



# Electricity

## Electricity: The Mysterious Force

What exactly is the mysterious force we call electricity? It is simply moving **electrons**. And what exactly are electrons? They are tiny particles found in **atoms**.

Everything in the universe is made of atoms—every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. There are over 100 different types of atoms found in the world around us that make up elements. Each element is identified and organized into the periodic table. Atoms of these elements are so small that millions of them would fit on the head of a pin.

Atoms are made of even smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons** and **neutrons**. The protons and neutrons are very small, but electrons are much, much smaller. Electrons spin around the nucleus in energy

levels a great distance from the nucleus. If the nucleus were the size of a tennis ball, the atom would be several kilometers in diameter. Atoms are mostly empty space.

If you could see an atom, it would look a little like a tiny center of spheres surrounded by giant invisible clouds. The electrons would be on the surface of the clouds, constantly spinning and moving to stay as far away from each other as possible on their **energy levels**. Electrons are held in their levels by an electrical force.

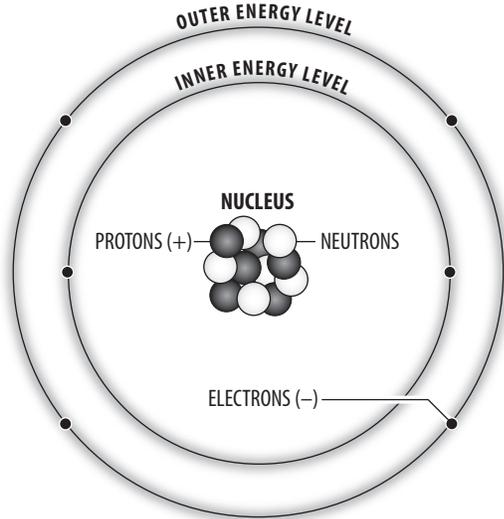
The protons and electrons of an atom are attracted to each other. They both carry an **electric charge**. An electric charge is a force within the particle. Protons have a positive charge (+) and electrons have a negative charge (-). The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other. When an atom is in balance, it has an equal number of protons and electrons. Neutrons carry no charge, and their number can vary.

## The Periodic Table of the Elements

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5	<b>Rb</b> Rubidium 85.4678	<b>Sr</b> Strontium 87.62	<b>Y</b> Yttrium 88.90585	<b>Zr</b> Zirconium 91.224	<b>Nb</b> Niobium 92.90638	<b>Mo</b> Molybdenum 95.94	<b>Tc</b> Technetium (98)	<b>Ru</b> Ruthenium 101.07	<b>Rh</b> Rhodium 102.90550	<b>Pd</b> Palladium 106.42	<b>Ag</b> Silver 107.8682	<b>Cd</b> Cadmium 112.411	<b>In</b> Indium 114.818	<b>Sn</b> Tin 118.710	<b>Sb</b> Antimony 121.760	<b>Te</b> Tellurium 127.60	<b>I</b> Iodine 126.90447	<b>Xe</b> Xenon 131.293																																																																		
6	<b>Cs</b> Cesium 132.90545	<b>Ba</b> Barium 137.327	<b>Hf</b> Hafnium 178.49	<b>Ta</b> Tantalum 180.9479	<b>W</b> Tungsten 183.84	<b>Re</b> Rhenium 186.207	<b>Os</b> Osmium 190.23	<b>Ir</b> Iridium 192.217	<b>Pt</b> Platinum 195.078	<b>Au</b> Gold 196.96655	<b>Hg</b> Mercury 200.59	<b>Tl</b> Thallium 204.3833	<b>Pb</b> Lead 207.2	<b>Bi</b> Bismuth 208.98038	<b>Po</b> Polonium (209)	<b>At</b> Astatine (210)	<b>Rn</b> Radon (222)																																																																			
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## Carbon Atom

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



The number of protons in an atom determines the kind of atom, or **element**, it is. An element is a substance in which all of the atoms are identical. An atom of hydrogen, for example, has one proton and one electron, and almost always no neutrons. Every stable atom of carbon has six protons, six electrons, and typically six neutrons. The number of protons is also called the **atomic number**. The atomic number is used to identify an element.

Electrons usually remain a relatively constant distance from the nucleus in well defined regions called energy levels. The level closest to the nucleus can hold two electrons. The next level can hold up to eight. The outer levels can hold even more. Some atoms with many protons can have as many as seven levels with electrons in them.

The electrons in the levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost levels do not. These electrons can be pushed out of their orbits. Applying a force can make them move from one atom to another. These moving electrons are electricity.

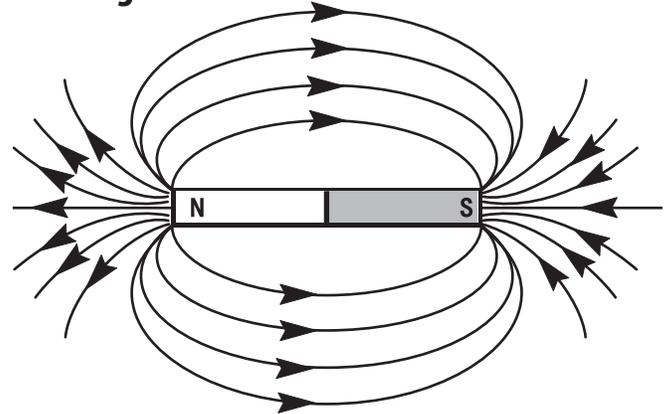
## Magnets

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

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

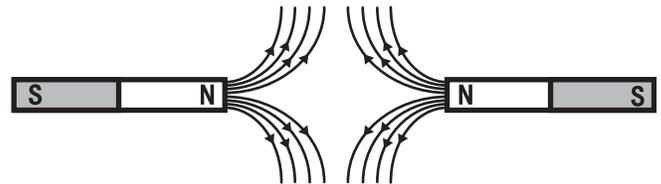
Spinning electrons create small **magnetic fields** and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic fields.

## Bar Magnet



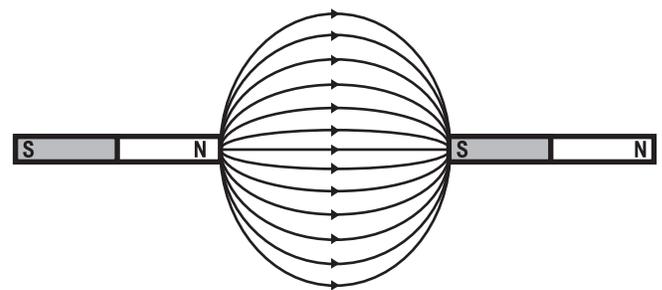
## Like Poles

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



## Opposite Poles

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



Magnets are different—most of the atoms' electrons spin in the same direction, which means the north- and south-seeking poles of the micro-magnets they create are aligned. Each micro-magnet works together to give the magnet itself a north- and south-seeking pole.

A magnet is often labelled with north (N) and south (S) poles. The magnetic force in a magnet flows from the north pole to the south pole.

Have you ever held two magnets close to each other? They don't act like most objects. If you try to push the south poles together, they repel each other. The two north poles also repel each other.

If you turn one magnet around, the north and the south poles are attracted to each other. The magnets come together with a strong force. Just like protons and electrons, opposites attract.



# Electricity

## Magnets Can Produce Electricity

We can use magnets to make electricity. A magnetic field can move electrons. Some metals, like copper, have electrons that are loosely held; they are easily pushed from their levels.

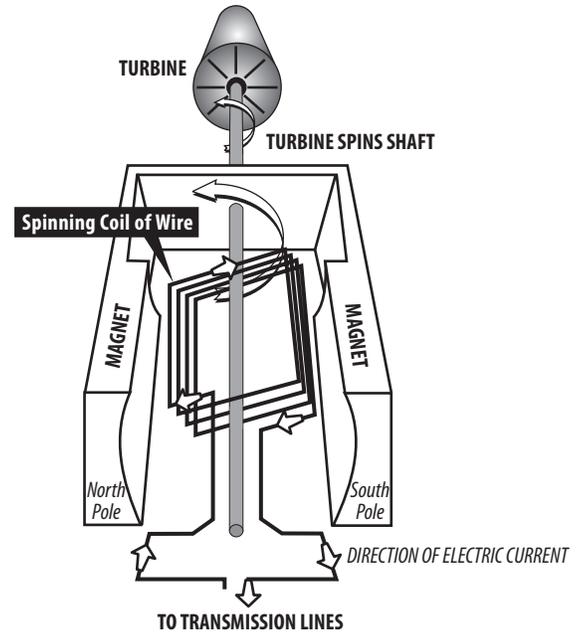
Magnetism and electricity are related. Magnets can create electricity and electricity can produce magnetic fields. Every time a magnetic field changes, an electric field is created. Every time an electric field changes, a magnetic field is created. Magnetism and electricity are always linked together; you can't have one without the other. This phenomenon is called **electromagnetism**.

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

The turbine is attached to a shaft in the generator. Inside the **generator** are magnets and coils of copper wire. The magnets and coils can be designed in two ways—the turbine can spin the magnets inside the coils or can spin coils inside the magnets. Either way, the electrons are pushed from one copper atom to another by the moving magnetic field.

Coils of copper wire are attached to the turbine shaft. The shaft spins the coils of wire inside two huge magnets. The magnet on one side has its north pole to the front. The magnet on the other side has its south pole to the front. The magnetic fields around these magnets push and pull the electrons in the copper wire as the wire spins. The electrons in the coil flow into transmission lines. These moving electrons are the electricity that flows to our houses. Electricity moves through the wire very quickly.

## Turbine Generator



## HYDROPOWER TURBINE GENERATORS

### HYDROELECTRIC PLANT



Photo of Safe Harbor Water Power Corporation on the Lower Susquehanna River in Pennsylvania.

## Batteries Produce Electricity

A **battery** produces electricity using two different metals in a chemical solution. A **chemical reaction** between the metals and the chemicals frees more electrons in one metal than in the other.

One end of the battery is attached to one of the metals; the other end is attached to the other metal. The end that frees more electrons develops a positive charge, and the other end develops a negative charge because it attracts the free, negatively charged electrons. If a wire is attached from one end of the battery to the other, electrons flow through the wire to balance the electrical charge.

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

## Electricity Travels in Circuits

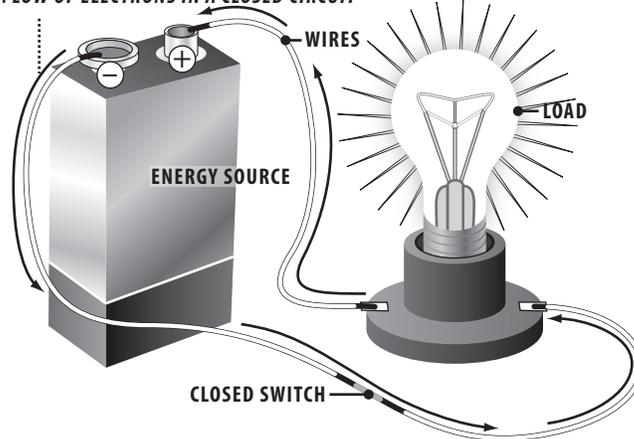
Electricity travels in closed loops, or **circuits**. It must have a complete path before the electrons can move. If a circuit is open, the electrons cannot flow. When we flip on a light switch, we close a circuit. The electricity flows from the electric wire through the light and back into the wire.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

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

In the United States, we use electricity to light our homes, schools, and businesses. We use it to warm and cool our homes and help us clean them. Electricity runs our TVs, DVD players, video games, and computers. It cooks our food and washes the dishes. It mows our lawns and blows the leaves away. It can even run our cars.

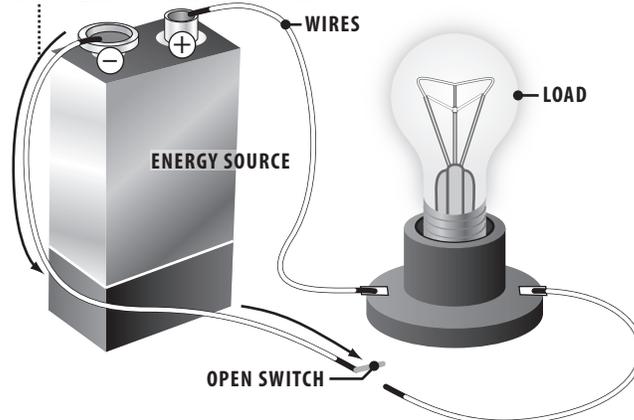
## Electric Circuits

### FLOW OF ELECTRONS IN A CLOSED CIRCUIT



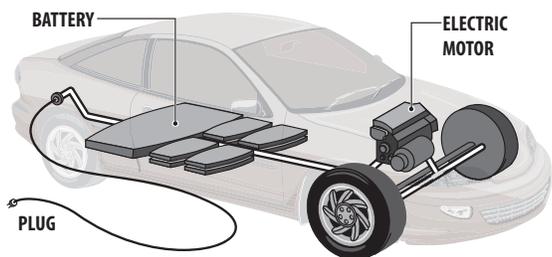
A closed circuit is a complete path allowing electricity to flow from the energy source to the load.

### FLOW OF ELECTRONS IN AN OPEN CIRCUIT



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

## How an Electric Vehicle Works



Recently, there has been more interest in using electricity to help reduce the amount of petroleum consumed by the transportation sector.

The plug-in hybrid electric vehicle (PHEV) and the dedicated electric vehicle (EV) are available to consumers in the open market. Many car manufacturers are offering PHEVs and EVs in more models.

As the diagram to the left shows, electric vehicles store electricity in large battery banks. They are plugged into a wall outlet (either a 240-volt or standard 120-volt) for several hours to charge. An electric motor powers the wheels, and acts as a generator when the brakes are applied, recharging the battery.



# Electricity

## Secondary Energy Source

Electricity is different from primary sources of energy. Unlike coal, petroleum, or solar energy, electricity is a **secondary source of energy**. That means we must use other energy sources to make electricity. It also means we can't classify electricity as renewable or nonrenewable.

Coal, which is nonrenewable, can be used to make electricity. So can hydropower, a renewable energy source. The energy source we use can be renewable or nonrenewable, but electricity is neither.

## Generating Electricity

Most of the electricity we use in the United States is generated by large power plants. These plants use many fuels to produce electricity. Thermal power plants use coal, biomass, petroleum, or natural gas to superheat water into steam, which powers a generator to produce electricity. Nuclear power plants use **fission** to produce the heat. Geothermal power plants use heat from inside the Earth. Wind farms use the kinetic energy in the wind to generate electricity, while hydropower plants use the energy in moving water.

## Moving Electricity

We use more electricity every year. One reason we use so much electricity is that it's easy to move from one place to another. It can be made at a power plant and moved long distances before it is used. There is also a standard system in place so that all of our machines and appliances can operate on electricity. Electricity makes our lives simpler and easier.

Let's follow the path of electricity from a power plant to a light bulb in your home. First, the electricity is generated at a power plant. It travels through a wire to a **transformer** that steps up, or increases, the **voltage**. Power plants step up the voltage because less electricity is lost along the power lines when it is at a higher voltage.

The electricity is then sent to a nationwide network of **transmission lines**. This is called the electric **grid**. Transmission lines are the huge tower lines you see along the highway. The transmission lines are interconnected, so if one line fails, another can take over the load.

Step-down transformers, located at **substations** along the lines, reduce the voltage from 350,000 volts to 12,000 volts. Substations are small fenced-in buildings that contain transformers, switches, and other electrical equipment.

The electricity is then carried over **distribution lines** that deliver electricity to your home. These distribution lines can be located overhead or underground. The overhead distribution lines are the power lines you see along streets.

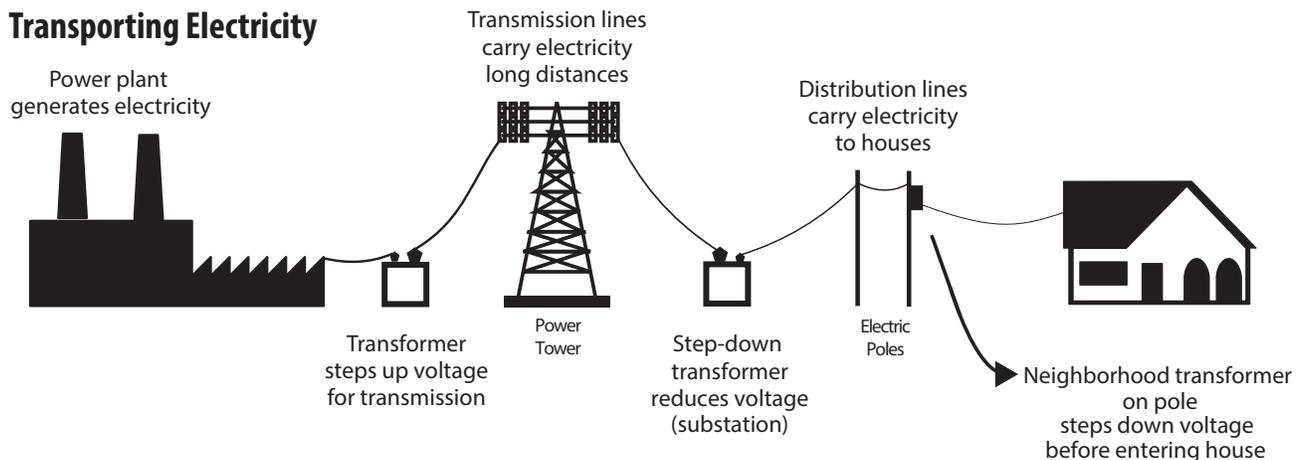
Before the electricity enters your house, the voltage is reduced again at another transformer, usually a large gray metal box mounted on an electric pole. This transformer reduces the electricity to the 120 or 240 volts that are used to operate the appliances in your home.

Electricity enters your home through a three-wire cable. Wires are run from the circuit breaker or fuse box to outlets and wall switches in your home. An electric meter measures how much electricity you use so that the utility company can bill you.

### TRANSMISSION LINES



### Transporting Electricity



## Fuels that Make Electricity

Four kinds of power plants produce most of the electricity in the United States: coal, natural gas, nuclear, and hydropower. Coal plants generate about 39 percent of the electricity we use. There are also wind, geothermal, waste-to-energy, and solar power plants, which together generate less than ten percent of the electricity produced in the United States.

### ▪ Fossil Fuel Power Plants

**Fossil fuel** plants burn coal, natural gas, or oil to produce electricity. These energy sources are called fossil fuels because they were formed from the remains of ancient sea plants and animals. Most of our electricity comes from fossil fuel plants.

Power plants burn the fossil fuels and use the heat to boil water into steam. The steam is channeled through a pipe at high pressure to spin a turbine generator to make electricity. Fossil fuel power plants produce emissions that can pollute the air and contribute to global climate change.

Fossil fuel plants are sometimes called thermal power plants because they use heat energy to make electricity. (*Therme* is the Greek word for heat.) Coal is used by most power plants because it is cheap and abundant in the United States.

There are many other uses for petroleum and natural gas, but the main use of coal is to produce electricity. Almost 93 percent of the coal mined in the United States is sent to power plants to make electricity.

### ▪ Nuclear Power Plants

Nuclear power plants are called thermal power plants, too. They produce electricity in much the same way as fossil fuel plants, except that the fuel they use is **uranium**, which isn't burned.

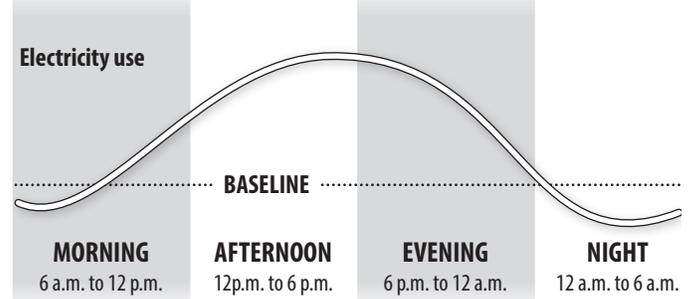
Uranium is a mineral found in rocks underground. A nuclear power plant splits the nuclei of uranium atoms to make smaller atoms in a process called **fission** that produces enormous amounts of thermal energy. The thermal energy is used to turn water into steam, which drives a turbine generator.

Nuclear power plants don't produce carbon dioxide emissions, but their waste is **radioactive**. Nuclear waste must be stored carefully to prevent contamination of people and the environment.

### ▪ Hydropower Plants

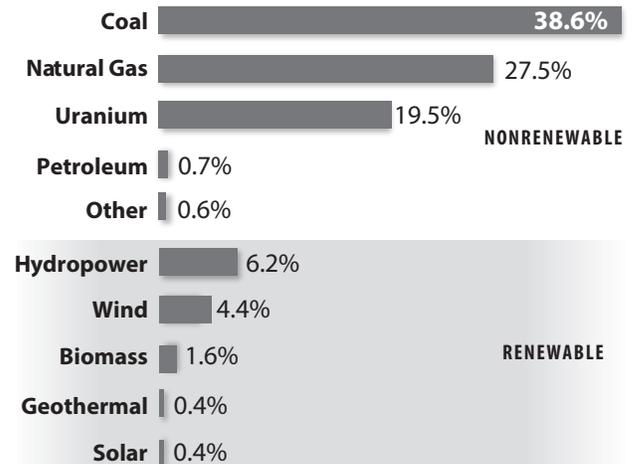
Hydropower plants use the energy in moving water to generate electricity. Fast-moving water is used to spin the blades of a turbine generator. Hydropower is called a **renewable** energy source because it is renewed by rainfall.

## Peak Demand



**Peak demand**, also called peak load, is the maximum load during a specified period of time.

## U.S. Electricity Net Generation, 2014

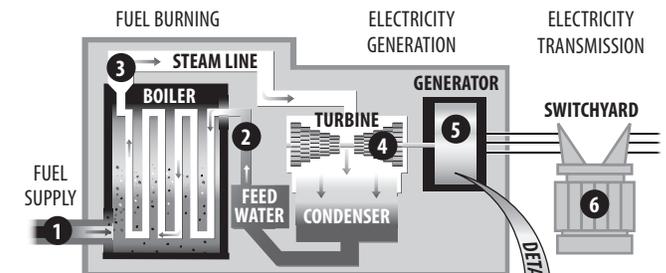


\* Total does not equal 100%, due to independent rounding.

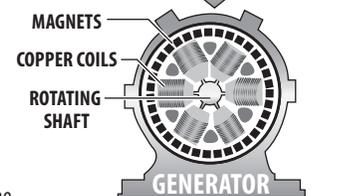
\*\* Other: non-biogenic waste, fossil fuel gases.

Data: Energy Information Administration

## Thermal Power Plant



1. Fuel is fed into a boiler, where it is burned to release thermal energy.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.





# Electricity

## What's a Watt?

We use electricity to perform many tasks. We use units called watts, kilowatts, and kilowatt-hours to measure the electricity that we use.

A **watt** is a measure of the electric power an appliance uses. Every appliance requires a certain number of watts to work correctly. Traditional light bulbs were rated by watts (60, 75, 100), as well as home appliances, such as a 1500-watt hairdryer. A **kilowatt** is 1,000 watts. It is used to measure larger amounts of electricity.

A **kilowatt-hour** (kWh) measures the amount of electricity used in one hour. Sometimes it's easier to understand these terms if you compare them to a car. A kilowatt is the *rate* of electric flow, or how much energy you are consuming at a specific instant. In a car, it would be similar to how fast you are driving at one instant. A kilowatt-hour is a quantity or amount of energy, or how much you consumed over a period of time. A kWh is like the distance traveled in a car.

We pay for the electricity we use in kilowatt-hours. Our power company sends us a bill for the number of kilowatt-hours we use every month. Most residential consumers in the United States pay about 12.5 cents per kilowatt-hour of electricity. In 2014, Washington state residents paid the least for electricity: 8.67 cents per kilowatt-hour. Hawaii residents paid the most: between 30 to 37 cents per kilowatt-hour, depending on the island.

## Cost of Electricity

How much does it cost to make electricity? It depends on several factors, such as:

- **Fuel Cost:** The major cost of generating electricity is the cost of the fuel. Many energy sources can be used. Hydropower is the cheapest way while solar cells are usually the most expensive way to generate power.
- **Building Cost:** Another key is the cost of building the power plant itself. A plant may be very expensive to build, but the low cost of the fuel can make the electricity economical to produce. Nuclear power plants, for example, are very expensive to build, but their fuel—uranium—is inexpensive. Coal-fired plants, on the other hand, are cheaper to build, but their fuel—coal—is more expensive.
- **Efficiency:** When figuring cost, you must also consider a plant's efficiency. Efficiency is the amount of useful energy you get out of a system. A totally efficient machine would change all the energy put in it into useful work. Changing one form of energy into another always involves a loss of usable energy.

In general, today's power plants use three units of fuel to produce one unit of electricity. Most of the lost energy is waste heat. You can see this waste heat in the great clouds of steam pouring out of giant cooling towers on some power plants. A typical coal plant burns about 4,500 tons of coal each day. About two-thirds of the chemical energy in the coal (3,000 tons) is lost as it is converted first to thermal energy, and then to motion energy, and finally into electrical energy.

## How Much Is a Watt?



**1 WATT**  
Small, LED flashlight



**1.5 KILOWATTS = 1500 WATTS**  
Blow dryer



**3 TO 5 MEGAWATTS =**  
**3,000,000 to 5,000,000 WATTS**  
Diesel-electric locomotive engines

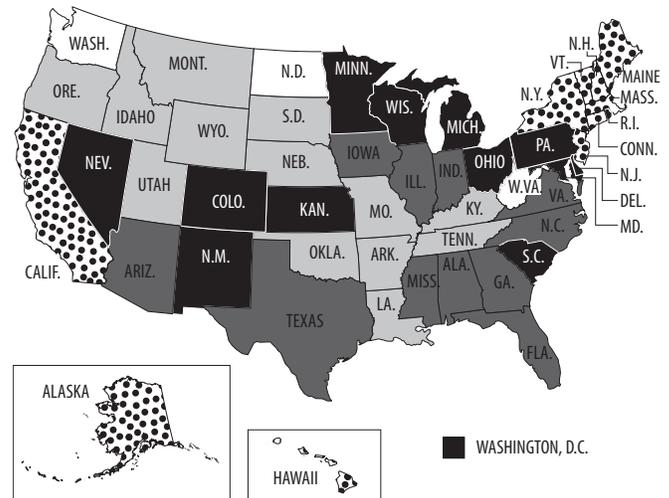


**2 GIGAWATTS =**  
**2,000,000,000 WATTS**  
Peak output of the Hoover Dam

## Average Residential Price for Electricity, 2014

PRICE PER KILOWATT-HOUR

- ◻ < 9.5¢ / kWh
- ◻ 9.5 to 11¢ / kWh
- ◻ 11 to 12¢ / kWh
- ◻ 12 to 15¢ / kWh
- ◻ > 15.00¢ / kWh





# Measuring Electricity

## Electricity Measurement

Electricity makes our lives easier, but it can seem like a mysterious force. Measuring electricity is confusing because we cannot see it. We are familiar with terms such as watt, volt, and amp, but we may not have a clear understanding of these terms. We buy a 60-watt light bulb, a tool that needs 120 volts, or a vacuum cleaner that uses 8.8 amps, and 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 (V)**. Using the water analogy, if a tank of water were suspended one meter above the ground with a 1-cm diameter 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 is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts (V)**. Just as the 10-meter high tank applies greater pressure than the 1-meter high tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply.

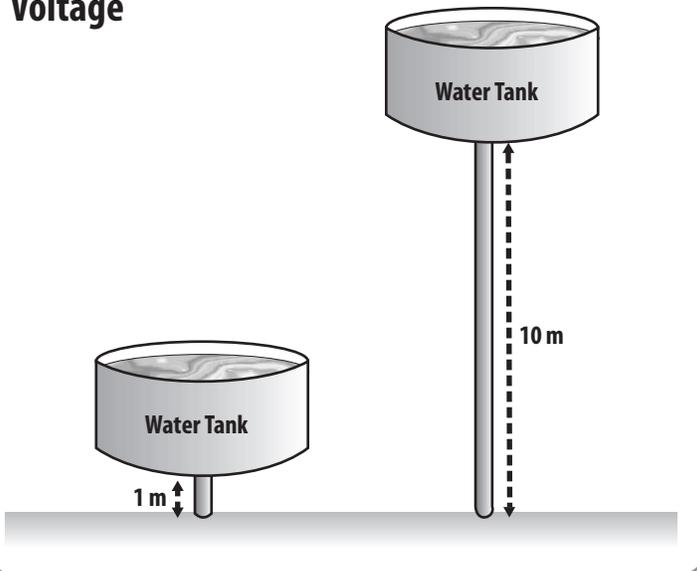
AA batteries are 1.5 volts; they apply a small amount of voltage or pressure for lighting small flashlight bulbs. A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster.

The standard voltage of wall outlets is 120 volts—a dangerous amount of voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.

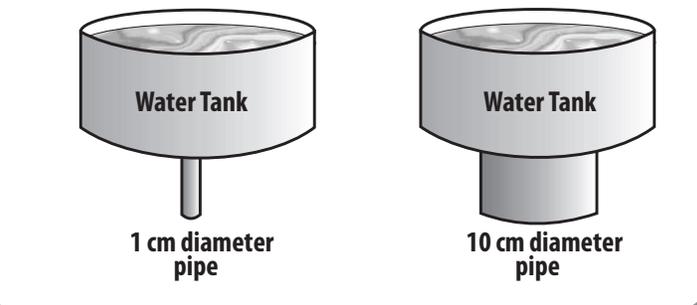
## Current

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

## Voltage



## Current



two points having a difference in voltage. Current is measured in **amperes** or **amps (A)**. One ampere is  $6.25 \times 10^{18}$  electrons per second passing through a circuit.

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



# Measuring Electricity

## Resistance

**Resistance (R)** is a property that slows the flow of electrons. Using the water analogy, resistance is anything that slows water flow, a smaller pipe or fins on the inside of a pipe. In electrical terms, the resistance of a conducting wire depends on the metal the wire is made of and its 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 that flows through a material is proportional to the voltage. In the substances he tested, he found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same.

This relationship is called **Ohm's Law**, and can be written in three simple formulas. If you know any two of the measurements, you can calculate the third, using the formulas to the right.

## Electric Power

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

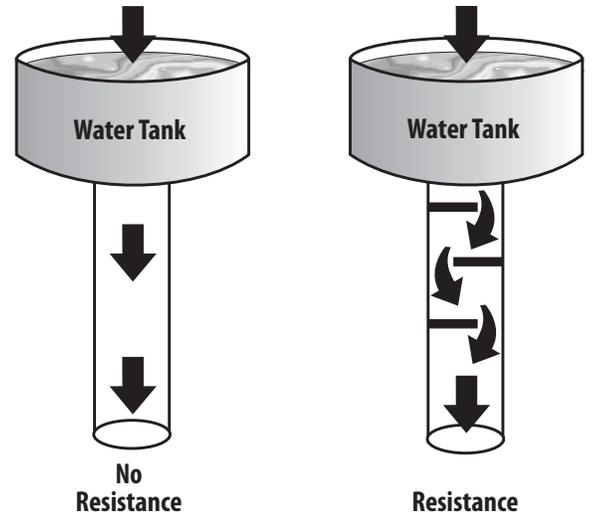
A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a 1-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

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

### ELECTRIC POWER FORMULA

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

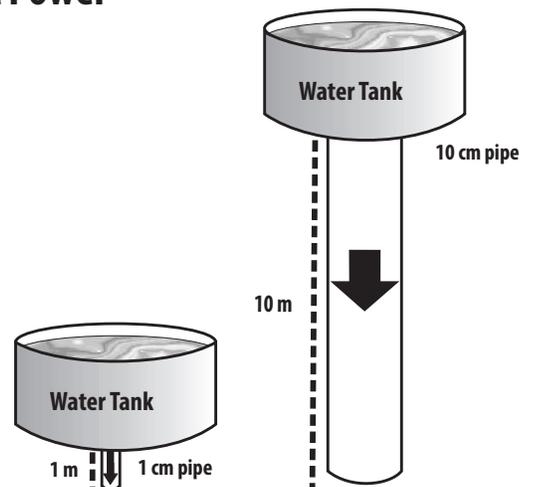
## Resistance



### OHM'S LAW

- **Voltage = current x resistance**  
 $V = I \times R$       or       $V = A \times \Omega$
- **Current = voltage / resistance**  
 $I = V / R$       or       $A = V / \Omega$
- **Resistance = voltage / current**  
 $R = V / I$       or       $\Omega = V / A$

## Electric Power



## Electrical Energy

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

The electrical energy that an appliance or device consumes can be determined only if you know how long (time) it consumes electric power at a specific rate (power). To find the amount of energy consumed, you multiply the rate of energy consumption (measured in 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)**

$$E = P \times t \quad \text{or} \quad E = W \times h = Wh$$

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

If a car travels for 1 hour at 40 miles per hour, it would travel 40 miles.

$$\text{Distance} = 40 \text{ mph} \times 1 \text{ hour} = 40 \text{ miles}$$

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

$$\text{Distance} = 40 \text{ mph} \times 3 \text{ hours} = 120 \text{ miles}$$

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.

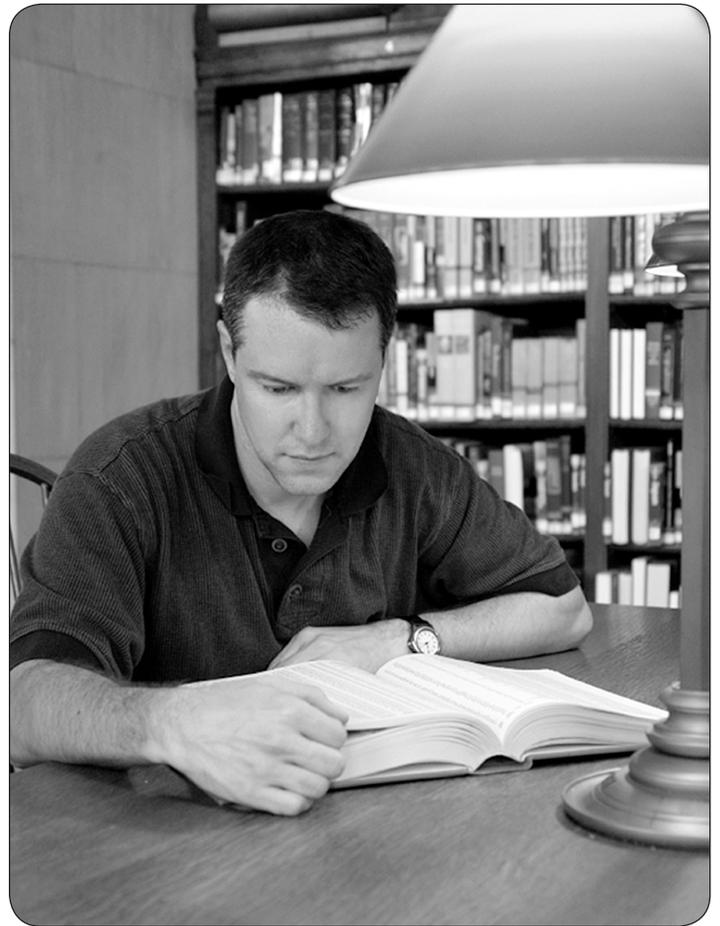
A person wouldn't say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip or a 120-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance represents the amount of work done.

The same applies with electric power. You would not say you used 100 watts of light energy to read your 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 bulb, for example, you would use the following formula:

▪ **Energy = Power x Time**

$$E = P \times t$$

$$\text{Energy} = 100 \text{ W} \times 5 \text{ hours} = 500 \text{ Wh}$$



One watt-hour is a very small amount of electrical energy. Usually, we measure electric power in larger units called **kilowatt-hours (kWh)** or 1,000 watt-hours (kilo = thousand). A kilowatt-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers is about 12.5 cents.

To calculate the cost of reading with a 100-W bulb for 5 hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

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

$$0.5 \text{ kWh} \times \$0.125/\text{kWh} = \$0.063$$

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



# History of Electricity

## Starting with Ben

Many people think Benjamin Franklin discovered electricity with his famous kite-flying experiments in 1752. Franklin is famous for tying a key to a kite string during a thunderstorm, proving that static electricity and lightning were indeed, the same thing. However, that isn't the whole story of electricity. Electricity was not "discovered" all at once. At first, electricity was associated with light. People wanted a cheap and safe way to light their homes, and scientists thought electricity might be a way.

## A Different Kind of Power: The Battery

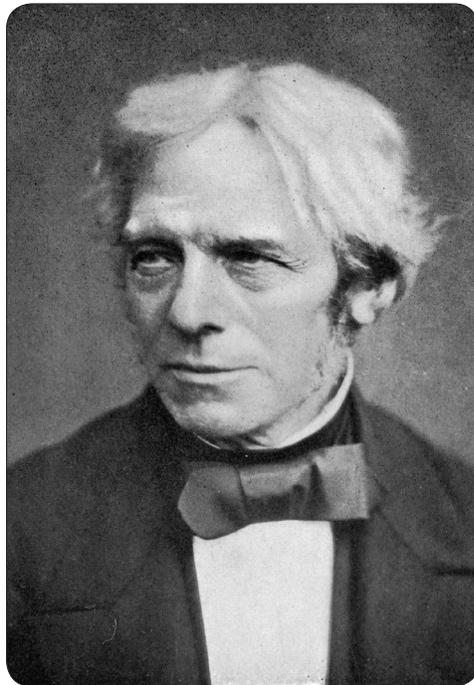
Learning how to produce and use electricity was not easy. For a long time there was no dependable source of electricity for experiments. Finally, in 1800, Alessandro Volta, an Italian scientist, made a great discovery. He soaked paper in salt water, placed zinc and copper on opposite sides of the paper, and watched the chemical reaction produce an electric current. Volta had created the first electric cell.

By connecting many of these cells together, Volta was able to "string a current" and create a **battery**. It is in honor of Volta that we rate batteries in **volts**. Finally, a safe and dependable source of electricity was available, making it easy for scientists to study electricity.

## A Current Began

An English scientist, Michael Faraday, was the first one to realize that an electric current could be produced by passing a magnet through a copper wire. It was an amazing discovery. Almost all the electricity we use today is made with magnets and coils of copper wire in giant power plants.

Both the electric generator and electric motor are based on this principle. A **generator** converts motion energy into electricity. A **motor** converts electrical energy into **motion energy**.



Michael Faraday

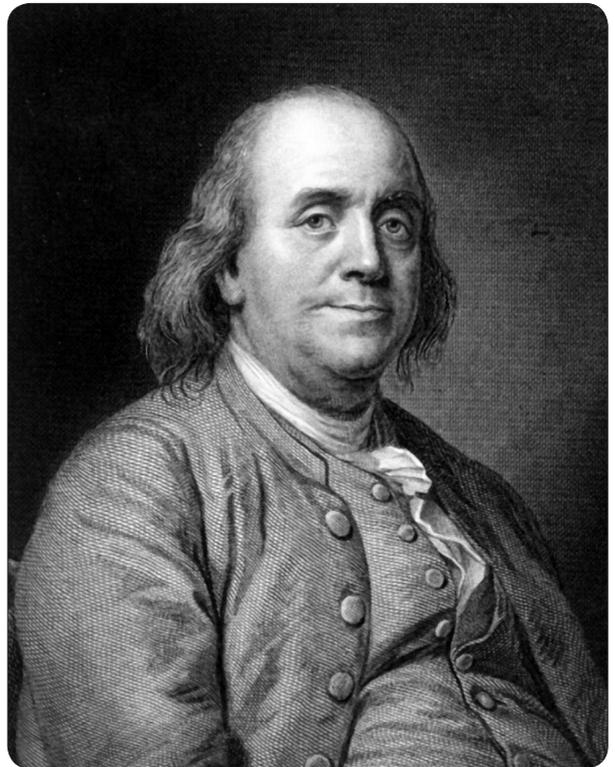


Image courtesy of NOAA Photo Library

Benjamin Franklin

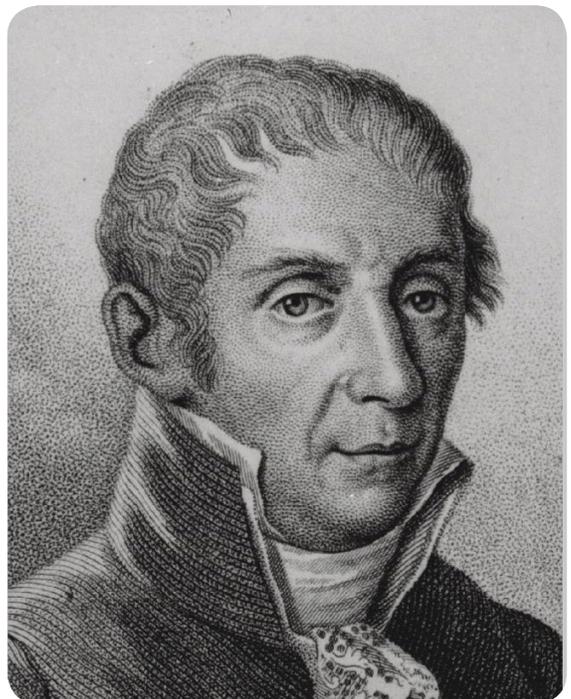


Image courtesy of Teylers Museum

Alessandro Volta

## Mr. Edison and His Light

In 1879, Thomas Edison focused on inventing a practical light bulb, one that would last a long time before burning out. The problem was finding a strong material for the **filament**, the small wire inside the bulb that conducts electricity. Finally, Edison used ordinary cotton thread that had been soaked in carbon. This filament didn't burn at all—it became **incandescent**; that is, it glowed.

The next challenge was developing an electrical system that could provide people with a practical source of energy to power these new lights. Edison wanted a way to make electricity both practical and inexpensive. He designed and built the first electric power plant that was able to produce electricity and carry it to people's homes.

Edison's Pearl Street Power Station started up its generator on September 4, 1882, in New York City. About 85 customers in lower Manhattan received enough power to light 5,000 lamps. His customers paid a lot for their electricity, though. In today's dollars, the electricity cost \$5.00 per kilowatt-hour! Today, electricity costs about 12.5 cents per kilowatt-hour for residential customers, about 11 cents for commercial, and about 7 cents per kilowatt-hour for industry.

## The Question: AC or DC?

The turning point of the electric age came a few years later with the development of **AC (alternating current)** power systems. Croatian scientist, Nikola Tesla came to the United States to work with Thomas Edison. After a falling out, Tesla discovered the rotating magnetic field and created the alternating current electrical system that is used very widely today. Tesla teamed up with engineer and business man George Westinghouse to patent the AC system and provide the nation with power that could travel long distances – a direct competition with Thomas Edison's DC system. Tesla later went on to form the Tesla Electric Company, invent the Tesla Coil, which is still used in science labs and in radio technology today, and design the system used to generate electricity at Niagara Falls.

Now using AC, power plants could transport electricity much farther than before. While Edison's **DC (direct current)** plant could only transport electricity within one square mile of his Pearl Street Power Station, the Niagara Falls plant was able to transport electricity over 200 miles!

Electricity didn't have an easy beginning. While many people were thrilled with all the new inventions, some people were afraid of electricity and wary of bringing it into their homes. They were afraid to let their children near this strange new power source. Many social critics of the day saw electricity as an end to a simpler, less hectic way of life. Poets commented that electric lights were less romantic than gaslights. Perhaps they were right, but the new electric age could not be dimmed.

In 1920, about two percent of U.S. energy was used to make electricity. In 2014, with the increasing use of technologies powered by electricity, it was almost 40 percent.

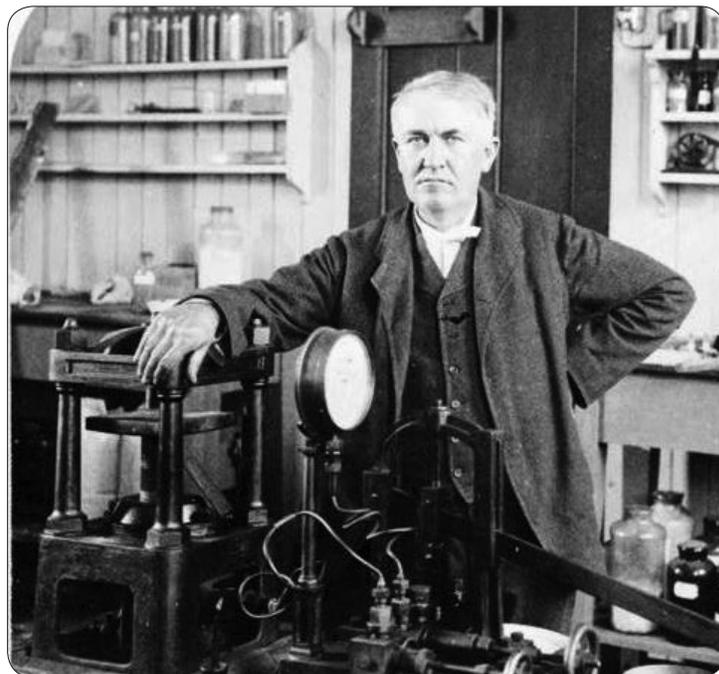


Image courtesy of U.S. Library of Congress

Thomas Edison in his lab in 1901.

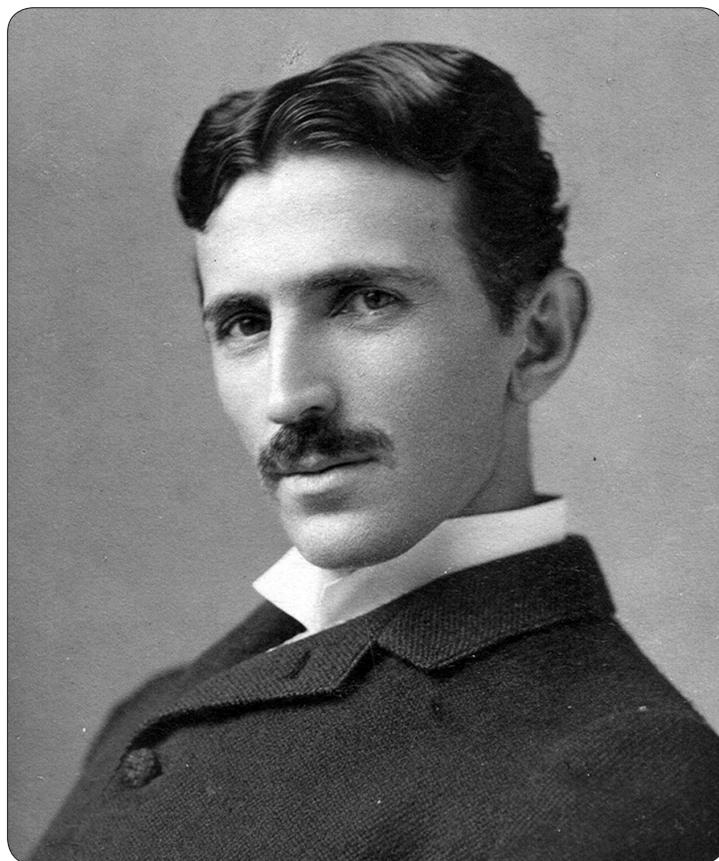


Photo by Napoleon Sarony

Nikola Tesla