CHAPTER 16

Alternative Energy and the Environment

This wind farm in Tarifa, Spain, has a generating capacity of 5 MW produced by just 12 wind turbines.

LEARNING OBJECTIVES

Alternatives to fossil fuels and nuclear energy include biofuels, solar energy, water power, wind power, and geothermal energy. Some of these are already being used, and efforts are under way to develop others. After reading this chapter, you should understand . . .

- The advantages and disadvantages of each kind of alternative energy;
- What passive, active, and photovoltaic solar energy systems are;
- What may be the important fuels of the future;
- Why water power is unlikely to become more important in the future;
- Why wind power has tremendous potential, and how its development and use could affect the environment;
- Whether biofuels are likely to help us move away from fossil fuels;
- What geothermal energy is, and how developing and using it affect the environment.

CASE STUDY

Using Wind Power in New Ways for an Old Application

On March 14, 2008, a new kind of sailing ship, the MV *Beluga SkySails,* completed its maiden voyage of 11,952 nautical miles, sailing from Bremen, Germany, to Venezuela and back carrying heavy industrial equipment (Figure 16.1). *SkySails* is novel in two ways. First of all, it did not use a set of fixed masts with traditional sails that had to be monitored constantly and their settings changed with each variation in the wind, thereby requiring either a large crew or very sophisticated and expensive equipment. Second, wind provided only part of the power—on the maiden voyage 20%—the rest coming from standard marine diesel engines.

Instead, this ship flew a huge kite that spread out over more than 160 square yards. Flying high above the ship, it caught more reliable winds aloft than occur at the surface, and required only a flexible cable to tether it to the ship. Diesel engines provided the steady energy; the kite-sail helped when wind was available, reducing fuel costs by $1,000 a day. With this saving, and also saving the expense of a large crew, *Beluga SkySails* was an economic success. At the end of the voyage, the ship's captain, Lutz Heldt, said, "We can once again actually 'sail' with cargo ships, thus opening a new chapter in the history of commercial shipping."

This ship takes another important step in the use of alternative energy, integrating it with another source. Also important is that the kite works *with* natural forces, unlike a traditional sailing ship's rigid masts, which had to withstand the force of the winds. Therefore, the *SkySails* is much less likely to be damaged by storms. These design elements can be helpful as we think through a major transition from fossil fuels to alternative energy.

FIGURE 16.1 Wind power is becoming so popular that it is even making a comeback as a way to propel ships. Here a new kind of sail, actually a cable-tethered kite, helps pull a new ship, the *Beluga SkySails*, through the ocean. (*Source: SkySails* website March 31, 2008. First retrofit SkySails-System aboard a cargo vessel—Initial operation successful SkySails pilot project on board the MS "Michael A." of the WESSELS Reederei GmbH & Co.KG based in Haren/Ems http://www.skysails.info/index.php?id=64&L=1&tx_ttnews[tt_news]=98&tx_ttnews[backP id]=6&cHash=c1a209e350 and http://www.skysails.info/index.php?id=64&L=1&tx_ttnews[tt_news]=104&tx_ttnews[back Pid]=6&cHash=db100ad2b6)

16.1 Introduction to Alternative Energy Sources

As we all know, the primary energy sources today are fossil fuels—they supply approximately 90% of the energy consumed by people. All other sources are considered **alternative energy** and are divided into renewable energy and nonrenewable energy. **Nonrenewable alternative energy** sources include nuclear energy (discussed in Chapter 17) and deep-earth geothermal energy (the energy from the Earth's geological processes). This kind of geothermal energy is considered nonrenewable for the most part because heat can be extracted from Earth faster than it is naturally replenished—that is, output exceeds input (see Chapter 3). Nuclear energy is nonrenewable because it requires a mineral fuel mined from Earth.

The **renewable energy** sources are solar; freshwater (hydro); wind; ocean; low-density, near-surface geothermal; and biofuels. Low-density, near-surface geothermal

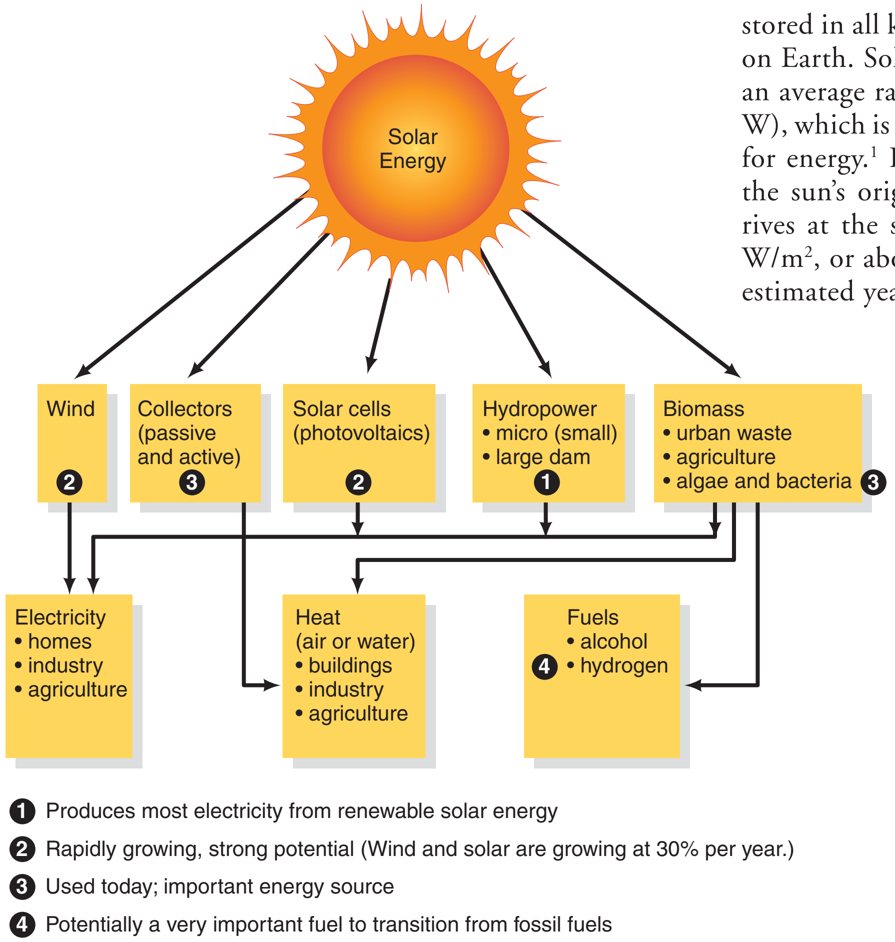


FIGURE 16.2 Routes of various types of renewable solar energy.

is simply solar energy stored by soil and rock near the surface. It is widespread and easily obtained and is renewed by the sun. Biofuels are made from biomass (crops, wood, and so forth). Renewable energy sources are often discussed as a group because they all derive from the sun's energy (Figure 16.2). We consider them renewable because they are regenerated by the sun within a time period useful to people.

The total energy we may be able to extract from alternative energy sources is enormous. For example, the estimated recoverable energy from solar energy is about 75 times as much as all the people of the world use each year. The estimated recoverable energy from wind alone is comparable to current global energy consumption.

16.2 Solar Energy

The total amount of solar energy reaching Earth's surface is tremendous. For example, on a global scale, ten weeks of solar energy is roughly equal to the energy stored in all known reserves of coal, oil, and natural gas on Earth. Solar energy is absorbed at Earth's surface at an average rate of 90,000 terawatts (1 TW equals 10^{12} W), which is about 7,000 times the total global demand for energy.[1] In the United States, on average, 13% of the sun's original energy entering the atmosphere arrives at the surface (equivalent to approximately 177 W/m^2, or about 16 W/ft^2, on a continuous basis). The estimated year-round availability of solar energy in the United States is shown in Figure 16.3. However, solar energy is site-specific, and detailed observation of a potential site is necessary to evaluate the daily and seasonal variability of its solar energy potential.[2]

Solar energy may be used by passive or active solar systems. **Passive solar energy systems** do not use mechanical pumps or other active technologies to move air or water. Instead, they typically use architectural designs that enhance the absorption of solar energy (Figure 16.4). Since the rise of civilization, many societies have used passive solar energy (see Chapter 22). Islamic architects, for example, have traditionally used passive solar energy in hot climates to cool buildings.

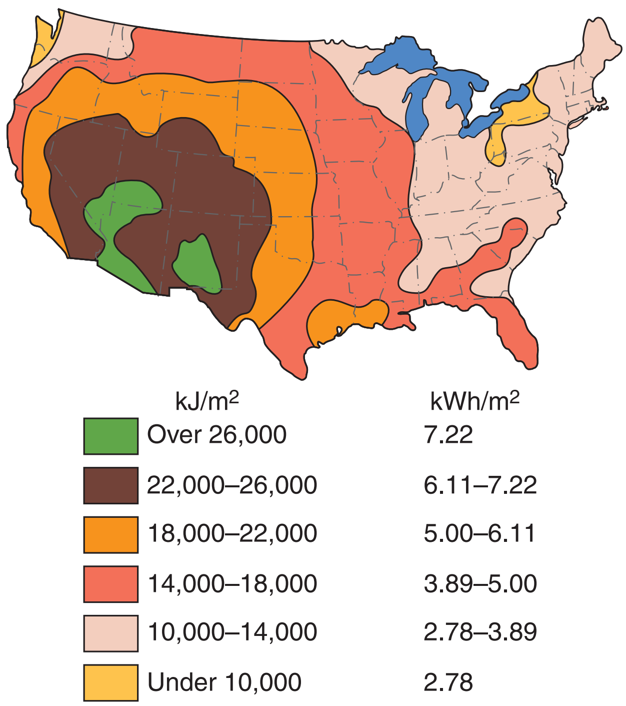
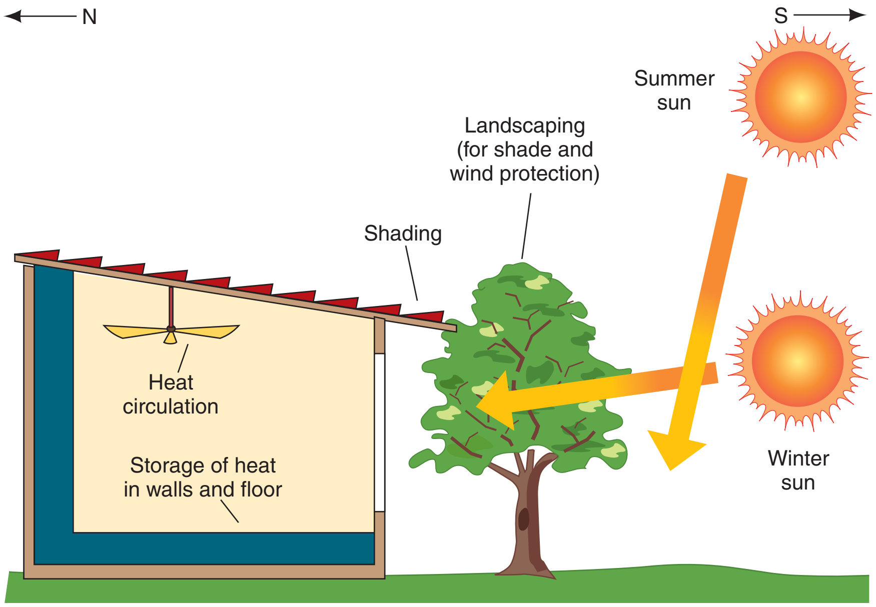


FIGURE 16.3 Estimated solar energy for the contiguous United States. (*Source*: Modified from Solar Energy Research Institute, 1978.)



(a)

(b)

FIGURE 16.4 **(a)** Essential elements of passive solar design. High summer sunlight is blocked by the overhang, but low winter sunlight enters the south-facing window. Deciduous trees shade the building in the summer and allow sunlight to warm it in the winter. These are best located on the southside in the northern hemisphere. Other features are designed to facilitate the storage and circulation of passive solar heat. **(b)** The design of this home uses passive solar energy. Sunlight enters through the windows and strikes a specially designed masonry wall that is painted black. The masonry wall heats up and radiates this heat, warming the house during the day and into the evening. The house is deep set into the ground, which provides winter and summer insolation. It is in a dry climate with few deceduous tres; hence conifers provide some shading. (*Source*: Moran, Morgan, and Wiersma, *Introduction to Environmental Science* [New York: Freeman, 1986]. Copyright by W.H. Freeman & Company. Reprinted with permission.)

Passive Solar Energy

Thousands of buildings in the United States—not just in the sunny Southwest but in other parts of the country, such as New England—now use passive solar systems. Passive solar energy promotes cooling in hot weather and retaining heat in cold weather. Methods include (1) overhangs on buildings to block summer (high-angle) sunlight but allow winter (low-angle) sunlight to penetrate and warm rooms; (2) building a wall that absorbs sunlight during the day and radiates heat that warms the room at night; (3) planting deciduous trees on the sunny side of a building. In summer, these shade and cool the building; in the winter, with the leaves gone, they let the sunlight in.

Passive solar energy also provides natural lighting to buildings through windows and skylights. Modern window glass can have a special glazing that transmits visible light, blocks infrared, and provides insulation.

Active Solar Energy

Active solar energy systems require mechanical power, such as electric pumps, to circulate air, water, or other fluids from solar collectors to a location where the heat is stored and then pumped to where the energy is used.

Solar Collectors

Solar collectors to provide space heating or hot water are usually flat, glass-covered plates over a black background where a heat-absorbing fluid (water or some other liquid) is circulated through tubes (Figure 16.5). Solar radiation enters the glass and is absorbed by the

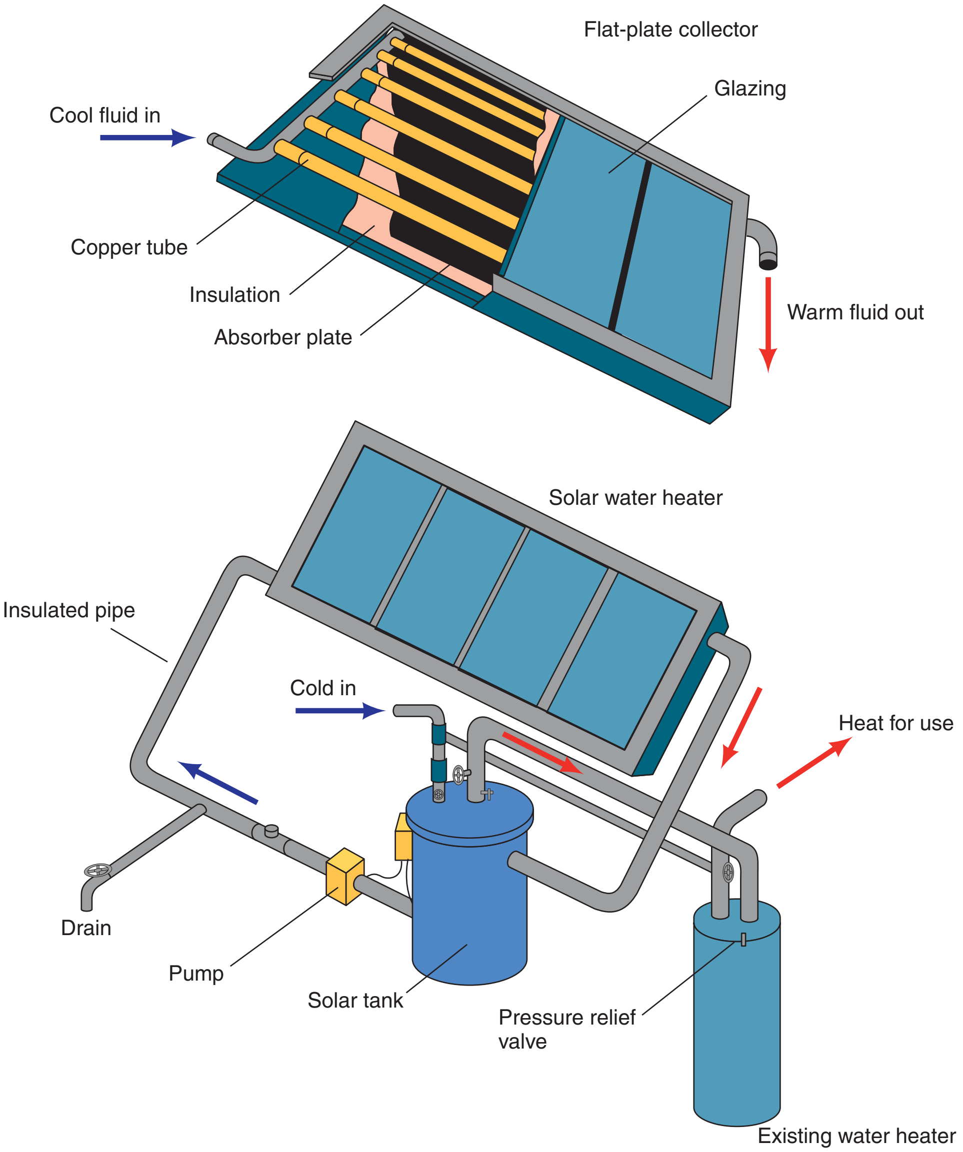


FIGURE 16.5 Detail of a flat-plate solar collector and pumped solar water heater. (*Source*: Farallones Institute, *The Integral Urban House* [San Francisco: Sierra Club Books, 1979]. Copyright 1979 by Sierra Club Books. Reprinted with permission.)

black background. Heat is emitted from the black material, heating the fluid in the tubes.

A second type of solar collector, the evacuated tube collector, is similar to the flat-plate collector, except that each tube, along with its absorbing fluid, passes through a larger tube that helps reduce heat loss. The use of solar collectors is expanding very rapidly; the global market grew about 50% from 2001 to 2004. In the United States, solar water-heating systems generally pay for themselves in only four to eight years.[3]

Photovoltaics

Photovoltaics convert sunlight directly into electricity (Figure 16.6). The systems use solar cells, also called *photovoltaic cells,* made of thin layers of semiconductors (silicon or other materials) and solid-state electronic components with few or no moving parts.

Photovoltaics are the world's fastest growing source of energy, with a growth rate of about 35% per year (doubling every two years). In the United States, the amount of photovoltaics shipped increased 90% between 2007 and 2008, with an average increase of 64% a year since

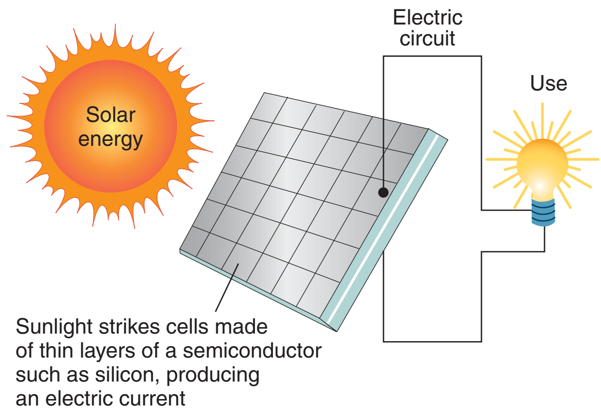


FIGURE 16.6 Idealized diagram illustrating how photovoltaic solar cells work.

(a)

(b)

FIGURE 16.7 **(a)** Panels of photovoltaic cells are used here to power a small refrigerator to keep vaccines cool. The unit is designed to be carried by camels to remote areas in Chad. **(b)** Photovoltaics are used to power emergency telephones along a highway on the island of Tenerife in the Canary Islands. [*Source:* **(a)** H. Gruyaeart/Magnum Photos. Inc. **(b)** Ed Keller]

2005.[4] The photovoltaic industry is expected to grow to $30 billion by 2010.[4]

Solar cell technology is advancing rapidly. While a few decades ago they converted only about 1 or 2% of sunlight into electricity, today they convert as much as 20%. The cells are constructed in standardized modules and encapsulated in plastic or glass, which can be combined to produce systems of various sizes so that power output can be matched to the intended use. Electricity is produced when sunlight strikes the cell. The different electronic properties of the layers cause electrons to flow out of the cell through electrical wires.

Large photovoltaic installations may be connected to an electrical grid. Off-the-grid applications can be large or small and include powering satellites and space vehicles, and powering electric equipment, such as water-level sensors, meteorological stations, and emergency telephones in remote areas (Figure 16.7).

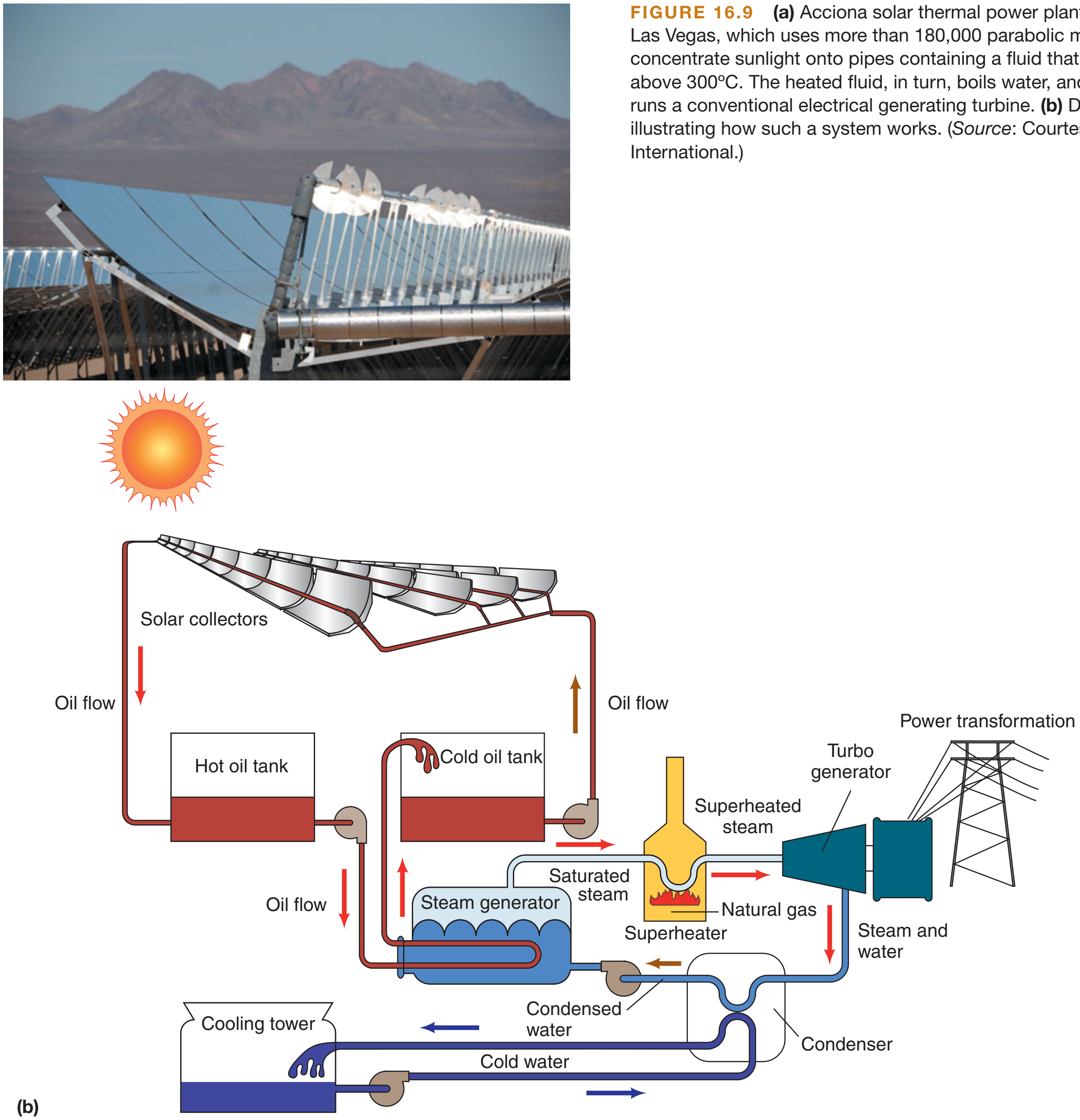
Off-the-grid photovoltaics are emerging as a major contributor to developing countries that can't afford to build electrical grids or large central power plants that burn fossil fuels. One company in the United States is manufacturing photovoltaic systems that power lights and televisions at an installed cost of less than $400 per household.[5] About half a million homes, mostly in villages not linked to a countrywide electrical grid, now receive their electricity from photovoltaic cells.[6]

Solar Thermal Generators

Solar thermal generators focus sunlight onto water-holding containers. The water boils and is used to run such machines as conventional steam-driven electrical generators. These include solar power towers, shown in Figure 16.8. The first large-scale test of using sunlight to boil water and using the steam to run an electric

FIGURE 16.8 Solar power tower at Barstow, California. Sunlight is reflected and concentrated at the central collector, where the heat is used to produce steam to drive turbines and generate electric power. [*Source:* Photograph by Daniel B. Botkin.]

(a)



(b)

FIGURE 16.9 **(a)** Acciona solar thermal power plant, south of Las Vegas, which uses more than 180,000 parabolic mirrors to concentrate sunlight onto pipes containing a fluid that is heated above 300°C. The heated fluid, in turn, boils water, and the steam runs a conventional electrical generating turbine. **(b)** Diagram illustrating how such a system works. (*Source*: Courtesy of LUZ International.)

generator was “Solar One,” funded by the U.S. Department of Energy. It was built in 1981 by Southern California Edison and operated by that company along with the Los Angeles Department of Water & Power and the California Energy Commission. Sunlight was concentrated onto the top of the tower by 1,818 large mirrors (each about 20 feet in diameter) that were mechanically linked to each other and tracked the sun. At the end of 1999, this power tower was shut down, in part because the plant was not economically competitive with other sources of electricity. New solar thermal generators are being built with very large output (Figure 16.9).

More recently, solar devices that heat a liquid and produce electricity from steam have used many mirrors without a tower, each mirror concentrating sunlight onto a pipe containing the liquid (as shown in Figures 16.8 and 16.9). This is a simpler system and has been considered cheaper and more reliable.[2]

Solar Energy and the Environment

The use of solar energy generally has a relatively low impact on the environment, but there are some environmental concerns nonetheless. One concern is the large variety of metals, glass, plastics, and fluids used in the manufacture and use of solar equipment. Some of these substances may cause environmental problems through production and by accidental release of toxic materials.

16.3 Converting Electricity from Renewable Energy into a Fuel for Vehicles

An obvious question about solar energy, as well as energy from wind, oceans, and freshwater, is how to convert this energy into a form that we can easily transport and can use to power our motor vehicles. Basically, there are two choices: Store the electricity in batteries and use electrical vehicles, or transfer the energy in the electricity to a liquid or gaseous fuel. Of the latter, the simplest is hydrogen.

An electrical current can be used to separate water into hydrogen and oxygen. Hydrogen can power fuel cells (see A Closer Look 16.1). As the hydrogen is combined again with oxygen, electrons flow between negative and positive poles—that is, an electric current is generated. Hydrogen can be produced using solar and other renewable energy sources and, like natural gas, can be transported in pipelines and stored in tanks. Furthermore, it is a clean fuel; the combustion of hydrogen produces water, so it does not contribute to global warming, air pollution, or acid rain. Hydrogen gas may be an important fuel of the future.[7] It is also possible to do additional chemical conversions, combining hydrogen with the carbon in carbon dioxide to produce methane (a primary component of natural gas) and then combining that with oxygen to produce ethanol, which can also power motor vehicles.

A CLOSER LOOK 16.1

Fuel Cells—An Attractive Alternative

Even if we weren't going to run out of fossil fuels, we would still have to deal with the fact that burning fossil fuels, particularly coal and fuels used in internal combustion engines (cars, trucks, ships, and locomotives), causes serious environmental problems. This is why we are searching not only for alternative energy sources but for those that are environmentally benign ways to convert a fuel to useable ways to generate power.[8] One promising technology uses fuel cells, which produce fewer pollutants, are relatively inexpensive, and have the potential to store and produce high-quality energy.

Fuel cells are highly efficient power-generating systems that produce electricity by combining fuel and oxygen in an electrochemical reaction. (They are not sources of energy but a way to convert energy to a useful form.) Hydrogen is the most common fuel type, but fuel cells that run on methanol, ethanol, and natural gas are also available. Traditional generating technologies require combustion of fuel to generate heat, then convert that heat into mechanical energy (to drive pistons or turbines), and convert the mechanical energy into electricity. With fuel cells, however, chemical energy is converted directly into electricity, thus increasing second-law efficiency (see Chapter 17) while reducing harmful emissions.

The basic components of a hydrogen-burning fuel cell are shown in Figure 16.10. Both hydrogen and oxygen are added to the fuel cell in an electrolyte solution. The hydrogen and oxygen remain separated from one another, and a platinum membrane prevents electrons from flowing directly to the positive side of the fuel cell. Instead, they are routed through an external circuit,

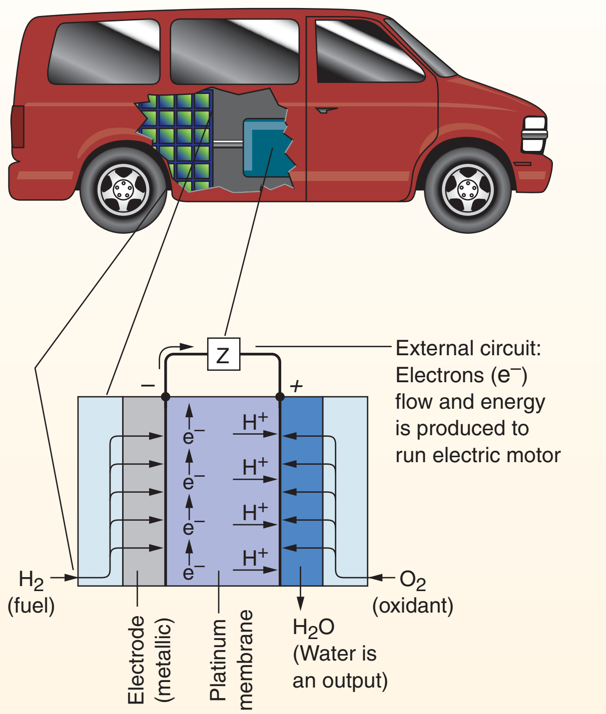


FIGURE 16.10 Idealized diagram showing how a fuel cell works and its application to power a vehicle.

and along the way from the negative to the positive electrode, they are diverted into an electrical motor, supplying current to keep the motor running.[9, 10] To maintain this reaction, hydrogen and oxygen are added as needed. When hydrogen is used in a fuel cell, the only waste product is water.[11]

Fuel cells are efficient and clean, and they can be arranged in a series to produce the appropriate amount of energy for a particular task. In addition, the efficiency of a fuel cell is largely independent of its size and energy output. They can also be used to store energy to be used as needed. Fuel cells are used in many locations. For example, they power buses at Los Angeles International Airport and in Vancouver. They also power a few buses in east San Francisco Bay[13] and provide heat and power at Vandenberg Air Force Base in California.[12] But this experimental technology is expensive, with buses estimated to cost more than $1 million each.[14]

Technological improvements in producing hydrogen are certain, and the fuel price of hydrogen may be substantially lower in the future.[15]

16.4 Water Power

Water power is a form of stored solar energy that has been successfully harnessed since at least the time of the Roman Empire. Waterwheels that convert water power to mechanical energy were turning in Western Europe in the Middle Ages. During the 18th and 19th centuries, large waterwheels provided energy to power grain mills, sawmills, and other machinery in the United States.

Today, hydroelectric power plants use the water stored behind dams. In the United States, hydroelectric plants generate about 80,000 MW of electricity—about 10% of the total electricity produced in the nation. In some countries, such as Norway and Canada, hydroelectric power plants produce most of the electricity used. Figure 16.11a shows the major components of a hydroelectric power station.

Hydropower can also be used to store energy produced by other means, through the process of pump storage (Figure 16.11b and c). During times when demand for power is low, excess electricity produced from oil, coal, or nuclear plants is used to pump water uphill to a higher reservoir (high pool). When demand for electricity is high (on hot summer days, for instance), the stored water flows back down to a low pool through generators to help provide energy. The advantage of pump storage lies in the timing of energy production and use. However, pump storage facilities are generally considered ugly, especially at low water times.

Small-Scale Systems

In the coming years, the total amount of electrical power produced by running water from large dams will probably not increase in the United States, where most of the acceptable dam sites are already in use and some dams are being dismantled (see Chapter 18). However, small-scale hydropower systems, designed for individual homes, farms, or small industries, may be more common in the future. These small systems, known as microhydropower systems, have power output of less than 100 kW.[16]

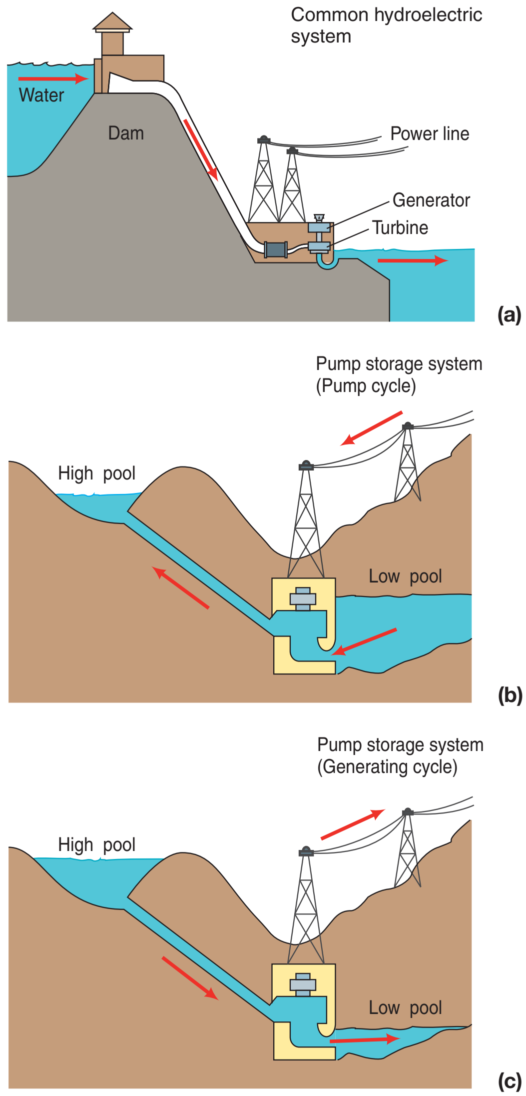


FIGURE 16.11 **(a)** Basic components of a hydroelectric power station. **(b)** A pump storage system. During light power load, water is pumped from low pool to high pool. **(c)** During peak power load, water flows from high pool to low pool through a generator. (*Source*: Modified from the Council on Environmental Quality, *Energy Alternatives: A Comparative Analysis* [Norman: University of Oklahoma Science and Policy Program, 1975].)

Many locations have potential for producing small-scale electrical power, either through small dams or by placing turbines in the free-flowing waters of a river. This is particularly true in mountainous areas, where energy from stream water is often available. Microhydropower development is site-specific, depending on local regulations, economic situations, and hydrologic limitations. Hydropower can be used to generate either electrical power or mechanical power to run machinery. Its use may help reduce the high cost of importing energy and may also help small operations become more independent of local utility providers. However, these systems can interfere with freshwater ecosystems, including fish habitats, and can take away from landscape beauty.

Because small dams can damage stream environments by blocking fish passage and changing downstream flow, careful consideration must be given to their construction. A few small dams cause little environmental degradation beyond the specific sites, but a large number of dams can have an appreciable impact on a region. (This principle applies to many forms of technology and development. The impact of a single development may be nearly negligible over a broad region; but as the number of such developments increases, the total impact may become significant.)

Water Power and the Environment

Water power is clean power in that it requires no burning of fuel, does not pollute the atmosphere, produces no radioactive or other waste, and is efficient. However, there are environmental prices to pay (see Chapter 21):

- Large dams and reservoirs flood large tracts of land that could have had other uses. For example, towns and agricultural lands may be lost.
- Dams block the migration of some fish, such as salmon, and the dams and reservoirs greatly alter habitats for many kinds of fish.
- Dams trap sediment that would otherwise reach the sea and eventually replenish the sand on beaches.
- Reservoirs with large surface areas increase evaporation of water compared to pre-dam conditions. In arid regions, evaporative loss of water from reservoirs is more significant than in more humid regions.
- For a variety of reasons, many people do not want to turn wild rivers into a series of lakes.

For all these reasons, and because many good sites for dams already have one, the growth of large-scale water power in the future (with the exception of a few areas, including Africa, South America, and China) appears limited. Indeed, in the United States there is an emerging social movement to remove dams. Hundreds of dams, especially those with few useful functions, are being considered for removal, and a few have already been removed (see Chapters 18 and 19). The U.S. Department of Energy forecasts that electrical generation from large hydropower dams will decrease significantly.

16.5 Ocean Energy

A lot of energy is involved in the motion of waves, currents, and tides in oceans. Many have dreamed of harnessing this energy, but it's not easy, for the obvious reasons that ocean storms are destructive and ocean waters are corrosive. The most successful development of energy from the ocean has been **tidal power**. Use of the water power of ocean tides can be traced back to the Roman occupation of Great Britain around Julius Caesar's time, when the Romans built a dam that captured tidal water and let it flow out through a waterwheel. By the 10th century, tides were used once again to power coastal mills in Britain.[17] However, only in a few places with favorable topography—such as the north coast of France, the Bay of Fundy in Canada, and the northeastern United States—are the tides strong enough to produce commercial electricity. The tides in the Bay of Fundy have a maximum range of about 15 m (49 ft). A minimum range of about 8 m (26 ft) appears necessary with present technology for development of tidal power.

To harness tidal power, a dam is built across the entrance to a bay or an estuary, creating a reservoir. As the tide rises (flood tide), water is initially prevented from entering the bay landward of the dam. Then, when there is sufficient water (from the oceanside high tide) to run the turbines, the dam is opened, and water flows through it into the reservoir (the bay), turning the blades of the turbines and generating electricity. When the bay is filled, the dam is closed, stopping the flow and holding the water in that reservoir. When the tide falls (ebb tide), the water level in the reservoir is higher than that in the ocean. The dam is then opened to run the turbines (which are reversible), and electric power is produced as the water is let out of the reservoir. Figure 16.12 shows the Rance tidal power plant

FIGURE 16.12 Tidal power station on the river Rance near Saint-Malo, France.

on the north coast of France. Constructed in the 1960s, it is the first and largest modern tidal power plant and has remained in operation since. The plant at capacity produces about 240,000 kW from 24 power units spread out across the dam. At the Rance power plant, most electricity is produced from the ebb tide, which is easier to control.

Tidal power, too, has environmental impacts. The dam changes the hydrology of a bay or an estuary, which can adversely affect the vegetation and wildlife. The dam restricts upstream and downstream passage of fish, and the periodic rapid filling and emptying of the bay as the dam opens and closes with the tides rapidly changes habitats for birds and other organisms.

16.6 Wind Power

Wind power, like solar power, has evolved over a long time. From early Chinese and Persian civilizations to the present, wind has propelled ships and has driven windmills to grind grain and pump water. In the past, thousands of windmills in the western United States were used to pump water for ranches. More recently, wind has been used to generate electricity. The trouble is, wind tends to be highly variable in time, place, and intensity.[18]

Basics of Wind Power

Winds are produced when differential heating of Earth's surface creates air masses with differing heat contents and densities. The potential for energy from the wind is large, and thus wind "prospecting" has become an important endeavor. On a national scale, regions with the greatest potential are the Pacific Northwest coastal area, the coastal region of the northeastern United States, and a belt within the Great Plains extending from northern Texas through the Rocky Mountain states and the Dakotas (Figure 16.13). Other windy sites include mountain areas in North Carolina and the northern Coachella Valley in Southern California. A site with average wind velocity of about 18 kilometers per hour (11 mph) or greater is considered a good prospect for wind energy development, although starting speeds for modern wind turbines can be considerably lower.[19]

In any location, the wind's direction, velocity, and duration may be quite variable, depending on local topography and temperature differences in the atmosphere. For example, wind velocity often increases over hilltops and when wind is funneled through a mountain pass (Figure 16.14). The increase in wind velocity over a mountain is due to a vertical convergence of wind, whereas in a pass the increase is partly due to a horizontal convergence. Because the shape of a mountain or a pass is often related to the local or regional geology, prospecting for wind energy is a geologic as well as a geographic and meteorological task. The wind energy potential of a region or site is determined by instruments that measure and monitor over time the strength, direction, and duration of the wind.

Significant improvements in the size of windmills and the amount of power they produce occurred from the late 1800s to the present, when many European countries and the United States became interested in

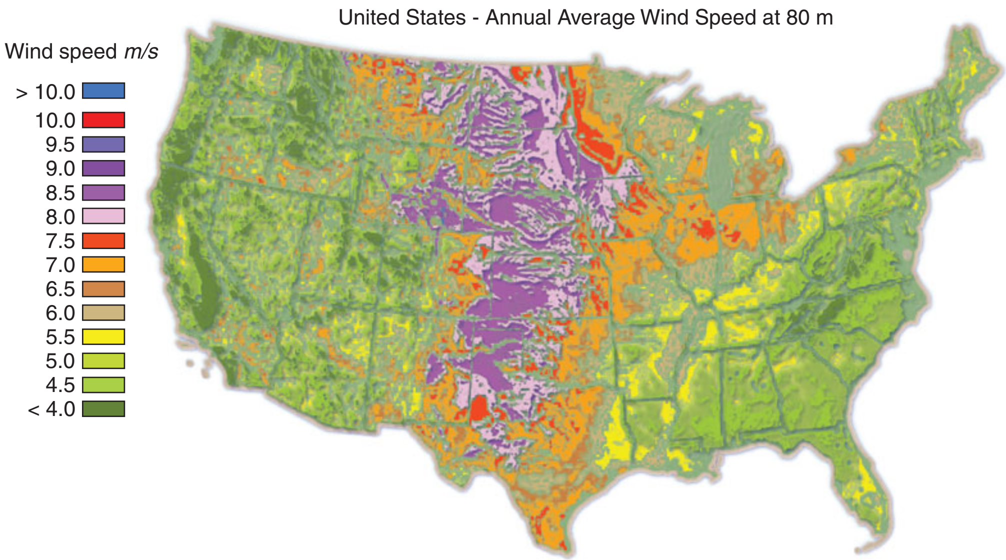


FIGURE 16.13 Wind energy potential in the United States.

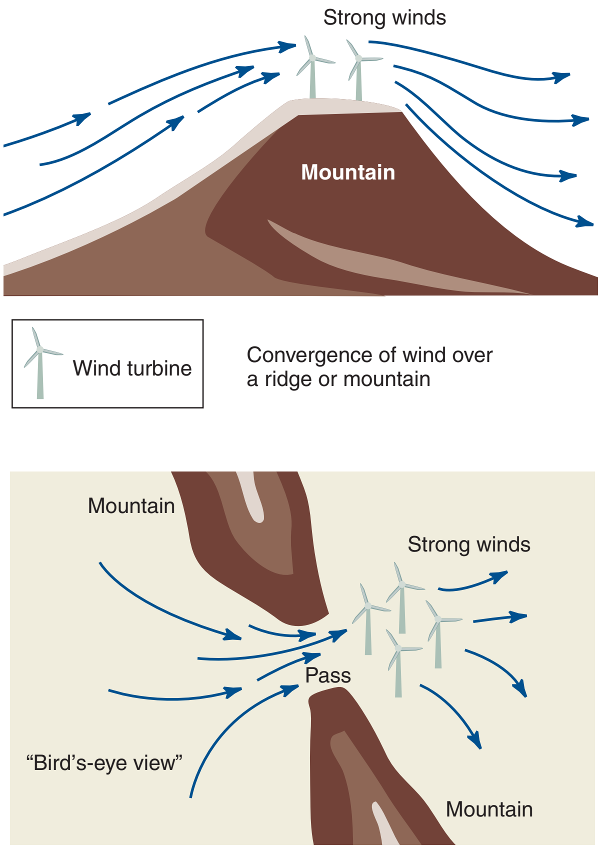


FIGURE 16.14 Idealized diagram showing how wind energy is concentrated by topography.

large-scale generators driven by wind. In the United States in the first half of the 20th century, thousands of small, wind-driven generators were used on farms. Most of these small windmills generated approximately 1 kW of power, which is much too little to be considered for central power-generation needs. Interest in wind power declined for several decades prior to the 1970s because of the abundance of cheap fossil fuels. Since the 1980s, interest in building windmills has revived greatly.

Today, wind energy is the cheapest form of alternative energy. Electricity produced from wind often costs less than that from natural gas and coal. Worldwide, wind power's generating capacity exceeded 120,000 megawatts in 2008. The United States has just taken over first place in having the largest installed wind energy capacity, now ahead of Germany, which had been the leader for a number of years, followed by Spain, China, India, and Italy.[20] U.S. wind power capacity reached 34,000 MW in 2007 (the most recent year for which data are available), increasing 33% a year on average since 2003.[21] Modern wind turbines are big, as much as 70 m (230 feet) high, as tall as a 23-story building, and have a generating capacity of more than 1 million watts—enough electricity for 500 modern U.S. homes (Figure 16.15).[22]

Much of the electricity produced from these large turbines is connected to the electrical grid, and many of them are installed in what are called "wind farms," which are providing large amounts of electricity. One of the biggest in the United States is the Horse Hollow Wind Energy Center near Abilene, Texas, owned and operated by Florida Power & Light. It has 421 wind turbines with a total generating capacity of 735 megawatts, enough to meet the electricity needs of approximately 220,000 homes, and enough for all domestic use for a city the size of Austin, Texas. (To put this in perspective, one large fossil fuel plant or nuclear power plant produces about 1,000 MW.) The Horse Hollow wind turbines are spread widely across approximately 47,000 acres, and the land is used for both ranching and energy production.[23]

Wind Power and the Environment

Wind energy does have a few disadvantages:

- Wind turbines can kill birds. (Birds of prey, such as hawks and falcons, are particularly vulnerable.)
- Wind turbines and wind farms may degrade an area's scenery.

However, although wind farms must often compete with other land uses, in many cases wind turbines can share land used for farms, military bases, and other facilities. Everything considered, wind energy has a relatively low environmental impact.

FIGURE 16.15 Windmills on a wind farm near Altamont, California, a mountain pass region east of San Francisco.

The Future of Wind Power

Wind power's continued use is certain. As noted earlier, the use of wind energy has been growing approximately 33% per year, nearly ten times faster than oil use. It is believed that there is sufficient wind energy in Texas, South Dakota, and North Dakota to satisfy the electricity needs of the entire United States. Consider the implications for nations such as China. China burns tremendous amounts of coal at a heavy environmental cost that includes exposing millions of people to hazardous air pollution. In rural China, exposure to the smoke from burning coal in homes has increased the rate of lung cancer by a factor of nine or more. China could probably double its current capacity to generate electricity with wind alone![24]

Wind energy supplies 1.5% of the world's demand for electricity, and its growth rate of more than 30% indicates that it could be a major supplier of power in the relatively near future.[25] One scenario suggests that wind power could supply 10% of the world's electricity in the coming decades and, in the long run, could provide more energy than hydropower, which today supplies approximately 20% of the electricity in the world. The wind energy industry has created thousands of jobs in recent years. Worldwide, more than half a million people are employed in wind energy, and according to the World Wind Energy Association, wind energy "creates many more jobs than centralized, nonrenewable energy sources."[26] Technology, meanwhile, is producing more efficient wind turbines, thereby reducing the price of wind power. All told, wind power is becoming a major investment opportunity.

16.7 Biofuels

Biofuel is energy recovered from biomass (organic matter). We can divide biofuels into three groups: firewood, organic wastes, and crops grown to be converted into liquid fuels.

Biofuels and Human History

Biomass is the oldest fuel used by humans. Our Pleistocene ancestors burned wood in caves to keep warm and cook food. Biofuels remained a major source of energy throughout most of the history of civilization. When North America was first settled, there was more wood fuel than could be used. Forests often were cleared for agriculture by girdling trees (cutting through the bark all the way around the base of a tree) to kill them and then burning the forests.

Until the end of the 19th century, wood was the major fuel source in the United States. During the mid-20th century, when coal, oil, and gas were plentiful, burning wood became old-fashioned and quaint, done just for pleasure in an open fireplace even though most of the heat went up the chimney. Now, with other fuels reaching a limit in abundance and production, there is renewed interest in using natural organic materials for fuel.

More than 1 billion people in the world today still use wood as their primary source of energy for heat and cooking.[13] But although firewood is the most familiar and most widely used biomass fuel, there are many others. In India and other countries, cattle dung is burned for cooking. Peat, a form of compressed dead vegetation, provides heating and cooking fuel in northern countries, such as Scotland, where it is abundant.

In recent years, however, biofuels have become controversial. Do biofuels offer a net benefit or disbenefit? (See Table 16.1.) In brief:

- Using wastes as a fuel is a good way to dispose of them. Making them takes more energy than they yield—but on the other hand, they reduce the amount of energy we must obtain from other sources.
- Firewood that regenerates naturally or in plantations that require little energy input will remain an important energy source in developing nations and locally in industrialized nations.
- Despite pressure from some agricultural corporations and some governments to promote crops grown solely for conversion into liquid fuels (called agrifuels), at present these are poor sources of energy. Most scientific research shows that producing agrifuels takes more energy than they yield. In some cases, there appears to be a net benefit, but the energy produced per unit of land area is low, much lower than can be obtained from solar and wind.

What it boils down to is that photosynthesis, though a remarkable natural process, is less efficient than modern photovoltaic cells in converting sunlight to electricity. Some algae and bacteria appear to provide a net energy benefit and can yield ethanol directly, but production of ethanol from these sources is just beginning and is experimental.[27]

Biofuels and the Environment

The conversion of farmland from food crops to biofuels appears to be one of the main reasons that food prices have risen rapidly worldwide, and that worldwide food production no longer exceeds demand. It also has environmental effects.

Biofuel agriculture competes for water with all other uses, and the main biofuel crops require heavy use of artificial fertilizers and pesticides.

Biofuels are supposed to reduce the production of greenhouse gases, but when natural vegetation is removed to grow biofuel crops, the opposite may be the case. The environmental organization Friends of the Earth says

Table 16.1 SELECTED EXAMPLES OF BIOMASS ENERGY SOURCES, USES, AND PRODUCTS

SOURCES	EXAMPLES	USES/PRODUCTS	COMMENT
Forest Products	Wood, chips	Direct burning,[a] charcoal[b]	Major source today in developing countries
Agriculture residues	Coconut husks, sugarcane waste, corncobs, peanut shells	Direct burning	Minor source
Energy crops	Sugarcane, corn, sorghum	Ethanol (alcohol)[c], gasification[d]	Ethanol is major source of fuel in Brazil for automobiles
Algae and bacteria	Special farms	Experimental	
Trees	Palm oil	Biodiesel	Fuel for vehicles
Animal residues	Manure	Methane[e]	Used to run farm machinery
Urban waste	Waste paper, organic household waste	Direct burning of methane from wastewater treatment or from landfills[f]	Minor source

[a]Principal biomass conversion.

[b]Secondary product from burning wood.

[c]Ethanol is an alcohol produced by fermentation, which uses yeast to convert carbohydrates into alcohol in fermentation chambers (distillery).

[d]Biogas from gasification is a mixture of methane and carbon dioxide produced by pyroclytic technology, Which is a thermochemical process that breaks down solid biomass into an oil-like liquid and almost pure carbon char.

[e]Methane is produced by anaerobic fermentation in a digester.

[f]Naturally produced in landfills by anaerobic fermentation.

that as much as 8% of the world's annual CO_2 emissions can be attributed to draining and deforesting peatlands in Southeast Asia to create palm plantations. The organization estimates that in Indonesia alone 44 million acres have been cleared for these plantations, an area equal to more than 10% of all the cropland in the United States, as large as Oklahoma and larger than Florida.[28]

The use of biofuels can pollute the air and degrade the land. For most of us, the smell of smoke from a single campfire is part of a pleasant outdoor experience. Under certain weather conditions, however, woodsmoke from many campfires or chimneys in narrow valleys can lead to air pollution. The use of biomass as fuel places pressure on an already heavily used resource. A worldwide shortage of firewood is adversely affecting natural areas and endangered species. For example, the need for firewood has threatened the Gir Forest in India, the last remaining habitat of the Indian lion (not to be confused with the Indian tiger). The world's forests will also shrink and in some cases vanish if our need for their products exceeds their productivity.

Biofuels do have some potential benefits. One is that certain kinds of crops, such as nuts produced by trees, may provide a net energy benefit in environments that are otherwise not suited to the growth of food crops. For example, some remote mountainous areas of China may become productive of biofuels. But this is not commonly the case.[29]

Another environmental plus is that combustion of biofuels generally releases fewer pollutants, such as sulfur dioxide and nitrogen oxides, than does combustion of coal and gasoline. This is not always the case for burning urban waste, however. Although plastics and hazardous materials are removed before burning, some inevitably slip through the sorting process and are burned, releasing air pollutants, including heavy metals. There is a conflict in our society as to whether it is better, in terms of the environment, to burn urban waste to recover energy and risk some increase in air pollution, or dump these wastes in landfills, which can then pollute soil and groundwater.

16.8 Geothermal Energy

There are two kinds of **geothermal energy**: deep-earth, high-density; and shallow-earth, low-density. The first makes use of energy within the Earth. The second is a form of solar energy: When the sun warms the surface soils, water, and rocks, some of this heat energy is gradually transmitted down into the ground.

The first kind of geothermal energy—deep-earth, high-density—is natural heat from the interior of the Earth. It is mined and then used to heat buildings and generate electricity. The idea of harnessing Earth's internal heat goes back more than a century. As early as 1904, geothermal power was used in Italy. Today, Earth's natural internal heat is being used to generate electricity in 21 countries, including Russia, Japan, New Zealand, Iceland, Mexico, Ethiopia, Guatemala, El Salvador, the Philippines, and the United States. Total worldwide production is approaching 9,000 MW (equivalent to nine large, modern coal-burning or nuclear power plants)—double the amount in 1980. Some 40 million people today receive their electricity from geothermal energy at a cost competitive with that of other energy sources. In El Salvador, geothermal energy is supplying 25% of the total electric energy used. However, at the global level, geothermal energy accounts for less than 0.15% of the total energy supply.[30]

This kind of geothermal energy may be considered a nonrenewable energy source when rates of extraction are greater than rates of natural replenishment. However, geothermal energy has its origin in the natural heat production within Earth, and only a small fraction of the vast total resource base is being used today. Although most geothermal energy production involves tapping high-heat sources, people are also using the low-temperature geothermal energy of groundwater in some applications.

FIGURE 16.16 Geysers Geothermal Field, north of San Francisco, California, is the largest geothermal power operation in the world and produces energy directly from steam.

Geothermal Systems

The average heat flow from the interior of the Earth is very low, about 0.06 watts per square meter (W/m^2). This amount is trivial compared with the 177 W/m^2 from sunlight at the surface, but in some areas the heat flow is high enough to be useful.[31] For the most part, high heat flow occurs mostly at plate tectonic boundaries (see Chapter 5), including oceanic ridge systems (divergent plate boundaries) and areas where mountains are being uplifted and volcanic islands are forming (convergent plate boundaries). You can see the effects of such natural heat flow at Yellowstone National Park. On the basis of geologic criteria, several types of hot geothermal systems (with temperatures greater than about 80°C, or 176°F) have been defined.

Some communities in the United States, including Boise, Idaho, and Klamath Falls, Oregon, are using deep-earth, high-density geothermal heating systems. A common type of geothermal system uses hydrothermal convection, where the circulation of steam and/or hot water transfers heat from the depths to the surface. An example is the Geysers Geothermal Field, 145 km (90 mi) north of San Francisco. It is the largest geothermal power operation in the world (Figure 16.16), producing about 1,000 MW of electrical energy. At the Geysers, the hot water is maintained in part by injecting treated wastewater from urban areas into hot rocks.

The second kind of geothermal energy—shallow-earth, low-density—is at much lower temperatures than geothermal sources and is used not to produce electricity but for heating buildings and swimming pools, and for heating soil to boost crop production in greenhouses. The potential for this kind of energy is huge, and it is cheap to obtain.[32] Such systems are extensively used in Iceland.

It may come as a surprise to learn that most groundwater can be considered a source of shallow-earth, low-density geothermal energy. It is geothermal because the normal heat flow from the sun to the Earth keeps the temperature of groundwater, at a depth of 100 m (320 ft), at about 13°C (55°F). This is cold for a shower but warmer than winter temperatures in much of the United States, where it can help heat a house. In warmer regions, with summer temperatures of 30–35°C (86–95°F), groundwater at 13°C is cool and thus can be used to provide air conditioning, as it does today in coastal Florida and elsewhere. In summer, heat can be transferred from the warm air in a building to the cool groundwater. In winter, when the outdoor temperature is below about 4°C (40°F), heat can be transferred from the groundwater to the air in the building, reducing the need for heating from other sources. "Heat pumps" for this kind of heat transfer are used in warm locations such as Florida and as far north as Juneau, Alaska, but are limited by extreme temperatures and can't function in the cold winters of northern New Hampshire or interior Alaska, such as in Fairbanks. (Juneau, on the coast, has a much more moderate climate because of the influence of the ocean waters.)

Geothermal Energy and the Environment

Deep-earth, high-density, geothermal energy development produces considerable thermal pollution from its hot wastewaters, which may be saline and highly corrosive. Other environmental problems associated with this kind of geothermal energy use include on-site noise, emissions of gas, and disturbance of the land at drilling sites, disposal sites, roads and pipelines, and power plants. The good news is that the use of deep-earth, high-density geothermal energy releases almost 90% less carbon dioxide and sulfur dioxide than burning coal releases to produce the same amount of electricity.[33] Furthermore, development of geothermal energy does not require large-scale transportation of raw materials or refining of chemicals, as development of fossil fuels does. Nor does geothermal energy produce the atmospheric pollutants associated with burning fossil fuels or the radioactive waste associated with nuclear energy.

Even so, deep-earth, high-density geothermal power is not always popular. For instance, on the island of Hawaii, where active volcanoes provide abundant near-surface heat, some argue that the exploration and development of geothermal energy degrade the tropical forest as developers construct roads, build facilities, and drill wells. In Hawaii, geothermal energy also raises religious and cultural issues. Some people, for instance, are offended by the use of the "breath and water of Pele," the volcano goddess, to make electricity. This points out the importance of being sensitive to the values and cultures of people where development is planned.

The Future of Geothermal Energy

By 2008, the United States produced only 7,500 MW of geothermal energy.[34] Globally, the likelihood is that high-density, deep-earth geothermal can be only a minor contributor to world energy demand, but that low-density, shallow-earth geothermal can be a major source of alternative and renewable energy.[35]

CRITICAL THINKING ISSUE

Should Wind Turbines Be Installed in Nantucket Sound?

In 2001, Cape Wind Associates proposed the Cape Wind Project, which would install 130 wind turbines, each higher than the Statue of Liberty, on floating offshore platforms distributed in Nantucket Sound (Figure 16.17), between Nantucket Island and the coast of Massachusetts. The 130 turbines would cover more than 62 square kilometers (24 square miles) and therefore would not be very close together. The turbines are expected to generate enough electricity for 420,000 homes, but although originally proposed in 2001, work on the $1 billion project has yet to begin. The federal government has received more than 40,000 comments about it, the greatest number ever about an alternative energy project,[31] and in response has held 50 public hearings.

Fishermen have expressed concern about possible effects on fish habitats, including spawning grounds. Shippers have expressed concern about possible dangers to commercial shipping. And some residents of Cape Cod, Martha's Vineyard, and Nantucket have opposed the project on aesthetic grounds—that the wind turbines will spoil the scenery.[36] The late senator Edward M. Kennedy, Democrat of Massachusetts, was one of the leaders in the fight against it, as is his nephew, Robert Kennedy Jr.[37]

Nantucket Sound is about 30 km (19 miles) wide between Nantucket Island and the mainland, while visibility at ground level is only about 19 kilometers (12 miles— limited by the curvature of the Earth). Thus, the turbines would be scattered points in the distance from either shore. They would, however, be visible from ships and boats passing through the channel, such as the yachts of wealthy residents on holiday.

It is worth noting that in the meantime, a Dutch company, Blue H, USA LLC, announced plans in March 2008 to put 120 turbines on floats 23 miles south of Martha's Vineyard and 45 miles west of New Bedford, farther away from the view of residents.[38] Further complicating matters, the National Park Service says that Nantucket Sound is eligible for listing on the National Register of Historic Places. And two tribes, the Mashpee Wampanoag of Cape Cod and the Aquinnah Wampanoag

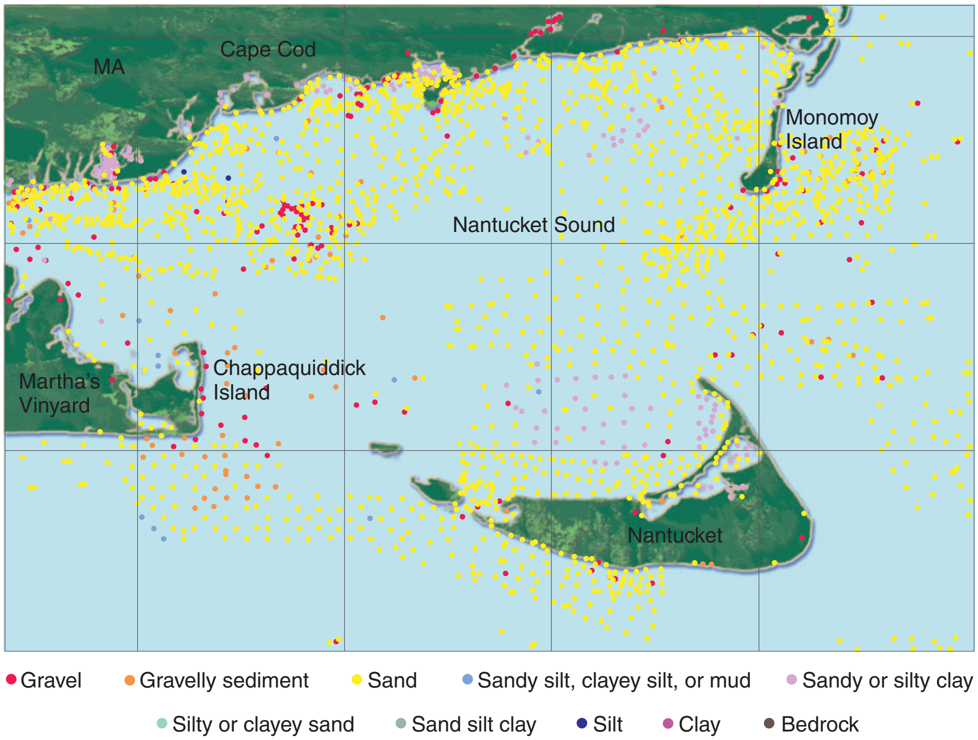


FIGURE 16.17 Map of Nantucket Sound.

of Martha's Vineyard, make two claims against the development: that it might be built over ancestral burial grounds and might interfere with a ritual that requires an unobstructed view of the sunrise.[39]

Critical Thinking Questions

1. Which of the arguments against the Cape Wind Project do you think is most justified? Explain your answer.
   a. The effect on scenic beauty
   b. The effect on fisheries
   c. The traditional cultural practices of Native Americans
2. Since another project would place 120 turbines farther away from the view of residents, what would justify continuation of the Cape Wind Project?
3. Do you think the Cape Wind Project could be important as a precedent for other offshore wind energy projects in the United States? Why or why not?
4. On balance, do you support the Cape Wind Project or oppose it? Explain your answer.

SUMMARY

- The use of renewable alternative energy sources, such as wind and solar energy, is growing rapidly. These energy sources do not cause air pollution, health problems, or climate changes. They offer our best chance to replace fossil fuels and develop a sustainable energy policy.
- Passive solar energy systems often involve architectural designs that enhance absorption of solar energy without requiring mechanical power or moving parts.
- Some active solar energy systems use solar collectors to heat water for homes.
- Systems to produce heat or electricity include power towers and solar farms.
- Photovoltaics convert sunlight directly into electricity.
- Hydrogen gas may be an important fuel of the future, especially when used in fuel cells.
- Water power today provides about 10% of the total electricity produced in the United States. Except in some developing nations, good sites for large dams are already in use. Water power is clean, but there is an environmental price to pay in terms of disturbance of ecosystems, sediment trapped in reservoirs, loss of wild rivers, and loss of productive land.
- Wind power has tremendous potential as a source of electrical energy in many parts of the world. Many

utility companies are using wind power as part of energy production or as part of long-term energy planning. Environmental impacts of wind installations include loss of land, killing of birds, and degradation of scenery.

- Biofuels are of three kinds: firewood, wastes, and crops grown to produce fuels. Firewood has been important historically and will remain so in many developing nations and many rural parts of developed nations. Burning wastes is a good way to dispose of them, and their energy is a useful by-product. Crops grown solely as biofuels appear to be a net energy sink or of only marginal benefit, at considerable environmental costs, including competition for land, water, and fertilizers, and the use of artificial pesticides. At present they are not a good option.
- Geothermal energy, natural heat from Earth's interior, can be used as an energy source. The environmental effects of developing geothermal energy relate to specific site conditions and the type of heat—steam, hot water, or warm water. Environmental impacts may involve on-site noise, industrial scars, emission of gas, and disposal of saline or corrosive waters.

REEXAMINING THEMES AND ISSUES

Human Population

As the human population continues to increase, so does global demand for energy. Environmental problems from increased use of fossil fuels could be minimized by controlling population growth, increasing conservation efforts, and using alternative, renewable energy sources that do not harm the environment.

Sustainability

Use of fossil fuels is not sustainable. To plan for energy sustainability, we need to rely more on alternative energy sources that are naturally renewable and do not damage the environment. To do otherwise is antithetical to the concept of sustainability.

Global Perspective

To evaluate the potential of alternative energy sources, we need to understand global Earth systems and identify regions likely to produce high-quality alternative energy that could be used in urban regions of the world.

Urban World

Alternative renewable energy sources have a future in our urban environments. For example, the roofs of buildings can be used for passive solar collectors or photovoltaic systems. Patterns of energy consumption can be regulated through use of innovative systems such as pump storage to augment production of electrical energy when demand is high in urban areas.

People and Nature

Many environmentalists perceive alternative energy sources, such as solar and wind, as being linked more closely with nature than are fossil fuels, nuclear energy, or even water power. This is because solar and wind energy development requires less human modification of the environment. Solar and wind energy allow us to live more in harmony with the environment, and thus we feel more connected to the natural world.

Science and Values

We are seriously considering alternative energy today because we value environmental quality and energy independence and want to plan for a future when we run out of fossil fuels. Recognizing that burning fossil fuels creates many serious environmental problems and that petroleum will soon become less available, we are trying to increase our scientific knowledge and improve our technology to meet our energy needs for the future while minimizing environmental damage. Our present science and technology can lead to a sustainable energy future, but we will need to change our values and our behavior to achieve it.

KEY TERMS

active solar energy systems **329**
alternative energy **327**
biofuel **338**
fuel cells **333**
geothermal energy **339**
nonrenewable alternative energy **327**
passive solar energy systems **328**
photovoltaics **330**
renewable energy **327**
solar collectors **329**
tidal power **335**
water power **334**
wind power **336**

STUDY QUESTIONS

1. What types of government incentives might encourage use of alternative energy sources? Would their widespread use affect our economic and social environment?
2. Your town is near a large river that has a nearly constant water temperature of about 15°C (60°F). Could the water be used to cool buildings in the hot summers? How? What would be the environmental effects?
3. Which has greater future potential for energy production, wind or water power? Which causes more environmental problems? Why?
4. What are some of the problems associated with producing energy from biomass?
5. It is the year 2500, and natural oil and gas are rare curiosities that people see in museums. Given the technologies available today, what would be the most sensible fuel for airplanes? How would this fuel be produced to minimize adverse environmental effects?
6. When do you think the transition from fossil fuels to other energy sources will (or should) occur? Defend your answer.

FURTHER READING

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