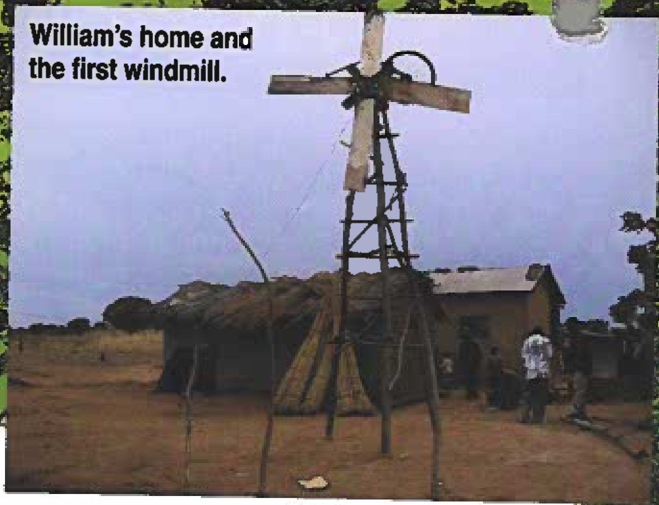
STEM Applications

1. **SCIENCE** The human body is adapted specifically for life in the conditions on Earth. When we send people into space, the conditions are much different. Find out what negative effects an astronaut may experience by being in space for prolonged periods. What happens to the person's muscles, ears, sense of touch, heart, spine, bones, lungs, stomach, and eyes? Why?
2. **TECHNOLOGY** Design an extraterrestrial character, either as a drawing or in 3D form, for use in a new movie. Specify where the character came from (a specific planet, another solar system, or other place). Research the conditions in that place and give the character the features it would need to live there. Create a basic 3D model of your character using computer software.
3. **ENGINEERING** Use a formal design process to design a vehicle to transport eggs up and down a flight of stairs without breaking. The vehicle must be able to carry at least 6 eggs in each trip. Build a prototype and test it thoroughly. Be sure to test it first without eggs to make sure the vehicle is stable. Make any design modifications necessary and retest the model. When you are sure the eggs will not break, add the eggs for your final tests. When you are satisfied with the result, document the design, your test procedures, and the results. Place the documentation in your portfolio.

CHAPTER 10

Energy


William's home and the first windmill.

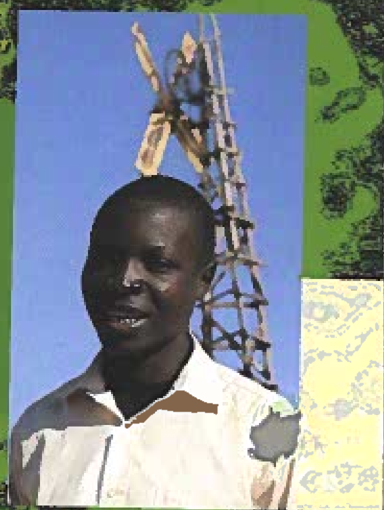
Better by Design

William Kamkwamba designs and makes windmills

When he was 14 years old, Malawian William Kamkwamba designed and built his family an electricity-generating windmill from spare parts and scrap, working from rough plans he found in a borrowed 5th-grade textbook. He first built a 5-meter prototype out of a broken bicycle, tractor fan blade, old shock absorber, and blue gum trees. He then built a 12-meter windmill to better catch the wind above the trees, and added a car battery for storage. He also added homemade light switches and circuit breakers. He has now built three windmills in his yard. The tallest is 39 feet. William is currently working on a design for a windmill powerful enough to pump water from wells and provide lighting for Masitala, a cluster of buildings where about 60 families live.


William used imagination and creativity to design windmills to help meet Masitala's energy needs. What products could you design that would either save or generate energy?

"I was thinking about electricity. I was thinking about what I'd like to have at home, and I was thinking, "What can I do?"



Reading Target

Summarizing Information

A *summary* is a short paragraph that describes the main idea of a selection of text. Making a summary can help you remember what you read. As you read each section of this chapter, think about the main ideas presented. Then use the Reading Target graphic organizer at the end of the chapter to summarize the chapter content.

Key Terms

- *biofuels*
- *biomass energy*
- *chemical energy*
- *conduction*
- *convection*
- *convection currents*
- *elastic materials*
- *electrical energy*
- *electromagnetic waves*
- *energy*
- *frequency*
- *fuel cell*
- *geothermal energy*
- *gravitational energy*
- *hydroelectricity*
- *kinetic energy*
- *mechanical energy*
- *nonrenewable energy*
- *nuclear energy*
- *nuclear fission*
- *nuclear fusion*
- *photovoltaic cells*
- *potential energy*
- *radiation*
- *renewable energy*
- *solar energy*
- *sound energy*
- *strain energy*
- *thermal energy*
- *wavelength*

Objectives

After reading this chapter, you will be able to:

- Explain society's dependence on energy.
- Describe the difference between potential and kinetic energy.
- Identify the various forms of energy and their applications
- Describe how energy can be changed from one form to another.
- Distinguish between nonrenewable and renewable sources of energy.
- List the advantages and disadvantages of each source of energy.
- Describe the components of energy and power systems.

Useful Web sites:
williamkamkwamba.typepad.com/

Every day we use energy in one form or another. When you ride your bicycle to meet friends, you are using your own physical energy to turn the pedals. When you fly a kite, wind provides energy to keep the kite in the air. The family car uses the energy in gasoline.

The sun provides heat energy when it shines through your windows and warms your house. In winter, the energy stored in wood, oil, or other fuels heats your home. When you turn on a light, you are using electrical energy.

Energy Basics

What is energy? *Energy* is the capacity to do work. To understand it more fully, we need to look at two categories: potential energy and kinetic energy.

Think about lifting a sledgehammer to drive a post into the ground. As you hold the hammer in the air, it has *potential energy*. Potential energy is also called "stored energy." Energy is stored in the hammer until it is dropped and the energy is released to hit the post. A stretched elastic band also has potential energy. When you wind up a spring in a toy, you are giving the spring potential energy. Once again, energy is being stored.

While working with springs, Robert Hooke discovered Hooke's Law, which says that the amount a spring extends is proportional to the force with which you pull it. By pulling twice as hard, you stretch it twice as far. Materials that obey Hooke's Law are known as *elastic materials*.

When the head of the hammer is dropped to hit the post or the spring is released to drive the toy, both the hammer and the toy gain kinetic energy. *Kinetic energy* is the energy an object has because it is moving. See **Figure 10-1**.

Forms of Energy

Energy is available in many different forms. **Figure 10-2** through **Figure 10-7** describe different forms of energy and the way energy gets things moving so that work is done.

Chemical Energy

A great deal of *chemical energy* is locked away in different kinds of substances. Chemical energy is found in the molecules that make up food, wood, gasoline, and oil. The energy is often released by burning the chemical. Burning rearranges the substance's molecules and releases heat.

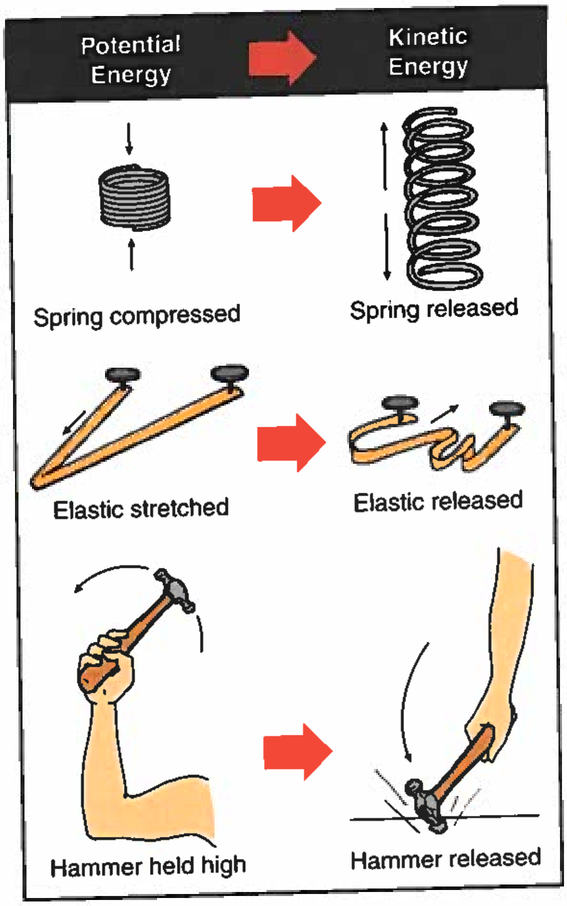


Figure 10-1. Examples of kinetic and potential energy.

Chemical energy is used in both natural and artificial systems. For example, the human body converts food into chemicals that provide the muscles with the energy to do work. Gasoline provides the chemical energy needed to keep a motorcycle moving. See Figure 10-2.

In artificial systems, chemical energy is often stored in batteries for future use. In the human body, it is stored in body cells in the form of a molecule called *ATP*. The body breaks down the ATP molecules as required to supply the energy we need.

Gravitational Energy

Objects always tend to move toward the lowest possible level. This is due to the *gravitational energy* (attraction or pull) of the Earth. It causes objects to fall. It is why water runs or objects roll downhill. For example, a skateboard at the top of a hill has gravitational energy. See Figure 10-3. This energy is available because of the pull of gravity.

While the skateboard is standing still at the top of the hill, the gravitational energy is potential energy. It changes to kinetic energy when the skateboard starts rolling down the hill.

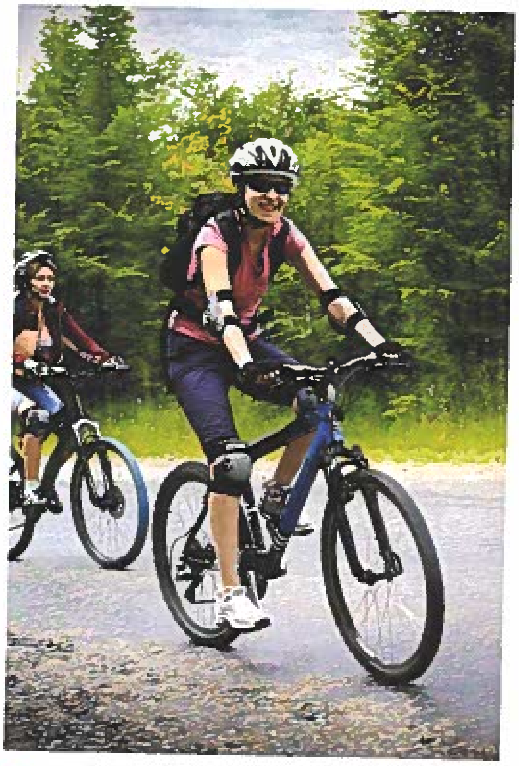


Figure 10-2. Chemical energy is used in natural systems, such as the human body, and in technological systems, such as engines.

Figure 10-3. Objects have gravitational energy because of their position. When is gravity useful to you?

Mechanical Energy

Energy of motion is *mechanical energy*. Mechanical energy is often associated with or caused by a machine. However, it is not always caused by a machine. Two good examples of mechanical energy are a waterfall (natural mechanical energy) and a hydroelectric power plant (machine-related mechanical energy). See Figure 10-4. The power plant harnesses the falling water's mechanical energy by using it to turn turbines. These turbines are connected to generators, which produce electricity.

Strain Energy

Certain materials that can be stretched or compressed have a tendency to return to their original shape. This is known as *strain energy* or the energy of deformation. It is the kind of energy most easily seen in a rubber band, a bungee cord, or a bow used to shoot arrows. See Figure 10-5. However, many materials, including steel and carbon fiber, have a constant elasticity, and so follow Hooke's Law. When constructing buildings, architects and engineers take these properties into account so that the structure does not buckle when heavy loads are applied.

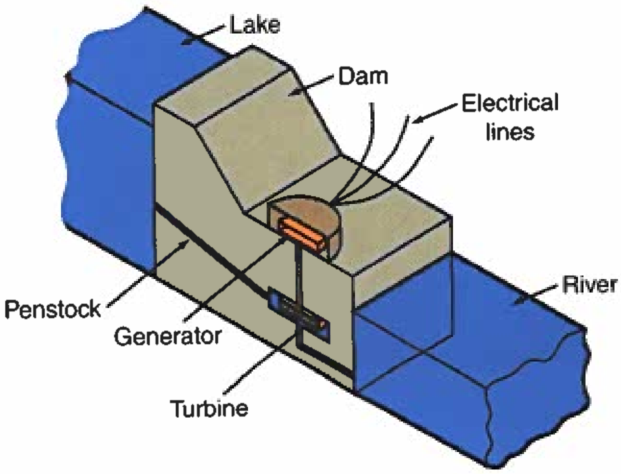


Figure 10-4. Mechanical energy is demonstrated in two ways: naturally by the falling water and machine-related by the movement of the turbines in a hydroelectric dam.

Figure 10-5. When an arrow is fired from a bow, the potential (strain) energy of the bow and string are converted to kinetic energy in the arrow.

Electrical Energy

Electrical energy is the movement of electrons from one atom to another in a conductor. This process is described in Chapter 11. Electrical energy provides the power to operate electrical devices such as motors and heaters. See **Figure 10-6**. It can move from place to place and readily changes into other forms such as heat, light, and sound. Electrical energy can be stored in batteries or produced in a generating station.

Thermal Energy

Thermal energy, or heat energy, occurs as the atoms of a material become more active. If you could look at atoms under an electron microscope, you would see that the atoms move about. The faster they move, the warmer the material.

Heat energy travels through matter in three ways: convection, conduction, and radiation. *Convection* occurs when expanded warm liquid or gas rises above a cooler liquid or gas. See **Figure 10-7A**. When liquid is heated, it expands and its volume increases. The amount of material (its mass) does not change. Since the mass is more spread out, hot liquid is less dense than cold liquid. In a mixture of hot and cold liquid, the cold liquid will sink to the bottom and the hot liquid will rise to the top. This creates a current in the liquid that is known as a convection current.

Conduction occurs when heat energy passes from molecule to molecule in a solid. The heat energy moves even though there is no obvious movement of the material. See **Figure 10-7B**.

Radiation occurs when heat energy is moving in the form of electromagnetic waves. For example, when you stand in the sunshine or in front of an electric heater, heat is transmitted through the air. No material is required between you and the source of heat for this type of heat energy. See **Figure 10-7C**.

Figure 10-6. Electrical energy provides the power to operate electrical devices. How many of the devices you use every day need electrical energy?

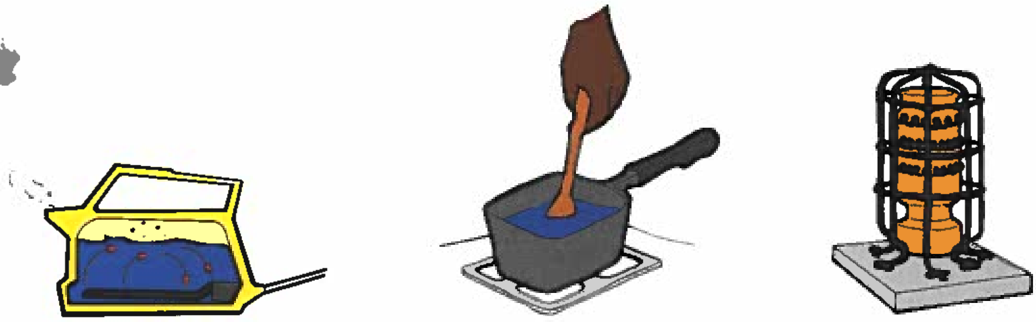


Figure 10-7. Heat energy can move through matter by convection, conduction, and radiation.

Solar Energy

Solar energy is related to heat energy. Another name for it is *radiant energy*. This type of energy comes to us from the sun. It travels in straight lines as a wave motion. See **Figure 10-8**. Objects such as TV pictures, lamps, and the sun are seen because of the light they send out. Most other objects can be seen because they reflect light.

Light travels at approximately 186,000 miles (300,000 km) per second. The speed of light does not change. Albert Einstein was the first to explain that a beam of light from the headlamp of a speeding train does not move faster than a beam of light from a stationary train.

Sound Energy

Sound energy is a form of kinetic energy. It is produced when matter, such as a tuning fork or human vocal cords, vibrates. The vibrating object has kinetic energy due to movement. The string on a guitar has potential energy when it is pulled back. When released, it has kinetic energy. See **Figure 10-9**. Sound energy moves at about 1100′ (331 m) per second. This is much slower than light energy.

Figure 10-8. A flashlight is an example of an object that sends out light in the form of light waves.

Figure 10-9. Sound waves carry vibrations from a source to our ears and make our eardrums vibrate.

Nuclear Energy

Nuclear energy occurs as atoms of certain material are split or are forced together. This action, called *nuclear fission*, creates huge amounts of energy. Most of it is in the form of heat. Nuclear plants therefore need large amounts of water for cooling. See **Figure 10-10**.

Figure 10-10. Uranium is used in nuclear power stations to produce heat to turn water into steam.

Electromagnetic Waves

The air around us is full of *electromagnetic waves* (waves of energy that have both electric and magnetic properties). An example is the gamma rays given off by nuclear reactions. Waves with medium wavelengths are X-rays that are useful in X-raying your teeth, but over-exposure can damage living cells. Ultraviolet rays come primarily from the sun and can cause sunburn. Infrared rays include the heat waves you feel when sitting in front of a radiant heater. Microwaves are in common use in microwave ovens and in satellite communications. Radio waves are used for communication and are the largest of all electrical waves.

All of these waves travel at the speed of light, but they differ from one another in several ways. They have different wavelengths and frequency, and in the amount of energy they can carry. *Wavelength* is the length of one wave cycle, as shown in **Figure 10-11**. *Frequency* is the number of cycles that occur in a second. Waves with the shortest wavelength have the highest frequency and carry the most energy.

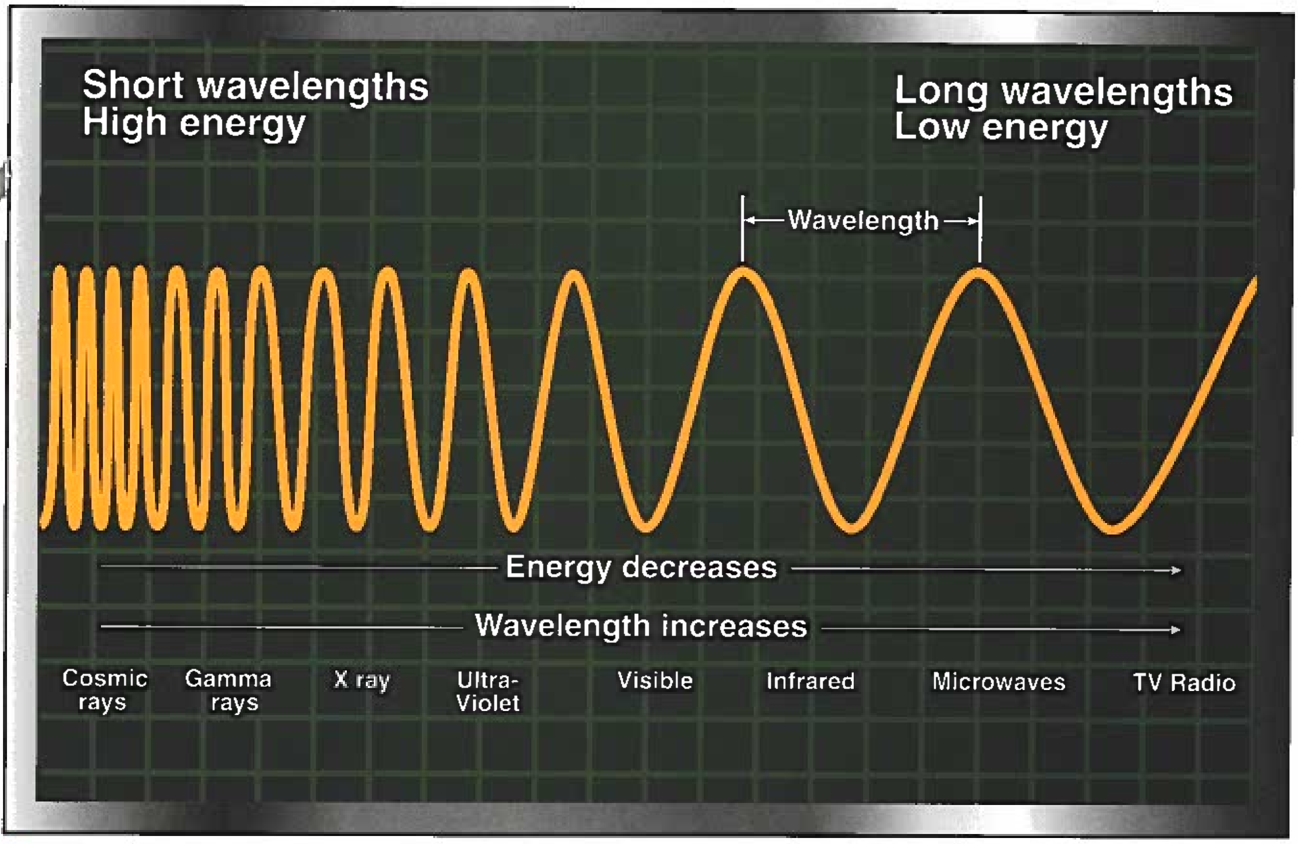


Figure 10-11. As the wavelength of an electromagnetic wave increases, its frequency, or cycles per second, decreases.

Science Application

Vibrations and Sound

Music can be made by causing part of an instrument, or the air inside the instrument, to vibrate. This vibration produces sound waves in the air that we hear as musical sounds. The frequency of the sound—the number of vibrations per second—is measured in hertz (Hz). String instruments have strings that are stretched tightly on the instrument, but are left free to vibrate. How fast they vibrate depends on how tight the strings are.

Science Activity

To demonstrate the principle of sound energy, make a simple string instrument. You will need four rubber bands, three empty boxes (such as a cereal box) of different sizes, and two 1/2″ dowel rods. Wrap the rubber bands around one of the boxes. Then place the dowels under the bands, 1″ from each end of the box, to lift them off the box. Pluck the rubber bands between the two dowels to make sounds. Perform the following experiments:

1. Move the dowels to different positions, such as 2″, 3″, and 4″ from the edges of the box. What difference does the position of the dowels make in the sound? Record your findings.
2. With the dowels 2″ from each edge of the box, tighten the rubber bands. What happens to the sound? Record your findings.
3. Repeat steps 1 and 2 for each box. What difference does the size of the box make? Is this any different from changing the position of the dowels? Record your findings.

Document your experiments and results. Record your ideas for other tests you could do to find out more about how string vibrations produce sound. What changes could you make to the instrument to improve the quality of sound? Place your report in your portfolio.

Energy Conversion

It is important to realize that energy can be neither created nor destroyed. We simply change its form. The first law of thermodynamics states that the total amount of energy in the universe remains constant. More energy cannot be created, and existing energy cannot be destroyed. It can only be converted from one form to another. Energy conservation is a rule of physics. It states that the total amount of energy is unchanged even though it may change from one type to another.

For example, the energy you use to pedal your bicycle comes from the food you eat. Your body has made a change in the form the energy takes. The chemical energy in the muscles is changed to kinetic energy of the bicycle. When the brakes are applied, this kinetic energy is changed into heat energy as a result of friction between the brake shoes and the wheel.

When a flashlight is switched on, the chemical energy in the battery is changed to electrical energy. Electrical energy is changed to light energy when the bulb is lit. A bungee jumper has gravitational energy because of the height above the ground. This energy is changed to kinetic energy during the dive. If the horn of a car blows, electrical energy becomes sound energy.

Losses during Conversion

When switching on a light bulb, you may expect to change all of the electrical energy to light energy. Not so! Only a portion of the electrical energy is converted into light energy. The rest is converted into heat energy. You can feel the heat produced by holding your hand near the light bulb. See Figure 10-12. In all energy changes, some of the energy is used as intended, but some is wasted. However, remember that although there has been a change in the form of energy, the total amount of energy remains the same: energy is neither created nor lost.

Figure 10-12. A light bulb is one example of energy conversion. Electrical energy converts into light energy and wasted heat energy.

Reducing Energy Waste

Partly because incandescent light bulbs waste so much energy, they will be banned in Canada by 2012 and in the United States by 2014. In the United States, they will start being phased out in 2012, beginning with the 100-watt bulb. In most of Europe, the ban is now being phased in, and incandescent bulbs are already banned in Australia and Cuba.

Where Does Energy Come From?

Much of the energy we use comes from the sun. The sun's heat keeps us warm. Heat from the sun also causes wind and rain. Most plants need light energy from the sun for growth. These plants provide humans and animals with the energy they need to do work. Over millions of years, some of these plants have been changed into petroleum and coal. These fossil fuels may be used to provide energy for machines.

All sources of energy make up two groups: nonrenewable and renewable. *Nonrenewable energy* sources will eventually be used up and cannot be replaced. They include coal, oil, natural gas, and nuclear energy. *Renewable energy* sources will always be available. They include the sun, wind, water, and geothermal energy. These two major groups are summarized in Figure 10-13.

Nonrenewable Sources of Energy

Most nonrenewable sources of energy were formed from the remains of living matter. Although other sources of energy are being explored, coal and petroleum are currently the most important nonrenewable sources of energy.

Coal

Coal developed from the remains of plants that died millions of years ago. For this reason, it is often referred to as a fossil fuel. The coal-forming plants probably grew in swamps. As the plants died, they gradually formed a thick layer of vegetable material. Sometimes, ancient seas covered this layer. Sediments (fine particles of sand or gravel) settled to the bottom to form layers of sandstone or shale. As this process was repeated, the layers of vegetable material became squeezed under great pressure and heat for a long time. The result was coal. See Figure 10-14.

Removing coal from the ground is called *mining*. Coal mines are of two types: surface mines and underground mines. Surface mining involves stripping away the soil and rock that lie over a coal deposit. The coal can then be dug up and hauled away. See Figure 10-15.

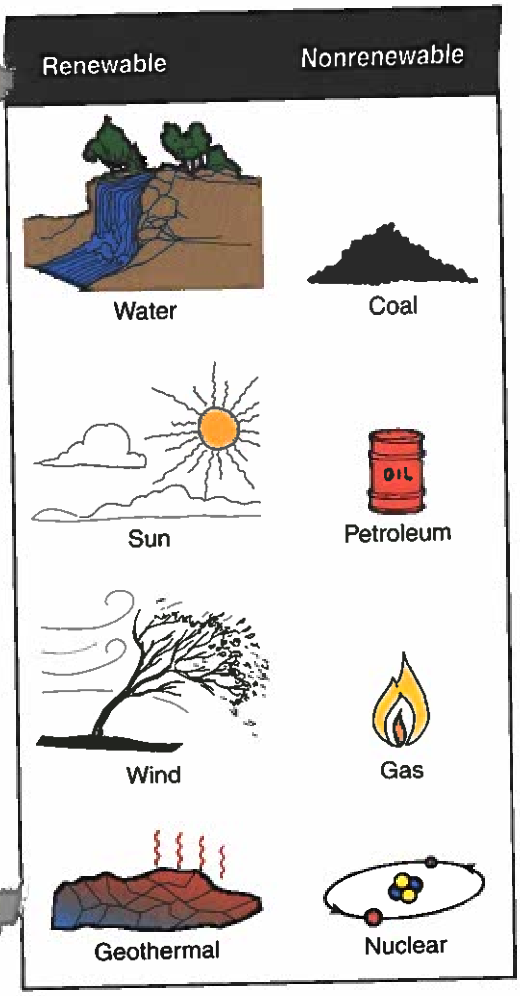


Figure 10-13. All energy comes from a source that is either renewable or nonrenewable.

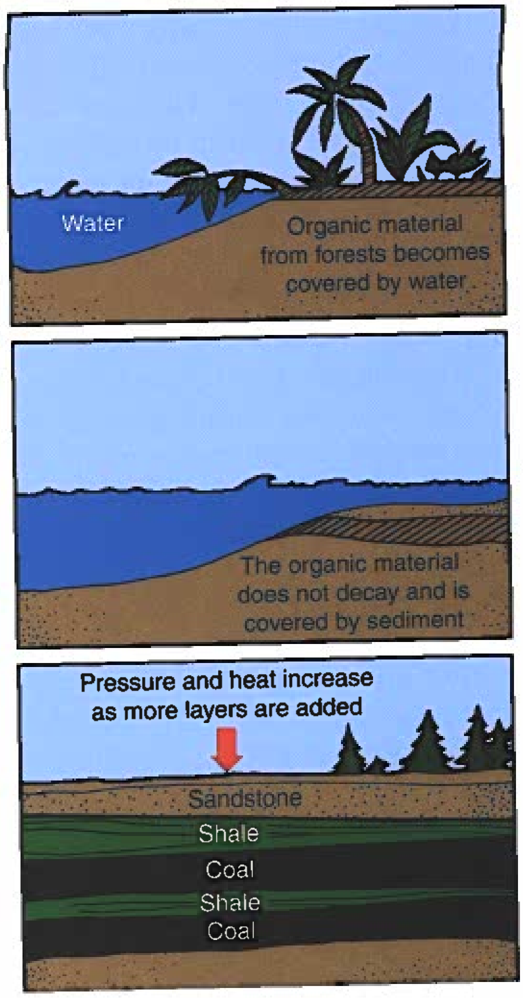


Figure 10-14. After millions of years of heat and pressure, organic material becomes coal.

Figure 10-15. In open pit or surface mining, a dragline removes soil and rock to expose a coal deposit.

Underground mining involves digging tunnels to reach the coal deposit. Miners go down a shaft in a large elevator and then ride through the tunnels in cars. The cars take them to the coal face where large machines rip coal from its million-year-old home. See Figure 10-16. Coal is primarily used as a fuel for electric power generating stations. It is also used to power industrial processes, particularly those manufacturing steel.

Petroleum and Natural Gas

Petroleum was formed from the bodies of countless billions of microscopic plants and animals that lived in the seas millions of years ago. As these plants and animals died, they sank to the bottom to mix with mud and sand on the sea floor. Fossil fuels formed as the result of millions of years of heat and pressure on their remains. As the deposits became buried deeper, the pressure and temperature increased. Over millions of years, the material was slowly changed into complex hydrocarbons that we call coal and gas. See Figure 10-17.

Oil and gas are removed from the ground by drilling deep holes. The holes are made either by drilling rigs located on land or by drilling platforms on the ocean. See Figure 10-18.

Figure 10-16. In an underground coal mine, coal cars carry coal and miners to and from the coal face.

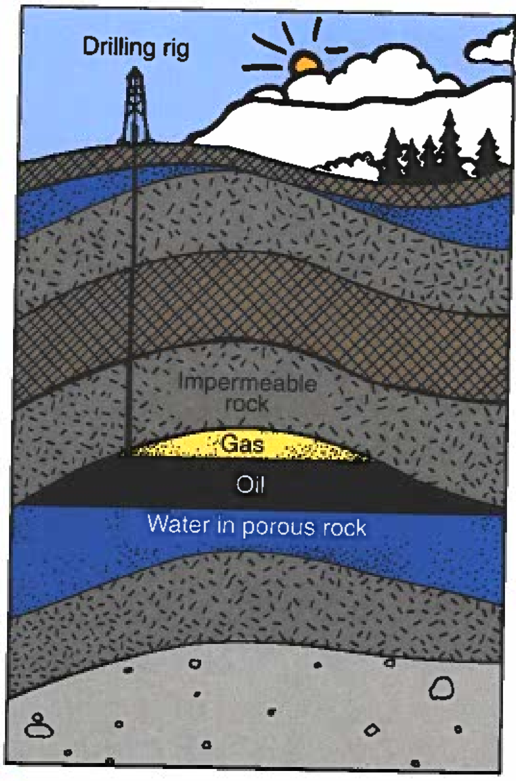


Figure 10-17. When an oil well is drilled, the oil may come out in a gusher. This is due to underground pressure. In other cases, the oil must be pumped to the surface.

Figure 10-18. An oil drilling rig removes oil from below the ground.

In its natural or crude form, oil removed from the ground is useless. Crude oil is processed in an oil refinery. The process involves heating the crude oil to approximately 350° C in a building known as a *fractionating tower*. As the crude oil heats, different compounds are separated. The lighter components rise to the top and the heavier components remain at the bottom. Light hydrocarbons such as ethane and propane come off the top of the distillation tower. They contain between one and four carbon atoms. See **Figure 10-19**. The next lightest are used for gasoline; they contain between five and ten carbon atoms. Diesel fuel contains between twelve and sixteen carbon atoms and is distilled off next. Finally, the heavy residues such as bitumen that contain more than twenty-five carbon atoms are distilled.

The supply of fossil fuels is limited. With our known reserves, and at our present rate of use, we probably have enough coal to last about 200 more years, natural gas for about 75 years, and oil for 60 years or less.

Nuclear Energy

Nuclear power currently provides 15% of the world's electricity. There are currently close to 500 nuclear power plants operating around the world. Nuclear energy is created using one of two processes: nuclear fission and nuclear fusion.

Nuclear Fusion

Nuclear fusion is the same process that powers our sun and the stars. It requires enormous temperatures and pressures. Nuclear fusion has been achieved in research fusion reactors on a limited scale. To date, however, continuous nuclear fusion has not been possible. If we could harness this power on Earth, fusion could be the key to unlimited clean energy.

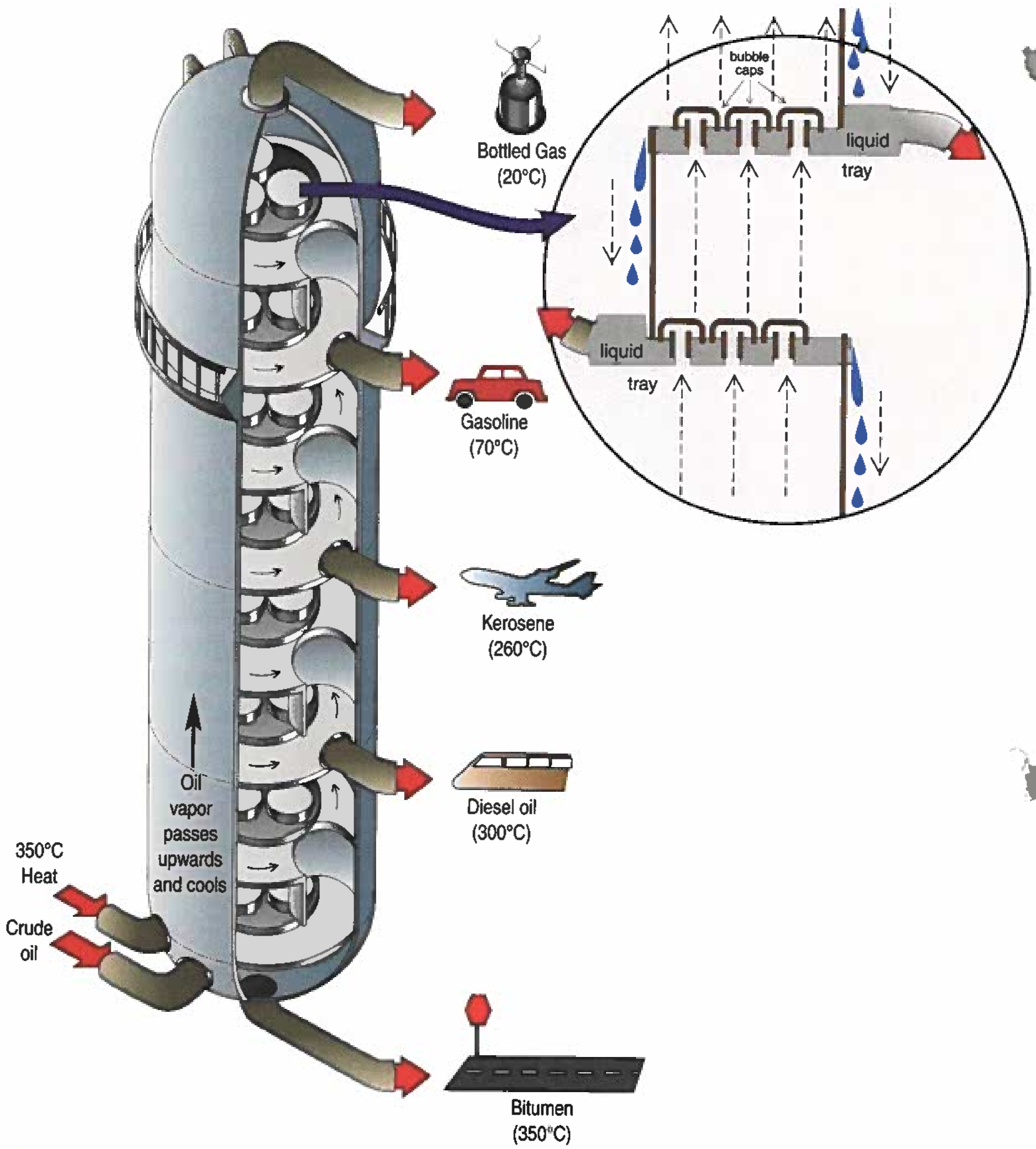


Figure 10-19. By distillation, or "cracking," crude oil can be converted into more than 800 products.

Nuclear Fission

At present, nuclear power stations use only the nuclear fission process. What is nuclear fission? Remember that all solids, liquids, and gases are composed of chemical elements. The smallest unit of each element that still retains the properties of that element is an atom. Although atoms are very small, they are made of even smaller subatomic particles called *protons*, *neutrons*, and *electrons*. At the center of each atom is a nucleus made up of protons and neutrons. See Figure 10-20.

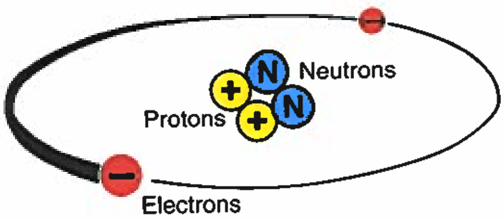


Figure 10-20. The nucleus of an atom contains protons (positively charged) and neutrons (no charge). Electrons, (negatively charged) orbit around the outside the nucleus in a "cloud."

Most atoms have a stable nucleus, which means they do not change. In a few atoms, the nucleus is unstable. These unstable nuclei try to become stable. They throw off particles or rays. These rays are called *radiation*. The atoms are radioactive.

Uranium is a metal. Its atoms have very large nuclei. Very large nuclei are often particularly unstable. When a neutron hits an atom of uranium, the nucleus of the atom splits. See **Figure 10-21**.

The atom splits into two parts, called *fission fragments*. Together, the fragments weigh slightly less than the original atom. The loss in mass turns into energy. On average, an atom that undergoes fission produces one, two, or three neutrons. These neutrons may hit other uranium nuclei. When they do, these nuclei may also split. This throws out more neutrons, and a chain reaction occurs.

To understand a chain reaction, imagine 200 marbles lying on a flat surface and arranged in a circle. What would happen if another marble was thrown at them? They would fly all around in different directions, and each marble would probably hit two or more other marbles. The single marble caused a chain reaction. This is what happens in nuclear fission. *Nuclear fission* is the energy produced by splitting atomic nuclei.

The heat produced by nuclear fission is used to heat water, which turns into steam. This steam is used to drive turbines. Generators attached to the turbines produce electricity.

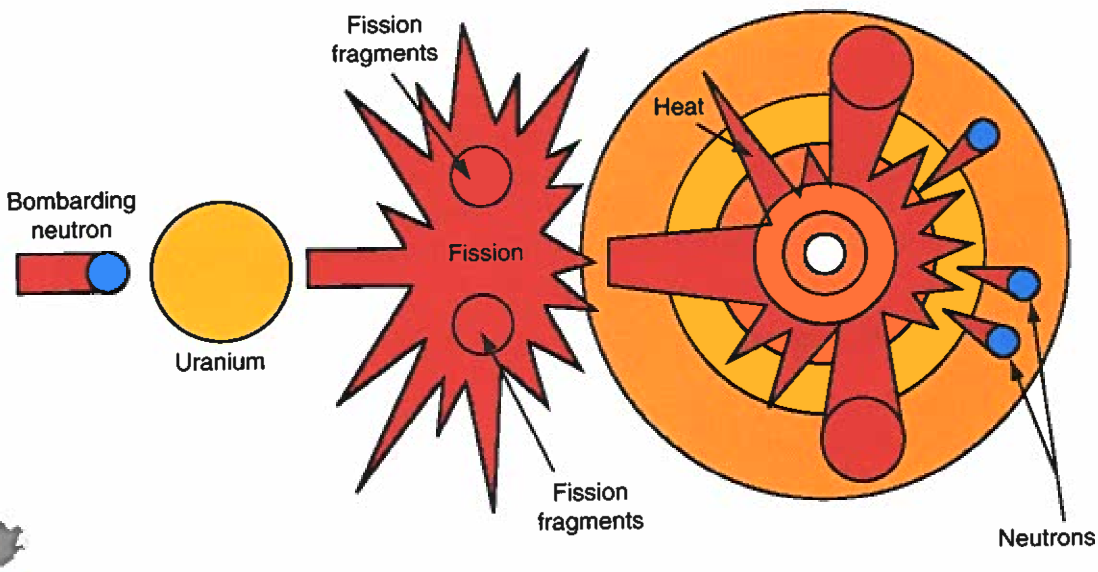


Figure 10-21. Nuclear fission occurs when an atom of uranium splits.

The fission process is noted for the large amount of heat energy it releases. The fissioning of 2.2 lb. (1 kg) of uranium produces about the same amount of heat as burning 2.9 *million* lb. (1.3 million kg) of coal!

Nuclear power has a number of disadvantages. First, some nuclear generating stations have been shut down because of technical and other problems. Second, the general public is concerned about the possibility of major disasters, such as the ones that happened at Three Mile Island (United States) and Chernobyl (Russia). Third, costs per kilowatt-hour are at least twice that of other conventional sources. Finally, safe disposal of nuclear waste is vital. Just a few minutes of exposure to a single bundle of spent fuel one year after it is removed from the reactor, at a distance of 12" (30 cm), would be fatal. Nuclear waste remains dangerously radioactive for thousands of years. How to best dispose of these wastes is a question that is still being debated worldwide.

Nevertheless, people who favor nuclear power point out that climate change and the cost and dangers of coal and petroleum production change our priorities. For example, the gas, oil, and coal-fired plants that produce most of the world's electricity cause more deaths in a year from mining accidents alone than can be traced to nuclear power plants in the past 50 years. Furthermore, fail-safe measures are built into new plants which "kick in" automatically in the event of an emergency. Today 70 percent of France's power is nuclear, compared to approximately 20 percent in the United States and United Kingdom.

Renewable Sources of Energy

Renewable energy is energy that can be replaced rapidly with natural processes. The energy provided by the source can be renewed as it is used. In the past, most energy has been obtained from burning nonrenewable fossil fuels. But as the nonrenewable sources of energy become scarce, alternative sources (solar, wind, tidal, geothermal, and biomass) are being developed.

By living in an industrialized world, people in many countries have enjoyed relative comfort and wealth for over 100 years. This has been largely due to the availability of cheap oil. We are now reaching the point when half the world's known oil supply will have been extracted, and the other half will be more expensive to extract and refine. Consequently, renewable energy sources are becoming increasingly important.

Solar Energy

Solar energy is one of the most important alternative sources of energy. The idea of collecting energy from the sun is a very good one. The main drawback is that this type of energy is not always available. In the winter and on cloudy days, there may be too little. At night, there is none. Yet these may be the times when energy is most needed. However, we can use solar panels to collect and store energy from the sun for later use.

The simplest type of solar panel collects heat directly from the sun's rays. The heat is carried away to provide hot water or to heat buildings. In one kind of solar panel, water flows through pipes or channels under a plate of glass. These pipes or channels are painted black to absorb heat better. This heat transfers to the water. Pipes carry it to the hot water system, where the heat is released. Solar panels are usually placed on the roof of a building. See **Figure 10-22**.

Photovoltaic Cells

Most solar energy is generated by two other methods. The first uses solar cells called ***photovoltaic cells*** to convert the sun's energy directly into electrical energy. The cells are silicon wafers. Photovoltaic cells work because visible and ultraviolet light are powerful enough to knock electrons free from atoms. The loose electrons move through conductors. This creates an electric current.

Photovoltaic solar power is best known for its use in space. The International Space Station (ISS) has eight solar arrays. Together, the arrays contain a total of 262,400 solar panels. See **Figure 10-23**. During its 90-minute orbit, approximately 40 minutes is without sunlight. An electrical power storage system with rechargeable batteries is therefore necessary.

Uses of solar power on Earth vary from portable devices, such as pocket calculators, to recreational use in distant locations. A remote home can be virtually self-sufficient with solar power. An inverter that converts direct current (DC) to alternating current (AC) can be used to run most domestic appliances.

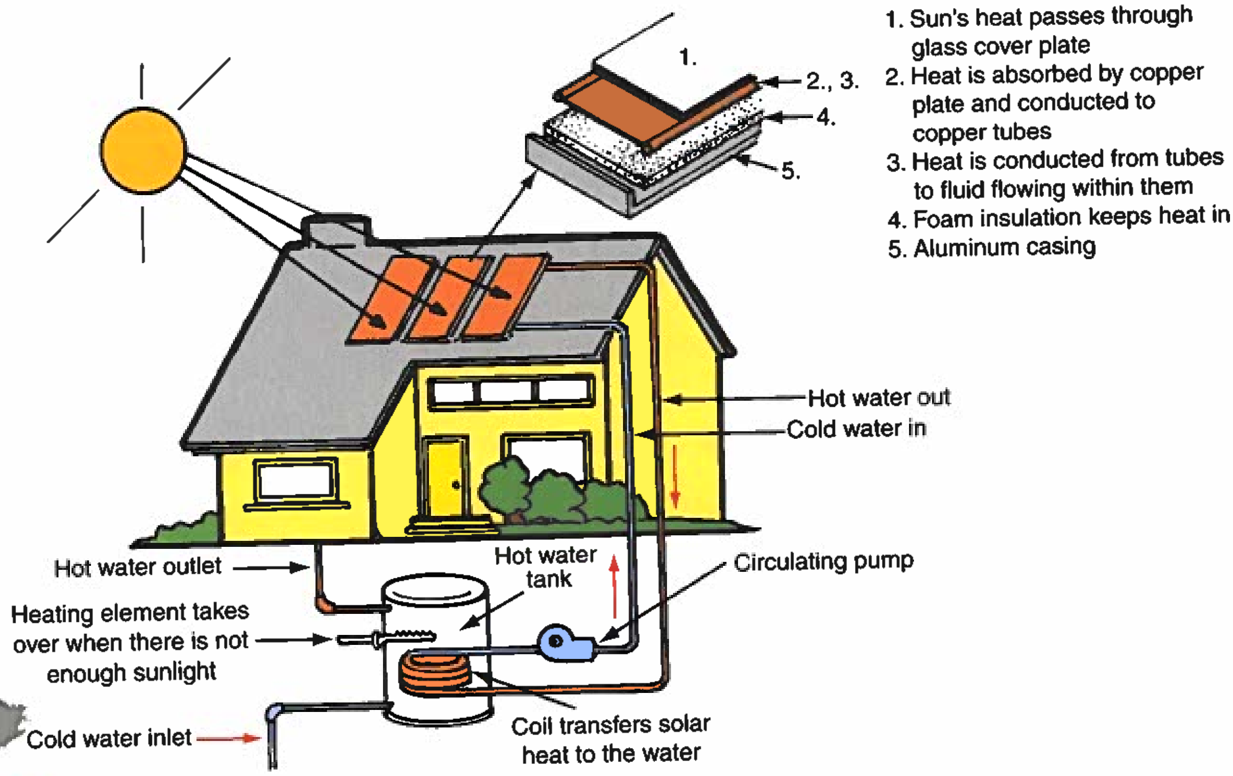


Figure 10-22. Solar panels collect heat from the sun. This heat is used to provide hot water.

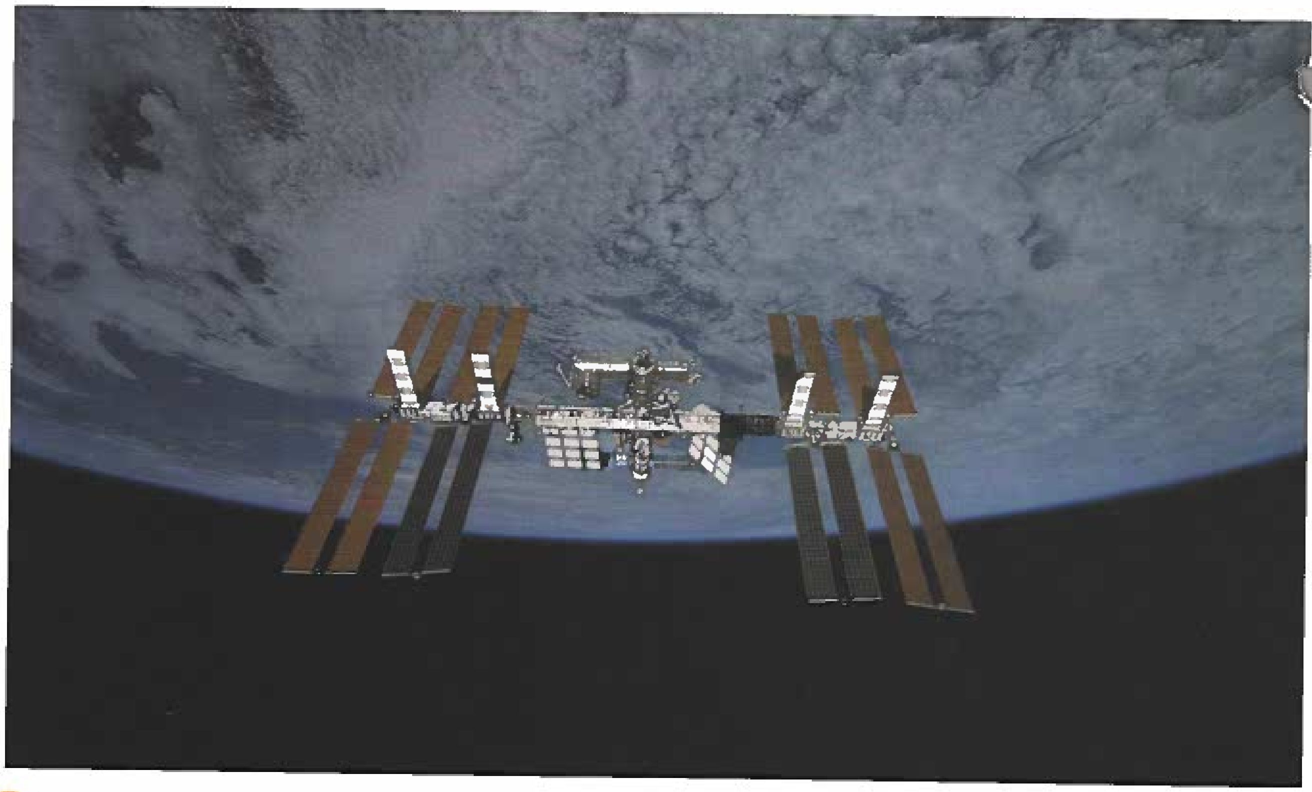


Figure 10-23. The International Space Station has solar panels that produce approximately 110 kW of power.

Concentrating Solar Power Systems

Solar power can also be produced by concentrating solar power (CSP) systems. CSP systems use mirrors to capture and focus the sun's rays on a single point. A fluid, such as water, is heated to high temperatures, which then drives a turbine. A large solar farm in the Mojave Desert, California, currently covers four square miles (10.3 sq.km) and uses 400,000 mirrors to capture the sun's energy. It produces enough electricity for 900,000 homes. Deserts in the southwestern United States are an abundant source of sunshine that could help meet the country's increasing demand for power without releasing any CO_2. This system differs from photovoltaic solar systems in which light interacts directly with semiconductor materials to generate power. See Figure 10-24.

Wind Energy

Wind is one of the oldest sources of energy. For many centuries, wind has turned wheels to grind grain and pump water. Today, wind is increasingly used to generate electricity. Wind power costs about half as much as power from a dam, and a large windmill can be erected and running in one week. Wind can spin wind turbines that are situated on top of high towers, where wind blows faster. The carbon fiber-reinforced blades can be up to 100 ft. (30 m) long, and there may be hundreds of turbines in one wind farm. See Figure 10-25.

Figure 10-24. A concentrating solar power (CSP) system.

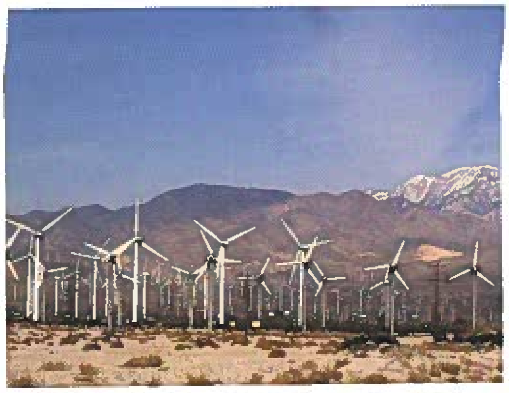


Figure 10-25. Wind turbines on a wind farm capture the kinetic energy in surface winds and convert it into electrical energy in the form of electricity.

As long as the sun continues to shine, the wind will continue to blow. Wind currents occur because of differences in temperature between different parts of the Earth. More heat from the sun reaches the equator than the poles. See **Figure 10-26**. This is because the sun's rays hit the Earth directly at the equator (A). Near the poles (B), they hit at an angle. The heat is spread over a wider area.

The air above the equator expands most and rises by convection. When it reaches about 30° latitude, the warm air cools and falls. At about 60° latitude, it meets cold air from the poles and rises over it. This air movement creates more convection currents. See **Figure 10-27**.

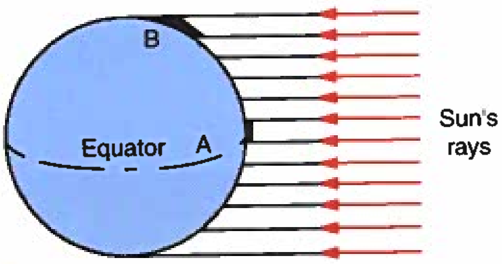


Figure 10-26. More solar heat is delivered at the equator than at the poles. Can you explain why?

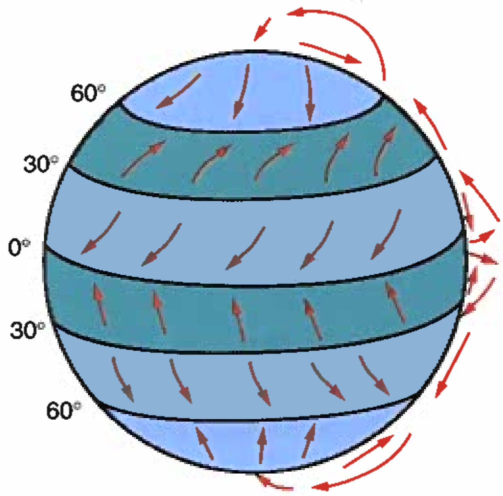


Figure 10-27. Air currents follow a certain pattern over the entire Earth.

Convection currents are also created as a result of the difference in temperature between the land and the sea. During the day, the land heats up more quickly than the sea. As the air warms up, it expands and becomes less dense. This causes it to rise. Cooler, denser air from the sea moves in to take its place. See Figure 10-28. At night, the land cools more quickly than the sea. The process reverses, and warm air rises from the sea. Cooler air from the land moves in to replace it, Figure 10-29.

The wind is free, but it is also unreliable. Meteorologists can determine where the most powerful winds blow. However, no one can predict when it will blow. Many turbines need a breeze of 8 mph (14 km/h) to start them rotating. At 40 mph (60 km/h) they are working at full capacity. At wind speeds above 55 mph (90 km/h), the turbine may have to be shut down to prevent damage to the equipment. Newer turbines have variable geometry blades that can flex, reducing their speed if the wind is too strong.

Currently, wind turbines provide only about 1% of electricity use in the United States. However, it is predicted that this amount may increase to 15% by 2020. Farmers who allow wind turbines to be constructed on their land could earn far more than they would earn by planting grain to produce ethanol.

Energy from Moving Water

The energy of moving water is found in rivers, estuaries, and oceans. Why do rivers flow? As shown in Figure 10-30, water uses gravitational energy to flow from higher ground to lower ground.

The sun evaporates water mainly from the sea and also from rivers, lakes, and plants. This water vapor rises to form clouds. The clouds move with the land breezes. When they reach high ground, they are forced to rise. This causes them to cool, and they cannot hold as much water. Water falls as rain on high ground and forms rivers.

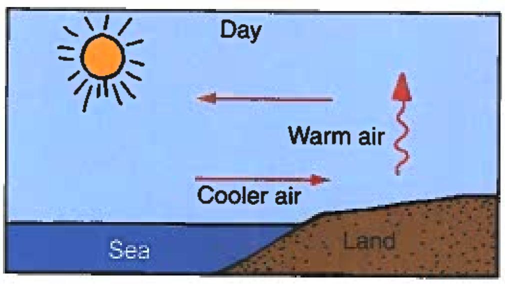


Figure 10-28. Sea breezes blow on shore as warmer air over land rises and cooler sea air moves in to replace it.

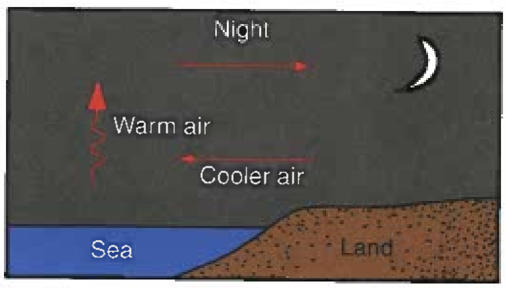


Figure 10-29. At night, land masses cool faster than oceans, causing the breezes to blow from land to sea.

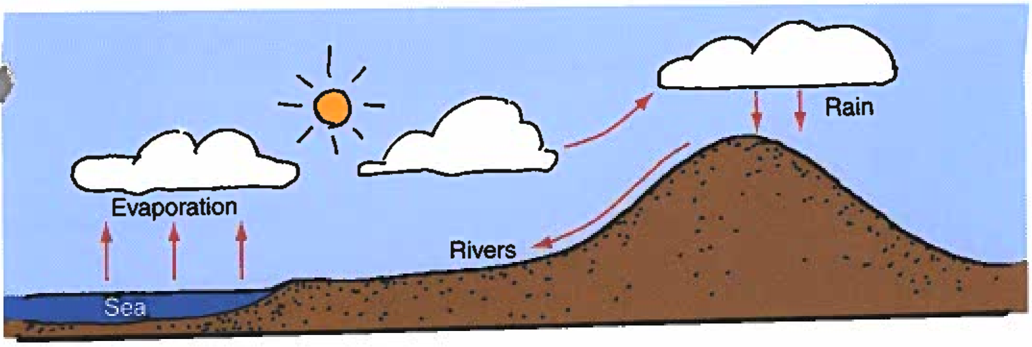


Figure 10-30. Rivers flow because of gravitational energy. Rains deliver the water to high ground. The water then flows to lower ground.

Hydroelectricity

Electricity generated from moving water over turbines is called *hydroelectricity*. Hydroelectric systems produce about 15% of the world's electricity, making hydroelectricity the most important renewable energy source. In Canada, about 60 percent of electrical power comes from hydroelectric systems.

In a hydroelectric system, water from rivers is generally stored behind a dam, as shown in **Figure 10-31**. To generate electricity, water flows through very large pipes called penstocks. The penstocks direct water onto turbine blades, spinning them. The turbines are connected to generators. See **Figure 10-32**.

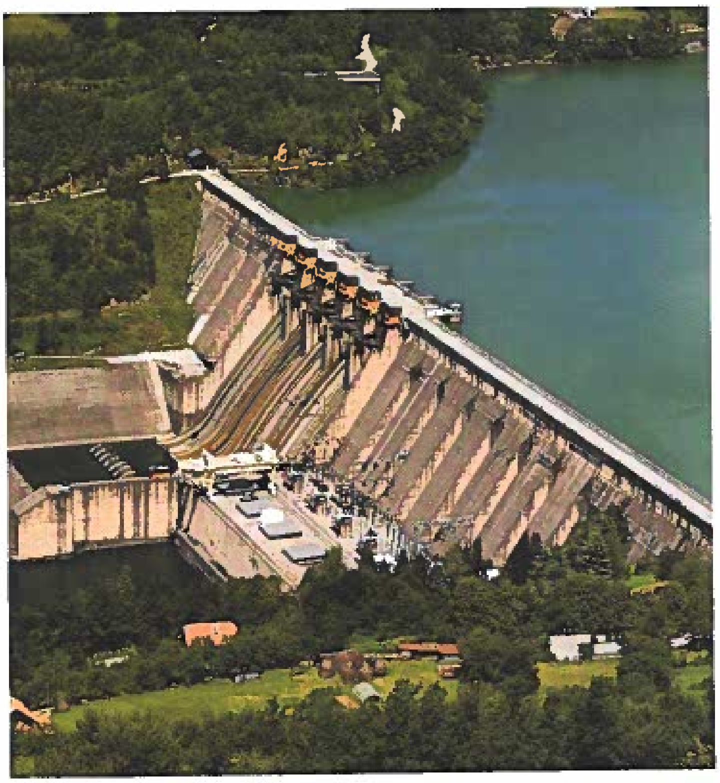


Figure 10-31. Dams store water that will be used to produce electricity.

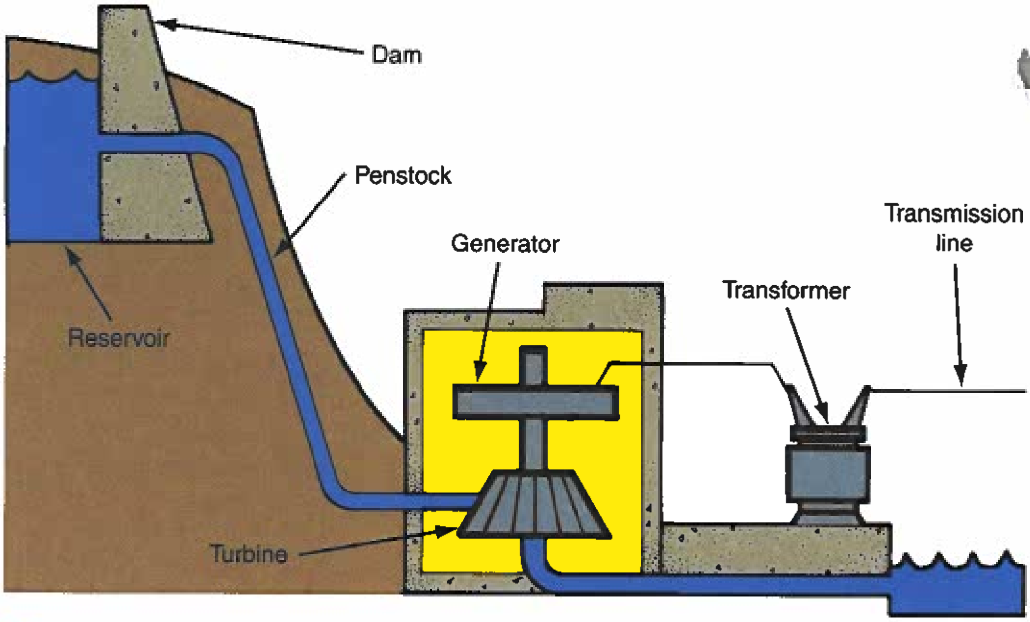


Figure 10-32. Stored water runs through the turbine with great force, causing it to spin rapidly. The turbine drives an electric generator, which produces electricity.

Hydroelectricity is economical compared to other electric power systems. After the initial expense of building the dam and generating station, the cost of producing electricity is small. No fuel is needed apart from the energy provided by the sun. However, hydroelectric power is not pollution-free. When a big dam is built, a large area of land is flooded. The vegetation and soils contain organic matter that rots underwater. This action creates carbon dioxide and methane gas. These gases enter the atmosphere and contribute to global climate change, especially in the tropics.

Wind and hydroelectric power systems complement each other. In winter, when rivers flow more slowly, wind power is at its strongest.

Tidal Energy

Tides from the sea are yet another alternate source of energy. Isaac Newton explained that tides occur because the moon pulls differently on oceans on the near and far sides of the earth. The different gravitational pull causes the surface water to bulge both toward and away from the moon, resulting in the rise and fall of tides every 12 hours.

The tides are regular and inexhaustible. The force of tidal currents can be used to produce electricity. The method is much the same as that used with waterfalls and rivers. The force of tidal water, however, can be captured when it is rising as well as when it is falling.

To understand this method, think of a dam-like structure being placed across the mouth of a bay. As the tide rises, the water flows through a tunnel in the dam. It turns a turbine inside the tunnel. As the tide falls, the water flows back toward the ocean. Once again, it turns the turbine. See Figure 10-33.

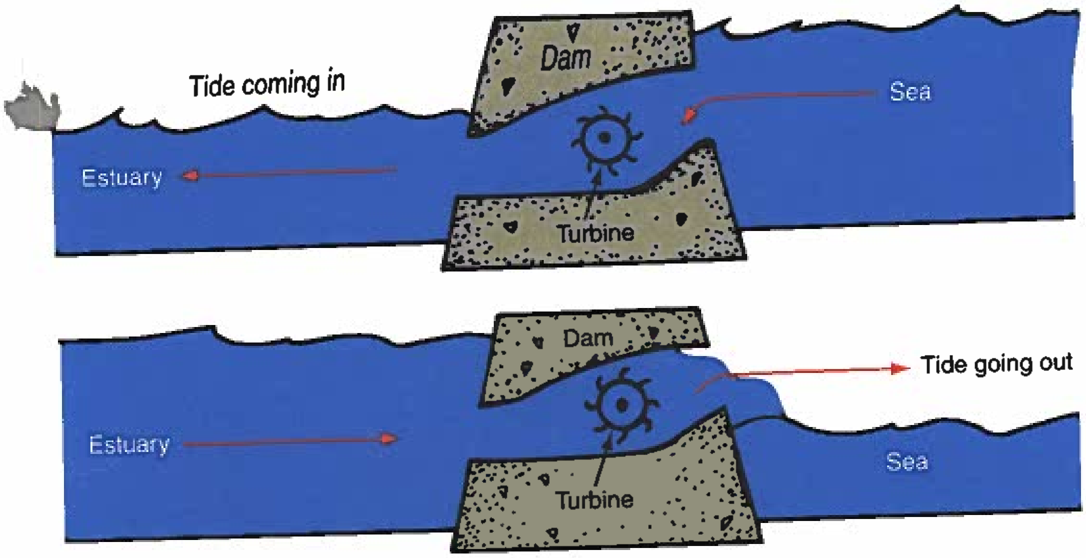


Figure 10-33. Tides can be used to produce electricity. Whether flowing into or out of the estuary, the water spins a turbine.

Newer technologies use large turbines lowered into deep ocean water to harness powerful tidal currents as water rushes past them. An average turbine can produce about two megawatts of power, similar to that of one wind turbine. A wave farm, to be built off the coast of California, is expected to be completed by 2012.

Geothermal Energy

Visitors to Yellowstone National Park will likely see Old Faithful erupting. A cone of boiling water shoots into the air at least 100 ft. (30 m) high at half-hour to two-hour intervals. This display is a demonstration of *geothermal energy*. It shows what happens when water is trapped underground, heated by hot rocks, and forced to the surface through cracks in the earth's crust.

Over 2,800 megawatts of electricity are generated from geothermal power plants in the United States. This electricity is used to supply four million homes with power. The total quantity of the earth's geothermal energy could satisfy the global consumption of energy for thousands of years. However, the challenge is to find a way to access the energy economically, because it mostly lies in depths of mile (1.6 km) or more below the surface.

To reach this energy source, a geothermal loop is made. See Figure 10-34. Two wells are drilled from the surface: an injection well and a production well. An explosive charge is placed at the bottom of the holes. The resulting fracture joins the holes. Cold water is pumped down the injection well. The hot water is forced to the surface through the production well. There, the mixture of steam and hot water powers a turbine generator to produce electricity. Next the steam is condensed by evaporation in the cooling tower. It is then pumped back down the injection well because it contains a high mineral content and cannot be allowed to pollute the surface.

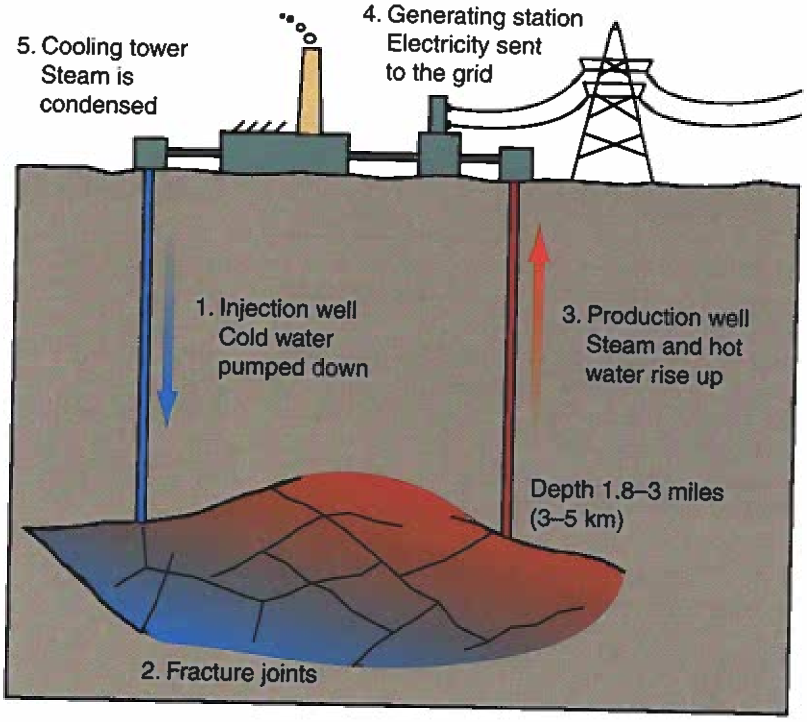


Figure 10-34. To produce geothermal energy, cold water is pumped down through one well to be heated by superheated rocks. Steam rises up a second well to the power plant.

Other Renewable Sources of Energy

Other renewable sources of energy are being developed in different parts of the world. The most important are:

- Energy from plants
- Energy from decomposing matter
- Hydrogen

Together, these sources produce only a very small part of our energy needs.

Energy from Plants

Energy from plants is called ***biomass energy***. Wood has been used as a fuel for thousands of years. It is still the most commonly used fuel in the developing world, where four out of five families depend on it as their main energy source. Some fast-growing plants can be burned as fuels, although currently they provide only 3 percent of the energy used in the United States.

When trees are harvested in North America, about 50% of the tree is converted into lumber or pulpwood. The remaining 50%, mainly branches, twigs, and bark, is often discarded, but can be used as fuel or made into other products. Many pulp and paper mills use wood-fired generators to make their own electricity. See **Figure 10-35**.

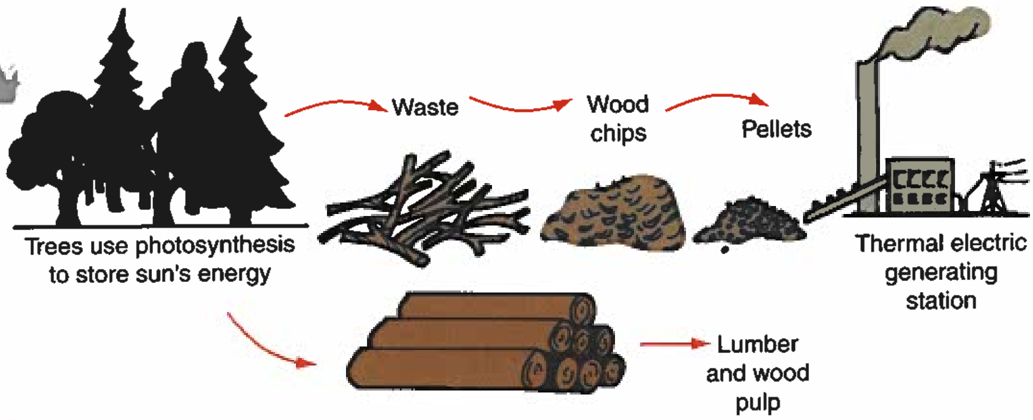


Figure 10-35. Waste wood products can provide energy for producing electricity. Wood is a biomass source of energy.

Biomass fuels, also known as *biofuels*, may also be in liquid form. Methanol and ethanol are alcohol fuels produced from biomass matter, such as corn, beets, sugar cane, wheat, and wood wastes. They are used as additives in gasoline and diesel fuel. Sugar produced from sugar cane can also be fermented to make alcohol, which can be mixed with gasoline to fuel vehicles. See Figure 10-36. In Brazil, 40 percent of the fuel used by cars is produced from sugar cane waste.

Because they are made from plants, biofuels are considered renewable. Unlike petroleum, the raw material for these fuels can be regenerated again and again. However, biofuels produce less heat than petroleum. Therefore, they are generally not used by themselves but are added in small amounts to gasoline.

Energy from Decomposing Matter

Another type of biofuel is decomposing matter. On farms, manure can be collected. Farms also have plant wastes. Pasture plants that have not been eaten, leftover feedstock, fruits, vegetables, and grains that are damaged or unsold are also sources for this type of energy.

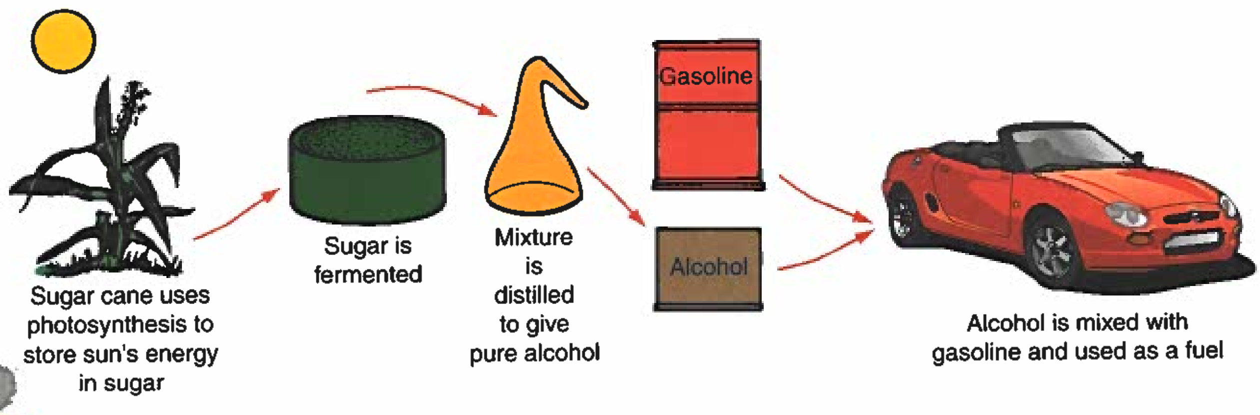


Figure 10-36. Sugar cane can be processed from cane and then used to produce alcohol. Blends of alcohol and gasoline are used to fuel automobiles.

When manure and organic wastes are put into closed tanks, bacteria will digest them. This produces methane gas, which scientists call *biogas*. Methane gas can be used for cooking, lighting, and running engines. It is a common method of producing energy in many parts of the world. In China, more than 24 million biogas digesters are in use, mostly in villages. Biogas is particularly easy to make on farms. A small biogas digester can produce enough gas for a family to use for cooking, heating, and lighting. See **Figure 10-37**.

Hydrogen

The word *hydrogen* comes from the Greek word meaning "water generator." The element was given this name because water is produced when hydrogen burns in the presence of oxygen. One of the first successful uses of hydrogen fuel was in the Saturn V rocket that took men to the moon. The space shuttle had a huge external tank filled with liquid hydrogen and liquid oxygen. This fuel not only lifted the shuttle into orbit but also produced the electricity needed during a mission.

The power to make the two elements combine comes from a fuel cell. A *fuel cell* is a device that allows hydrogen and oxygen to combine, without combustion, to generate electricity. A reaction occurs when electrons are released from the hydrogen and travel to the oxygen through an external circuit. As electrons travel through the circuit, they generate a current that can power electrical devices. When hydrogen fuel is used on space missions, the reaction also benefits astronauts in another way. The only by-product is water, which is the water that astronauts drink.

If fuel cells produce energy without any toxic by-products, why don't we use them in other vehicles? The main reason is cost. Fuel cells use platinum, a very expensive metal. Currently hydrogen, as a fuel, cannot compete economically with petroleum. Other issues also remain. The hydrogen fuel tank takes up most of the trunk space. Also, there are currently very few hydrogen fueling stations across North America. In addition, temperatures below freezing present a major problem when the by-product of the motor is water.

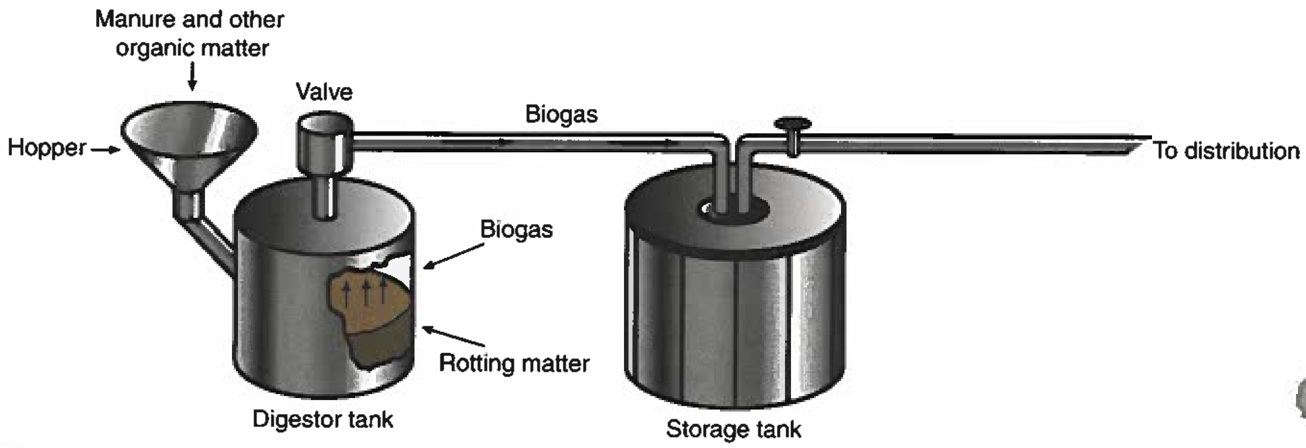


Figure 10-37. A biogas digester uses waste organic material to produce methane gas.

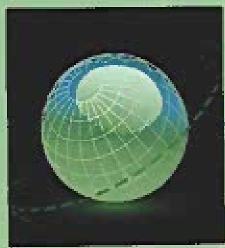
Environmentalists point out that, in order to be pollution-free, hydrogen must be made using renewable energy. If the hydrogen is manufactured by using fossil fuels, we are only shifting pollution from vehicle tailpipes to hydrogen production plants. We will have done nothing to reduce air pollution and greenhouse gases, if this happens. However, experimental vehicles are now on the road. Both Chicago and Vancouver have buses powered by hydrogen fuel cells.

Energy from Garbage: A Problem

Many people would like to believe that waste disappears when it is burned or that it can provide a nonpolluting source of renewable energy. Waste that is burned in a furnace or boiler generates heat, steam, and electricity, but the burnt waste does not disappear. It is transformed into ashes and gas. When this happens, chemical reactions in the atmosphere lead to the formation of new compounds. Some of these compounds are extremely toxic and carcinogenic (cancer-causing). These compounds include dioxins, acidic gases, particulates, and heavy metals.

Think **Green**

Renewable vs. Green Energy



Many people think that if a source of energy is renewable, it is automatically "green." Is this really true? As you can see in the "Energy from Garbage: A Problem" section, it is not.

Renewable energy sources *can* be green, or environmentally friendly. Solar energy, for example, is a green energy source unless the technology used to capture it contributes significantly to pollution or hazardous waste production. Currently, most solar energy systems are good sources of green energy.

Think about the other renewable sources of energy described in this chapter. What overall effects does each one have on the environment? Remember to include all elements of the environment: air, water, land, and human, wildlife, and plant populations. How environmentally friendly is each source of renewable energy?

Energy and Power Systems

Like all other technological systems, energy and power systems include inputs, processes, outputs, and feedback. Understanding these individual components is critical to understanding the system as a whole. (To refresh your memory on systems, refer to Figure 7-29.)

Energy and power systems have many types of inputs. Wind is an input for windmills. The sun is an input for solar power systems. Water falling by gravity is an input for waterwheels and turbines within dams. Other inputs include the people who develop, operate, and maintain the systems and the materials and machines that compose the systems.

Processes within energy and power systems are typically conversion processes. The conversion types include:

- Mechanical-to-electrical (electrical generating stations)
- Electrical-to-mechanical (electric motors)
- Chemical-to-mechanical (internal combustion engines)
- Chemical-to-electrical (batteries and fuel cells)

Other processes include the management and operation of the system.

Outputs of energy and power systems are typically the outputs of the conversion process. Power systems are often used to power other technological systems. For example, they can include the wheel rotation on an automobile, the thrust of a jet engine, the distribution of electricity to homes and businesses, the light from a flashlight, or the heating of water in a water heater. There are also societal outputs, such as the convenience of riding lawn mowers or readily available electrical power. Environmental outputs include the heat, smoke, and carbon dioxide produced by burning fossil fuels.

Feedback in energy and power systems is generally provided by system monitoring. This may include measuring and observing the speed of a motor, the amount of current flowing through an electrical wire, or the temperature of water in an aquarium.

End Note

Sources of energy can be divided into two groups: renewable and nonrenewable. Nonrenewable energy—coal, oil, and natural gas—cannot be replaced. Renewable energy—sun, wind, and water—will always be available.

Currently, most cars and trucks use nonrenewable petroleum products to power their engines. Research is underway to find a suitable replacement. Whatever fuel is used in the future should be a clean, sustainable energy source that will prevent climate change, air pollution, and further damage to the environment.

The technology exists to move toward a life without dependence on oil. The answer may be to think small, rather than big. Individuals should be encouraged to generate some of their own solar or wind power. In Germany, fifty percent of the owners of windmills are small farmers. If they generate more than is needed for their own use, they can return their surplus power to the power grid and receive credit for these surpluses. This system is called *net-metering*.

Summary

- The two basic categories of energy are potential energy and kinetic energy.
- Energy takes many different forms: chemical, gravitational, strain, electrical, heat, light, sound, and nuclear.
- Energy can be neither created nor destroyed. However, during energy conversions, some of the energy may be converted into an unwanted form.
- Some sources of energy are nonrenewable. When we use them up, they will no longer exist. These sources include coal, petroleum, natural gas, and nuclear energy.
- Some sources of energy are renewable and can be replaced as needed. These sources include energy from the sun, wind, water, and heat from deep within the Earth.
- The inputs into energy and power systems vary depending on the type of energy. Processes are usually conversion processes, and outputs are the results of the conversion processes. Feedback is provided by system monitoring.

Reading Target

Summarizing Information

Copy the following graphic organizer onto a separate sheet of paper. For each chapter section (topic) listed in the left column, write a short, one-paragraph summary of the topic in the right column. Do not write in this book.

Chapter Section (Topic)	Summary
Energy Basics	
Forms of Energy	
Energy Conversion	
Where Does Energy Come From?	
Nonrenewable Sources of Energy	
Renewable Sources of Energy	
Energy and Power Systems	

Test Your Knowledge

Write your answers to these review questions on a separate sheet of paper.

1. What category of energy does a wound spring have?
2. What category of energy does a falling boulder have?
3. List the nine forms of energy and give one example of each.
4. Give three examples to show that energy can neither be created nor destroyed.
5. List three examples of nonrenewable energy sources and three examples of renewable energy sources.
6. What are the major problems in using nuclear energy to produce electricity?
7. Describe two methods of collecting energy from the sun.
8. What is the major disadvantage of wind turbines as a source of electrical energy?
9. Describe how geothermal energy is used to produce electricity.
10. Describe the general inputs, processes, and outputs of a nuclear power system. What feedback mechanisms are needed?

Critical Thinking

1. Explain this statement: "Not all sources of clean energy are sustainable, and not all sustainable sources of energy are clean."
2. Nuclear energy is currently considered a nonrenewable source of energy. How might this type of energy be made renewable?
3. Think about society and the general attitude in the United States about conserving energy. How has this attitude changed during your lifetime? How might this affect the adoption or rejection of new technologies related to energy and fuel development?

Apply Your Knowledge

1. Think back to a time when a power failure occurred in your area. List the devices you were unable to use. Imagine that the power stayed off for 48 hours. What alternative sources of energy could you use?
2. List five devices in a typical home that use energy. Describe the energy change(s) that take place when each is used.
3. List the ways in which you use energy each day around the house, in traveling, at school, and for leisure. State whether the energy comes from a renewable or nonrenewable source.
4. Research the Internet, your library, or your public service utility to find ways to save energy. Create a poster that illustrates conservation ideas relating to your yard or garden, the vehicles your friends or parents drive, the types of food you buy, or the amount of recycling you do.
5. Research the number of households in the United States that had solar water heaters in the years 1990, 1995, 2000, 2005, and 2010. Also find out the average initial cost of a midsize solar water heater in each of those years. Plot your findings on a graph and study the result. Can you see a trend in either or both of these factors? What can you conclude from these trends, if anything? What effect might these trends have on future development of solar water systems? What does your data reveal about the acceptance and popularity of the use of solar energy in the home?
6. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **ENGINEERING** Using popsicle sticks, rubber bands, or other commonly available items, design and make a working model of a wind turbine. Try to find a way to connect the turbine to a simple shaft in such a way that when wind turns the turbine, the shaft moves. Shaft movement can be either reciprocal (back and forth) or rotary. Test your model by taking it outside or by using a fan set on low speed. Keep in mind that the turbine must be strong enough to withstand the force of the wind.
2. **SCIENCE** When you place a bowl of water in direct sunlight, solar energy helps evaporate the water. This fact can be used to design a water purifier. For example, you could remove the salt from ocean water to make drinking water. Design a solar water purifier that removes the salt from a solution of saltwater. Use materials that are easily available. Test your design and document your results. Include your design in your portfolio.
3. **MATH** The Smith family is considering installing a new solar water heater. The new water heater will replace an older electric model. Before they can decide whether the solar water heater is a good investment, they want to find out how much money it will save them. In addition to the difference in actual operating costs, they want to know how long it will take them to achieve a return on their investment (ROI). Given the information below, calculate the ROI for the Smiths' new solar water heater. Show your work.
   - Estimated annual cost to run the current electric water heater: $187.50
   - Estimated annual cost to run the solar water heater: $148.64
   - Startup costs for the solar water heater, including installation: $2,340.00

   Several ROI calculators are also available on the Internet. Find one such site and input the same information you used in your calculations. Does the result match your calculation? If not, why?

The photos on this page show both old windmills, which produce mechanical power, and new wind turbines, which produce electrical power. Which pictures show windmills? Which show turbines? How is (or was) the power of each used?

CHAPTER 11

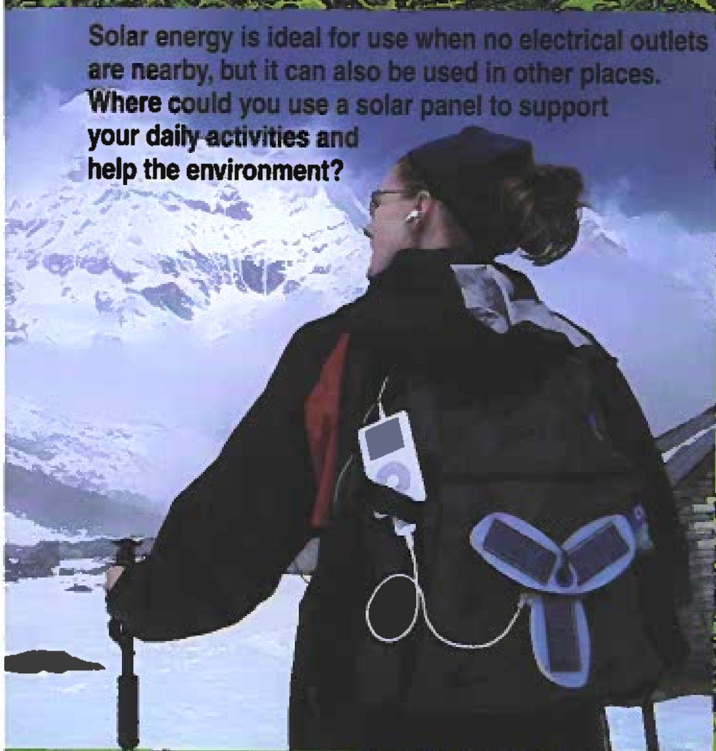
Electricity and Magnetism

Better by Design

Christopher Horner designed the Solio™ solar charger

Using a solar panel allows you to generate your own free, clean electricity directly from the sun.

Christopher Horner and his design team want you to capture the sun's energy and convert it into electricity to power your portable electronics. When opened, a Solio hybrid charger captures light from the sun. When sunlight hits the solar cells, it creates an electric current. This current can either be used directly or stored in its battery. The stronger the sunlight, the more electricity is generated. According to Chris, using a solar-powered Solio is 100 times better for the environment than using a wall charger.



Solar energy is ideal for use when no electrical outlets are nearby, but it can also be used in other places. Where could you use a solar panel to support your daily activities and help the environment?

"We must make renewable energy tangible to the consumer who wants power on the go."