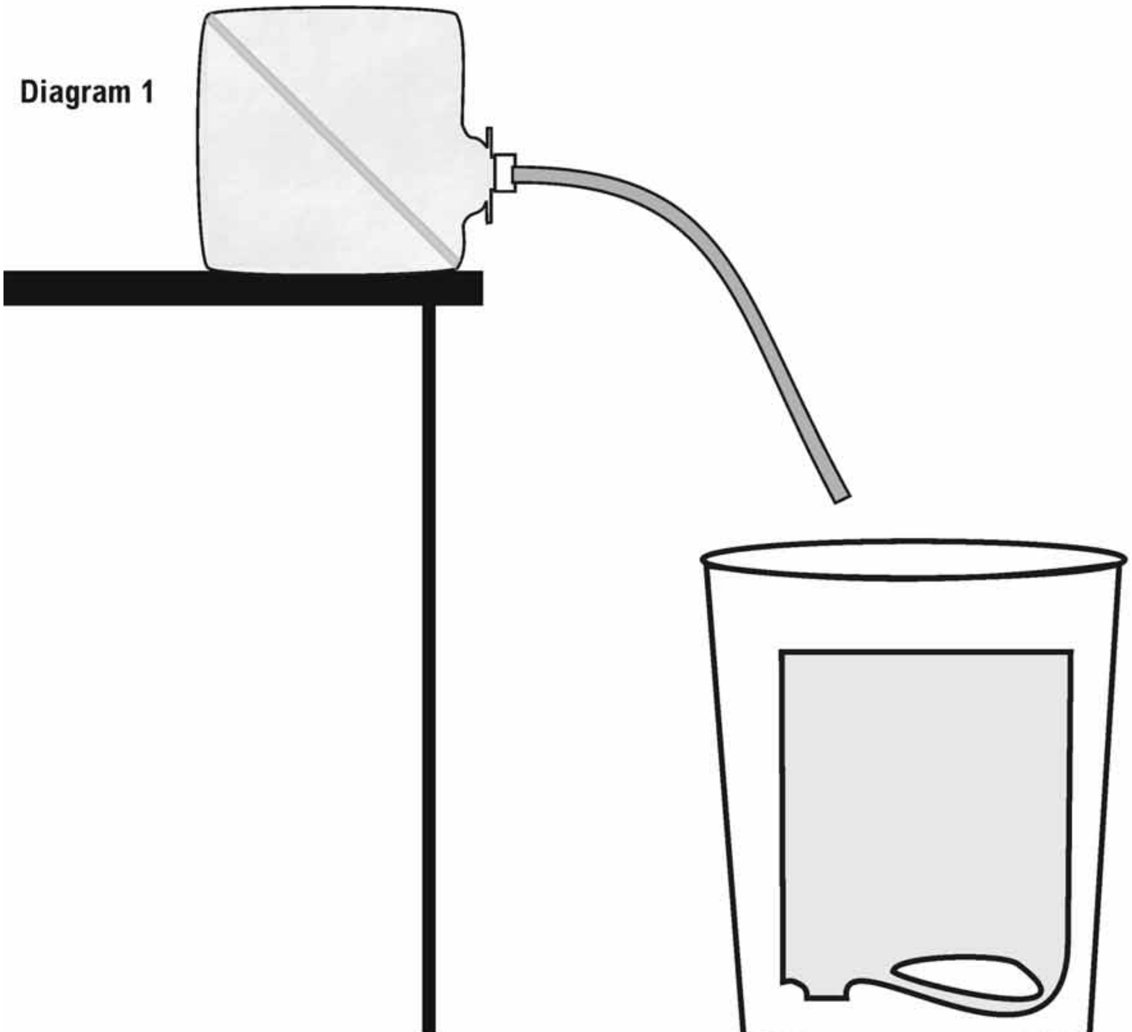
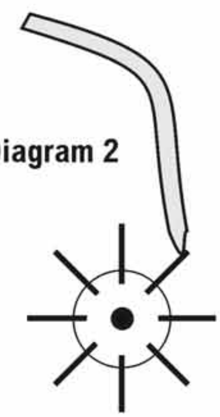


**Diagram 2**



# EXPLORING TURBINE BLADES

PURPOSE: To determine the number of blades that more effectively converts the energy of flowing water into electricity.

MATERIALS: turbine, water reservoir unit, water collection bucket, multimeter, alligator clips, funnel, meter stick, water supply

QUESTION: How does changing the number of blades on a water-driven turbine affect electrical output?

HYPOTHESIS: Develop a hypothesis to address the question, using this format:
If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent - the variable that changes): number of blades
Responding Variable (dependent - the variable that is measured): electrical output
Controlled Variables (variables that are constant): distance to water source, force of water

PROCEDURE:

1. Attach the multimeter to the ends of the turbine wires with the alligator clips. Set it to the 200 mA setting.
2. Place the turbine in the water collection bucket with the wide opening at the top. Fill the water reservoir unit and place it on a table about 50 cm higher than the top of bucket. Pinch the hose together and remove the clamp.
3. Holding the end of the hose at the level of the top of the turbine assembly, allow the water to flow, pointing the hose so that the water flows on the blades for 10 seconds and record the most consistent output reading. Empty the bucket back into the water reservoir 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 8 blades. Make sure the position of the hose remains constant for all trials.

DATA TABLE:

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

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

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

QUESTION: What do you think the result would be if you added 8 additional blades to the hub?

# EXPLORING RESERVOIR HEIGHT

PURPOSE: To explore how the height of the water reservoir affects the output of a turbine.

MATERIALS: turbine unit with 8 blades, water reservoir unit, water collection bucket, multimeter, alligator clips, water supply, funnel, meter stick

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

HYPOTHESIS: Develop a hypothesis to address the question, using this format:
If (manipulated variable) then (responding variable) because...

Manipulated Variable (independent - the variable that changes): height of reservoir
Responding Variable (dependent - the variable that is measured): electrical output
Controlled Variable (variable that is constant): amount of water in reservoir

PROCEDURE:

1. Place the turbine unit into the water collection bucket.
2. Fill the 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 bucket 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 with water.
6. Repeat Steps 1 - 5 two times. Calculate the average output.
7. Repeat Steps 1 - 6 at reservoir heights of 65 and 100 cm.

DATA TABLE:

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

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

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

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

# EXPLORING COPPER WRAPS

PURPOSE: To determine the optimum number of copper coils which will lead to the greatest electrical output.

QUESTION: How does the number of copper wire wraps effect the electrical output?

HYPOTHESIS: Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because …

Manipulated Variable (independent or the one variable that changes):
Responding Variable (dependent or the variable you measure): Electrical Output
Controlled Variables (variables that are kept the same):

MATERIALS:

PROCEDURE:

1. Decide how many wraps of coil to use on your stator.
2. Use the Benchmark Turbine from Exploration #1 that had the best electrical output.
3. Place the Hydropower model into the water collection bucket.
4. Fill the reservoir unit with one gallon of water.
5. Place the bottom of your water reservoir unit at the optimum height as determined in the Exploration #2.
6. Place the hose in the mouth of the hydropower model and let the water flow.
7. Record the electrical output as soon as possible to control the loss of water variable.
8. Empty water collection bucket back into the reservoir, make sure there is one gallon of water in the reservoir.
9. Repeat steps 3-7 two more times for a total of three trials.
10. Repeat steps 1-8 with different numbers of copper wire wraps.

DATA TABLE:

Graph your data: The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

Conclusion: Using results from your data table support your reasoning and explain how many wraps of coil are most effective in producing electricity. Include why you think this is the case.

# INDEPENDENT TURBINE INVESTIGATION

PURPOSE: To determine the optimum ___________________ which will lead to the greatest electrical output.

QUESTION: How does ________________ effect the electrical output?

HYPOTHESIS: Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because …

Manipulated Variable (independent or the one variable that changes):
Responding Variable (dependent or the variable you measure): Electrical Output
Controlled Variables (variables that are kept the same):

MATERIALS

PROCEDURE:

1.
2.
3.
4.
5.

DATA TABLE:

Graph your data: The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

Conclusion: Using results from your data table support your reasoning and explain how many wraps of coil are most effective in producing electricity. Include why you think this is the case.

# ISSUE ORGANIZER

**ADVANTAGES OF ACTIONS**

**DISADVANTAGES OF ACTIONS**

**SCENARIO:**

**STAKEHOLDER:**

**POSITION & THREE REASONS**

**FACTS TO SUPPORT REASONS**

# GLOSSARY

alternating current (AC) – electric current that reverses direction many times per second.

alternative energy – energy derived from sources that do not consume natural resources or harm the environment to the extent that fossil fuels do.

appurtenant works – supplementary features of a dam such as outlets, spillways, power plants, and tunnels.

arch dam – a concrete, masonry, or timber dam with the alignment curved upstream.

buttress dam – a dam consisting of a watertight part supported at intervals on the downstream side by a series of buttresses.

cofferdam – a temporary dam structure enclosing all or part of a construction area so that construction can be performed. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse.

conventional hydropower plant – a facility that uses available water from rivers, streams, canals and reservoirs to produces 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.

direct current (DC) – electric current that flows in one direction.

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.

embankment dam – any dam constructed of excavated natural materials, such as dirt and rock, or of industrial waste materials.

Federal Energy Regulatory Commission (FERC) – the federal agency that licenses hydropower projects of nonfederal facilities.

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 waterwheel or turbine.

generator – a machine that converts mechanical energy into electrical energy.

geothermal – refers to the radiogenic heat supply from the interior of the Earth.

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 tailwater level.

head water – the water level above a powerhouse.

hydrokinetic energy – captured moving energy from the flow of water across or through blades to power a generator, similar to how a wind turbine captures the wind.

hydropower – the use of water to generate electricity.

kilowatt – a unit of electrical power equal to 1,000 watts.

kinetic energy – the energy of motion.

micro hydropower – a small facility capable of producing up to 100 kilowatts of power.

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.

non-overflow dam – a dam that diverts excess water to spillways to control the pressure and potential energy of the dam.

Ohm's Law – the law that explains the relationship between current, voltage and resistance in an electrical circuit. In all electrical circuits, the current (I) of that circuit is directly proportional to the voltage (W) applied to that circuit and inversely proportional to the resistance (R) of that same circuit.

oscillating water column – a facility built into a cliff that captures wave energy.

osmotic power – technology that generates electricity using osmosis.

overflow dam – a dam that allows excess water to spill over its rim.

penstock – a closed conduit or pipe for conducting water to a waterwheel, turbine or powerhouse.

photovoltaic – producing electricity directly from radiant energy.

potential energy – stored energy; potential energy includes stored chemical and stored gravitational energy.

power plant – the equipment attached to a dam that generates electricity, including the turbines and generators.

pumped storage plant – a hydropower facility with two reservoirs (one higher than the other) used for peak generation. Water from the lower reservoir is pumped into the higher reservoir to be stored until demand is high.

renewable energy source – an energy source with a short term replenish rate, including biomass, geothermal, hydropower, solar and wind.

reservoir – a natural or artificial pond or lake for storing and regulating water.

run-of-river project – a hydropower facility with turbines placed in fast flowing sections of rivers to generate power without impeding the river's natural flow.

salter duck – a machine that can capture the energy in the movement of ocean waves.

small hydro – a hydropower project that produces 30 MW or less of electricity.

spillway – a channel for overflow of water from a reservoir.

stator – a stationary part of a motor about which a motor revolves.

TAPCHAN system – a tapered channel facility built into a cliff that generates electricity from energy in the waves.

tail water – the water downstream of a dam's powerhouse.

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 power – hydropower derived from the rise and fall of the tides.

trough – the lowest point of a wave.

turbine – a waterwheel with a series of curved blades or buckets that converts the kinetic energy of a moving fluid to mechanical power.

wicket gate – an adjustable element of a dam that controls the flow of water to the turbine passage.

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