Introduction to Energy

What is Energy?

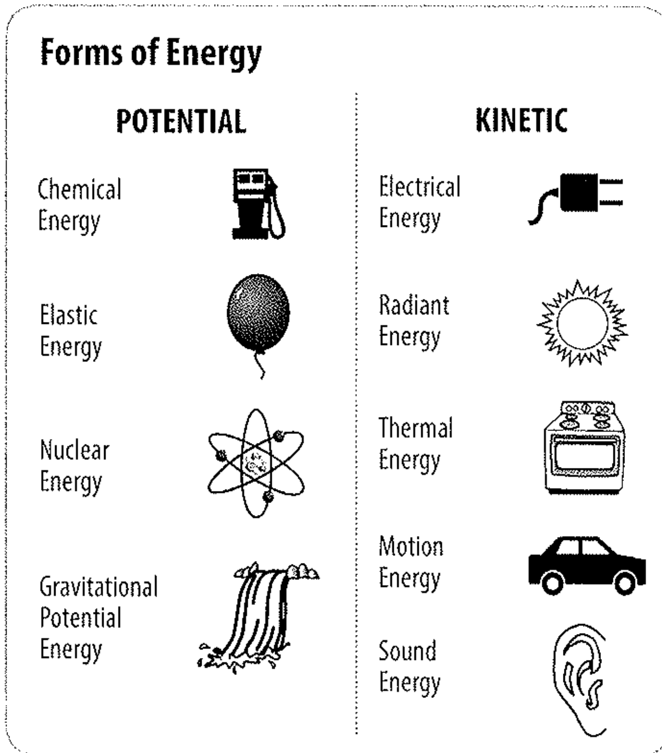
Energy does things for us. It moves cars along the road and boats on the water. It bakes a cake in the oven and keeps ice frozen in the freezer. It plays our favorite songs and lights our homes at night so that we can read good books. Energy helps our bodies grow and our minds think. Energy is a changing, doing, moving, working thing.

Energy is defined as the ability to produce change or do work, and that work can be divided into several main tasks we easily recognize:

- Energy produces light.
- Energy produces heat.
- Energy produces motion.
- Energy produces sound.
- Energy produces growth.
- Energy powers technology.

Forms of Energy

There are many forms of energy, but they all fall into two categories–potential or kinetic.



POTENTIAL ENERGY

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

- **Chemical energy** is energy stored in the bonds of atoms and molecules. It is the energy that holds these particles together. Biomass, petroleum, natural gas, and propane are examples of stored chemical energy.

  During photosynthesis, sunlight gives plants the energy they need to build complex chemical compounds. When these compounds are later broken down, the stored chemical energy is released as heat, light, motion, and sound.
- **Elastic energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of elastic energy.
- **Nuclear energy** is energy stored in the nucleus of an atom—the energy that binds the nucleus together. The energy can be released when small nuclei are combined or large nuclei split apart. Nuclear power plants split the nuclei of uranium atoms in a process called **fission**. The sun combines the nuclei of hydrogen atoms into helium atoms in a process called **fusion**. In both fission and fusion, mass is converted into energy, according to Einstein's Theory, $E = mc^2$.
- **Gravitational potential energy** is the energy of position or place. A rock resting at the top of a hill has gravitational potential energy because of its position. Hydropower, such as water in a reservoir behind a dam, is an example of gravitational potential energy.

KINETIC ENERGY

Kinetic energy is energy in motion—the motion of electromagnetic 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 called electrons, protons, and neutrons. Applying a force can make some of the electrons move. Electrons moving through a wire are called **electricity**. Lightning is another example of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Solar energy is an example of radiant energy.
- **Thermal energy**, or heat, is the internal energy in substances—the vibration and movement of atoms and molecules within substances. The faster molecules and atoms vibrate and move within substances, the more energy they possess and the hotter they become. Geothermal energy is an example of thermal energy.
- **Motion energy** is the movement of objects and substances from one place to another. According to Newton's Laws of Motion, objects and substances move when an unbalanced force acts on them. Wind is an example of motion energy.
- **Sound energy** 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 wave.

Introduction to Energy

Conservation of Energy

Your parents may tell you to conserve energy. "Turn out the lights," they say. But to scientists, conservation of energy can mean something quite different. The Law of Conservation of Energy says energy is neither created nor destroyed.

When we use energy, we do not exhaust it or run out—we just change its form. That's really what we mean when we say we are using energy. We change one form of energy into another. A car engine burns gasoline, converting the chemical energy in the gasoline into motion or mechanical energy that makes the car move. Old-fashioned windmills changed the kinetic energy of the wind into motion energy to grind grain. Solar cells change radiant energy into electrical energy.

Energy can change form, but the total quantity of energy in the universe remains the same. The only exception to this law is when a small amount of matter is converted into energy during nuclear fusion and fission.

Energy Efficiency

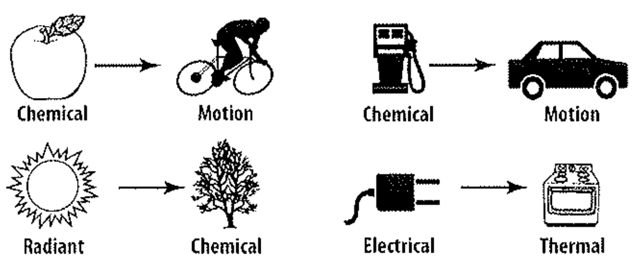
Energy efficiency is how much useful energy you can get out of a system. In theory, a 100 percent energy efficient machine would change all of the energy put in it into useful work. Converting one form of energy into another form always involves a loss of usable energy, usually in the form of thermal energy.

In fact, most energy transformations are not very efficient. The human body is no exception. Your body is like a machine, and the fuel for your "machine" is food. Food gives us the energy to move, breathe, and think. Your body is very inefficient at converting food into useful work. Most of the energy taken in by your body is released as heat.

An incandescent light bulb isn't efficient either. These light bulbs convert ten percent of the electrical energy into light and the rest (90 percent) is converted into thermal energy. That's why these light bulbs are so hot to the touch.

Most electric power plants that use steam to spin turbines, are about 35 percent efficient. It takes three units of fuel to make one unit of electricity. Most of the other energy is lost as waste heat. The heat dissipates into the environment where we can no longer use it as a practical source of energy.

Energy Transformations

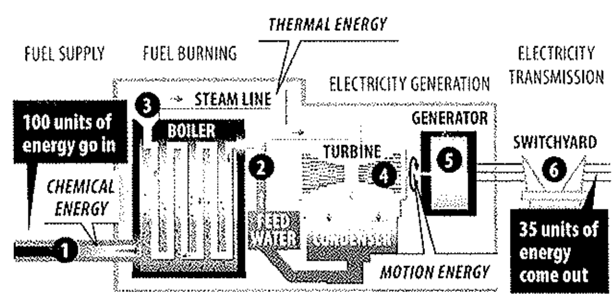


Energy at a Glance, 2013

	2012	2013
World Population	7,020,760,225	7,098,231
U.S. Population	313,873,685	316,128,839
World Energy Production	513.695 Q	524.507 Q
U.S. Energy Production	79.219 Q	81.942 Q
• Renewables	8.838 Q	9.298 Q
• Nonrenewables	70.381 Q	72.644 Q
World Energy Consumption	518.086 Q	528.743 Q
U.S. Energy Consumption	95.056 Q	97.785 Q
• Renewables	8.798 Q	9.298 Q
• Nonrenewables	86.258 Q	88.487 Q

Data: Energy Information Administration
Q = Quad (10^{15} Btu) see Measuring Energy on page 23

Efficiency of a Thermal Power Plant



How a Thermal Power Plant Works

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.

Introduction to Energy

Sources of Energy

People have always used energy to do work for them. Thousands of years ago, early humans burned wood to provide light, heat their living spaces, and cook their food. Later, people used the wind to move their boats from place to place. A hundred years ago, people began using falling water to make electricity.

Today, people use more energy than ever from a variety of sources for a multitude of tasks and our lives are undoubtedly better for it. Our homes are comfortable and full of useful and entertaining electrical devices. We communicate instantaneously in many ways. We live longer, healthier lives. We travel the world, or at least see it on television and the internet.

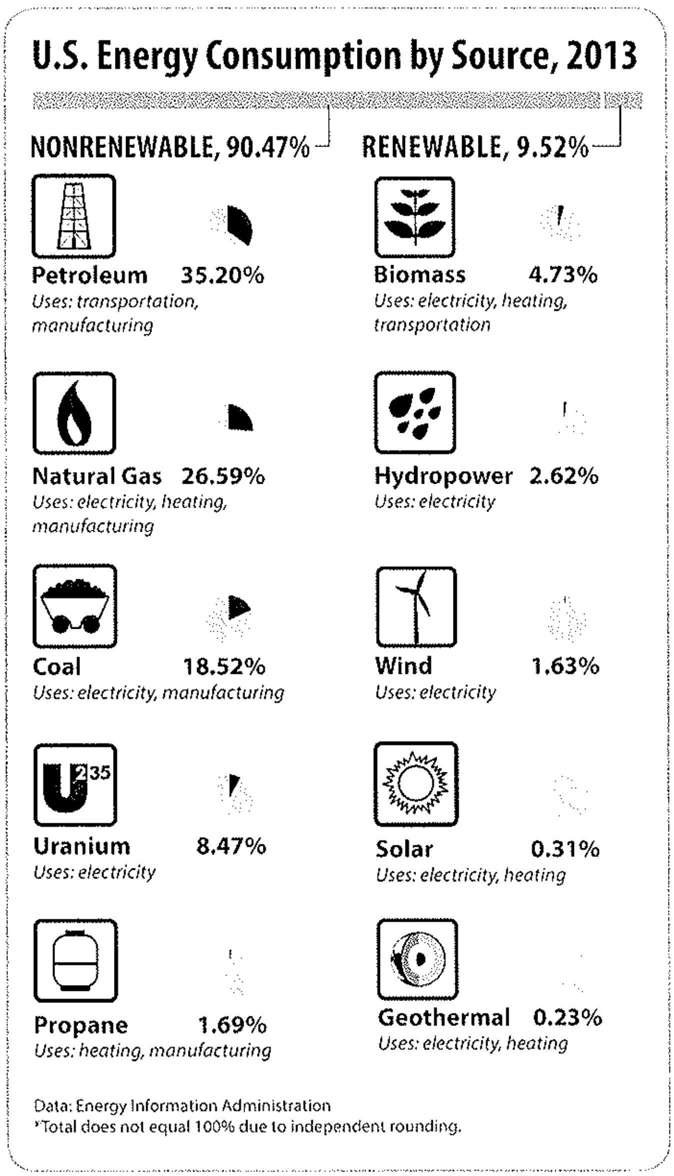
The ten major energy sources we use today are classified into two broad groups—nonrenewable and renewable.

Nonrenewable energy sources include coal, petroleum, natural gas, propane, and uranium. They are used to generate electricity, to heat our homes, to move our cars, and to manufacture products from candy bars to cell phones.

These energy sources are called nonrenewable because they cannot be replenished in a short period of time. Petroleum, a **fossil fuel**, for example, was formed hundreds of millions of years ago, before dinosaurs existed. It was formed from the remains of ancient sea life, so it cannot be made quickly. We could run out of economically recoverable nonrenewable resources some day.

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

Is electricity a renewable or nonrenewable source of energy? The answer is neither. Electricity is different from the other energy sources because it is a **secondary energy source**, which means we have to use another energy source to make it. In the United States, coal is the number one fuel for generating electricity.



Measuring Energy

"You can't compare apples and oranges," the old saying goes. That holds true for energy sources. We buy gasoline in gallons, wood in cords, and natural gas in cubic feet. How can we compare them when they are all measured differently? With **British thermal units** (Btu), that's how. The energy contained in gasoline, wood, or other energy sources can be measured by the amount of heat in Btu it can produce.

One Btu is the amount of thermal energy needed to change the temperature of one pound of water one degree Fahrenheit. A single Btu is quite small. 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 Btu of energy.

Every day the average American uses about 847,000 Btu. We use the term quad (Q) to measure very large quantities of energy. A quad is one quadrillion (1,000,000,000,000,000) Btu. The United States uses about one quad of energy every 3.7 days. In 2007, the U.S. consumed 101.296 quads of energy, an all-time high.

Elements and Isotopes

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

Atomic Structure

Atoms are made of smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons**, which carry a positive (+) charge, and **neutrons**, which carry no charge, that are approximately the same size. Nuclear energy is contained within the nucleus and the strong nuclear force holds the protons and neutrons together.

Protons and neutrons are very small, but electrons are much smaller. Electrons carry a negative (-) charge and move around the nucleus in areas of probability, called energy levels. These areas are different distances from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.

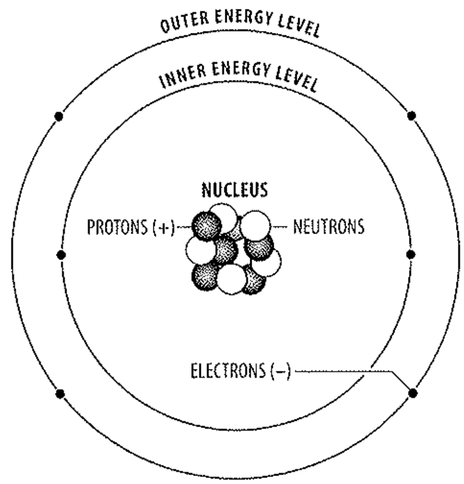
If you could see an atom, it might look a little like a tiny center of spheres surrounded by giant clouds (or energy levels). Electrons are found in these energy levels. Since protons have a positive charge and electrons have a negative charge, they are attracted to each other. This electrical force holds the electrons in their energy level. The energy level closest to the nucleus can hold up to two electrons. The next energy level can hold up to eight. Additional energy levels can hold more than eight electrons.

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

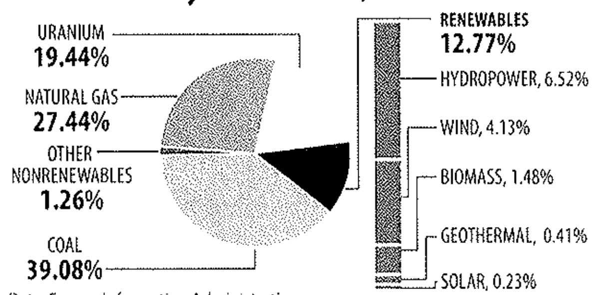
When an atom is neutral, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons help hold the nucleus together.

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.



U.S. Electricity Production, 2013



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

Elements

A substance whose atoms all have the same number of protons is called an element. The number of protons is given by an element's **atomic number**, which identifies elements. For example, all atoms of hydrogen have an atomic number of one and all atoms of carbon have an atomic number of six. This means that all hydrogen atoms contain one proton and that all carbon atoms contain six protons. An atom is measured by its **atomic mass**, which is based on its number of protons, neutrons, and electrons.

Radioactive Isotopes

While many **isotopes** of the elements are stable, some isotopes are unstable and their nuclei emit particles and/or energy to become more stable. Isotopes of elements that are unstable and emit particles or energy are labeled radioactive because they are radiating particles or energy. When particles are given off, isotopes of new elements are usually made. The most common particles given off are **alpha particles** (a helium nucleus without electrons $^{4}_{2}He$) and **beta particles** (an energetic electron $^{0}_{-1}\beta$). Release of high energy **gamma radiation** is also a common method of achieving stability, but the type of isotope remains the same. Unstable isotopes may give off an alpha or beta particle, but never both together. However, gamma radiation may be given off along with either alpha or beta emissions.

The following are two examples of unstable isotopes that change identities when they release particles:

Beta emission $^{14}_{6}C \rightarrow ^{0}_{-1}\beta + ^{14}_{7}N$

Alpha emission $^{238}_{92}U \rightarrow ^{4}_{2}He + ^{234}_{90}Th$

In the first example, a neutron in the nucleus of carbon-14 releases a beta particle ($^{0}_{-1}\beta$) and changes into a proton. Since the atom now has seven protons instead of six, it has become a different element, nitrogen, but still has an atomic mass of 14. It is now the isotope nitrogen-14.

In the second example, **uranium**-238 releases an alpha particle ($^{4}_{2}He$). The alpha particle is made of two protons and two neutrons. That means the atom now contains 90 protons and 144 neutrons (giving a total of 234 nucleons or particles in the nucleus). With 90 protons, it is now the element thorium and has an atomic mass of 234. It is the isotope thorium-234.

The process of nuclei becoming more stable is called radioactive decay. The time required for one half of the atoms of the original radioactive isotope to decay into another isotope is known as its **half-life**. Some substances have half-lives measured in milliseconds while others take billions of years. Uranium-238 has a half-life of 4.6 billion years. Short half-lives result in high activities since a large number of particles or amounts of energy are emitted in relatively short time periods.

What is Radiation?

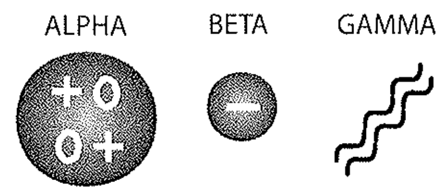
Energy traveling in the form of waves or high speed particles is called **radiation.** The sun produces radiant energy—energy that travels in electromagnetic waves. Wireless technologies, radar, microwave ovens, medical x-rays, and radiation therapy to treat cancer are all examples of how radiation can be used. Radiation can come in the form of electromagnetic waves (radio, microwave, infrared, visible light, ultraviolet light, x-rays, and gamma rays) and high speed particles (alpha and beta particles). Radiation is classified into two categories—**ionizing** radiation, which has enough energy to ionize atoms, and non-ionizing. When discussing nuclear science, radiation generally refers to ionizing radiation such as alpha particles, beta particles, and gamma rays.

Alpha particles, beta particles, and/or gamma rays can be emitted from different isotopes of elements. We say these isotopes are radioactive and also call them **radionuclides.** An isotope is stable when there is close to a 1:1 ratio of protons and neutrons. If an isotope has too few or too many neutrons, the isotope becomes unstable and radioactive. Many elements with fewer than 84 protons have stable isotopes and radioactive isotopes; however, all isotopes of elements with 84 or more protons are radionuclides.

A Radioactive World

There are many natural sources of radiation that have been present since the Earth was formed. In the last century, we have added to this natural background radiation with some artificial sources. It may surprise you to know that for an average person, 50 percent of all exposure to radiation comes from natural sources. Much of our exposure to artificial sources is attributable to medical procedures, and commercial and industrial sources.

There are three major sources of naturally occurring radiation. They are cosmic radiation, terrestrial radiation, and internal radiation. Cosmic radiation is the radiation that penetrates the Earth's atmosphere and comes from the sun and outer space. Terrestrial radiation is the radiation emitted from the earth, rocks, building materials, and water. The human body naturally contains some radiation. This is called internal radiation.



We are constantly using radioactive materials in our daily lives. These include medical radiation sources (such as CT scans and medical and dental x-rays), older TV's, older luminous watches, some smoke detectors, left-over radiation from the testing of nuclear weapons, and a variety of industrial uses. Another major source of natural radiation is from **radon** gas, a gas commonly found in the Earth.

Radon

Radon is a colorless and odorless radioactive gas found throughout the United States, and is one type of terrestrial radiation. It is formed during the natural radioactive decay of uranium and thorium atoms in the soil, rocks, and water. Since radon is a gas, it can get into the air of the buildings where we live, work, and play. According to the Environmental Protection Agency (EPA), radon causes thousands of deaths from lung cancer each year. Behind smoking, exposure to radon gas is the second leading cause of lung cancer in the U.S.

Most radon enters buildings from the soil. Radon enters buildings through cracks in solid floors, construction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, and cavities inside walls. Some radon can also enter a home through the water supply. Both new and older homes are susceptible to radon gas build-up. Since most exposure to radon occurs at home, it is important to measure the level of radon in your home, and limit radon exposure where necessary.

The EPA recommends that all homes be tested for radon. Simple test kits are available at most home improvement stores, are inexpensive, and are easy to use. Qualified testers can also be used and are a good choice to perform tests when buying or selling a home.

Electricity and Magnetism

Electrical Energy

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

Magnets

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

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

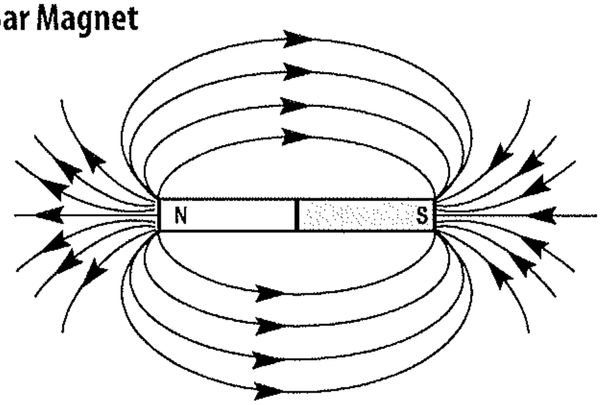
Spinning electrons create small magnetic fields and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic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

Electromagnetism

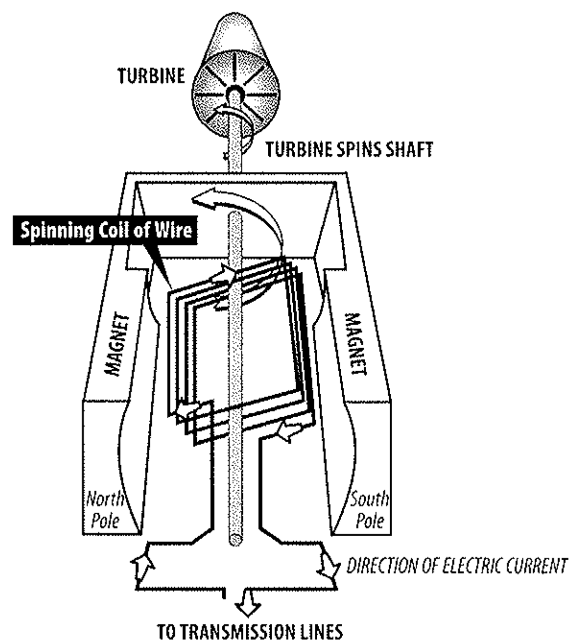
A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called electromagnetism. A changing magnetic field can produce electricity. Every time there is a change in an electric field, a magnetic field is produced. We can use this 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 changing 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. Magnets used to produce electric current are called electromagnets.

Bar Magnet



Turbine Generator

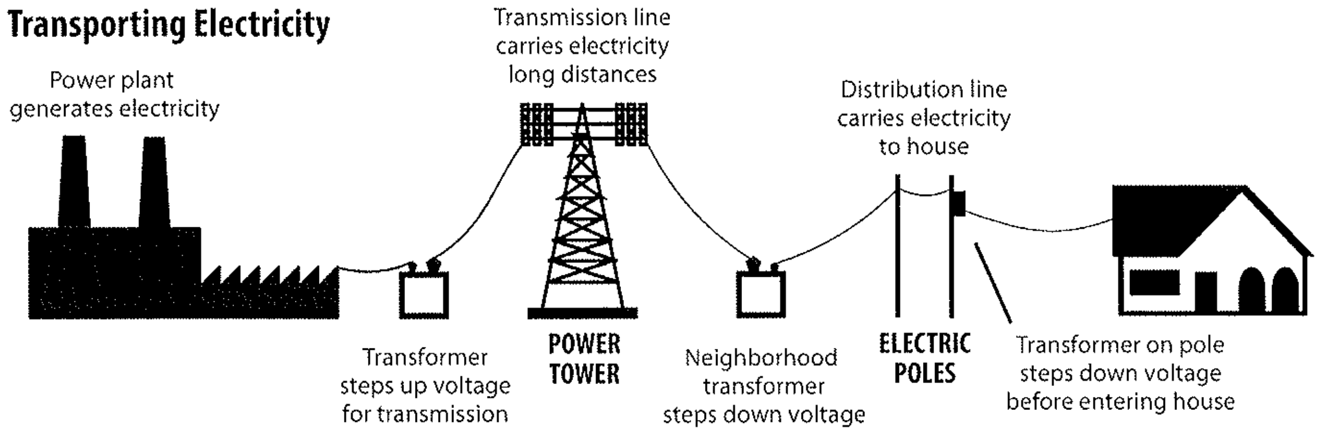


Generating Electricity

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

An electric generator is actually an electric motor that runs backward. Work is done to cause magnets to spin within coils of wire to produce electricity. Depending on the generator's design,

Electricity and Magnetism



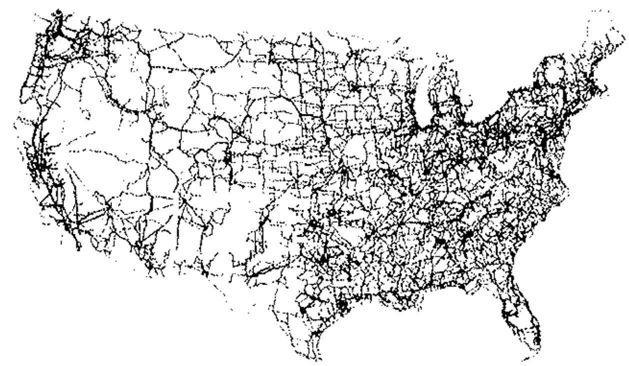
work can also cause the wires to move. When the wire moves through the external magnetic field, electrons in the wire are pulled and move through the wire. These electrons can be directed out of the generator as electricity.

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

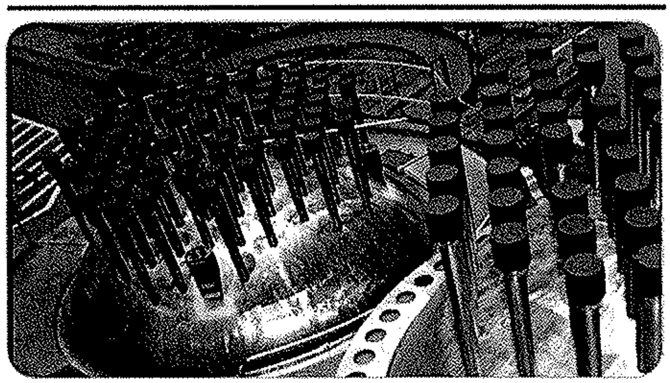
Power plants use huge turbine generators to generate the electricity that we use in our homes and businesses. Different types of power plants use different fuels to change water into steam. Power plants can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used to spin the turbines. Splitting uranium atoms in a nuclear power plant can also produce the thermal energy needed to generate steam.

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

The Continental U.S. Electric Grid



NUCLEAR REACTOR



Generating Electricity With Nuclear Energy

Fission occurs when an atom's nucleus splits into smaller nuclei. Nuclear energy is released from the nucleus of atoms as they fission and is transformed into thermal energy, kinetic energy, and radiant energy. Just like burning coal and natural gas, thermal energy from nuclear reactions can be used to convert water to steam for turning the blades of a turbine. The motion of the turbine turns a generator and makes electricity to power our homes, businesses, and schools.