

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.

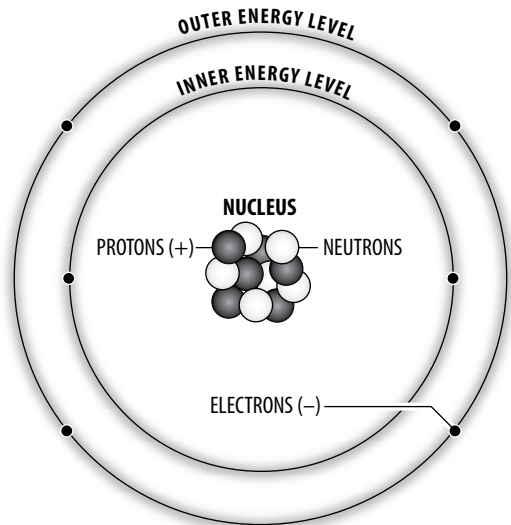
The protons and electrons of an atom are attracted to each other. They both carry an **electric charge**. An electric charge is a force within the particle. Protons have a positive charge (+) and electrons have a negative charge (-). The positive charge of the protons is equal to the negative charge 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

		Group																	
		1											18						
		IA											VIIIA						
1	1	H Hydrogen 1.00794											2	He Helium 4.002602					
	2	Li Lithium 6.941	Be Beryllium 9.012182																
	3	Na Sodium 22.989770	Mg Magnesium 24.3050	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	4	K Potassium 39.0983	Ca Calcium 40.078	Sc Scandium 44.955910	Ti Titanium 47.867	V Vanadium 50.9415	Cr Chromium 51.9961	Mn Manganese 54.938049	Fe Iron 55.845	Co Cobalt 58.933200	Ni Nickel 58.6934	Cu Copper 63.546	Zn Zinc 65.409	Ga Gallium 69.723	Ge Germanium 72.64	As Arsenic 74.92160	Se Selenium 78.96	Br Bromine 79.904	Kr Krypton 83.798
	5	Rb Rubidium 85.4678	Sr Strontium 87.62	Y Yttrium 88.90585	Zr Zirconium 91.224	Nb Niobium 92.90638	Mo Molybdenum 95.94	Tc Technetium (98)	Ru Ruthenium 101.07	Rh Rhodium 102.90550	Pd Palladium 106.42	Ag Silver 107.8682	Cd Cadmium 112.411	In Indium 114.818	Sn Tin 118.710	Sb Antimony 121.760	Te Tellurium 127.60	I Iodine 126.90447	Xe Xenon 131.293
	6	Cs Cesium 132.90545	Ba Barium 137.327		Hf Hafnium 178.49	Ta Tantalum 180.9479	W Tungsten 183.84	Re Rhenium 186.207	Os Osmium 190.23	Ir Iridium 192.217	Pt Platinum 195.078	Au Gold 196.96655	Hg Mercury 200.59	Tl Thallium 204.3833	Pb Lead 207.2	Bi Bismuth 208.98038	Po Polonium (209)	At Astatine (210)	Rn Radon (222)
	7	Fr Francium (223)	Ra Radium (226)		Rf Rutherfordium (261)	Db Dubnium (262)	Sg Seaborgium (266)	Bh Bohrium (264)	Hs Hassium (277)	Mt Meitnerium (268)	Ds Darmstadtium (281)	Rg Roentgenium (280)	Cn Copernicium (285)	Uut Ununtrium (284)	Fl Flerovium (289)	Uup Ununpentium (288)	Lv Livermorium (293)	Uus Ununseptium (294)	Uuo Ununoctium (294)
				Lanthanides	57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
				Actinides	89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

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.

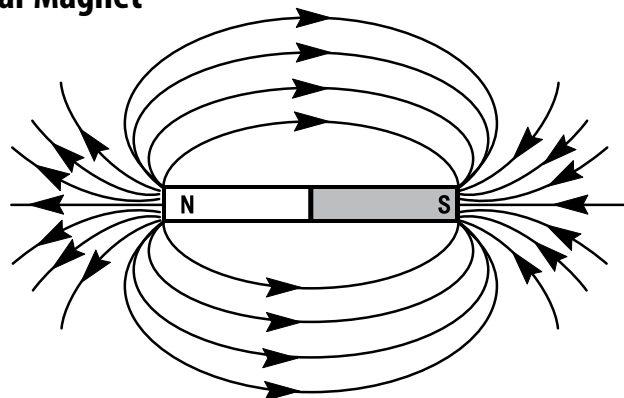
Magnets

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.

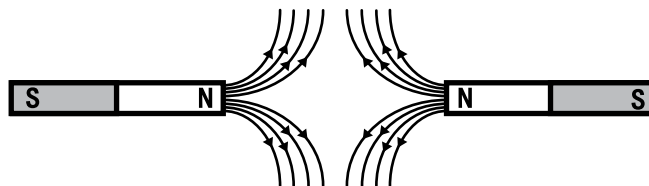
Spinning electrons create small **magnetic fields** and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their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

Bar Magnet



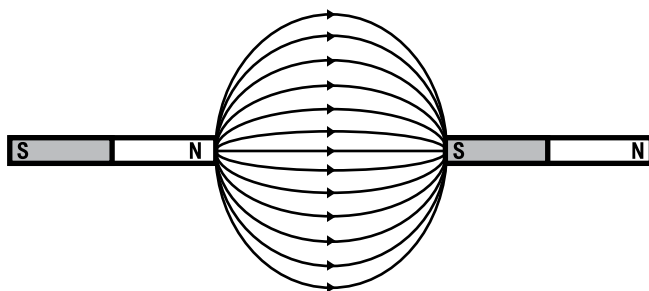
Like Poles

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.

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.

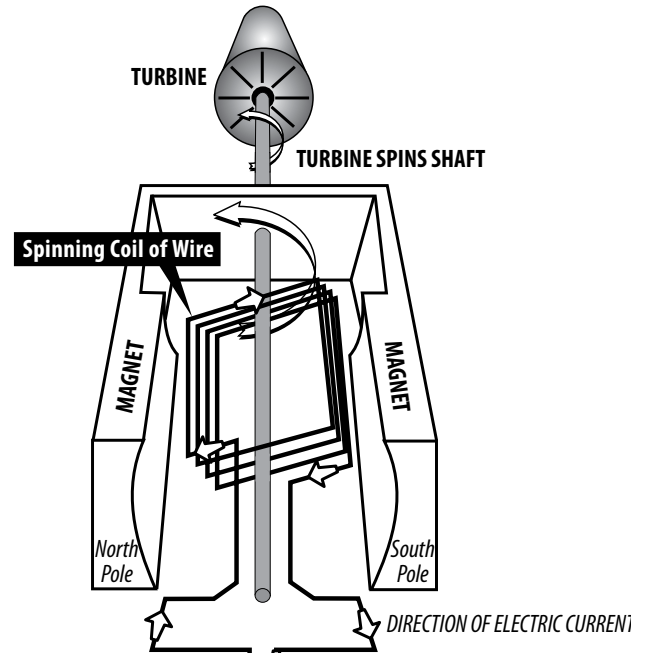
The turbine is attached to a shaft in the generator. Inside the **generator** are magnets and coils of copper wire. The magnets and coils can be designed in two ways—the turbine can spin the magnets inside the coils or can spin coils inside the magnets. Either way, the electrons are pushed from one copper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

HYDROELECTRIC PLANT



Turbine Generator



HYDROPOWER TURBINE GENERATORS



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

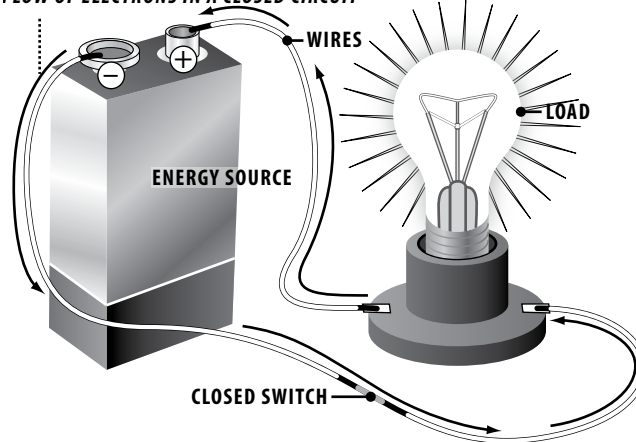
Electricity travels in closed loops, or **circuits**. It must have a complete path before the electrons can move. If a circuit is open, the electrons cannot flow. When we flip on a light switch, we close a circuit. The electricity flows from the electric wire through the light and back into the wire. 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.

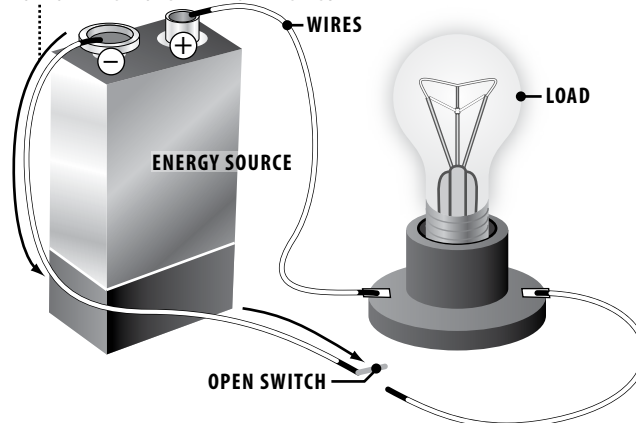
Electric Circuits

FLOW OF ELECTRONS IN A CLOSED CIRCUIT



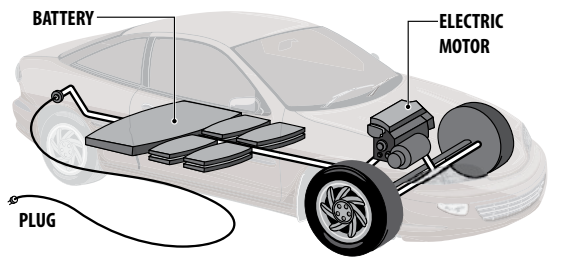
A closed circuit is a complete path allowing electricity to flow from the energy source to the load.

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 or battery 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.

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 and natural gas, which are 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.

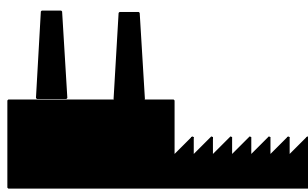
Electricity enters your home through a three-wire cable. Wires are run from the circuit breaker or fuse box to outlets and wall switches in your home. An electric meter measures how much electricity you use so that the utility company can bill you.

TRANSMISSION LINES



Transporting Electricity

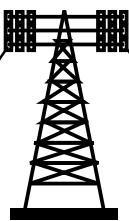
Power plant generates electricity



Transformer steps up voltage for transmission



Transmission lines carry electricity long distances



Power Tower

Step-down transformer reduces voltage (substation)



Distribution lines carry electricity to houses



Electric Poles



Neighborhood transformer on pole steps down voltage before entering house

Fuels that Make Electricity

Four kinds of power plants produce most of the electricity in the United States: natural gas, coal, nuclear, and hydropower. Natural gas plants generate about 32 percent of the electricity we use, and coal generates about 30 percent. 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 natural gas, coal, 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 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 and natural gas are used by most power plants because they are 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. About 91 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.

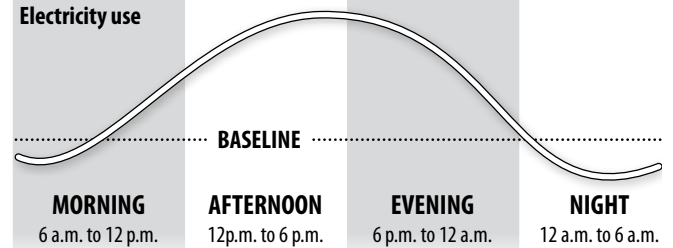
Uranium is a mineral found in rocks underground. A nuclear power plant splits the nuclei of uranium atoms to make smaller atoms in a process called **fission** that produces enormous amounts of thermal energy. The thermal energy is used to turn water into steam, which drives a turbine generator.

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

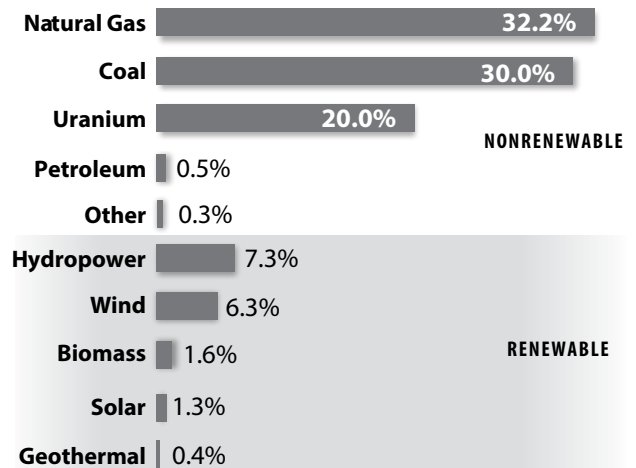
Hydropower plants use the energy in moving water to generate electricity. Fast-moving water is used to spin the blades of a turbine generator. Hydropower is called a **renewable** energy source because it is renewed by rainfall.

Peak Demand



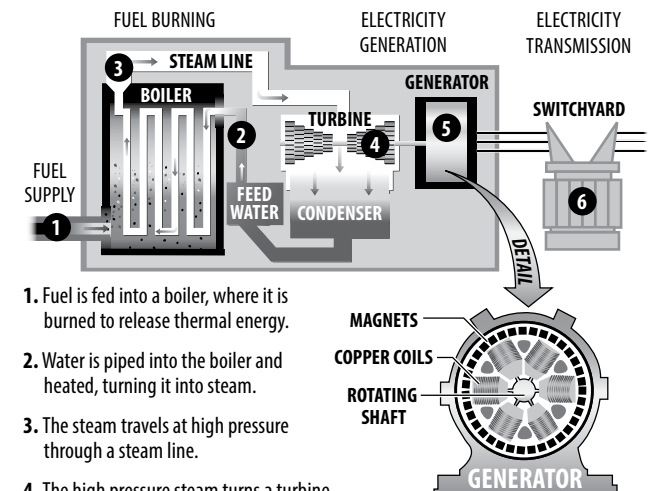
Peak demand, also called peak load, is the maximum load during a specified period of time.

U.S. Electricity Net Generation, 2017



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

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 12.9 cents per kilowatt-hour of electricity. In 2017, Washington State residents paid the least for electricity: 9.66 cents per kilowatt-hour. Hawaii residents paid the most: 29.5 cents per kilowatt-hour on average.

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

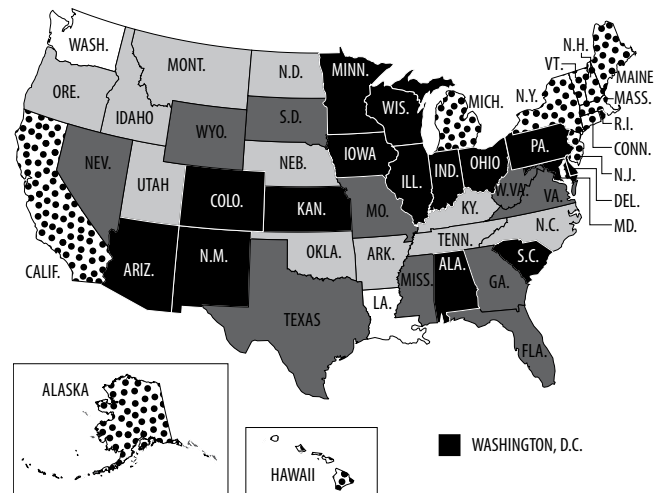


2 GIGAWATTS =
2,000,000,000 WATTS
Peak output of the Hoover Dam

Average Residential Price for Electricity, 2017

PRICE PER KILOWATT-HOUR

< 10¢ / kWh
 11 to 12¢ / kWh
 10 to 11¢ / kWh
 12 to 15¢ / kWh
 > 15.00¢ / kWh



Data: Energy Information Administration