



**FIGURE 9.19 Biofuels** Biofuels (E85 and biodiesel) are available for purchase in many parts of the world.

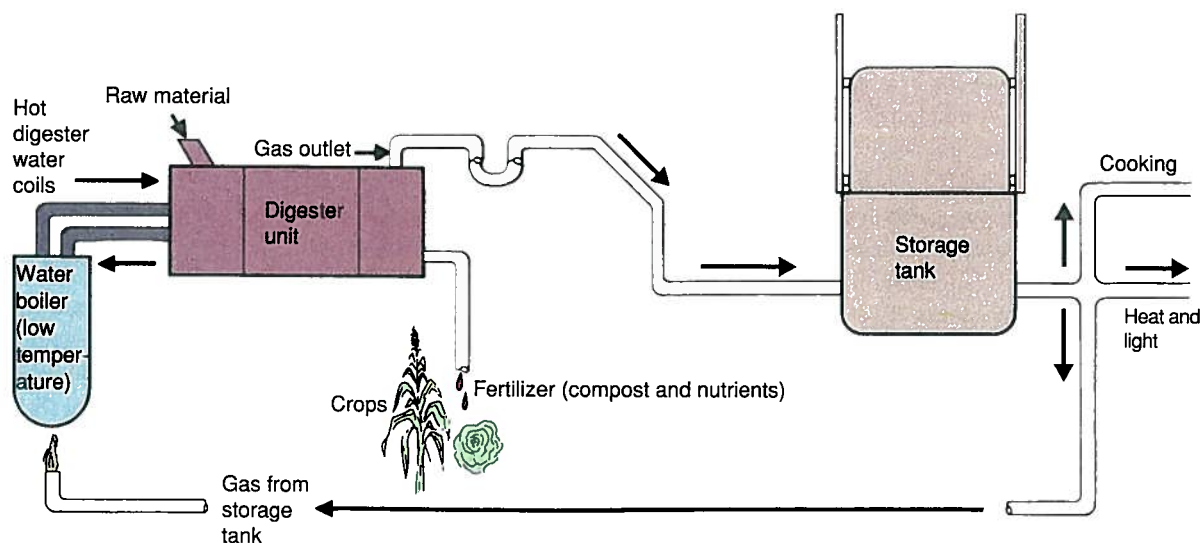
mixture, consisting primarily of methane and carbon dioxide, known as biogas. The most commonly used technology involves small digesters on farms that generate gas for use in the home or for farm-related activities. China has 500,000 small methane digesters in homes and on farms; India has 100,000; and Korea has 50,000. (See figure 9.20.) Anaerobic digestion can also be used with sewage treatment plants to produce methane. The methane collected can be used to provide heat or run machinery in the plant. (See figure 9.21.) Anaerobic digestion also occurs in landfills. In many landfills the methane gas produced eventually escapes into



**FIGURE 9.21 Anaerobic Bioreactor** This bioreactor is used to produce methane from municipal sewage sludge.

the atmosphere. However, the gas can be extracted by inserting perforated pipes into the landfill. In this way, the gas will travel through the pipes, under natural pressure, to be used as an energy source, rather than simply escaping into the atmosphere to contribute to greenhouse gas emissions. Some newer landfills have even been designed to encourage anaerobic digestion, which reduces the volume of the waste and provides a valuable energy by-product.

**Pyrolysis** Pyrolysis is a thermochemical process for converting solid biomass to a more useful fuel. Biomass is heated or partially burned in an oxygen-poor environment to produce a hydrocarbon-rich gas mixture, an oil-like liquid, and a carbon-rich solid residue. Traditionally, in developing countries, the solid residue produced is charcoal, which has a higher energy density than the original fuel



**FIGURE 9.20 Methane Digester** In the digester unit, anaerobic bacteria convert animal waste into methane gas. This gas is then used as a source of fuel. The sludge from this process serves as a fertilizer. In many less-developed countries, this type of digester has the advantages of providing a source of energy and a supply of fertilizer and managing animal wastes, which helps reduce disease.

The traditional charcoal kilns are simply mounds of wood or wood-filled pits in the ground that are covered with earth. However, the process of carbonization is very slow and inefficient in these kilns, and more sophisticated kilns are replacing the traditional ones. The liquid residue or “bio-oil” produced can be easily transported and refined into other products. The process is similar to refining crude oil.

Gasification is a form of pyrolysis, carried out with more air and at high temperatures, to optimize the gas production. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen, and methane, together with carbon dioxide and nitrogen. The gas is more versatile than the original solid biomass, and it can be used as a source of heat or used in internal combustion engines or gas turbines to produce electricity. During the Second World War, countries such as Australia and Germany even used it to power vehicles.

### **Environmental Issues**

Although the use of biomass and waste as a source energy is often thought of as being environmentally benign, it has many significant environmental impacts.

**Habitat and Biodiversity Loss** It is estimated that throughout the world there are 1.3 billion people who cannot obtain enough wood or must harvest wood at a rate that exceeds its growth. This has resulted in the destruction of much forest land in Asia and Africa and has hastened the rate of desertification in these regions. (See figure 9.22.)

Another issue associated with biomass energy is the loss of biodiversity. Destroying natural ecosystems to plant sugarcane, grains, palm oil, or other plants can reduce the biodiversity of a region. The plantations lack the complexity of a natural ecosystem and are susceptible to widespread damage by pests or disease.

**Air Pollution** Burning wood is a source of air pollution. Often the people in developing countries use wood in open fires or poorly designed, inefficient stoves. This results in the release of high amounts of smoke (particulate matter) and other products of



**FIGURE 9.22 Desertification** The demand for fuelwood in many regions has resulted in the destruction of forests. This is a major cause of desertification.

incomplete combustion, such as carbon monoxide and hydrocarbons, which contribute to ill health and death.

Respiratory illnesses are particularly common among women and children who spend the most time in the home. Even in the developed world, air pollution from the burning of biomass is a problem. Some cities, such as London, England, have a total ban on burning wood. Vail, Colorado, permits only one wood-burning stove per dwelling. Many areas require woodstoves to have special pollution controls that reduce the amount of particulates and other pollutants released.

The burning of solid waste presents some additional problems. Because solid waste is likely to contain a mixture of materials, including treated paper and plastic, there are additional air pollutants not found in other forms of biomass.

**Carbon Dioxide and Global Warming** A consensus exists among scientists that biomass fuels and wastes used in a sustainable manner result in no net increase in atmospheric carbon dioxide. Some scientists would even go as far as to declare that sustainable use of biomass would result in a net decrease in atmospheric carbon dioxide. This is based on the assumption that all the carbon dioxide given off by the use of biomass fuels was recently taken in from the atmosphere by photosynthesis. Increased substitution of biomass fuels for fossil fuels would therefore help reduce the potential for global warming, which is caused by increased atmospheric concentrations of carbon dioxide.

**Effects on Food Production** Although the use of marginal or underutilized land to grow energy crops may make sense, using fertile cropland does not. Since there are millions of people in the world who do not have enough food to eat, the conversion of land from food crops to energy crops presents ethical issues.

The use of crop residues and animal waste as a source of energy also presents some problems. These materials supply an important source of organic matter and soil nutrients for farmers. This is particularly true among subsistence farmers in the developing world. They cannot afford fertilizer and rely on these materials to maintain soil fertility. However, they also need energy. Thus, they must make difficult decisions about how to use this biomass resource.

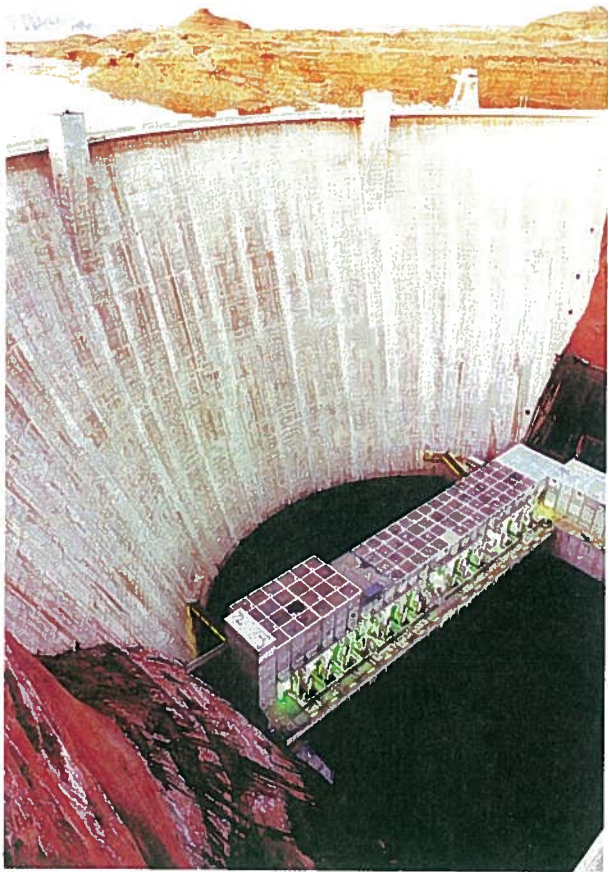
## **HYDROELECTRIC POWER**

People have long used water to power a variety of machines. Some early uses of water power were to mill grain, saw wood, and run machinery for the textile industry. Flowing water creates energy that can be captured and turned into electricity. This is called hydroelectric power, or *hydropower*.

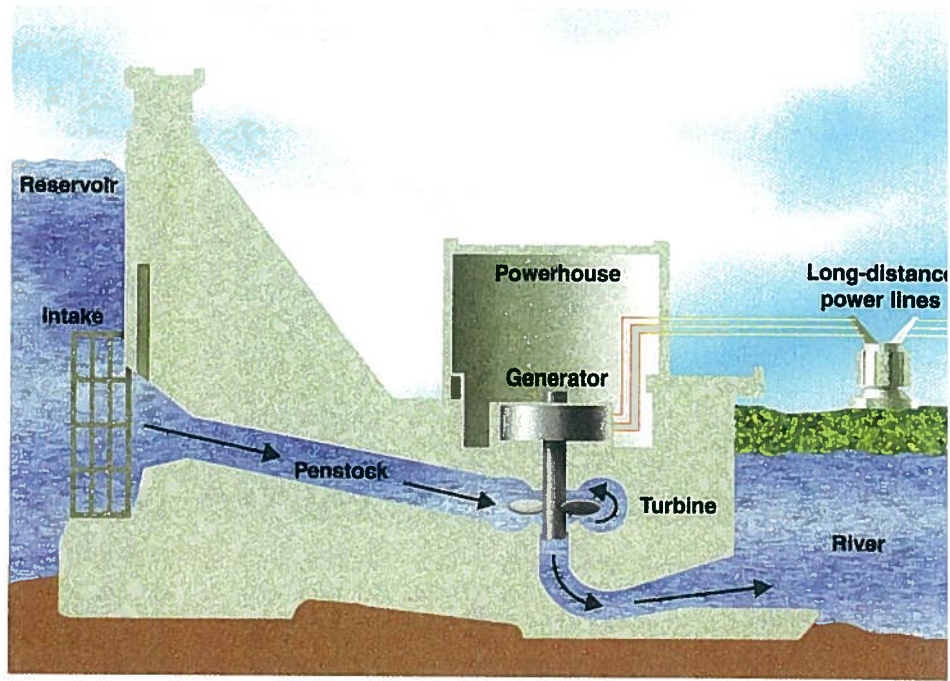
### **Technology for Obtaining Hydropower**

The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. (See figure 9.23.) Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. But hydroelectric power does not necessarily require a large dam. In some areas of the world where the streams have steep gradients and a constant flow of water, hydroelectricity may be generated





(a) Glen canyon dam



(b) Hydroelectric power plant

**FIGURE 9.23 Hydroelectric Power Plant** (a) The water impounded in this reservoir is used to produce electricity. In addition, this reservoir serves as a means of flood control and provides an area for recreation. (b) This figure shows how a hydroelectric dam produces electricity.

Source: (b) Tennessee Valley Authority.

without a reservoir. Such sites are usually found in mountainous regions and can support only small power-generating stations. Some hydroelectric power plants just use a small canal to channel the river water through a turbine. A small microhydroelectric power system can produce enough electricity for a home, farm, or ranch.

At present, hydroelectricity produces about 2.2 percent of the world's energy supply, or about 16 percent of the world's electricity. In some areas of the world, hydroelectric power is the main source of electricity. More than 35 nations already obtain more than two-thirds of their electricity from falling water. In South and Central America, 65 percent of the electricity used comes from hydroelectric power, compared to 44 percent in the developing world as a whole. Norway gets 99 percent of its electricity and over 65 percent of all its energy from hydroelectricity.

### ***Potential for Additional Hydropower***

The potential for developing hydroelectric power is best in mountainous regions and large river valleys. Some areas of the world, such as Canada, the United States, Europe, and Japan, have already developed most of their hydroelectric potential. About 50 percent of the U.S. hydroelectric capacity has been developed. In contrast, Africa has developed only 5 percent of its potential, half of which comes from only three dams: Kariba in East Africa, Aswan on the Nile, and Akosombo in Ghana.

Over the past 10 years, the energy furnished by hydroelectricity worldwide increased by about 17 percent. The World

Energy Council estimates that it would be technically possible to triple the electricity produced by hydropower with current technology. The less-developed countries, which have developed about 10 percent of their hydropower, will experience most of this growth.

The projected increase will come mainly from the development of plants on large reservoirs. However, the construction of "mini-hydro" (less than 10 megawatts) and "microhydro" (less than 1 megawatt) plants is also increasing. Such plants can be built in remote places and can supply electricity to small areas. China has over 80,000 such small stations, and the United States has nearly 1500.

Today's large dams rank among humanity's greatest engineering feats. Table 9.4 lists the locations and sizes of the largest hydroelectric facilities.

Hydroelectric dam projects figure prominently in the economic and investment plans of many developing countries. Egypt electrified virtually all of its villages with power from Aswan. In 2006 China completed construction of a huge hydroelectric dam, known as the Three Gorges Dam, on the Yangtze River. It is the largest hydroelectric dam in the world. Although the dam is complete, it is not expected to reach its full generating capacity of 22,500 megawatts until 2011.

### ***Environmental Issues***

It is important to recognize that the construction of a reservoir for a hydroelectric plant causes environmental and social problems. These impacts, however, must be weighed against the environmental

**TABLE 9.4 World's Largest Hydroelectric Plants**

Name	Country	Rated Capacity Megawatts
Three Gorges Dam	China	22,500
Itaipu	Brazil/Paraguay	14,000
Guri (Simón Bolívar)	Venezuela	10,200
Tucuruí	Brazil	7,960
Grand Coulee	United States	6,809
Sayano Shushenskaya	Russia	6,400
Krasnoyarskaya	Russia	6,000
Robert-Bourassa	Canada	5,616
Churchill Falls	Canada	5,429
Bratskaya	Russia	4,500
Ust Ilimskaya	Russia	4,320
Yaciretá	Argentina/Paraguay	4,050

impacts of alternative sources of electricity. Hydroelectric power plants do not emit any of the standard atmospheric pollutants, such as carbon dioxide or sulfur dioxide given off by fossil fuel-fired power plants. In this respect, hydropower is better than burning coal, oil, or natural gas to produce electricity because it does not contribute to global warming or acid rain.

The most obvious impact of hydroelectric dams is the flooding of vast areas of land, much of it previously forested or used for agriculture. The size of reservoirs created can be extremely large. The Robert-Bourassa project on the Le Grande River in the James Bay region of Quebec has already submerged over 10,000 square kilometers (3861 square miles) of land, and if future plans are carried out, the eventual area of flooding in northern Quebec will be larger than the country of Switzerland. The construction of the Three Gorges Dam in China inundated 153 towns and 4500 villages and caused the displacement of over a million people. In addition, numerous archeological sites were submerged and the nature of the scenic canyons of the Three Gorges was changed.

Large dams and reservoirs can have other impacts on a watershed. Damming a river can alter the amount and quality of water in the river downstream of the dam as well as prevent fish from migrating upstream to spawn. These impacts can be reduced by requiring minimum flows downstream of a dam and by creating fish ladders that allow fish to move upstream past the dam. Silt, normally carried downstream to the lower reaches of a river, is trapped by a dam and deposited on the bed of the reservoir. This silt slowly fills a reservoir, decreasing the amount of water that can be stored and used for electrical generation. The river downstream of the dam is also deprived of silt, which normally fertilizes the river's floodplain during high-water periods. Bacteria present in decaying vegetation can also change mercury, which is sometimes present in rocks underlying a reservoir, into a form that is soluble in water. The mercury accumulates in the bodies of fish and poses a health hazard to those who depend on these fish for food.

## SOLAR ENERGY

The sun is often mentioned as the ultimate answer to the world's energy problems. It provides a continuous supply of energy that far exceeds the world's demands. In fact, the amount of energy received from the sun each day is 600 times greater than the amount of energy produced each day by all other energy sources combined. The major problems with solar energy are its intermittent and diffuse nature. It is available only during the day when it is sunny, and it is spread out over the entire Earth, falling on many places like the oceans where it is difficult to collect. All systems that use solar energy must store energy or use supplementary sources of energy when sunlight is not available. Because of differences in the availability of sunlight, some parts of the world are more suited to the use of solar energy than others.

Solar energy is utilized in three ways:

1. In a passive heating system, the sun's energy is converted directly into heat for use at the site where it is collected.
2. In an active heating system, the sun's energy is converted into heat, but the heat must be transferred from the collection area to the place of use.
3. The sun's energy also can be used to generate electricity by heating water to turn turbines or by using photovoltaic cells.

### Passive Solar Systems

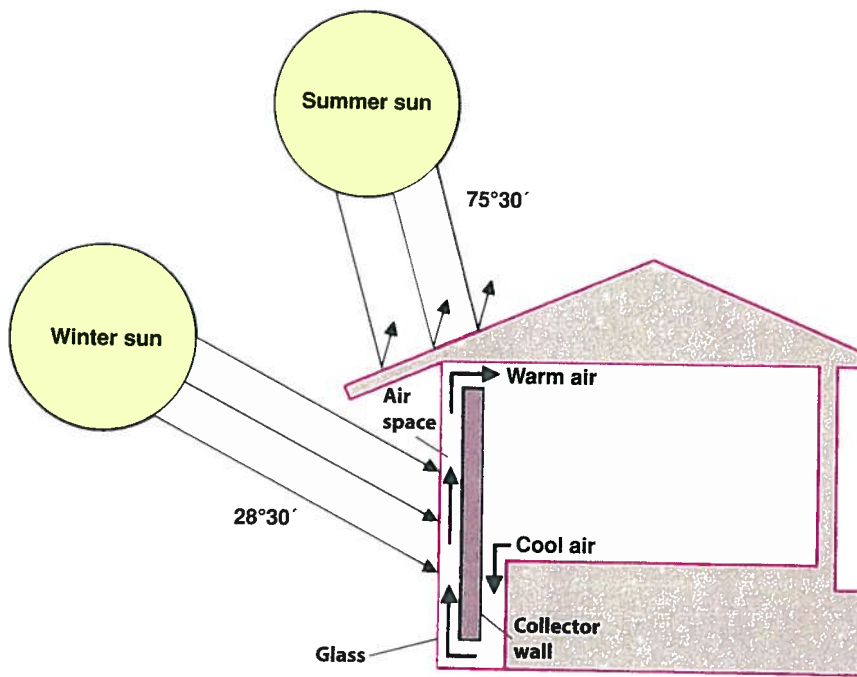
Anyone who has walked barefoot on a sidewalk or blacktopped surface on a sunny day has experienced the effects of passive solar heating. In a **passive solar system**, light energy is transformed to heat energy when it is absorbed by a surface. Some of the earliest uses of passive solar energy were to dry food and clothes and to evaporate seawater to produce salt. Homes and buildings can be designed to use passive solar energy for heating. (See figure 9.24.)

In the Northern Hemisphere, the south side of a building always receives the most sunlight. Therefore, buildings designed for passive solar heating usually have large south-facing windows. Materials that absorb and store the sun's heat can be built into the sunlit floors and walls. The floors and walls heat up during the day and slowly release heat at night, when the heat is needed most. This passive solar design feature is called *direct gain*.

Other passive solar heating design features include sunspaces and trombe walls. A *sunspace* (which is much like a greenhouse) is built on the south side of a building. As sunlight passes through glass or other glazing, it warms the sunspace. Proper ventilation allows the heat to circulate into the building. On the other hand, a *trombe wall* is a very thick, south-facing wall painted black and made of a material that absorbs a lot of heat. A pane of glass or plastic glazing, installed a few centimeters in front of the wall, helps hold in the heat. The wall heats up slowly during the day; then, as it cools gradually during the night, it gives off its heat inside the building.

Many of the passive solar heating design features also provide daylighting. *Daylighting* is simply the use of natural sunlight to brighten a building's interior, reducing the need for electricity to light the interior of a building. To lighten north-facing rooms and upper levels, a clerestory—a row of windows near the peak of the roof—is often used along with an open floor plan inside that allows the light to bounce throughout the building.





**FIGURE 9.24 Passive Solar Heating** The length of overhang in this home is designed for solar heating at the latitude of St. Louis, Missouri ( $38^{\circ}\text{N}$ ). In this design, a wall 30 to 40 centimeters (12 to 16 inches) thick is used to collect and store heat. The collector wall is located behind a glass wall and faces south. During a midwinter day, when the sun's angle is 28 degrees, light energy is collected by the wall and stored as heat. At night, the heat stored in the wall is used to warm the house. Natural convection causes the air to circulate past the wall, and the house is heated. During a midsummer day, when the sun's angle is 75 degrees, the overhang shades the collector wall from the sun.

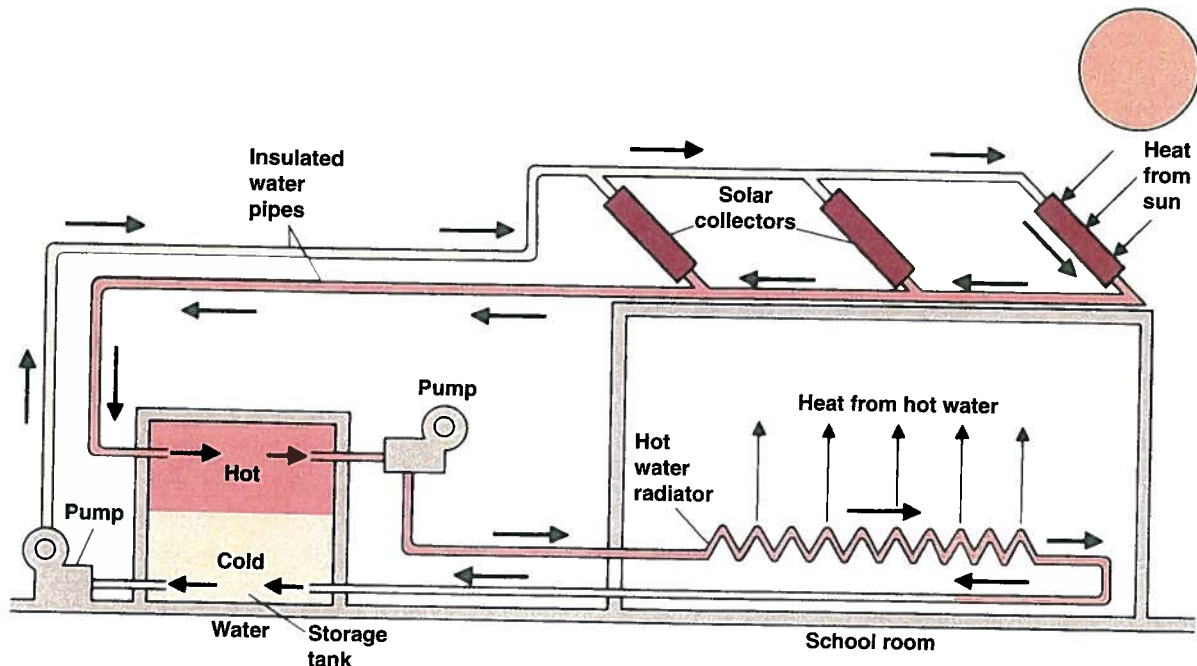
Of course, too much solar heating and daylighting can be a problem during hot summer months. There are design features that can help keep passive solar buildings cool in the summer. For instance, overhangs can be designed to shade windows when the sun is high in the summer. Sunspaces can be closed off from the rest of the building. And a building can be designed to use fresh-air ventilation in the summer.

### Active Solar Systems

An **active solar system** requires a solar collector, a pump, and a system of pipes to transfer the heat from the site of production to the area to be heated. (See figure 9.25.)

Active solar collector systems take advantage of the sun to provide energy for domestic water heating, pool heating, ventilation air preheating, and space heating. Water heating for domestic use is generally the most economical application of active solar systems. The demand for hot water is fairly constant throughout the year, so the solar system provides energy savings year-round. Successful use of solar water heating systems requires careful selection of components and proper sizing.

An active solar water heating system can be designed with components sized large enough to provide heating for pools or a combined function of heating both domestic water and space. Space heating requires



**FIGURE 9.25 Solar Heating Designs** An active solar system requires a solar collector, a pump, a heat storage system, and a system of pipes to convey the heat from one place to another.



a heat-storage system and additional hardware to connect with a heat distribution system. An active solar space heating system makes economic sense if it can offset considerable amounts of heating energy from conventional systems over the life of the building or the system. Rock, water, or specially produced products are used to store heat. The hot liquid in the pipes heats the storage medium, which is used to release heat when the sun is not shining.

Active solar systems are most easily installed in new buildings, but in some cases they can be installed in existing structures. A major consideration in the use of an active solar system is the initial cost of installation.

### **Solar-Generated Electricity**

Solar energy can be used to generate electricity in two different ways. It can be used to create steam that is used to run a turbine similar to that of a conventional power plant, or photovoltaic cells can be used to generate electricity directly from sunlight.

**Conventional Electric Generation** To produce electricity using a turbine, the energy from the sun must be collected and concentrated to heat water to steam. There are basically two designs used. One design, called a *solar furnace*, uses mirrors to focus the light at a central point that raises the temperature and allows for the production of steam. An 11-megawatt plant known as the PS10 solar power tower is currently operating in Spain and another 17-megawatt plant known as the Solar Tres Power Tower is currently being built. Several other projects are being planned throughout the world.

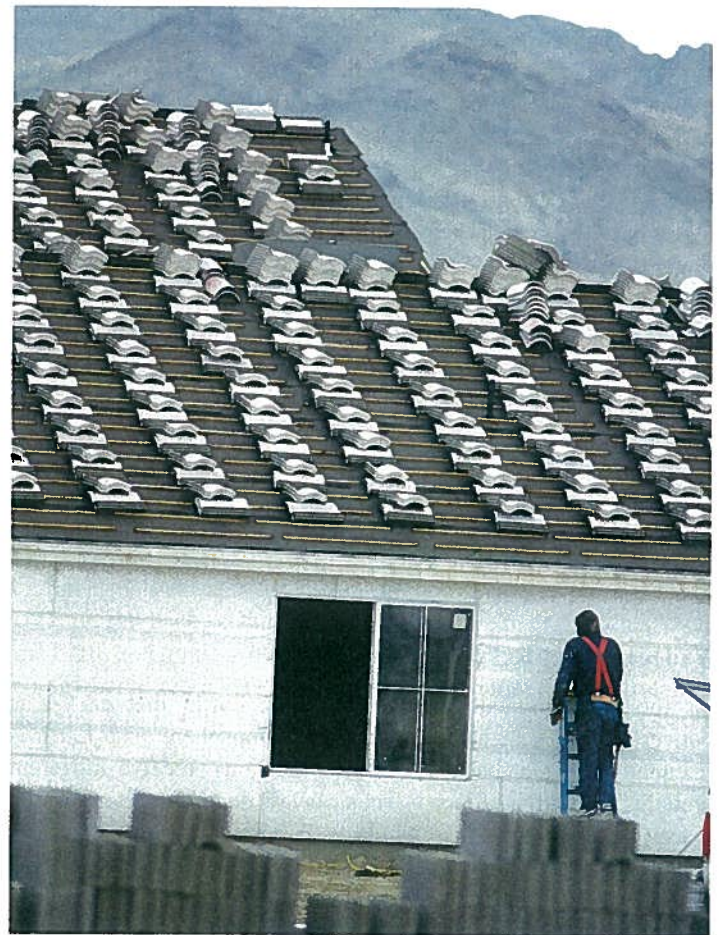
Currently, the most successful commercial design is the parabolic trough, which can heat oil in pipes to 390°C (734°F). (See figure 9.26.) This heat can be transferred to water, which is turned into steam that is used to run conventional electricity-generating turbines. The 354-megawatt Solar Energy Generating System (SEGS) in the Mojave Desert in California is the largest solar electric generation facility in the world. The 64-megawatt Nevada Solar One plant opened in 2007 and several plants are being built in Spain.

**Photovoltaics** Photovoltaics (PV) are solid-state semiconductor devices that convert light directly into electricity. Photovoltaics are usually made of silicon with traces of other elements. Although making PV cells and modules requires advanced technology, they are very simple to use. PV modules are generally low-voltage DC devices, although arrays of PV modules can be wired for higher voltages, with no moving or wearing parts. Once installed, a PV array generally requires no maintenance other than an occasional cleaning. Most PV systems contain storage batteries, which require some water and maintenance similar to that required by the battery in an automobile.

Thin-film solar cells use layers of semiconductor materials only a few micrometers thick. Thin-film technology has now made it possible for solar cells to double as rooftop shingles, roof tiles, building façades, or the glazing for skylights or atria. (See figure 9.27.) The solar cell version of shingles offers the same protection and durability as ordinary asphalt shingles.



**FIGURE 9.26 Solar Generation of Electricity** This solar-powered electricity-generating plant is capable of generating electricity at a cost that is competitive with other methods of generating electricity.



**FIGURE 9.27 Photovoltaic Shingles** The shingles that will be installed on this roof will produce electricity and protect the occupants from the weather.



# Water Connections

## SOLAR STILLS AND DRINKING WATER

Many people who live in remote areas have a problem obtaining safe and adequate drinking water. Many remote arid regions have an abundance of solar energy and little potable water. Because of their remoteness, they must rely on local sources of energy to purify their water. Local sources of water may be contaminated or the groundwater may be too salty. However, these

sources of water can be converted to drinking water by using a solar still, a simple device that can be constructed of readily available materials. Energy from the sun is used to evaporate the water, which then condenses on a glass surface and runs to a collecting tank. The impurities are left behind in the still. The still needs to be flushed periodically to remove the impurities.

Three factors drive the photovoltaic industry: cost of the solar installation, efficiency of the system, and government policy. As the cost of the system is reduced and efficiency increases, the price per kilowatt-hour of electricity falls. Currently the price is about 20 US cents per kilowatt-hour, which is much more than people pay for electricity from the power company. A typical commercial solar cell has an efficiency of 15 percent, but new designs suggest that efficiencies up to 40 percent are possible. If these new systems can be produced economically, they will compete effectively with conventional power plants.

In recent years, the amount of PV power installed worldwide has increased dramatically, from 314 megawatts in 1997 to about 5700 megawatts in 2006—an 18-fold increase in 10 years. Three countries dominate in the amount of photovoltaics installed—Germany has 50 percent, Japan has 30 percent, and the United States has 10 percent. Their dominance is the result of government policies that encourage the use of photovoltaics with tax advantages and other incentives.

### Environmental Issues

Since solar energy is renewable, it has minimal environmental impact. Thermal systems that use mirrors require large amounts of land to position the mirrors. The SEGS system in California covers 6.4 km<sup>2</sup> (2.5 mi<sup>2</sup>). The installation of photovoltaics on buildings does not require additional space and is often incorporated into the design of the building.

## WIND ENERGY

As the sun's radiant energy strikes the Earth, that energy is converted into heat, which warms the atmosphere. The Earth is unequally heated because various portions receive different amounts of sunlight. Since warm air is less dense and rises, cooler, denser air flows in to take its place. This flow of air is wind. For centuries, wind has been used to move ships, grind grains, pump water, and do other forms of work. In more recent times, wind has been used to generate electricity. (See figure 9.28.)

Some areas are better suited for producing wind energy than others. Figure 9.29 shows the wind energy potential of regions within the United States. However, location can be a problem.



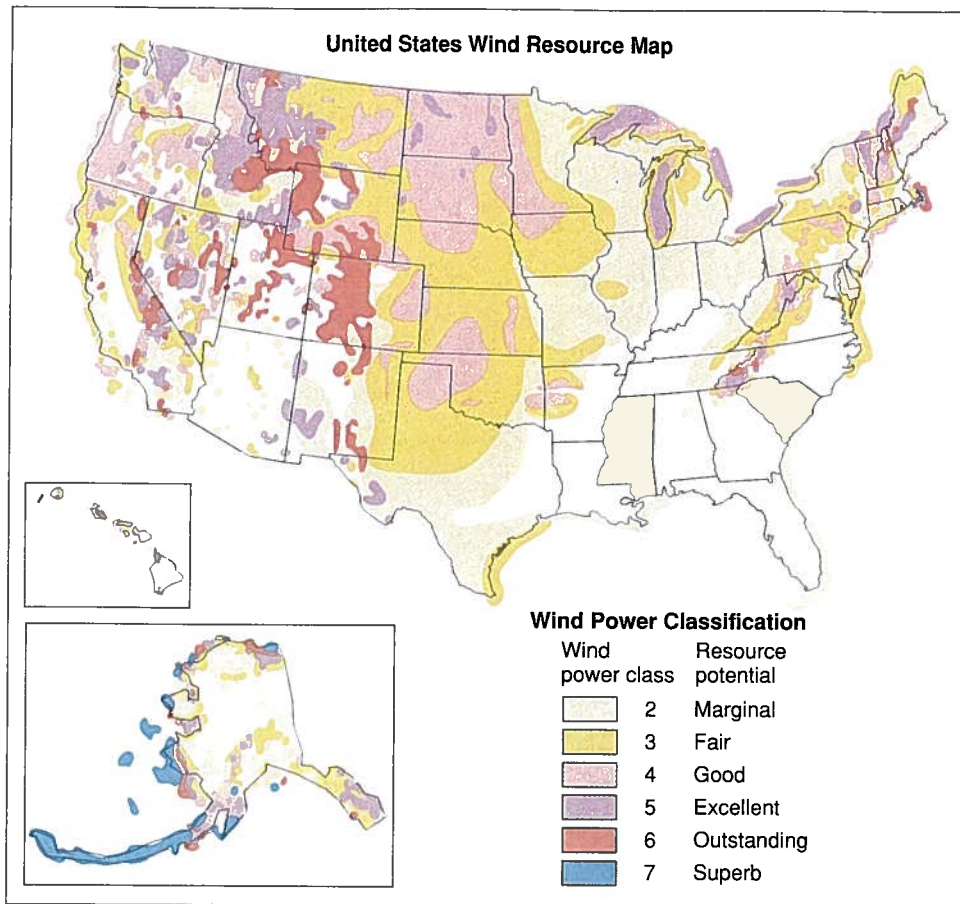
**FIGURE 9.28 Wind Energy** Fields of wind-powered generators can produce large amounts of electricity.

Although places such as the Dakotas have the strongest winds, they are remote from energy-using population centers, and large losses in the amount of electricity would occur as it is transmitted through electric lines.

Because winds are variable, so is the amount of energy generated by each wind turbine. This means that electrical energy from wind must be coupled with other, more reliable sources of energy.

### Future Development

Since the technology to generate electricity from wind is relatively easy to install, sizable increases in capacity occur each year. Europe is the leader in the amount of installed capacity, with a total installed capacity of 56,535 megawatts at the end of 2007. This is an increase of 18 percent in one year. Germany, Denmark, and Spain get more than 10 percent of their electricity from wind generation. Although there has been rapid development of new



**FIGURE 9.29 Wind Energy Potential** This map ranks regions of the United States in terms of their potential to supply electricity from wind energy.

Source: U.S. Department of Energy.

wind power capacity, it is important to recognize that the total electrical energy produced by wind today is about 0.5 percent of total worldwide electricity consumption.

In the United States, a push for energy deregulation and concerns about smog, acid rain, and global warming are driving policy makers to require electric utilities to sell electricity from renewable sources. Twenty-nine states have established renewable portfolio standards that require that a certain percentage of electricity be produced from renewable sources by specified dates. The federal government also has provided economic incentives to utilities to construct wind and other renewable electrical-generating facilities. Since wind turbines are easy to site and install, wind energy projects have benefited from these policy decisions. Currently, 35 states have wind power installations.

According to the American Wind Energy Association, wind energy capacity expanded by 46 percent in 2007. However, wind still is responsible for only about 1 percent of all electricity generated in the United States. In 2008, the U.S. Department of Energy published a report that stated that it was technically feasible to generate 20 percent of electricity in the United States from wind by 2030.

### Environmental Issues

Wind generators do have some negative effects. The moving blades are a hazard to birds and produce a noise that some find

annoying. Newer windmills, however, have slower-moving rotors that many birds such as the golden eagle find easier to avoid. Vibrations from the generators can also cause structural problems. In addition, some people consider the sight of a large number of wind generators to be visual pollution.

## GEOTHERMAL ENERGY

**Geothermal energy** is obtained in two different ways. In geologically active areas where hot magma approaches the surface, the heat from the underlying rock can be used to heat water. The heated water can then be used directly either to heat buildings or to generate electricity by way of a steam turbine.

The United States produces about 30 percent of the world's geothermally generated electricity. The Pacific Gas and Electric Company (PG&E) has been producing electricity from geothermal energy since 1960. PG&E's complex of generating units located north of San Francisco is the largest in the world and provides 700 megawatts of power, enough for 700,000 households, or 2.9 million people. However, to put this in perspective, geo-thermal electricity accounts for less than 1 percent of total electricity consumption in the United States. Other countries that pro-

duce significant amounts of geothermal electricity are the Philippines, Italy, Mexico, Japan, New Zealand, Indonesia, and Iceland. In Iceland, half of the geothermal energy is used to produce electricity and half is used for heating. In the capital, Reykjavik, all of the buildings are heated with geothermal energy at a cost that is less than 25 percent of what it would be if oil were used.

It is also possible to use heat pumps to obtain geothermal energy from areas that are not geologically active. All objects contain heat energy, which can be extracted from and transferred to other locations. Geothermal heat pumps act in a manner similar to a refrigerator, which extracts heat from its interior and exports it to the coils on the back of the unit. A heat pump can extract heat from the Earth and transfer it to a building. Typically the amount of heat energy harvested is three to four times the amount of electrical energy used to run the system. Over 50 percent of heating of buildings due to geothermal energy is the result of increased use of heat pumps.

### Technology for Obtaining Geothermal Energy

In areas where a hot mass is near the surface, geothermal energy is tapped by drilling wells to obtain steam. The steam is then used to power electrical generators. (See figure 9.30.)

Geothermal heat pump systems utilize a closed loop of underground pipes. A water-antifreeze solution is circulated through the



# CAMPUS SUSTAINABILITY INITIATIVE



## WESTERN WASHINGTON UNIVERSITY PURCHASES GREEN POWER FROM NORTH DAKOTA WIND FARMS

In 2008, Western Washington University (WWU) in Bellingham, Washington, entered into an agreement with Puget Sound Energy (PSE) to purchase green power from North Dakota wind farms instead of renewable projects in the Pacific Northwest.

Since 2002 PSE has been recognized as offering one of the top 10 green power programs in the United States. In order to provide its customers with renewable purchase options, PSE buys energy from a variety of renewable energy suppliers. About 86 percent of its renewable power is from wind and 14 percent from the burning of biomass. Customers pay a premium of 1.25 cents per kWh to purchase green energy. In 2007, about 200,000 customers participated and purchased about 200 million kWh of electrical energy from renewable sources. This is enough energy to supply about 17,000 homes.

For several years, the U.S. Environmental Protection Agency has ranked WWU among the top 10 green energy purchasers in higher education. Since the fall of 2005, WWU has purchased all of its electrical energy through PSE from a 100 percent renewable source in the Pacific Northwest. This was made possible by Western students voting in 2004 to implement a student fee to offset the cost of purchasing renewable energy—a first in the United States.

Until 2008, WWU purchased renewable energy credits, also known as green tags, from projects located in the Pacific Northwest through PSE. These green tags replace traditional sources of electricity with sustainable sources of energy such as wind, biomass, or solar power. However, Western students continued their research into renewable energy and sought how best to optimize their purchase of green power in terms of combating global warming. That led to a Memorandum of Agreement between WWU and PSE, in which the utility agreed to purchase power from two North Dakota wind projects. WWU selected North Dakota based on new standards that show that North Dakota is one of the most carbon-intensive regions of the United States in terms of energy generation because of the number of coal-fired power plants in the region. Because North Dakota produces most of its electricity from coal, it has a large carbon footprint. Supporting green energy options in North Dakota encourages renewable energy production in North Dakota and results in a larger ultimate carbon offset than if the power were purchased from renewable sources in Washington. Because hydroelectric power plants supply large amounts of electricity in the Pacific Northwest, use of green power from local sources does not offset as much carbon.

pipes and heat is extracted from the solution and transferred to the building.

### *Environmental Issues*

The use of geothermal energy from geologically active areas creates some environmental problems. The steam contains hydrogen sulfide gas, which has the odor of rotten eggs and is an unpleasant form of air pollution. (The sulfides from geothermal sources can, however, be removed.) The minerals in the steam corrode pipes and equipment, causing maintenance problems. The minerals are also toxic to fish if waste water is discharged into local bodies of water.

## TIDAL POWER

Tides are caused by the gravitational force exerted by the moon and the sun. The magnitude of the gravitational attraction between two objects depends on the masses of the objects and the distance between them. The moon exerts a larger gravitational force on the Earth because, although it is much smaller in mass than the sun, it is a great deal closer than the sun. This force of attraction causes the oceans, which make up 71 percent of the Earth's surface, to bulge along an axis pointing toward the moon. (There is actually a bulge on the side of the Earth farthest from the moon also because

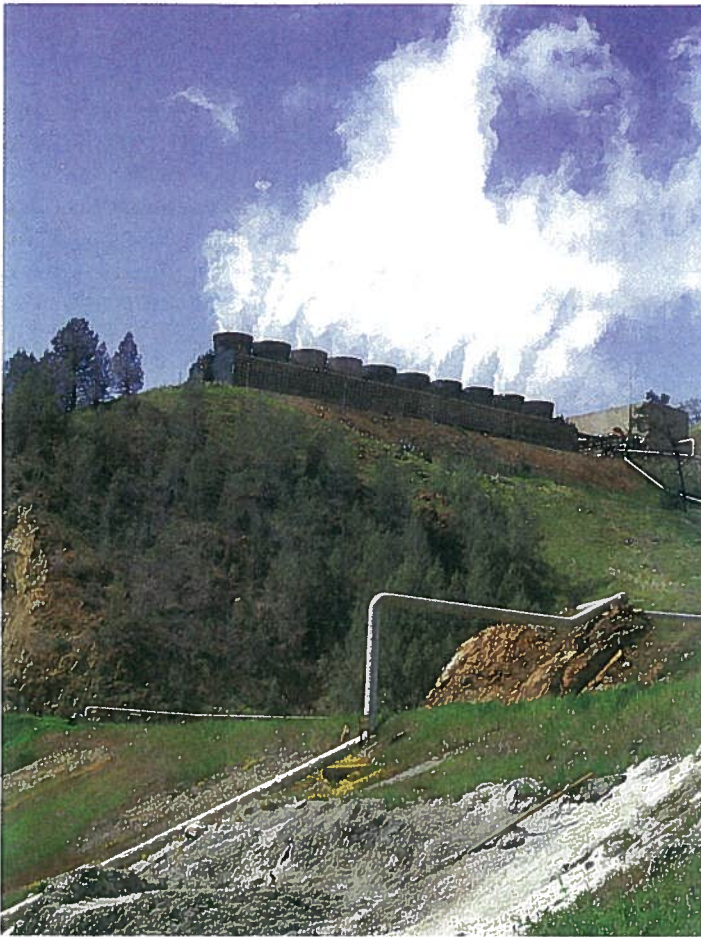
the moon is pulling the Earth away from the water on its surface.) Tides are produced by the rotation of the Earth beneath this bulge in its watery coating, resulting in the rhythmic rise and fall of water levels that can be observed along coasts. Thus, there are two high and two low tides each day. When the sun, moon, and Earth are in a line, the combined effects of sun and moon generate higher tides.

Certain coastal regions experience higher tides than others. This is a result of the amplification of tides caused by local geographical features such as bays and inlets. To produce practical amounts of power, a difference between high and low tides of at least 5 meters (16 feet) is required. About 40 sites around the world have this magnitude of tidal range. The higher the tides, the more electricity can be generated from a given site and the lower the cost of electricity produced. Due to the constraints just described, it has been estimated that only 2 percent, or 60 gigawatts, can potentially be recovered for electricity generation.

### *Technology for Obtaining Tidal Energy*

The technology required to convert tidal energy into electricity is very similar to that used in traditional hydroelectric power plants. The first requirement is a dam or "barrage" across a tidal bay or estuary. Building such dams is expensive. Therefore, the best tidal sites are those where a bay has a narrow opening, thus reducing the





**FIGURE 9.30 Geothermal Power Plant** Steam obtained from geothermal wells is used to produce electricity.

length of dam required. At certain points along the dam, gates and turbines are installed. When the difference in the elevation of the water on the two sides of the barrage is adequate, the gates are opened. This “hydrostatic head” that is created causes water to flow through the turbines, turning an electric generator to produce electricity.

Although the technology required to harness tidal energy is well established, tidal power is expensive, and only one major tidal generating station is in operation. This is a 240-megawatt facility (1 megawatt = 1 million watts) at the mouth of the La Rance river estuary on the northern coast of France (a large coal or nuclear power plant generates about 1000 megawatts of electricity). La Rance generating station has been in operation since 1966 and has been a very reliable source of electricity for France. (See figure 9.31.) Elsewhere, there is a 20-megawatt facility at Annapolis Royal in Nova Scotia, Canada, a 0.4-megawatt tidal power plant near Murmansk, Russia, and a 0.5-megawatt facility on Jangxia Creek in the East China Sea. A 252-megawatt facility is currently being built in South Korea and other sites throughout the world are being evaluated for their potential.

A new style of tidal power generator is being developed in the Dalupiri Ocean Power Plant in the Philippines. This new system is a submerged turbine referred to as a *hydro turbine*. Changing tides in the area generate ocean currents that can turn a hydro turbine. It is estimated that a 1-kilometer (0.62-mile) “tidal bridge” made up of a series of these turbines could generate more electricity than a large nuclear plant. The completed project in the Philippines will span 4 kilometers (2.5 miles) and will include 274 turbines with a generating capacity of 2.3 gigawatts during peak tidal flow.

### ***Environmental Issues***

Tidal energy is a renewable source of electricity and does not contribute to global warming. However, changing tidal flows by damming a bay or estuary could result in negative impacts on aquatic and shoreline ecosystems, as well as affecting navigation and recreation.

Studies undertaken to identify the environmental impacts of tidal power have determined that each site is different and the impacts depend greatly on local geography. Local tides changed only slightly due to the La Rance barrage, and the environmental impact has been negligible, but this may not be the case for all other sites. In all cases the barriers and turbines will affect the migration of fish and other marine species.

## **ENERGY CONSERVATION**

Conservation is not a way of generating energy, but it is a way of reducing the need for additional energy, and it saves money for the consumer. Some conservation technologies are sophisticated,



**FIGURE 9.31 Tidal Generating Station** La Rance River Estuary Power Plant in France is the world’s largest tidal electrical-generating station.



while others are quite simple. For example, if a small, inexpensive wood-burning stove were developed and used to replace open fires in the less-developed world, energy consumption in these regions could be reduced by 50 percent.

Many observers have pointed out that demanding more energy while failing to conserve is like demanding more water to fill a bathtub while leaving the drain open. To be sure, conservation and efficiency strategies by themselves will not eliminate demands for energy, but they can make the demands much easier to meet, regardless of what options are chosen to provide the primary energy.

Energy efficiency improvements have significantly reduced the need for additional energy sources. Consider these facts:

- Total primary energy use per capita in the United States has changed very little in the past 10 years and the real per capita gross domestic product increased by nearly 20 percent.
- National energy intensity (energy use per unit of GDP) fell 20 percent between 1997 and 2006.

Even though the United States is much more energy-efficient today, the potential is still enormous for additional cost-effective energy savings.

Many conservation techniques are relatively simple and highly cost effective. More efficient and less energy-intensive industry and domestic practices could save large amounts of energy. Improved automobile efficiency, better mass transit, and increased railroad use for passenger and freight traffic are simple and readily available means of conserving transportation energy.

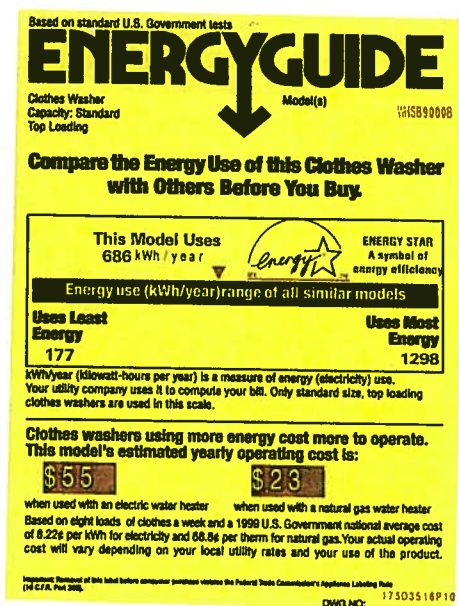
Several technologies that reduce energy consumption are now available. (See figure 9.32.) Highly efficient fluorescent lightbulbs that can be used in regular incandescent fixtures give the same amount of light for 25 percent of the energy, and they produce less heat. Since lighting and air conditioning (which removes the heat from inefficient incandescent lighting) account for 25 percent of U.S. electricity consumption, widespread use of these lights could significantly reduce energy consumption. Low-emissive glass for windows can reduce the amount of heat entering a building while allowing light to enter. The use of this glass in new construction and replacement windows could have a major impact on the energy picture. Many other technologies, such as automatic dimming devices or automatic light-shutoff devices, are being used in new construction.

The shift to more efficient use of energy needs encouragement. Often, poorly designed, energy-inefficient buildings and machines can be produced inexpensively. The short-term cost is low, but the long-term cost is high. The public needs to be educated to look at the long-term economic and energy costs of purchasing poorly designed buildings and appliances.

Electric utilities have recently become part of the energy conservation picture. In some states, they have been allowed to make money on conservation efforts; previously, they could make money only by building more power plants. This encourages them to become involved in energy conservation education, because teaching their customers how to use energy more efficiently allows them to serve more people without building new power plants.



(a)



(b)



(c)

**FIGURE 9.32 Energy Conservation** The use of (a) fluorescent lightbulbs, (b) energy-efficient appliances, and (c) low-emissive glass could reduce energy consumption significantly.



In many metropolitan areas, emissions from automobiles are a major contributor to air-quality problems. An increase in the efficiency with which the chemical energy of fuel is converted to the motion of automobiles would greatly reduce air pollution. Because sources of fossil fuels are limited, they will become less available and greater efficiency will extend the limited supplies. There has been an ongoing process of modifying vehicles to improve performance and fuel efficiency. These include: reducing vehicle weight by using lighter materials, streamlining the shape to reduce air resistance, using better tires, and many other modifications. To further increase energy efficiency, more innovative techniques are required.

A great deal of energy is needed to get a vehicle to begin moving from a stop (accelerate), and it takes an equal amount of energy to stop a vehicle once it is moving (decelerate). Internal combustion engines operate most efficiently when they are running at a specific speed (rpm) and work at less than peak efficiency when the vehicle is accelerating or decelerating. Thus, using an internal combustion engine to accelerate is not efficient and contributes significantly to air pollution. When the brakes are applied to stop the vehicle, the kinetic energy possessed by the moving vehicle is converted to heat in the braking system. So the energy that has just been used to accelerate the vehicle is lost as heat when the vehicle is brought to a stop. Furthermore, in metropolitan areas, an automobile sits

in traffic with its engine running a significant amount of the time. Thus, the stop-and-go traffic common in city driving provides conditions that significantly reduce the efficient transfer of the chemical energy of fuel to the kinetic energy of turning wheels.

Current hybrid electric vehicles use highly efficient electric motors to provide the energy to start the car moving (accelerate) and when the car is being driven at low speed. An internal combustion engine provides the extra power needed to reach higher speeds on the highway. In conventional vehicles, a great deal of energy is wasted while the car idles in traffic or at stoplights. In hybrid vehicles, only the electric motors powered by batteries are used in stop-and-go traffic, so no fuel is used. The battery is recharged when the car switches back to the gas engine, and in a process called *regenerative braking*, the kinetic energy of the car is captured during braking and stored as electrochemical energy in the battery. Since the internal combustion engine is only used to assist at high speeds, it is smaller, weighs less, and consumes less fuel than engines of conventional vehicles.

Although Toyota and Honda have sold hybrid electric vehicles since 1999, U.S. automakers did not produce a hybrid until 2004. Even then, their focus was on large vehicles that produced only modest fuel economy improvements. In 2008, several standard-sized, hybrid cars produced by U.S. manufacturers became available on a limited basis.

## ARE FUEL CELLS IN THE FUTURE?

Fuel cells use hydrogen as a fuel to produce electrical energy that can be used to do a variety of jobs. Although numerous types of fuel cells are available, the most common is the proton exchange membrane (PEM) fuel cell. Although the specific reactions within the fuel cell involve several steps, they can be summarized as follows: Pressurized hydrogen gas enters the fuel cell and comes in contact with a platinum catalyst that causes the hydrogen molecules ( $H_2$ ) to split into hydrogen ions ( $H^+$ ) and electrons. Hydrogen ions are also known as *protons*. A proton exchange membrane allows protons ( $H^+$ )—but not the electrons—to flow through it. The electrons instead flow through an electric circuit to do work such as generating light or running a motor. The hydrogen ions flow through the proton exchange membrane and recombine with the electrons that have passed through the circuit and with oxygen to form water.

The advantages of fuel cells over other power sources are numerous. With a low operating temperature and minimal noise generation, fuel cells are safe to install in semiexposed areas. Cells are also self-sustaining, making them ideal for locations far removed from traditional electricity production facilities. Because they can operate separately from the power lines associated with most electricity distribution systems, the risk of weather-related power outages is also diminished. Their most important benefit, however, is that they do not pollute. When they are fueled by pure hydrogen,

water, heat, and electricity are the only by-products. Although currently powered by modified fossil fuels, fuel cells are capable of extracting far greater quantities of energy from each unit of fuel than other methods of power generation, thereby reducing the need for fossil fuel extraction.

The automobile industry is working hard to produce fuel cells that are small enough and powerful enough to power cars. They are currently used in some bigger vehicles like buses. (See figure 9.33.)



**FIGURE 9.33** Experimental Fuel Cell Bus Citaro fuel cell bus is the latest model with fuel cells from DaimlerChrysler AG in Germany. This picture shows one of 30 buses that were delivered to 10 European cities in 2003.



However, there are significant technological challenges to the use of fuel cells. One of the most significant is the need to produce hydrogen. Using fossil fuels to produce hydrogen does not improve the energy picture and actually produces more greenhouse gases. Therefore, it is necessary that nuclear or renewable sources of energy

such as solar energy be used to produce the hydrogen. Further technological problems include the need to develop a hydrogen infrastructure so that fuel cell automobiles will be able to obtain fuel on an as-needed basis.

## ISSUES & ANALYSIS

### Does Ethanol Fuel Make Sense?

To evaluate the feasibility of using ethanol as fuel it is necessary to do some accounting from two points of view: energy gain and economic competitiveness.

#### Energy Analysis

Many studies have assessed the amount of energy necessary to produce ethanol. Currently in North America, ethanol is made by fermenting the starch in corn. It is essentially the same process as that used to make beer and wine. Therefore, the energy input to make ethanol includes fuel used by farmers to till, plant, harvest, and transport corn. In addition, fertilizer, herbicides, and other agricultural chemicals require energy to produce and apply. Finally, the fermenting of corn to make ethanol and the distillation of the ethanol from a dilute solution both require energy. Various attempts have been made to account for all of these energy inputs and the results range from zero net energy gain to a net gain of 30 percent. If it takes 1 unit of energy to produce about 1.3 units of energy as ethanol, the net gain is 0.3 units.

The amount of ethanol produced in 2007 was about 7 billion gallons. If the amount of energy need to produce the energy is subtracted, the net gain in energy is equivalent to about 1.6 billion gallons of ethanol. This is less than 1 percent of the amount of gasoline used in 2007.

#### Economic Analysis

A gallon of ethanol has 67.2 percent of the energy of a gallon of gasoline, so in order to compete economically, a gallon of ethanol must cost about 67.2 percent of a gallon of gasoline. Since a gallon of ethanol has less energy than gasoline, vehicles will travel fewer miles on a gallon of ethanol than on a gallon of gasoline. Most ethanol is used in E85 fuel, which contains 85 percent ethanol and 15 percent gasoline. The following charts show the amount of fuel needed to provide the same amount of energy and the price per gallon needed to provide equivalent amounts of energy per dollar spent.

<i>Gallons Needed to Provide Equivalent Energy</i>		
<i>Gasoline</i>	<i>Ethanol</i>	<i>E85 fuel</i>
1	1.49	1.42

<i>Price/Gallon to Provide Equivalent Energy per Dollar</i>		
<i>Gasoline</i>	<i>Ethanol</i>	<i>E85 fuel</i>
\$3.00	\$2.00	\$2.15

#### Other Economic Issues

- Currently in the United States those who sell ethanol for fuel receive a \$0.51/gallon tax credit, which effectively reduces the price of ethanol fuel by 51 cents per gallon at the taxpayer's expense. If that subsidy were removed, the price of ethanol fuel would be 51 cents higher, and ethanol would not be competitive with gasoline. In nearly all markets, if the 51 cent/gallon subsidy for ethanol were removed, the price of ethanol fuel would be more expensive than gasoline.
- Most of the corn produced in the United States is used for animal feed. Higher demand for corn to make ethanol has caused an increase in the price of corn, which results in higher feed prices for livestock and leads to higher prices for meat products.
- High prices for corn encourages farmers to plant more corn (2007 was a record crop). If more farmland is planted to corn, then less land is planted to wheat, soybeans, and other crops, which results in increased prices for those commodities and higher food prices in general.
- Some studies attempt to assign economic values to soil erosion, increased cost of food, and other factors. Many of those studies show no net gain from the production of ethanol.

#### What Do You Think?

- Is it important to provide ethanol as a fuel?
- Would you use ethanol?
- Should the production of ethanol be subsidized?

## SUMMARY

A resource is a naturally occurring substance of use to humans, a substance that can potentially be extracted using current technology. Reserves are known deposits from which materials can be extracted profitably with existing technology under present economic conditions.

Coal is the world's most abundant fossil fuel. Coal is obtained by either surface mining or underground mining. Problems associated with coal extractions are disruption of the landscape due to surface mining and subsidence due to underground mining. Black lung disease, waste heaps, water and air pollution, and acid mine drainage are additional problems. Oil was originally chosen as an alternative to coal because it was more convenient and less expensive. However, the supply of oil is limited. As oil becomes less readily available, multiple offshore wells, secondary recovery methods, and increased oil exploration will become common. Natural gas is another major source of fossil-fuel energy. The primary problem associated with natural gas is transport of the gas to consumers.

Fossil fuels are nonrenewable: The amounts of these fuels are finite. When the fossil fuels are exhausted, they will have to be replaced with other forms of energy, probably renewable forms. Hydroelectric power can be increased significantly, but its development requires flooding areas and thus may require the displacement of people. The use of geothermal and tidal energy is limited by geographic locations. Wind power may be used to generate electricity but may require wide, open areas and a large number of wind generators. Solar energy can be collected and used in either passive or active systems and can also be used to generate electricity. Lack of a constant supply of sunlight is solar energy's primary limitation. Fuelwood is a minor source of energy in industrialized countries but is the major source of fuel in many less-developed nations. Biomass can be burned to provide heat for cooking or to produce electricity, or it can be converted to alcohol or used to generate methane. In some communities, solid waste is burned to reduce the volume of the waste and also to supply energy.

Energy conservation can reduce energy demands without noticeably changing standards of living.

## THINKING GREEN

1. Contact your local electric utility or visit its website and determine what percentage of the electricity produced comes from fossil fuels, nuclear, hydroelectric, or other renewable energy sources.
2. Does your electric utility offer an opportunity to purchase green energy? If so, what does it cost?
3. Calculate your monthly carbon footprint. The average carbon dioxide produced per person in the United States is 1.7 tons of CO<sub>2</sub> per month (20 tons per year).

**Note:** If there are several persons in your household, divide the total energy used in each category by the number of people in the household to determine your individual energy usage.

<i>Energy Use</i>	<i>Tons of CO<sub>2</sub></i>
Kilowatt-hours of electricity $\times 0.0006 =$	
Therms of natural gas $\times 0.00591 =$	
Gallons of heating oil $\times 0.01015 =$	
Gallons of gasoline $\times 0.0087 =$	

## WHAT'S YOUR TAKE?

Alcohol fuel is cheaper than gasoline because it is subsidized by the federal government. In addition, farmers receive subsidies to grow corn from which alcohol is made. Should the government subsidize the production

of alcohol for fuel? Choose one side or the other and develop arguments to support your point of view.



## REVIEW QUESTIONS

1. Why are fossil fuels important?
2. Distinguish between reserves and resources.
3. What are the advantages of surface mining of coal compared to underground mining? What are the disadvantages of surface mining?
4. Compare the environmental impacts of the use of coal and the use of oil.
5. What are some limiting factors in the development of new hydroelectric generating sites?
6. What factors limit the development of tidal power as a source of electricity?
7. In what parts of the world is geothermal energy available? What creates it?
8. Why can wind be considered a form of solar energy?
9. Compare a passive solar-heating system with an active solar-heating system.
10. What problems are associated with the use of solid waste as a source of energy?
11. List three energy conservation techniques.

## CRITICAL THINKING QUESTIONS

1. Given what you know about the economic and environmental costs of different energy sources, would you recommend that your local utility company use hydroelectricity or coal to supplement electric production? What criteria would you use to make your recommendation?
2. Coal-burning electric power plants in the Midwest have contributed to acid rain in the eastern United States. Other energy sources would most likely be costlier than coal, thereby raising electricity rates. Should citizens of another state be able to pressure these utility companies to change the method of generating electricity? What mechanisms might be available to make these changes? How effective are these mechanisms?
3. Imagine you are an official with the Department of Energy and are in the budgeting process for alternative energy research. Where would you put the money? Why?
4. Given your choices from question 3, what do you think the political repercussions of your decision would be? Why?
5. Do you believe that large dam projects like the Three Gorges Dam project in China are, on the whole, beneficial or not? What alternatives would you recommend? Why?
6. Energy conservation is one way to decrease dependence on fossil fuels. What are some things you can do at home, work, or school that would reduce fossil-fuel use and save money?
7. What alternative energy resources that the text has outlined are most useful in your area? How might these be implemented?