Energy Efficiency and Renewable Energy

16

Iceland's Vision of a Renewable-Energy Economy

CORE CASE STUDY

Iceland, a tiny northern European island nation roughly the size of Guatemala or the U.S. state of Kentucky, is located just 320 kilometers (200 miles) south of the North Pole. Because about three-fourths of this island consists of volcanoes, glaciers, and hot springs, most of Iceland's 319,000 people live in its capital city of Reykjavik.

The island, which sits on the boundary of the Eurasian and North American tectonic plates (Figure 14-4, p. 347), has 20 active volcanoes. They are fed by molten rock (magma) that rises close to the surface (Figure 14-3, p. 346), under Iceland's abundant glaciers, lakes, and hot springs.

Iceland gets almost three-fourths of its overall energy and almost all of its electricity from two renewable sources. One is *geothermal energy* from superheated groundwater and steam found close to its surface (Figure 16-1). This energy supplies electricity and provides heat for 80% of Iceland's houses and for producing vegetables in greenhouses. The other renewable energy source is *hydroelectric power.*

Because it has no fossil fuel deposits, Iceland imports oil to run its cars, some of its factories, and the fleet of fishing boats that help to supply 60% of its income. This may change. By 2050–2060, Iceland has plans to eliminate its dependence on nonrenewable oil and to become the world's first country to run its economy entirely on renewable energy.

Bragi Arnason, a University of Iceland professor often called "Dr. Hydrogen," suggested this idea in the 1970s. He proposed that the country could eliminate its fossil fuel imports and strengthen its economy by using electricity produced by its ample geothermal, hydroelectric, and wind power resources to decompose water into hydrogen and oxygen gases. The clean-burning hydrogen could then used to power the country's transportation system, factories, and fishing boats. When hydrogen is combined with oxygen in a fuel cell to produce electricity, the only byproduct is water vapor. Thus burning hydrogen fuel avoids emissions of CO_2 and other air pollutants that are produced when fossil fuels are burned. Iceland could also boost its economy by exporting excess hydrogen to other countries.

In 1999, Daimler, Royal Dutch Shell, Norsk Hydro, and Icelandic New Energy announced plans to work together to turn Bragi Arnason's dream into reality by 2050–2060. In 2003, the world's first commercial hydrogen filling station, built and run by Royal Dutch Shell, opened in Reykjavik. Norsk Hydro is providing the electricity and technology to produce the hydrogen fuel.

Between 2003 and 2007, the station fueled three prototype fuel-cell buses provided by Daimler. The use of a new set of such buses is planned for the future. In 2008, the station began fueling a fleet of 10 Toyota Prius test vehicles converted to burn hydrogen in fuel cells; three of the cars are available for rental to tourists. Since 2008, a whale-watching boat (an important part of the country's rapidly growing ecotourism business) has been partially powered by a hydrogen fuel cell.

These early steps in Iceland's transformation are designed to provide the experience needed to eventually run all of the country's cars, factories, and ships on hydrogen. Although they face considerable technological challenges, Icelanders hope to create a model for a renewable-energy economy within your lifetime.

In this chapter, we look at how we can cut energy waste, and we consider the potential of major renewable energy resources.

Birkir Fanndal

Figure 16-1 The Krafla *geothermal power* station in northern Iceland has been in operation since 1977. Beneath the station, 20 deep geothermal wells provide steam for generating electricity. There are no coal-burning power plants to emit CO_2 and other air pollutants into Iceland's skies and no nuclear power plants that produce long-lived radioactive wastes.

Key Questions and Concepts

16-1 Why is energy efficiency an important energy source?

CONCEPT 16-1 We could save as much as 43% of all the energy we use by improving energy efficiency.

16-2 How can we cut energy waste?

CONCEPT 16-2 We have a variety of technologies for sharply increasing the energy efficiency of industrial operations, motor vehicles, and buildings.

16-3 What are the advantages and disadvantages of solar energy?

CONCEPT 16-3 Passive and active solar heating systems can heat water and buildings effectively, and the costs of using direct sunlight to produce high-temperature heat and electricity are coming down.

16-4 What are the advantages and disadvantages of producing electricity from the water cycle?

CONCEPT 16-4 Water flowing over dams, tidal flows, and ocean waves can be used to generate electricity, but environmental concerns and limited availability of suitable sites may limit the use of these energy resources.

16-5 What are the advantages and disadvantages of producing electricity from wind?

CONCEPT 16-5 When environmental costs of energy resources are included in market prices, wind energy is the least expensive and least polluting way to produce electricity.

16-6 What are the advantages and disadvantages of biomass as an energy source?

CONCEPT 16-6A Solid biomass is a renewable resource, but burning it faster than it is replenished produces a net gain in atmospheric greenhouse gases, and creating biomass plantations can degrade soil and biodiversity.

CONCEPT 16-6B Liquid biofuels derived from biomass can be used in place of gasoline and diesel fuels, but creating biofuel plantations could degrade soil and biodiversity and increase food prices and greenhouse gas emissions.

16-7 What are the advantages and disadvantages of geothermal energy?

CONCEPT 16-7 Geothermal energy has great potential for supplying many areas with heat and electricity and generally has a low environmental impact, but locations where it can be exploited economically are limited.

16-8 What are the advantages and disadvantages of hydrogen as an energy source?

CONCEPT 16-8 Hydrogen fuel holds great promise for powering cars and generating electricity, but to be environmentally beneficial, it would have to be produced without the use of fossil fuels.

16-9 How can we make a transition to a more sustainable energy future?

CONCEPT 16-9 We can make a transition to a more sustainable energy future if we greatly improve energy efficiency, use a mix of renewable energy resources, and include environmental costs in the market prices of all energy resources.

Note: Supplements 2 (p. S4), 6 (p. S39), 10 (p. S59), and 13 (p. S78) can be used with this chapter.

Just as the 19th century belonged to coal and the 20th century to oil,
the 21st century will belong to the sun, the wind, and energy from within the earth.

LESTER R. BROWN

16-1 Why Is Energy Efficiency an Important Energy Resource?

▶ **CONCEPT 16-1 We could save as much as 43% of all the energy we use by improving energy efficiency.**

We Waste Huge Amounts of Energy

The world will rely increasingly on a mix of renewable energy resources. In addition, however, many analysts urge us to make much greater use of a strategy not usually thought of as a source of energy—that is, **energy conservation,** a decrease in energy use based primarily on reducing unnecessary waste of energy. The best way to conserve energy is to improve **energy efficiency**—the measure of how much work we can

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.

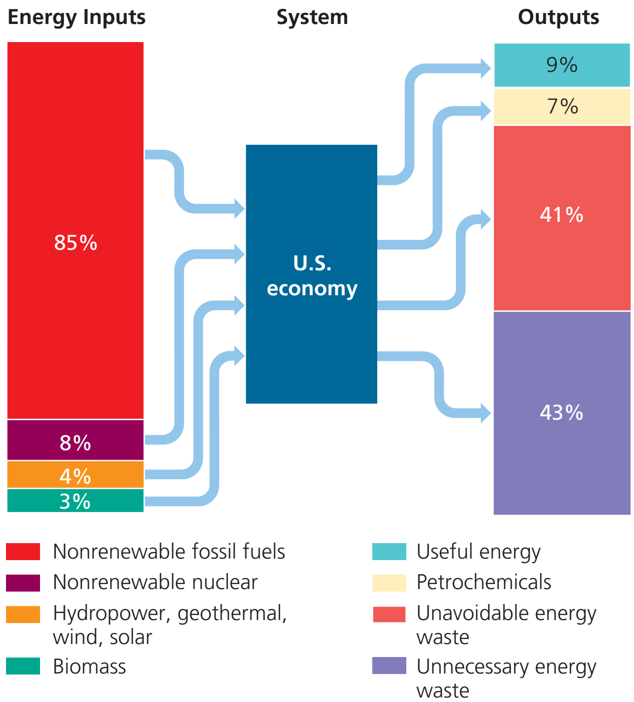


Figure 16-2 Flow of commercial energy through the U.S. economy. Only 16% of all commercial energy used in the United States ends up performing useful tasks or being converted to petrochemicals; the rest is unavoidably wasted because of the second law of thermodynamics (41%) or is wasted unnecessarily (43%). **Questions:** What is an example of unavoidable energy waste? What is an example of unnecessary energy waste? (Data from U.S. Department of Energy)

get from each unit of energy we use. For example, people who drive energy-efficient cars use less fuel per kilometer (or per mile) than do those who drive less efficient vehicles. You may be surprised to learn that 84% of all commercial energy used in the United States is wasted (Figure 16-2). About 41% of this energy is wasted unavoidably because of the degradation of energy quality imposed by the second law of thermodynamics (**Concept 2-4B**, p. 40).

CONCEPT LINK

The other 43% is wasted unnecessarily, mostly due to the inefficiency of incandescent lights, furnaces, industrial motors, coal and nuclear power plants, most motor vehicles, and other devices. Another reason is that many people live and work in leaky, poorly insulated, badly designed buildings. Unnecessary energy waste costs the United States an average of about $570,000 per minute. (See the Guest Essay by Amory Lovins at CengageNOW™.)

For many years, Americans have been buying gas-guzzling sport utility vehicles (SUVs), trucks, and minivans and moving from cities to larger and often energy-inefficient houses in far-flung suburbs, where they must depend on cars for getting around. Now, three of every four Americans commute to work, mostly in gas-guzzling vehicles, and only 5% rely on more energy-efficient mass transit. As a result, two-thirds of the oil consumed in the United States is used for transportation, and 60% of the country's oil is imported.

Canada is even less energy efficient than the United States is, and most developing countries are three times less efficient. On the other hand, Japan, Germany, and France are two to three times *more* energy efficient than the United States is.

Reducing energy waste has numerous economic and environmental advantages (Figure 16-3). To most energy analysts, *reducing energy waste is the quickest, cleanest, and usually the cheapest, way to provide more energy, reduce pollution and environmental degradation, slow global warming, and increase economic and national security* (**Concept 16-1**). The cheapest and cleanest power plant in the world—one that emits no greenhouse gases and produces no radioactive wastes—is the one we do not have to build because of reductions in energy waste. According to energy-efficiency expert Amory Lovins, improving energy efficiency is equivalent to buying oil—which now sells for $100–150 a barrel—for $15 a barrel. (See Lovins' Guest Essay on this topic at CengageNOW.)

Four widely used devices waste large amounts of energy unnecessarily:

- An *incandescent lightbulb* uses only 5–10% of the electricity it draws to produce light, while the other 90–95% is wasted as heat. It is really a *heat bulb*.

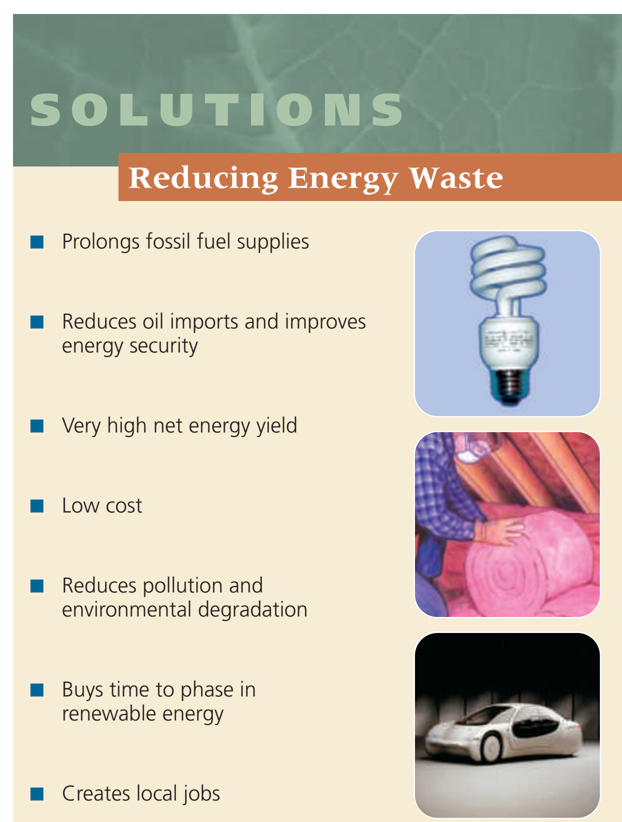


Figure 16-3 Advantages of reducing unnecessary energy waste and thereby improving energy efficiency. Global improvements in energy efficiency could save the world an average of about $1.9 million per minute! **Question:** Which two of these advantages do you think are the most important? Why?

- A motor vehicle with an *internal combustion engine* wastes about 94% of the energy in its fuel.

- A *nuclear power plant* (Figure 15-17, p. 387), producing electricity for space heating or water heating, wastes about 83% of the energy in its nuclear fuel and probably 92% when we include the additional energy used in the nuclear fuel cycle (Figure 15-19, p. 389) to dig up and to process its uranium fuel, store its radioactive wastes for thousands of years, and to retire the highly radioactive plant at the end of its useful life.

- A *coal-fired power plant* (Figure 15-12, p. 383) wastes 66% of the energy released by burning coal to produce electricity and probably 75–80% if we include the energy needed to dig up the coal and transport it to the plant.

Energy-efficiency experts say we can no longer afford to build our societies around such energy-wasting and environmentally harmful devices, which some call the *outdated four.* They call for us to replace these energy-wasting dinosaurs with more energy-efficient and less polluting and climate-changing alternatives over the next few decades.

Such alternatives include compact fluorescent and light emitting diode (LED) lights, fuel cells to power motor vehicles and provide heat and electricity for buildings, and wind and solar cell farms to produce electricity. These replacements could be coupled with a mix of existing energy-saving measures such as using more insulation; plugging air leaks; using energy-efficient windows, appliances, and building design; and recycling and reusing most materials.

In 2008, Lester Brown estimated that shifting to more energy-efficient lighting and appliances alone over the next two decades could save the world enough electricity to avoid building more than 1,400 large coal-burning power plants, thereby also avoiding great amounts of climate-changing CO_2 emissions.

Net Energy Efficiency—Honest Energy Accounting

Recall that the only energy that really counts is *net energy* (Science Focus, p. 374). The *net energy efficiency* of a system used to heat a house, for example, is determined by combining the efficiencies of all steps in the energy conversion for the entire system.

Figure 16-4 shows the net energy efficiency for heating two well-insulated homes. One is heated with electricity produced at a nuclear power plant, transported by wire to the home, and converted to heat (*electric resistance heating*). The other is heated passively: direct solar energy enters through high-efficiency windows facing the sun and strikes heat-absorbing materials that store the heat for slow release.

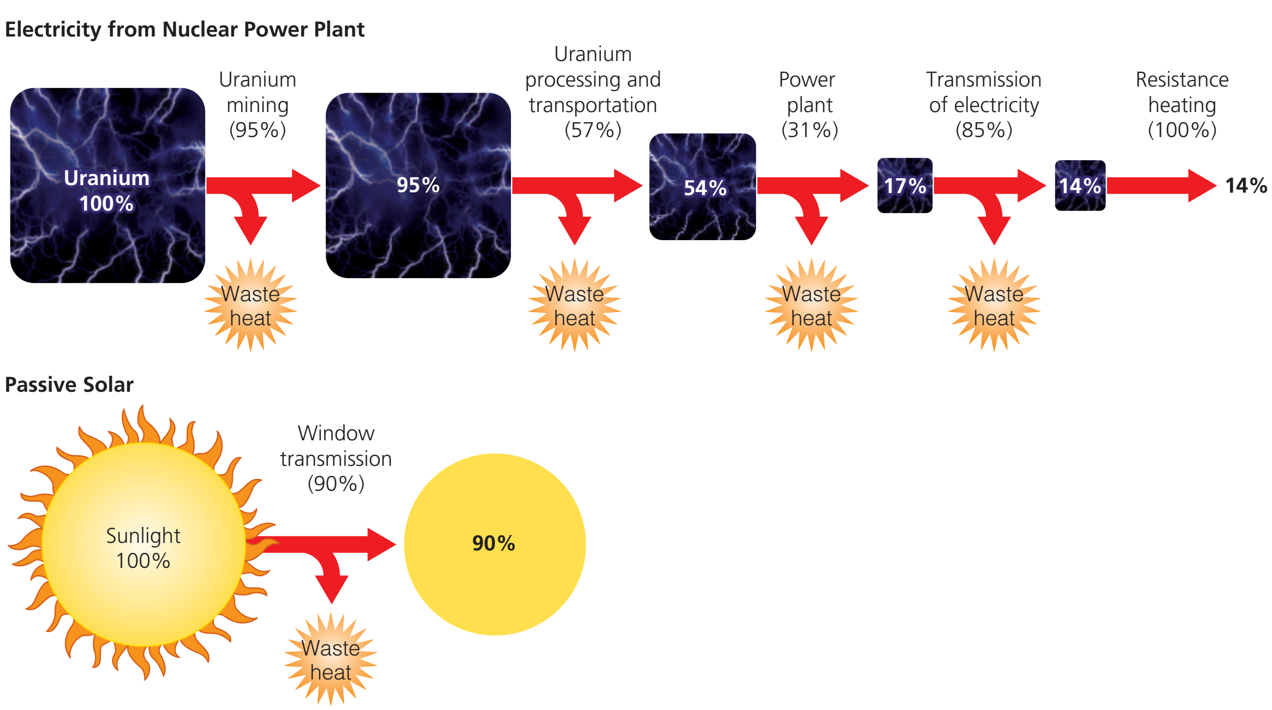


Figure 16-4 Comparison of the net energy efficiency for two types of space heating. The cumulative net efficiency is obtained by multiplying the percentage of energy available from the source (shown inside the square before each step) by the energy efficiency for that step (shown in parentheses). So 100 × 0.95 = 95%; 95 × 0.57 = 54%; and so on. About 83% of the energy used to provide space heating by electricity produced at a nuclear power plant is wasted. If the additional energy needed to deal with nuclear wastes and to retire the highly radioactive nuclear plant after its useful life is included, the net energy yield for a nuclear plant is only about 8% (or 92% waste). Burning coal or any fossil fuel to generate electricity at a power plant and transmitting electricity long distances to heat water or space is also inefficient. By contrast, with passive solar heating, only about 10% of incoming solar energy is wasted.

16-2 How Can We Cut Energy Waste?

▶ **CONCEPT 16-2 We have a variety of technologies for sharply increasing the energy efficiency of industrial operations, motor vehicles, and buildings.**

We Can Save Energy and Money in Industry

Industry accounts for about 30% of the world's and 38% of U.S. energy consumption, mostly from production of metals, chemicals, cement, and paper. The largest consumer of energy in the manufacturing section is the petrochemical industry, which produces products such as fertilizers, plastics, and detergents. It is followed by the global steel and cement industries. There are many ways for industries to cut energy waste (**Concept 16-2**).

Some companies save energy and money by using **cogeneration,** or **combined heat and power (CHP),** systems. In such a system, two useful forms of energy (such as steam and electricity) are produced from the same fuel source. For example, the steam produced in generating electricity in a CHP system can be used to heat the plant or other nearby buildings, rather than released into the environment and wasted. The energy efficiency of these systems is as high as 80% (compared to 30–40% for coal-fired boilers and nuclear power plants), and they emit one-third as much CO_2 per unit of energy produced as do conventional coal-fired boilers. Cogeneration has been widely used in Europe for years and its use in the United States and in China is growing.

Another way to save energy and money in industry is to *replace energy-wasting electric motors,* which consume one-fourth of the electricity produced in the United States. Most of these motors are inefficient because they run only at full speed with their output throttled to match the task—somewhat like driving a car with the engine racing and keeping your foot on the brake pedal to control the speed. Each year, a heavily used electric motor consumes about ten times its purchase price in electricity—equivalent to using $200,000 worth of gasoline each year to fuel a $20,000 car. The energy savings from replacing all such motors would equal the output of 150 large coal-fired or nuclear power plants.

Recycling materials such as steel and other metals is a third way for industry to save energy and money. Producing steel from recycled scrap iron in an electric arc furnace uses 75% less energy than producing steel from virgin iron ore. Switching three-fourths of the world's steel production to such furnaces would cut energy use in the global steel industry by almost 40% and sharply reduce its CO_2 emissions. Similarly, if all of the world's energy-intensive cement producers used today's most energy-efficient dry kiln process, the global cement industry could cut its energy use by 42% and greatly reduce its CO_2 emissions.

A fourth way for industry to save energy is to *switch from low-efficiency incandescent lighting to higher-efficiency fluorescent and LED lighting.* A compact fluorescent bulb uses one-fourth as much electricity as an incandescent bulb, lasts ten times as long, and saves at least $30 in replacement costs during its lifetime. Even better, light-emitting diodes (LEDs) will be increasingly available for industrial lighting; an LED uses about one-seventh of the electricity used by an incandescent bulb and can last about 100 times as long. New York City is saving $6 million a year in maintenance and electricity costs by replacing the traditional bulbs in most of its traffic lights with LED bulbs.

The world's grid systems that transmit electricity from power plants to industries and cities waste large amounts of energy, also making them a candidate for the energy dinosaur list. Converting the outdated U.S. electrical grid system into a more responsive and energy-efficient, digitally controlled network could save the nation $100 billion a year, according to the Electric Power Research Institute. China plans to build an efficient and reliable ultra-high voltage (UHV) electricity network by 2020 and to become the global leader in ultra-high-voltage technology, equipment manufacturing, and sales.

Utility companies also waste large amounts of energy by encouraging electricity use instead of reducing electricity waste. State utility commissions in the United States have rewarded utilities for selling more kilowatt-hours by building more power plants. In the 1980s, some energy analysts proposed that state commissions instead provide financial rewards to utilities for the kilowatt-hours they save customers by helping them to improve their energy efficiency. The U.S. state of California has had great success using such a save-a-watt approach.

One outstanding case of industrial energy savings concerns the Dow Chemical Company, which operates 165 manufacturing plants in 37 countries. Dow set out to reduce its total energy consumption by 25% between 2007 and 2015. These savings will be added to the company's cuts of 22% since 1996. If it reaches its goal, the company will have cut its energy consumption in half within 20 years.

Dow's annual energy savings, due to a mix of large and small improvements in efficiency, now equal slightly more than the total amount of energy consumed each year by the nation of New Zealand. The company's CEO estimates that energy efficiency improvements cost Dow about $1 billion between 1996 and 2006, but resulted in savings of about $5 billion. And there are more savings to come.

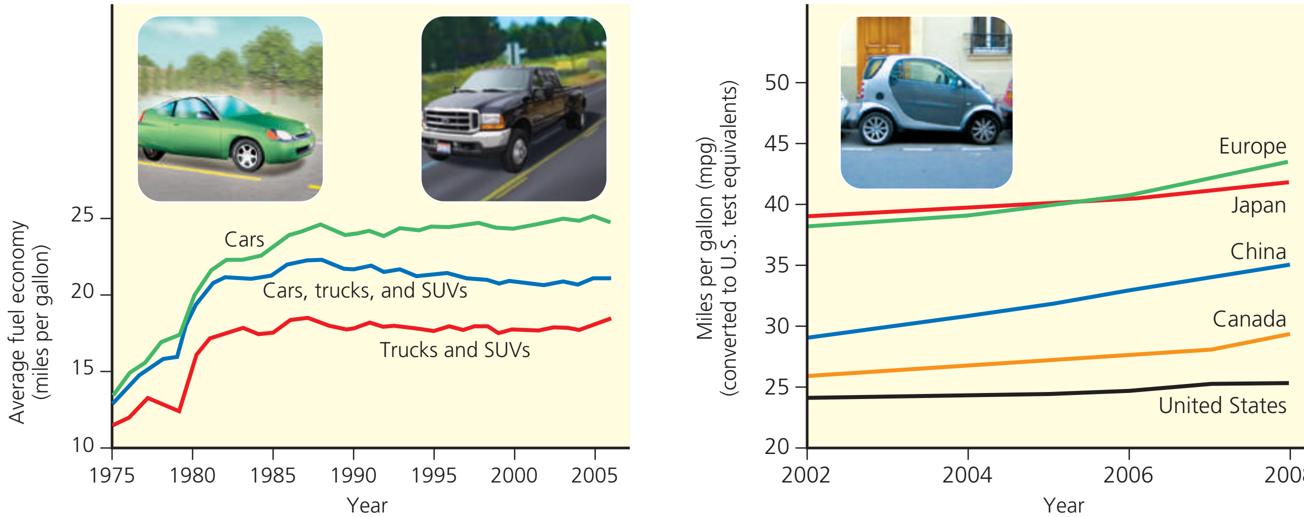


Figure 16-5 Average fuel economy of new vehicles sold in the United States, 1975–2008 (left) and fuel economy standards in other countries, 2002–2008 (right). According to scientist Joseph Romm, no gasoline-powered car assembled in North America would meet China's current fuel-efficiency standard, which is a minimum allowable standard unlike the less stringent fleet-average standard used in the United States. (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, International Council on Clean Transportation)

We Can Save Energy and Money in Transportation

Transportation accounts for two-thirds of U.S. oil consumption and is a major source of the country's urban air pollution and inputs of CO_2 into the atmosphere.

Between 1973 and 1985, average fuel efficiency for new vehicles sold in the United States rose sharply because of government-mandated *corporate average fuel economy* (*CAFE*) standards. However, since 1985, the average fuel efficiency for new vehicles sold in the United States (Figure 16-5, left) decreased to about 9 kilometers per liter (kpl) (21 miles per gallon (mpg)). This was mostly because there was no increase in the CAFE standards until 2008, and because mileage standards for popular trucks and SUVs are not as high as those for cars.

Fuel economy standards in Europe, Japan, China, and Canada are much higher than those in the United States (Figure 16-5, right). A 2008 law raised CAFE standards in the United States to 15 kpl (35 mpg) to be attained by 2020. This will still put U.S. fuel efficiency standards much lower than those of the other countries shown in Figure 16-5.

The good news is that fuel-efficient cars are available (**Concept 16-2**). Car companies like to tout their fuel-efficient vehicles. But no vehicle should be called fuel-efficient unless it gets at least 15 kpl (35 mpg), according to fuel efficiency experts. An example of such a gas-sipping vehicle is the Toyota Prius hybrid-electric car. It has a combined city and highway average fuel efficiency of 20 kpl (46 mpg)—more than twice the fuel efficiency of the average new car sold in the United States.

The bad news is that gas-sipping vehicles account for less than 1% of all car and truck sales in the United States. One reason is that the inflation-adjusted price of gasoline in the United States, despite recent increases, is still fairly low—costing less per liter than bottled water. Gasoline prices are much higher in Japan and most European nations, because their governments have set higher fuel-efficiency standards and imposed high gasoline taxes to encourage greatly improved fuel efficiency (Figure 16-5, right).

Another reason is that most U.S. consumers do not realize that gasoline costs them much more than the price they pay at the pump. According to a 2005 study by the International Center for Technology Assessment, the hidden costs of gasoline for U.S. consumers, having to do with environmental and health costs and security issues, were about $3.18 per liter ($12 per gallon). Adding this to an $1.06 per liter ($4 per gallon) pump price of gasoline for U.S. consumers would yield a *true cost* of about $4.24 per liter ($16 per gallon). In fact, in 2008, hidden costs and pump prices were rising above these levels. Filling a 20-gallon (75-liter) tank would cost about $320, and consumers would demand much more energy-efficient cars and efficient and widely available mass transportation options.

These hidden costs include government subsidies and tax breaks for oil companies, car manufacturers and road builders; costs of pollution control and cleanup; costs of military protection of oil supplies in the Middle East (not including the two Iraq wars); time wasted in traffic jams; and increased illnesses and deaths from air and water pollution, which have increased medical bills and health insurance premiums. Consumers pay for these costs, but not at the gas pump. Including all or most of the harmful environmental and health costs of gasoline and other goods and services in their market prices would give consumers more accurate information about the environmental impacts of the items and services they buy.

One way to include more of the real costs of gasoline in its market price is through gasoline taxes, which are politically unpopular in the United States. But analysts call for reducing payroll and income taxes to balance increases in gas taxes, thereby relieving consumers of any additional financial burden.

THINKING ABOUT
The Real Cost of Gasoline

Do you think that the estimated hidden costs of gasoline should be included in its price at the pump? Explain. Would you favor much higher gasoline taxes if payroll taxes were eliminated or sharply reduced? Explain.

A *third* reason for low fuel efficiency is that in 2008, more than half of all U.S. consumers, compared to 5% in 1990, owned SUVs, pickup trucks, minivans, and other large, inefficient vehicles. And *fourth,* the government has not given buyers large enough tax breaks to encourage them to buy more fuel-efficient vehicles. For example, in the United States, small businesses that paid $50,000 for a gas-guzzling Hummer used exclusively for business purposes in 2005 got a tax deduction of up to $25,000. People buying or leasing a $22,000, gas-sipping, hybrid car got a much smaller deduction of up to $3,100.

Energy expert Amory Lovins has proposed a *feebate* program in which fuel-inefficient vehicles would be taxed heavily and the resulting revenue would be given to buyers of efficient vehicles as rebates (not tax deductions). For example, the tax on a $50,000 Hummer H2 that averages about 5 kpl (12 mpg) might be $10,000. And the same amount could go as a rebate to the buyer of a $22,000 hybrid car that averages 20 kpl (46 mpg). Within a short time, such a program—endorsed by the U.S. National Academy of Sciences—would greatly increase sales of gas-sipping vehicles. It would also focus carmakers on producing and making their profits from such vehicles, and it would cost the government (taxpayers) nothing.

THINKING ABOUT
Feebates

Do you support implementation of a feebate program? Explain. Why do you think this hasn't been done?

More Energy-Efficient Vehicles Are on the Way

There is growing interest in developing *superefficient and ultralight cars* that could eventually get 34–128 kpl (80–300 mpg) (**Concept 16-2**). (See Amory Lovins' Guest Essay on this topic at CengageNOW.)

One of these vehicles is the energy-efficient, gasoline–electric *hybrid car* (Figure 16-6, left), invented by Ferdinand Porsche in 1900 and improved with modern technology by Japanese automobile companies such as Toyota and Honda. It has a small traditional gasoline-powered motor and an electric motor used to provide the energy needed for acceleration and hill climbing. The most efficient models of these cars get up to 20 kpl (46 mpg) on the highway and emit about 65% less CO_2 per kilometer driven than a comparable conventional car emits.

The next step in the evolution of more energy-efficient motor vehicles will probably be the *plug-in hybrid electric vehicle*—a hybrid with a second and more powerful battery that can be plugged into a standard outlet and recharged (Figure 16-6, right). By running primarily on electricity, they could easily get the equivalent of at least 43 kpl (100 mpg) for ordinary driving and up to 430 kpl (1,000 mpg), if used only for trips of less than 64 kilometers (40 miles). Manufacturers hope to have a variety of plug-in hybrids available by

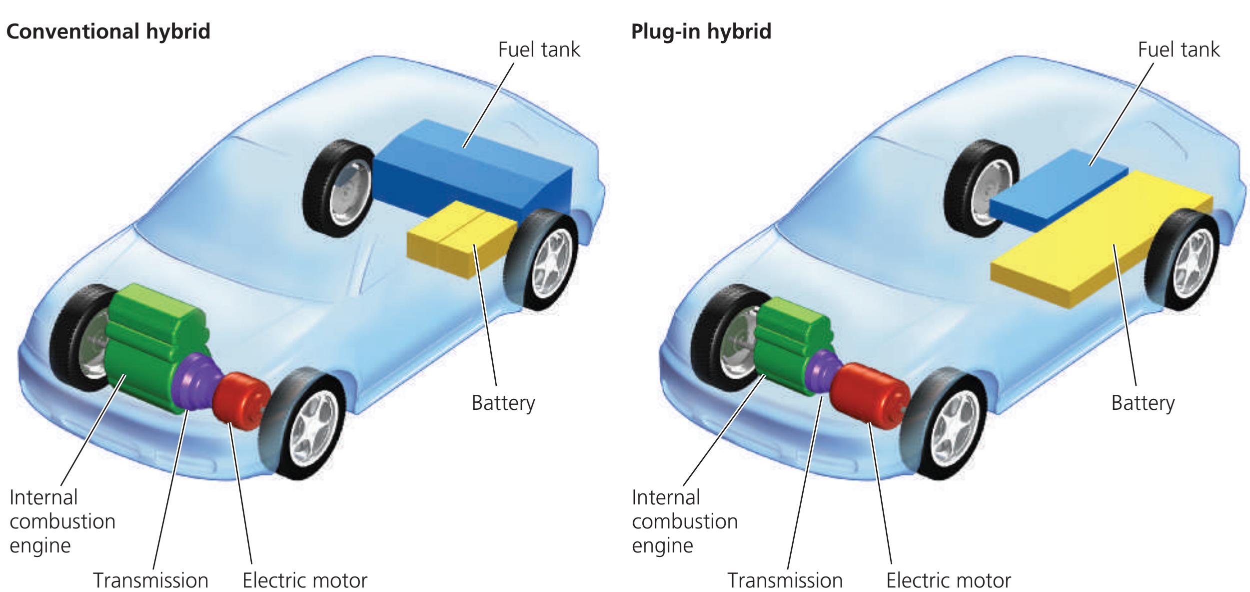


Figure 16-6 Solutions: general features of a car powered by a *hybrid gasoline–electric engine* (left). A *plug-in hybrid* vehicle (right) has a smaller internal combustion engine and a second and more powerful battery that can be plugged into a standard 110-volt outlet and recharged. This allows it to run farther on electricity alone.

SCIENCE FOCUS

The Search for Better Batteries

The major obstacle standing in the way of mass-market, plug-in, hybrid-electric vehicles is the difficulty with developing a battery that can store enough energy to power a vehicle over long distances without overheating or even catching fire.

One promising type of battery is a *lithium-ion battery,* commonly used in laptop computers and cell phones. It can pack a lot of energy into a small space. It can also weigh one-sixth as much as, and take up less than half the space of, the nickel-metal hydride batteries used to power today's conventional hybrid-electric vehicles. However, current lithium-ion batteries have an occasional tendency to overheat, release oxygen, and in rare cases burst into flames. Scientists are working to improve these batteries. General Motors plans to produce a hybrid-electric vehicle with a powerful lithium-ion battery between 2010 and 2017.

Scientists are also looking for other types of batteries that do not contain flammable components. One battery manufacturer is using nanotechnology (Science Focus, p. 362) to make electrodes out of a nanophosphate material that will not heat up and release flammable oxygen.

In the quest for lightweight, inexpensive batteries, scientist Angela Belcher at the Massachusetts Institute of Technology, is working on an entirely new type of battery. She has genetically engineered a virus that can latch onto and coat itself with conductive materials to form a miniscule nanowire. If perfected, such viral batteries could essentially grow themselves, using water as a solvent, and yield none of the often-toxic wastes produced by the manufacture and disposal of conventional batteries.

Another approach is to power a car with an *ultracapacitor,* a battery-like device that stores and releases energy very quickly. If it works, this device would make batteries obsolete.

Critical Thinking

Would you buy a plug-in hybrid vehicle with a lithium-ion battery? Why or why not?

2010, and some analysts project that they could dominate the motor vehicle market by 2020. The key is to develop a battery that will have enough range and be strong, safe, reliable, and affordable enough to use in a mass auto market (see Science Focus, above).

Replacing the current U.S. vehicle fleet with highly efficient plug-in hybrid vehicles over 2 decades, would cut U.S. oil consumption by 70–90%, eliminate the need for oil imports, save consumers money, and reduce CO_2 emissions by 27%, according to a 2006 Department of Energy study. If the batteries in this national car fleet were recharged mostly with electricity generated by wind, solar energy, hydropower, and geothermal energy instead of by coal-burning power plants, U.S. emissions of CO_2 would drop by 80–90%, which would greatly help to slow global warming and projected climate change.

Another option is an *energy-efficient diesel car,* which accounts for 45% of new passenger car sales in Europe. Modern diesel engines are quiet and are 30% more fuel efficient, emitting 20% less CO_2 than conventional gasoline-powered engines. European car companies have also greatly reduced air pollution from diesel engines, although the engines emit more nitrogen oxides and particulates than comparable conventional and hybrid vehicles do. Diesel fuel can be made from coal, plant material, or cooking oil. Running these vehicles on a fuel called *biodiesel,* discussed later in this chapter, would reduce their air pollution emissions and increase their energy efficiency. Also, hybrid-electric diesel cars would be more fuel efficient than conventional hybrid-electric vehicles.

The next stage in the development of superefficient cars could be an electric vehicle that uses a *fuel cell.* Fuel cells are at least twice as efficient as internal combustion engines, have no moving parts, require little maintenance, and use hydrogen gas as fuel to produce electricity without emitting CO_2 and other air pollutants. Most major automobile companies have developed prototype fuel-cell cars, which if successful, could replace many energy-wasting internal combustion engines. Some fuel-cell cars could be in showrooms by 2012, but some analysts believe that it will be 2020 before these cars will be mass produced. The basic challenge is to bring the costs down. (We discuss fuel cells in more detail later in this chapter.) **GREEN CAREER:** Fuel-cell technology

The fuel efficiency for all types of cars could nearly double if car bodies were to be made of *ultralight* and *ultrastrong* composite materials such as fiberglass and the carbon-fiber composites used in bicycle helmets and in some racing cars.

RESEARCH FRONTIER

Developing better and more affordable hybrid and fuel-cell vehicles. See **academic.cengage.com/biology/miller**.

We Can Design Buildings That Save Energy and Money

We can realize huge savings in energy by designing and building for energy efficiency (**Concept 16-2**) and retrofitting existing buildings to make them more energy efficient. In fact, a 2007 U.N. study concluded that better architecture and energy savings in buildings could save 30– 40% of the energy used globally. For example, orienting a building so it can get more of its heat from the sun can save up to 20% of heating costs and as much as 75% when the building is well insulated and airtight—a simple application of the solar energy **principle of sustainability** (see back cover).

The 13-story Georgia Power Company building in the U.S. city of Atlanta, Georgia, uses 60% less energy than conventional office buildings of the same size use. The largest surface of the building faces south to capture solar energy. Each floor extends out over the one below it. This blocks out the higher summer sun to reduce air conditioning costs but allows the lower winter sun to help light and heat each floor during the day. In the building's offices, energy-efficient compact fluorescent lights focus on work areas instead of illuminating entire rooms. Such green buildings have been used widely in Europe for almost 2 decades, especially in Germany and the Netherlands, and are beginning to catch on in the United States.

Green architecture, based on energy-efficient and money-saving designs, makes use of natural lighting, passive solar heating, geothermal heat pumps for heating and cooling, cogeneration, solar hot water heaters, solar cells, fuel cells, natural ventilation, recycled building materials, energy-efficient appliances and lighting, motion sensors for lighting, rainwater collection, recycled waste water, waterless urinals, composting toilets, and nontoxic paints, glues, and building materials. Some green designs also include *living roofs,* or *green roofs,* covered with soil and vegetation (Figure 16-7). They have been used for decades in Europe (Photo 11 in the Detailed Contents) and are becoming more common in the United States.

Another important element of energy-efficient design is *superinsulation.* A house can be so heavily insulated and airtight that heat from direct sunlight, appliances, and human bodies can warm it with little or no need for a backup heating system, even in extremely cold climates. An air-to-air heat exchanger prevents buildup of indoor air pollution. The building cost for such a house is typically 5% more than that for a conventional house of the same size. The extra cost is paid back by energy savings within about 5 years, and the homeowner can save $50,000–100,000 over a 40-year period. Superinsulated houses in Sweden use 90% less energy for heating and cooling than typical American homes of the same size use.

Since the mid-1980s, there has been growing interest in *straw bale houses* (Photos 9 and 10 in the Detailed Contents). The walls of these superinsulated houses are made by stacking compacted bales of low-cost straw (a renewable resource) and then covering the bales on the outside and inside with plaster or adobe. (See the Guest Essay about straw bale and solar energy houses by Nancy Wicks at CengageNOW.)

Green building certification standards now exist in 21 countries, spurred by the World Green Building Council, established in 1999. Since 2001, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program has accredited more than 25,000 building professionals in energy and environmental design. It has established guidelines, and it awards its much-coveted silver, gold, and platinum standard certifications to buildings meeting certain standards. **GREEN CAREER:** Environmental architect

Mark Farina/City of Chicago, Illinois

Figure 16-7 A *green* or *living roof* on City Hall in the U.S. city of Chicago, Illinois. It saves energy, improves air quality, reduces storm water runoff and thus pollution of waterways, and provides habitat for birds.

One platinum standard building is China's Ministry of Science and Technology in Beijing. Its surrounding area is paved with porous bricks made of fly ash left over from burning coal. These bricks allow water to flow through them and to help replenish the city's aquifer. Solar cells made in China provide about 10% of the building's electricity, and it has a solar hot water heating system also made in China. A soil substitute used in its energy-saving roof garden is 75% lighter and holds three to four times more water per cubic meter than dirt can hold. The use of concrete building blocks filled with insulating foam also saves energy.

This is an impressive showcase building, but China lags far behind other countries in energy-efficient building design. Nevertheless, within 20 years, China expects to be the world's leader in this area and to sell its innovative designs and materials in the global marketplace.

We Can Save Energy and Money in Existing Buildings

Most of the world's buildings were not built with energy efficiency as a priority, but many of them can be retrofitted to save energy (**Concept 16-2**). Here are some ways to do so:

- *Insulate and plug leaks.* About one-third of the heated air in typical U.S. homes and buildings escapes through holes, cracks, and closed single pane windows (Figure 16-8, p. 408). The resulting energy loss is roughly equal to the energy in all the oil flowing through the Alaska pipeline every year. During hot weather, these windows and cracks let heat in, increasing the use of air conditioning.

VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 16-8 A *thermogram,* or infrared photo, showing heat loss (red, white, and orange) around the windows, doors, roofs, and foundations of houses and stores in Plymouth, Michigan. Many homes and buildings in the United States and other countries are so full of leaks that their heat loss in cold weather and heat gain in hot weather are equivalent to what would be lost through a large window-sized hole in a wall of the house. **Question:** How do you think the place where you live would compare to these houses in terms of heat loss?

Adding insulation and plugging leaks are two of the quickest, cheapest, and best ways to save energy and money in any building.

- *Use energy-efficient windows.* Replacing leaky windows with energy-efficient windows can cut expensive heat losses from a house by two-thirds, lessen cooling costs in the summer, and reduce CO_2 emissions. Widely available superinsulating windows do the job of 8–12 panes of glass. They can be expensive, but energy savings usually pay back investment costs within a few years and then save money for their owners.
- *Stop other heating and cooling losses.* Leaky heating and cooling ducts in attics and crawl spaces beneath houses allow 20–30% of a home's heating and cooling energy to escape and draw unwanted moisture and heat into the home. Careful sealing of duct joints can reduce this loss. Some new home designs place the air ducts inside the home's thermal envelope so that escaping hot or cool air is fed back into the living space. Also, using light-colored roofing shingles instead of dark singles—or using living roofs (Photo 11 in the Detailed Contents)—can cut electricity use for air conditioning.
- *Heat houses more efficiently.* In order, the most energy-efficient devices we can use to heat space are superinsulation; a geothermal heat pump that transfers heat stored in the earth to a home (discussed later in this chapter); passive solar heating; a high-efficiency, conventional heat pump (in warm climates only); small cogenerating microturbines; and a high-efficiency (85–98%) natural gas furnace. The most wasteful and expensive way to heat a space is to use electric resistance heating with electricity produced by a coal-fired or nuclear power plant.
- *Heat water more efficiently.* One approach is a roof-mounted solar hot water heater, now being used widely in China and a number of other countries. Another option is a *tankless instant water heater* (about the size of a suitcase) fired by natural gas or LPG. (Using electricity for this purpose is not efficient.) These devices, used widely in many parts of Europe, heat water instantly as it flows through a small burner chamber, providing hot water only when it is needed, and using about 25–30% less energy than traditional water heaters use. They cost 2–4 times more than conventional water heaters, but save money in the long run because they last 3–4 times longer and cost less to operate than conventional water heaters cost. They work. One of the authors (Miller) used them along with passive and active solar hot water heaters in an office and living space for 15 years.
- *Use energy-efficient appliances.* According to the Environmental Protection Agency, if all U.S. households used the most efficient frost-free refrigerator now available, 18 large power plants could close. Microwave ovens can cut electricity use for cooking by 25–50% and convection ovens cut energy use by about 20%. Clothes dryers with moisture sensors cut energy use by 15%, and front-loading washers use 55% less energy and 67% less water than do top-loading models. TV sets, computers, and other appliances in their standby mode use about 5% of U.S. residential electricity. Consumers can reduce this energy waste by plugging their computers, TV sets, and other devices having a standby feature into a power strip (such as Smart Strip) that cuts off power when it detects that the device has been turned off.
- *Use energy-efficient lighting.* A compact fluorescent bulb produces as much light as a regular incandescent bulb, but lasts up to ten times longer and

uses one-fourth as much energy, which pays for its higher price in a few months. According to the U.S. Department of Energy, replacing 30 incandescent bulbs with compact fluorescent bulbs can save consumers more than $1,000 over the life of the bulbs. According to a 2005 estimate by the U.S. National Renewable Energy Laboratory, replacing a ten-watt incandescent lightbulb with an equivalent compact fluorescent bulb saves over its lifetime enough energy to drive a Toyota Prius hybrid car from New York City to San Francisco, California. The world may be on the way to phasing out this outdated, energy-wasting device. Over the next 5–10 years, Australia, Canada, Brazil, China, and a growing list of other countries are phasing out the sale of incandescent bulbs. And the United States is phasing in higher efficiency standards for lighting, which will basically phase out traditional incandescent bulbs by 2014. In 2008, Lester Brown estimated that shifting to more energy-efficient lighting could cut the world's electricity use enough to avoid building more than 700 large coal-fired power plants, a number equal to about one-third of the world's existing coal-burning plants.

One problem is that the average compact fluorescent bulb contains a small amount of toxic mercury—roughly the amount that would fit on the tip of a ballpoint pen. However the total amount of mercury in all such bulbs is a tiny fraction of the amount of mercury released by coal-fired power plants, a large portion of which is produced to light energy-wasting incandescent bulbs. And the mercury in compact fluorescent bulbs can be recycled, whereas the mercury continuously spewed into the atmosphere by coal-burning power plants can never be retrieved, except by ingesting it through food and water from the environment.

Within the next 2 decades, both incandescent and fluorescent bulbs may be replaced by even more efficient, pea-sized light-emitting diodes (LEDs) and organic LEDs (OLEDs) when their prices come down (see **westinghouselighting.com**).

Figure 16-9 summarizes ways in which you can save energy in the place where you live.

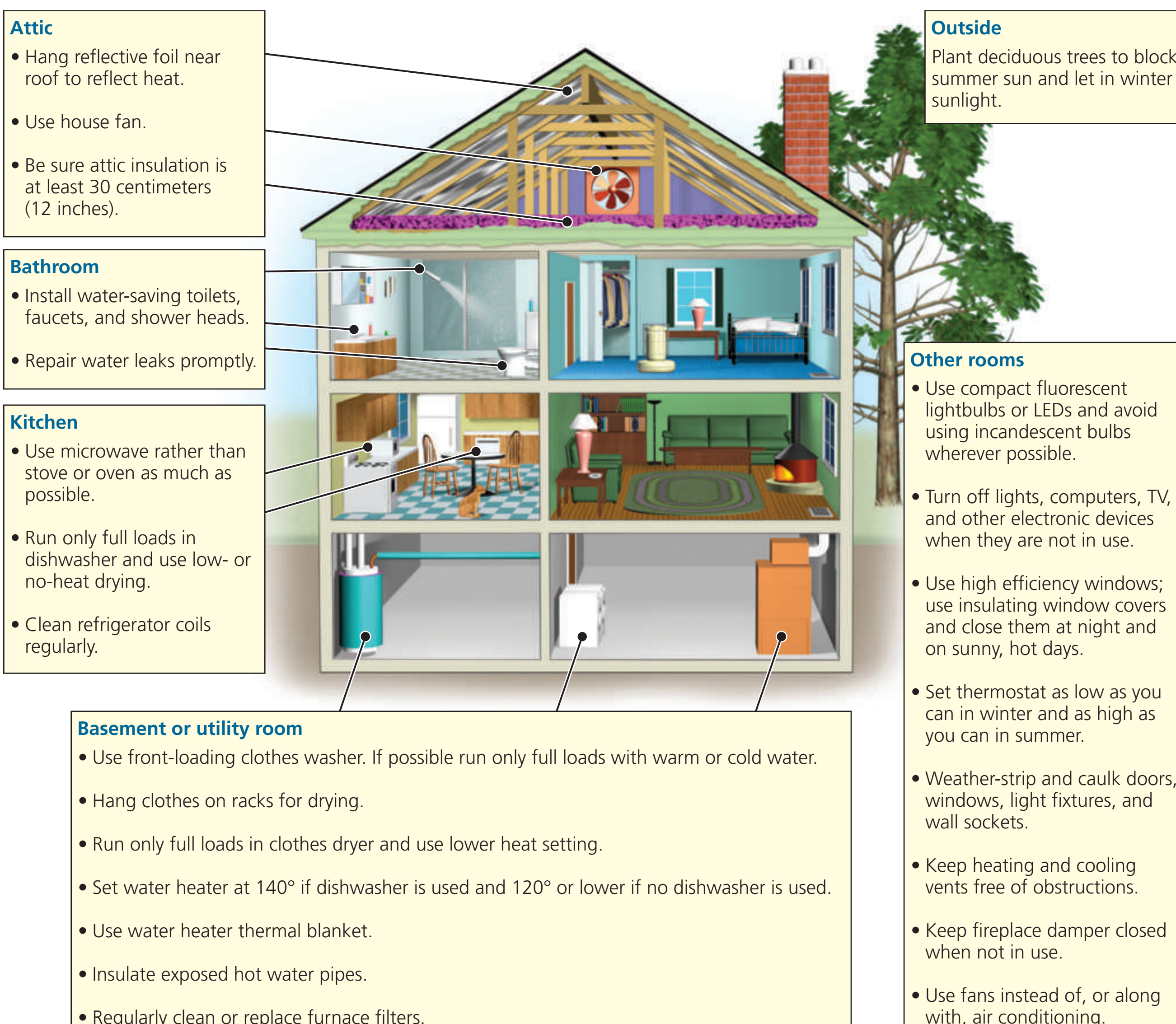


Figure 16-9 **Individuals Matter:** Ways in which you can save energy where you live.

Why Are We Still Wasting So Much Energy?

With such an impressive array of benefits, why is there so little emphasis on improving energy efficiency? One reason is a glut of relatively low-cost fossil fuels. As long as energy remains artificially cheap, primarily because market prices do not include the harmful environmental and health costs of its production and use, people are more likely to waste it and less likely to invest in improving energy efficiency.

Another reason is that there are few large and long-lasting governmental tax breaks, rebates, low-interest, long-term loans, and other economic incentives for consumers and businesses to invest in improving energy efficiency. Also, the U.S. federal government has done a poor job of encouraging fuel efficiency in motor vehicles (Figure 16-5, right).

Some analysts are concerned about what they call a *rebound effect,* in which some people might start using more energy if they save money by improving energy efficiency. For example, a household that saves energy and money by adding more insulation and plugging air leaks might decide that it can raise the thermostat during winter or lower it during the summer. Or people driving an energy efficient car might decide that they can drive more. However, studies reveal that, overall, this rebound effect has been quite small.

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its emphasis on improving energy efficiency? Cast your vote online at **academic.cengage.com/biology/miller**.

We Can Use Renewable Energy in Place of Nonrenewable Energy Sources

One of nature's four **principles of sustainability** (see back cover) is to *rely mostly on solar energy.* We can get renewable solar energy directly from the sun or indirectly from moving water, wind, and biomass, none of which would exist without direct solar energy. Another form of renewable energy is geothermal energy from the earth's interior, which is widely used to provide heat and produce electricity in Iceland (Figure 16-1, **Core Case Study**) and other parts of the world. Studies show that with increased and consistent government backing, renewable energy could provide 20% of the world's electricity by 2025 and 50% by 2050.

Making a major shift toward a variety of locally available renewable energy resources over the next few decades would

- Result in a more decentralized and efficient energy economy that is less vulnerable to supply cutoffs from terrorist attacks and natural disasters such as hurricanes.
- Improve national security for many countries by reducing their need to import oil from the Middle East.
- Reduce trade deficits that grow when a country imports oil.
- Greatly reduce emissions of climate-changing greenhouse gases and other air pollutants.
- Create large numbers of jobs, including high-paying jobs for skilled workers. Already the production, installation, and maintenance of various types of renewable energy systems provide approximately 2.4 million jobs worldwide, according to a 2007 study by the Worldwatch Institute.
- Save consumers money.

If renewable energy is so great, why does it provide only 18% of the world's energy and 7% of the energy used in the United States? One reason is that, since 1950, government tax breaks, subsidies, and funding for research and development of renewable energy resources have been much lower than those for fossil fuels (especially oil) and nuclear power, although subsidies for renewables have increased in recent years. Another reason is that the prices we pay for fossil fuels and nuclear power do not include the environmental and health costs of producing and using them.

If these two economic handicaps—*inequitable subsidies* and *inaccurate pricing*—were eliminated, energy analysts say that many forms of renewable energy would be cheaper than fossil fuels or nuclear energy and would quickly take over the marketplace.

Some governments are increasing their use of renewable energy. The European Union got 10% of its electricity from renewable energy in 2007 and aims to get 34% of its electricity from renewable energy by 2020, mostly by relying more on wind power. In 2006, China got 8% of its total energy and 17% of its electricity from renewable energy. By contrast, the United States got 7% of its total energy and 9% of its electricity from renewable energy in 2006.

In 2005, China set a goal of getting 15% of its total energy and 21% of its electricity from renewable energy sources by 2020. By contrast, the U.S. Energy Information Agency projects that the United States will get only 10% of its total energy from renewable sources by 2030. But several studies show that with a crash program, the United States could get 20% of its total energy and 25% of its electricity from renewable sources by 2020.

Denmark now gets 20% of its electricity from wind and has plans to increase this to 50% by 2030. Brazil gets 40% of its automotive fuel from ethanol made from sugarcane residue, and could phase out its use of gasoline within a decade. And Iceland plans to get all of its energy from renewable resources by 2050 (**Core Case Study**).

Throughout the rest of this chapter, we explore these growing renewable energy options.

16-3 What Are the Advantages and Disadvantages of Solar Energy?

▶ **CONCEPT 16-3 Passive and active solar heating systems can heat water and buildings effectively, and the costs of using direct sunlight to produce high-temperature heat and electricity are coming down.**

We Can Heat Buildings and Water with Solar Energy

Buildings and water can be heated by passive and active solar heating systems (Figure 16-10).

A **passive solar heating system** absorbs and stores heat from the sun directly within a well-insulated structure without the need for pumps or fans to distribute the heat (Figure 16-10, left). Energy-efficient windows or attached greenhouses face the sun to collect solar energy directly. Walls and floors of concrete, adobe, brick, stone, or salt-treated timber, and metal or plastic water tanks can store much of the collected solar energy as heat and release it slowly throughout the day and night. A small backup heating system such as a vented natural gas or propane heater may be used, but is not necessary in many climates. (See the Guest Essay by Nancy Wicks at CengageNOW.)

Using passive solar energy is not new. For thousands of years, people have intuitively followed this **principle of sustainability**. They have oriented their dwellings to take advantage of heat and light from the sun and used adobe and thick stonewalls that collect and store heat during the day and gradually release it at night. On a life cycle cost basis, good passive solar and superinsulated design is the cheapest way to heat a home or small building in sunny areas (see Case Study, p. 412).

An **active solar heating system** absorbs energy from the sun by pumping a heat-absorbing fluid (such as water or an antifreeze solution) through special collectors usually mounted on a roof or on special racks to face the sun (Figure 16-10, right). Some of the collected heat can be used directly. The rest can be stored in a large insulated container filled with gravel, water, clay, or a heat-absorbing chemical for release as needed.

Figure 16-11 (p. 412) lists the major advantages and disadvantages of using passive or active solar heating systems for heating buildings (**Concept 16-3**). They can be used to heat new homes in areas with adequate sunlight. (See Figures 11 and 13, p. S66 and p. S67, in Supplement 10 for maps of solar energy availability in the world and in North America.) But solar energy cannot be used to heat existing homes and buildings that are not oriented to receive sunlight or that are blocked from sunlight by other buildings or trees.

Active solar collectors using a fairly simple technology can also provide hot water. In China, some 2,000 companies have built and installed more inexpensive rooftop solar water heaters than have been installed in the rest of the world combined. They are used in homes, apartment buildings (Figure 16-12, p. 412), office buildings, schools, and hotels. A villager or apartment dweller can install such a rooftop system for as little as $200. Once the initial cost is paid, the hot water is essentially free.

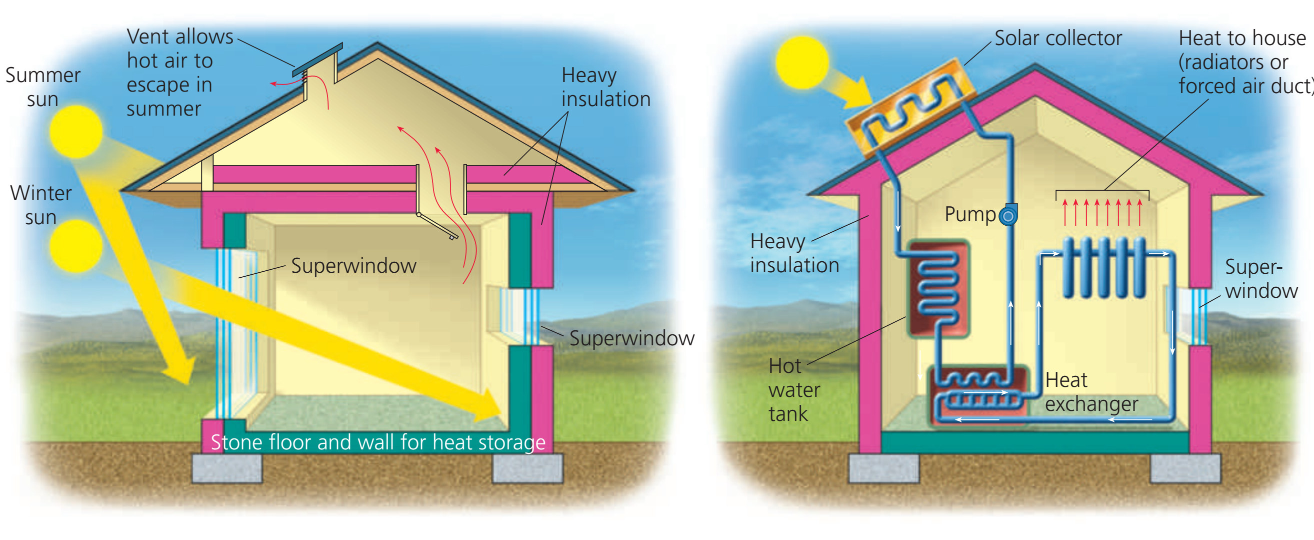


Figure 16-10 Solutions: passive and active solar heating for a home.

TRADE-OFFS

Passive or Active Solar Heating

Advantages	Disadvantages
Energy is free	Need access to sun 60% of time
Net energy is moderate (active) to high (passive)	Sun can be blocked by trees and other structures
Quick installation	Environmental costs not included in market price
No CO_2 emissions	Need heat storage system
Very low air and water pollution	High cost (active)
Very low land disturbance (built into roof or windows)	Active system needs maintenance and repair
Moderate cost (passive)	Active collectors unattractive

Figure 16-11 Advantages and disadvantages of heating a house with passive or active solar energy (**Concept 16-3**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 16-12 Rooftop solar hot water heaters on apartment buildings in the Chinese city of Kunming in the Yunnan province. Such heaters are now required on all new buildings and their use is growing rapidly in urban and rural areas of China.

In 2007, one in ten Chinese households used the sun to heat their water, and by 2030, half of all households in China may be doing so—an excellent example of applying the solar energy **principle of sustainability** (see back cover). Such systems are also widely used in Germany, Japan, Greece, Austria, and Turkey. And in Spain and Israel, all new buildings are required by law to have rooftop systems for heating water and space. Soon millions of households in developing countries such as India and Brazil may turn to this simple and inexpensive technology.

■ **CASE STUDY**

The Rocky Mountain Institute—A Solar-Powered Office and Home

In 1984, energy analyst Amory Lovins built a large, solar-heated, solar-powered, superinsulated, partially earth-sheltered home and office for the Rocky Mountain Institute in Snowmass, Colorado (USA) (Figure 16-13), an area with extremely cold winters.

This 372-square-meter (4,000-square-foot) office–home has no conventional heating system because of a combination of passive solar energy from the sun, heavy roof insulation, thick stonewalls, energy-efficient windows with the equivalent to 8–12 panes of glass, and a heat-waste recovery system. The structure gets 99% of its hot water, 95% of its daytime lighting, and 90% of its household electricity from the sun. Its heating bill, in an area with very severe winters, is less than $50 a year.

Each year, the home portion of the structure consumes a little more electricity than a single 100-watt incandescent lightbulb would consume if it were lit all year, due mostly to use of energy-efficient lights, refrigerators, and other electrical devices. The institute uses solar cells to generate its electricity, and the excess power not used by the home and office is sold to an electric utility. The savings from these energy-efficiency investments repaid their costs in only 10 months and have been making money ever since.

We Can Cool Buildings Naturally

Direct solar energy actually works against us when we want to keep a building cool, but we can use indirect solar energy (mainly wind) and other natural services to help cool buildings. For example, we can open windows to take advantage of breezes, and use fans to keep the air moving. And a living roof (Figure 16-7 and Photo 11 in the Detailed Contents) can make a huge difference in keeping a building cool.

Many technologies are available to help us make use of natural cooling services. For example, when there is no breeze, superinsulation and high-efficiency windows help to keep hot air outside. Here are some other ways to keep cool:

- Block the high summer sun with window overhangs or awnings.
- Use a light-colored roof to reflect as much as 80% of the sun's heat (compared to only 8% for a dark-colored roof).
- Suspend reflective insulating foil in an attic to block heat from radiating down into a house.
- Place plastic *earth tubes* underground where the earth is cool year-round. In this inexpensive geothermal cooling system, a tiny fan can pipe cool and partially dehumidified air into a house. One of the authors (Miller) used them for 15 years in his passively heated and cooled office and home at a cost of about $1 per summer. Adding an air purification system is important for people who are allergic to pollen and molds, but this is also necessary with conventional cooling systems.
- Use geothermal heat pumps for cooling (and heating in winter)

Robert Millman/Rocky Mountain Institute

Figure 16-13 *Sustainable energy:* This facility at the Rocky Mountain Institute in the U.S. state of Colorado is a home and headquarters for a nonprofit center for the study of energy efficiency and sustainable use of energy and other resources. It is also an example of energy-efficient passive solar design.

We Can Use Sunlight to Produce High-Temperature Heat and Electricity

Solar thermal systems concentrate and transform energy from the sun into high-temperature thermal energy (heat), which can then be used directly or to heat water and produce steam to generate electricity. These systems are used mostly in desert areas with ample sunlight. Figure 16-14 summarizes some advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

One type uses a *central receiver system,* such as that shown in the top drawing in Figure 16-14 and in Figure 16-15 (p. 414). In very large systems, the central receiver is called a *power tower.* Huge arrays of computer-controlled mirrors called *heliostats* track the sun and focus sunlight on this central heat collection tower. Such a plant is in operation in southern Spain (Figure 16-15), which has the world's largest concentrated solar power research center and is the second largest user of solar energy in Europe, after Germany.

In another type of system, sunlight is collected and focused on oil-filled pipes running through the middle of a large array of curved solar collectors (bottom drawing, Figure 16-14). This concentrated sunlight can generate temperatures high enough to produce steam for running turbines and generating electricity. Such a plant is operating in southern Spain, and several others have been operating in the California desert since the 1980s.

Most analysts do not expect widespread use of such technologies over the next few decades because of their

TRADE-OFFS

Solar Energy for High-Temperature Heat and Electricity

Advantages	Disadvantages
Moderate net energy	Low efficiency
Moderate environmental impact	High costs
No CO_2 emissions	Environmental costs not included in market price
Fast construction (1–2 years)	Needs backup or storage system
Costs reduced with natural gas turbine backup	Need access to sun most of the time
	Vulnerable to sabotage
	May disturb desert areas

Figure 16-14 Advantages and disadvantages of using solar energy to generate high-temperature heat and electricity (**Concept 16-3**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 16-15 **Solutions:** Commercial solar power tower plant operated by Solúcar, an Abengoa company, near the city of Seville in southern Spain. This plant, which began operating in 2007, uses an array of 624 mirrors to reflect and focus sunlight on a receiver atop a 35-story tower. The resulting concentrated heat converts water into steam that spins turbines and generates enough electricity to power 6,000 homes.

Courtesy of Abengoa

high costs, low net energy yields, and the limited number of suitable sites. But they can be useful in especially sunny desert areas (see Figures 11, 13, and 19 in Supplement 10, pp. S66, S67, and S70). The dream of tapping the vast input of solar energy in Africa's Sahara Desert to provide electricity for Europe may soon become a reality. Algeria has begun construction of a series of solar thermal power plants in the Sahara (to be backed up natural gas at night) and plans to send the electricity by cable to Europe. One advantage of such desert solar systems is that their electricity production peaks during the day when air conditioning and other electrical needs also peak.

Mark Edwards/Peter Arnold, Inc.

Figure 16-16 **Solutions:** woman in India uses a solar cooker to prepare a meal for her family.

THINKING ABOUT
Using Solar Energy to Produce High Temperature Heat

CONCEPT LINKS

Use the first and second laws of thermodynamics (**Concepts 2-4A** and **2-4B**, p. 40) and the related concept of net energy (Science Focus, p. 374) to explain why generating high-temperature heat and electricity from direct solar energy is likely to be quite costly without significant government subsidies and tax breaks.

On a smaller scale, inexpensive *solar cookers* can focus and concentrate sunlight to cook food, especially in rural, sunny areas (Figure 16-16). A solar cooker can be built for $2–10 by fitting an insulated box big enough to hold three or four pots with a transparent, removable top. Solar cookers help to reduce deforestation from fuelwood harvesting, and they save time and labor needed to collect firewood (Figure 16-3, p. 135). They also reduce indoor air pollution and premature deaths from smoky fires.

We Can Use Solar Cells to Produce Electricity

Solar energy can be converted directly into electrical energy by **photovoltaic (PV) cells,** commonly called **solar cells** (Figure 16-17). Most solar cells are thin

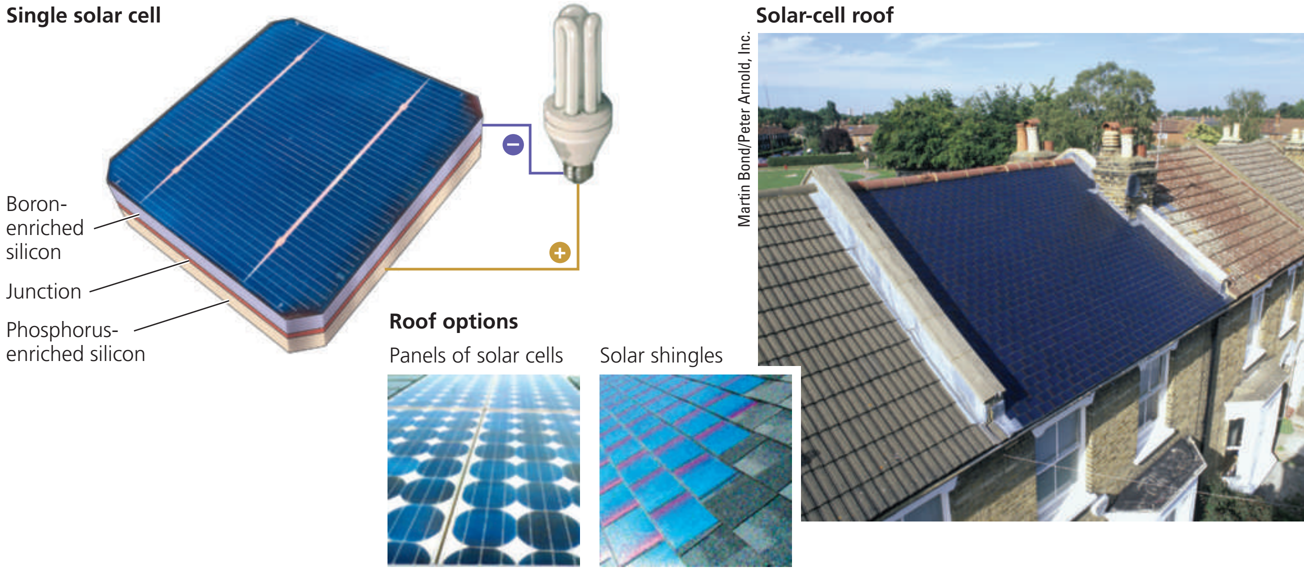


Figure 16-17 **Solutions:** Photovoltaic (PV) or solar cells can provide electricity for a house or other building using solar-cell roof shingles, as shown in this house in Richmond Surrey, England. Solar-cell roof systems that look like a metal roof are also available. In addition, new thin-film solar cells can be applied to windows and outside walls.

wafers of purified silicon with trace amounts of metals that allow them to function as semiconductors to produce electricity. A typical solar cell has a thickness ranging from less than that of a human hair to a sheet of paper. When sunlight strikes these transparent cells, they emit electrons, and many cells wired together in a panel can produce electrical power.

The cells can be connected to existing electrical grid systems or to batteries that store the electrical energy until it is needed. Some countries require power companies to pay homeowners and businesses for any excess electrical energy that they produce and feed back into the grid system.

Solar cells have no moving parts, are safe and quiet, require little maintenance, produce no pollution or greenhouse gases during operation, and last as long as a conventional fossil fuel or nuclear power plant. The semiconductor material used in solar cells can be made into paper-thin rigid or flexible sheets that can be incorporated into traditional-looking roofing materials (Figure 16-17, right) and attached to walls, windows, and clothing.

Easily expandable banks of solar cells can be used in developing countries to provide electricity for many of the nearly 1.6 billion people in rural villages not connected to an electrical grid (Figure 16-18). Such systems provide lighting at a lower cost than do increasingly costly kerosene lamps, and they do so without CO_2 emissions. With financing from the World Bank, India is installing solar-cell systems in 38,000 villages that are located long distances from power grids.

One of the largest solar-cell power plants went on line in 2007 in Portugal. On a sunny day, it generates enough electricity to power 8,000 homes. There are other large systems in southern Spain and in the desert near Tucson, Arizona (USA) (Figure 16-19, p. 416). Other even larger systems are being built in South Korea and in Leipzig, Germany. One U.S. utility plans to install an array of solar cell systems atop the rooftops

Peter Arnold, Inc.

Figure 16-18 **Solutions:** solar cells used to provide electricity for a remote village in Niger, Africa. **Question:** Do you think your government should provide aid so poor countries can obtain such solar cells? Explain.

Figure 16-19 **Solutions:** This solar-cell power plant in the U.S. state of Arizona near the city of Springerville has been in operation since 2000 and is the world's largest solar-cell power plant. Analysis shows that the plant, which is attached to the area's electrical grid, paid back the energy needed to build it in less than 3 years.

of commercial buildings in Southern California that would produce enough electricity to power 162,000 homes.

Such systems are also an option for private companies, which can sell excess electricity to public utilities. Google is building a huge solar cell project for its California headquarters that will generate enough electricity to power 1,000 homes and allow Google to save 30% of its current power use.

Electricity from solar cells in China is still in its infancy. But China plans to use solar cells and wind turbines to provide electricity for 29,000 rural villages and is building one of the world's largest solar-cell power stations. The Chinese city of Shanghai has plans to install 100,000 rooftop, solar-cell systems and to rapidly expand such systems to an increasing number of the city's 6 million rooftops. By 2007, China was the world's third largest producer of solar cells, after Germany and Japan, and it plans to be the world's largest producer by 2025. Figure 16-20 lists the advantages and disadvantages of using solar cells (**Concept 16-3**).

The high cost of using solar cells to produce electricity is the key problem. Table 16-1 compares the total costs of producing electricity from various renewable and nonrenewable sources. Note that when their generating costs and their estimated harmful environmental costs are combined, wind, geothermal, and hydropower are the three cheapest ways to produce electricity, and nuclear power, coal, and solar cells are the most expensive. Still, using solar cells is cheaper than building centralized power plants and electric transmission grids in areas of developing countries that currently have little or no electricity (Figure 16-18).

The current high cost of producing electricity from solar cells is expected to drop considerably because of increased mass production and new and more efficient designs. Advances in nanotechnology (Science Focus, p. 362) may lead to mass production of energy-efficient nanosolar cells. The possible result: a dirt-cheap, flex-

Table 16-1

Total Costs of Electricity from Different Sources in 2004 (in U.S. cents per kilowatt-hour)

Electricity Source	Generating Costs	Environmental Costs	Total Costs
Wind	4.7–6.3	0.1–0.3	4.8–6.6
Geothermal	4.8	1.0 (approximately)	5.8
Hydropower	4.9–8.5	0.3–1.1	5.2–9.6
Natural gas	5.2–6.5	1.1–4.5	6.3–11.0
Biomass	5.5–6.4	1.0–3.4	6.5–9.8
Nuclear*	5.9–12.0	0.2–0.7	6.1–12.7
Coal	4.5–5.4	3.0–17.0	7.5–22.4
Solar cells	12.4–26.0	0.7	13.1–26.7

*Plant only. Costs are much higher if entire nuclear fuel cycle is included.

Source: Data from U.S. Energy Information Administration and a variety of sources compiled by the Worldwatch Institute.

ible, solar-cell material 50 times thinner than today's solar panels. **GREEN CAREER:** Solar cell technology

RESEARCH FRONTIER

Developing more efficient and affordable solar cells. See **academic.cengage.com/biology/miller**.

The Solar Power Industry Is Expanding Rapidly

Currently, solar cells supply less than 0.2% of the world's electricity, although annual production of solar cells has been growing rapidly (see Figure 12, p. S67, in Supplement 10). Energy analysts say that with increased research and development, plus much greater and more consistent government tax breaks and other subsidies, solar cells could provide 16% of the world's electricity by 2040.

In 2007, Nanosolar, a company in California's Silicon Valley, began mass-producing wafer-thin solar cells printed like newspaper ink on flexible and light aluminum foil. According to Nanosolar, they can be produced at half the cost of producing more rigid conventional solar cells. And further cost reductions from mass production should allow these cells to produce electricity at a price comparable to that of coal-generated electricity. If this happens on a large scale, solar cells could become the world's most widely used way to produce electricity within 2 decades.

According to an International Energy Agency (IEA), installing large-scale solar-cell systems on just 4% of the world's desert land could generate enough electricity to meet the entire world's annual power demand. If the costs come down and these projections are correct, the production, sale, and installation of solar cells could become one of the world's largest and fastest-growing businesses and would represent a major step on the path to sustainability.

Germany, where the weather is often cloudy and rainy, seems an unlikely country to be the world's leading user and producer of solar cells. Nevertheless, more than 300,000 solar-cell systems in Germany supply 55% of the electricity produced by all the solar cells in the world. One reason for this is that the German government has spent $1.9 billion on solar-cell research and development since the 1990s. The government also passed a law that requires utility companies to buy excess electricity produced by solar cells in homes and businesses at almost four times the market prices. As a result, solar panels are sources of income for homes and businesses, some of which have generated solar-cell electricity for 20 years.

The government's investment has paid off. The country's revenues from selling solar cells and wind turbines throughout the world have grown. And

TRADE-OFFS

Solar Cells

Advantages	Disadvantages
Fairly high net energy yield	Need access to sun
Work on cloudy days	Low efficiency
Quick installation	Need electricity storage system or backup
Easily expanded or moved	Environmental costs not included in market price
No CO_2 emissions	High costs (but should be competitive in 5–15 years)
Low environmental impact	High land use (solar-cell power plants) could disrupt desert areas
Last 20–40 years	DC current must be converted to AC
Low land use (if on roof or built into walls or windows)	
Reduces dependence on fossil fuels	

Figure 16-20 Advantages and disadvantages of using solar cells to produce electricity (**Concept 16-3**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

German cities and towns have benefited from more jobs and increased income.

General Electric, the world's largest power generation company, has gotten into the solar-cell business and may help the United States to become a major player in the solar-cell market. The U.S. state of New Mexico will have the world's largest solar-cell power plant, which when completed, will have 65 times the electrical output of the solar-cell plant in Arizona (Figure 16-19)—currently the largest. It will generate enough electricity to power 240,000 homes.

In 2007, Jim Lyons, chief engineer for General Electric, projected that solar cells will be the world's number one source of electricity by the end of this century. If that happens, it will represent a huge global application of the solar energy **principle of sustainability** (see back cover).

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on solar cells for producing electricity? Cast your vote online at **academic.cengage.com/biology/miller**.

16-4 What Are the Advantages and Disadvantages of Producing Electricity from the Water Cycle?

▶ **CONCEPT 16-4 Water flowing over dams, tidal flows, and ocean waves can be used to generate electricity, but environmental concerns and limited availability of suitable sites may limit the use of these energy resources.**

We Can Produce Electricity from Falling and Flowing Water

Water flowing from higher to lower elevations in rivers and streams can be controlled by dams and reservoirs and used to produce electricity. This form of energy is called *hydropower.* It is an indirect form of solar energy because it is based on the evaporation of water, which is deposited at higher elevations where it can flow to lower elevations in rivers as part of the earth's solar-powered water cycle (Figure 3-17, p. 66).

The most common approach to harnessing hydropower is to build a high dam across a large river to create a reservoir. Some of the water stored in the reservoir is allowed to flow through huge pipes at controlled rates, spinning turbines and producing electricity (Figure 13-12, p. 325, and Figure 13-15, p. 327).

Hydropower is the world's leading renewable energy source used to produce electricity, and it is the third cheapest way to produce electricity when environmental costs are included (Table 16-1). In order, the world's top five producers of hydropower are Canada, China, Brazil, the United States, and Russia. In 2006, hydropower supplied about 16% of the world's electricity, including 99% of Norway's, 75% of New Zealand's, and 21% of China's electricity. It supplied 7% of electricity used in the United States, (but about 50% of that used on the West Coast).

Hydropower is also widely used to produce electricity in Iceland and is an important part of that country's plan to develop the world's first renewable energy economy (**Core Case Study**). Hydroelectric power production in Iceland will increase as global warming slowly melts its glaciers and increases the amount of water flowing down its rivers.

According to the United Nations, only about 13% of the world's technically exploitable potential for hydropower has been developed. Much of this untapped potential is in China (which plans to more than double its hydropower output by 2020), India, South America, Central Africa, and parts of the former Soviet Union.

Some analysts expect the contribution of large-scale hydropower plants to fall slowly over the next several decades as many existing reservoir systems fill with silt and become useless faster than new plants are built. Also, there is growing concern over emissions of methane, a potent greenhouse gas, from the anaerobic decomposition of submerged vegetation in reservoirs.

Another problem is that global warming is projected to greatly increase prolonged drought in many areas of the world throughout this century. This, coupled with the fact that less water will be stored as ice and snow in mountainous areas, will reduce the flow of water in rivers that have been dammed to provide flood control, irrigation water, and electric power (Figure 13-15, p. 327). As the water flow drops in such rivers, electric power production from their hydropower facilities will drop.

Figure 16-21 lists the advantages and disadvantages of using large-scale hydropower plants to produce electricity (**Concept 16-4**).

TRADE-OFFS

Large-Scale Hydropower

Advantages

- Moderate to high net energy
- High efficiency (80%)
- Large untapped potential
- Low-cost electricity
- Long life span
- No CO_2 emissions during operation in temperate areas
- Can provide flood control below dam
- Provides irrigation water
- Reservoir useful for fishing and recreation

Disadvantages

- High construction costs
- High environmental impact from flooding land to form a reservoir
- Environmental costs not included in market price
- High CO_2 emissions from rapid biomass decay in shallow tropical reservoirs
- Danger of collapse
- Uproots people
- Decreases fish harvest below dam
- Decreases flow of natural fertilizer (silt) to land below dam

Figure 16-21 Advantages and disadvantages of using large dams and reservoirs to produce electricity (**Concept 16-4**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

Should the world greatly increase its dependence on large-scale dams for producing electricity? Cast your vote online at **academic.cengage.com/biology/miller**.

The use of *micro-hydropower generators* may become an increasingly important way to produce electricity. These floating turbines—about the size of an overnight suitcase—use the power of flowing water to turn a rotor with blades that feed generators to produce electric current. Such a generator can be placed in any stream or river without altering its course to provide electricity at a very low cost with almost zero environmental impact.

Tides and Waves Can Be Used to Produce Electricity

We can also produce electricity from flowing water by tapping into the energy from *ocean tides* and *waves.* In some coastal bays and estuaries, water levels can rise or fall by 6 meters (20 feet) or more between daily high and low tides. Dams have been built across the mouths of some bays and estuaries to capture the energy in these flows for hydropower. However, due to limited satisfactory locations and the high costs of such projects, only two large tidal energy dams are currently operating, one at La Rance on the northern coast of France, and the other in Nova Scotia's Bay of Fundy. South Korea, North Korea, China, New Zealand, India, Great Britain, and Russia plan to build tidal flow plants at suitable sites. But globally, sites with large enough daily tidal flows are limited.

In 2006, Verdant Power began installing six underwater turbines to tap the tidal flow of the East River near New York City. The turbines resemble wind turbines as they swivel to face the incoming and outgoing tides. If the project is successful, as many as 300 turbines may be used in the river. Such a system powers a town in Norway. However, such systems are limited.

For decades, scientists and engineers have been trying to produce electricity by tapping wave energy along seacoasts where there are almost continuous waves. Large snake-like chains of floating steel tubes are being installed off the coast of Portugal. Their up and down motion with the wave action generates electricity. In 2008, the system generated enough electricity to power 15,000 homes.

Wave power facilities are being developed in northern California and in some coastal areas in Ireland and near Cornwall in Great Britain. However, most analysts expect tidal and wave power sources to make only a small contribution to world electricity supplies, primarily because there are few suitable sites, the costs are high, and the equipment is vulnerable to corrosion and storm damage (**Concept 16-4**). However, improved technology could greatly increase the production of electricity from waves sometime during this century.

16-5 What Are the Advantages and Disadvantages of Producing Electricity from Wind?

CONCEPT 16-5 When environmental costs of energy resources are included in market prices, wind energy is the least expensive and least polluting way to produce electricity.

Using Wind to Produce Electricity Is an Important Step toward Sustainability

The difference in solar heating of the earth between the equator and the poles together with the earth's rotation create flows of air called *wind* (Figure 7-3, p. 142). This indirect form of solar energy can be captured by wind turbines and converted into electrical energy (Figure 16-22, p. 420, and the front cover of this book). Because today's wind turbines can be as tall as 30 stories and can have blades as long as a jumbo jet plane, they can tap into the stronger, more reliable, and less turbulent winds found at higher altitudes. This allows a single modern wind turbine to generate about 20 times more electricity than a turbine installed in the 1980s.

Since 1990, wind power has been the world's second fastest-growing source of energy (see Figure 15, p. S68, in Supplement 10); solar-cell production is growing the fastest (Figure 12, p. S67, in Supplement 10). In Germany, 20,000 land-based wind turbines generate 5% of the country's electricity. Germany's goal is to get 30% of its electricity from wind by 2030, mostly by developing offshore wind farms.

In 2004, Stanford University engineers Cristina L. Archer and Mark Z. Jacobson mapped the global potential for wind energy (see Figure 14, p. S68, in Supplement 10). Their data indicate that capturing only

Wind turbine **Wind farm** **Wind farm (offshore)**

Figure 16-22 **Solutions:** A single wind turbine (left) can be used to produce electricity. But increasingly, they are being used in interconnected arrays of ten to hundreds of turbines. These *wind farms* or *wind parks* can be located on land (middle and front cover of this book) or offshore (right). Land lying under these turbines can still be used to grow crops and raise cattle. **Question:** Would you object to having a wind farm located near where you live? Why or why not?

one-fifth of the wind energy at the world's best sites could generate more than seven times the amount of electricity currently used in the world and thus help to phase out energy-wasting coal-burning and nuclear power plants (p. 402) during this century. The key is to develop modern power grids to distribute the electricity to users.

Analysts expect increasing use of offshore wind farms because wind speeds over water are often stronger and steadier than those over land and some countries such as Germany and Great Britain are running out of acceptable land sites for wind turbines. Offshore installation costs are higher and some coastal towns and cities oppose such installations because of their visual pollution. But this problem may be solved by the development of huge turbines that could be anchored on floating platforms (not unlike large floating oil rigs, Figure 15-1, p. 370) far enough from shore to be invisible to coastal residents and to take advantage of stronger and more constant offshore winds.

Figure 16, p. S69, and Figure 19, p. S70, in Supplement 10 show the areas where wind power potential is highest in the United States and in the world. Wind farms operating in 36 states produce almost 1% of the country's electricity, with Texas and California leading the way.

This percentage could well be expanded dramatically. The DOE calls the four Great Plains states of North Dakota, South Dakota, Kansas, and Texas the "Saudi Arabia of wind power." Scientists calculate that wind farms in favorable sites in these four states alone could produce nearly three times the total amount of electricity currently generated from all U.S. power plants. These wind resources are in some of the country's least densely populated areas. In addition, a 2005 study by the U.S. Department of Energy estimated that offshore wind resources within 9–18 kilometers (5–10 nautical miles) of the U.S. coastline could produce enough electricity to meet all of the country's current electricity needs.

Producing Electricity from Wind Energy Is a Rapidly Growing Global Industry

Europe is leading the world into the *age of wind energy,* producing about three-fourths of the world's wind-generated power. European companies—mostly in Denmark, Germany, and Spain—manufacture 80% of the wind turbines sold in the global marketplace. They are aided by strong and consistent government subsidies, tax breaks, and low-cost loans.

In order, the countries with the highest total installed wind power capacity in 2007 were Germany, the United States, Spain, India, and Denmark. Wind power capacity is also increasing dramatically in Canada, France, Portugal, and Australia. China plans to continue its rapid expansion of wind power and to sell the turbines it manufactures at prices lower than those charged by most other countries in the global marketplace. By mid-2008, the amount of electricity produced globally by wind turbines was enough to meet the electricity needs of 150 million people, according to the Earth Policy Institute.

A 2007 National Academy of Sciences study estimated that, with enough government support, the United States could become the world's largest producer and consumer of wind power over the next 20 years. Wind turbines could be mass-produced on assembly lines using some of the idled factory capacity of the U.S. steel and automobile industries. This would create many jobs for laid-off skilled workers and bring economic recovery to such areas.

Wind Energy Is Booming but Still Faces Challenges

Wind is abundant, widely distributed, and cannot run out. A wind farm can be built fairly quickly and expanded as needed, can be controlled by a single laptop computer, and at good sites, can produce electricity at costs that are competitive with those of coal, natural gas, and hydropower (Table 16-1). Within a few years, wind is expected to be the cheapest way to produce electricity. If the environmental costs of various energy resources are included, wind energy is already the cheapest and least polluting way to produce electricity (Table 16-1) (**Concept 16-5**).

Like any energy source, wind power has some drawbacks. Areas with the greatest wind power potential are often sparsely populated, and located far from energy-thirsty cities. Thus, to take advantage of the enormous potential for electricity from wind energy, countries such as the United States will have to invest in a long overdue upgrading and expansion of their outdated electrical grid systems.

Another problem is that winds can die down and thus require a backup source of power, such as natural gas, for generating electricity. Scientists are also working on ways to store wind energy. One way is to store it in the batteries of a nationwide fleet of plug-in hybrid-electric vehicles (Figure 16-6, right). They would be recharged, mostly at night by cheaper off-peak, wind-generated electricity. Electricity produced by wind can also be passed through water and used to produce hydrogen fuel, which could be thought of as "stored" wind power.

In 2007, a group of U.S. utilities announced a plan to use electricity from wind to power compressors that will pump pressurized air deep underground into aquifers in the state of Iowa. Compressed air could also be stored in underground caverns and abandoned natural gas wells. The wind energy stored in the compressed air could then be released slowly to spin turbines and generate electricity when wind power is not available. This process is being used in Germany.

Studies indicate that wind turbines kill as many as 40,000 birds and bats each year in the United States. Most wind turbines involved in these deaths were built 20 years ago from now outdated designs, and some were built in bird migration corridors. This problem is being solved and is far from being the highest cause of death for birds. Each year, according to Defenders of Wildlife, glass windows, buildings, and electrical transmission towers in the United States kill more than 1 billion birds; electric transmission lines, up to 175 million; housecats and feral cats, 100 million; hunters, more than 100 million; and cars and trucks, 50–100 million.

Most studies show that as long as wind farms are not located along bird migration routes, birds fly around them. Wind power developers now make sophisticated studies of bird migration paths in order to avoid them when building wind farms. Newer turbines also reduce this problem by using slower blade rotation speeds and by not providing places for birds to perch or nest. According to the Audubon Society's vice president Betsy Loyless, "If we don't find ways to reduce global warming pollution, far more birds and people will be threatened by climate change than by wind turbines."

Some people in populated areas and in coastal areas oppose wind farms as being unsightly and noisy—a "not in my backyard (NIMBY)" attitude. But in windy parts of the U.S. Midwest, many farmers and ranchers have a "put it in my backyard (PIMBY)" attitude, and some have become wind developers themselves. A single wind turbine on 0.1 hectare (0.25 acre) of land can produce about $300,000 worth of electricity a year. Farmers, without having to put up any money, typically receive $3,000–10,000 a year in royalties for each turbine erected on a small plot of their land. And they can still use that land for growing crops or grazing cattle. Many no longer do this, because they can make much more money leasing their land for wind turbines.

Figure 16-23 lists advantages and disadvantages of using wind to produce electricity. According to energy

TRADE-OFFS

Wind Power

Advantages

- Moderate to high net energy yield
- High efficiency
- Moderate capital cost
- Low electricity cost (and falling)
- Very low environmental impact
- No CO_2 emissions
- Quick construction
- Easily expanded
- Can be located at sea
- Land below turbines can be used to grow crops or graze livestock



Disadvantages

- Steady winds needed
- Backup systems needed when winds are low
- Plastic components produced from oil
- Environmental costs not included in market price
- High land use for wind farm
- Visual pollution
- Noise when located near populated areas
- Can kill birds and interfere with flights of migratory birds

Figure 16-23 Advantages and disadvantages of using wind to produce electricity (**Concepts 16-5**). With sufficient and consistent incentives, wind power could supply more than 10% of the world's electricity and 10–25% of the electricity used in the United States by 2020. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

analysts, wind power has more benefits and fewer serious drawbacks than any other energy resource, except for energy efficiency.

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on wind power? Cast your vote online at **academic.cengage.com/biology/miller**.

16-6 What Are the Advantages and Disadvantages of Biomass as an Energy Source?

▶ **CONCEPT 16-6A** **Solid biomass is a renewable resource, but burning it faster than it is replenished produces a net gain in atmospheric greenhouse gases, and creating biomass plantations can degrade soil and biodiversity.**

▶ **CONCEPT 16-6B** **Liquid biofuels derived from biomass can be used in place of gasoline and diesel fuels, but creating biofuel plantations could degrade soil and biodiversity and increase food prices and greenhouse gas emissions.**

We Can Get Energy by Burning Solid Biomass

Biomass consists of plant materials (such as wood and agricultural waste) and animal wastes that can be burned directly as a solid fuel or converted into gaseous or liquid **biofuels.** Biomass is an indirect form of solar energy because it consists of combustible organic (carbon-containing) compounds produced by photosynthesis.

Solid biomass is burned mostly for heating and cooking, but also for industrial processes and for generating electricity. Wood, wood wastes, charcoal (made from wood), animal manure, and other forms of solid biomass used for heating and cooking, supply 10% of the world's energy, 35% of the energy used in developing countries, and 95% of the energy needs in the poorest countries.

In urban areas, wood chips and urban waste can be used to produce both electricity and heat for *district heating systems.* Such systems supply nearly half of the heat for residential and commercial buildings in Sweden. A similar system supplies heat for about 80% of the downtown area of the U.S. city of St. Paul, Minnesota.

But wood is a renewable fuel only as long if it is not harvested faster than it is replenished. The problem is, about 2.7 billion people in 77 developing countries face a *fuelwood crisis* and often are forced to meet their fuel needs by harvesting wood faster than it can be replenished.

One way to produce solid biomass fuel is to plant fast-growing trees (such as cottonwoods, poplars, and sycamores), shrubs, perennial grasses (such as switchgrass and miscanthus), and water hyacinths in *biomass plantations.* But repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. And clearing forests and grasslands for such plantations destroys or degrades biodiversity (**Concept 16-6A**). In agricultural areas, *crop residues* (such as sugarcane residues, rice husks, cotton stalks, and coconut shells) and *animal manure* can be collected and burned or converted into gaseous or liquid biofuels.

Figure 16-24 lists the general advantages and disadvantages of burning solid biomass as a fuel (**Con-**

TRADE-OFFS

Solid Biomass

Advantages	Disadvantages
Large potential supply in some areas	Nonrenewable if harvested unsustainably
Moderate costs	Moderate to high environmental impact
No net CO_2 increase if harvested, burned, and replanted sustainably	Environmental costs not included in market price
Plantation can be located on semiarid land not needed for crops	Increases CO_2 emissions if harvested and burned unsustainably
Plantation can help restore degraded lands	Low photosynthetic efficiency
Can make use of agricultural, timber, and urban wastes	Soil erosion, water pollution, and loss of wildlife habitat
	Plantations could compete with cropland
	Often burned in inefficient and polluting open fires and stoves

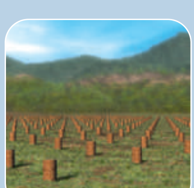


Figure 16-24 General advantages and disadvantages of burning solid biomass as a fuel (**Concept 16-6A**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

cept 16-6A). One problem is that clearing forests reduces the uptake of CO_2, and burning biomass produces CO_2. However, if the rate of use of biomass does not exceed the rate at which it is replenished by new plant growth (which takes up CO_2), there is no net increase in CO_2 emissions, but often this is a big if.

HOW WOULD YOU VOTE? ✓

Should we greatly increase our dependence on burning solid biomass to provide heat and produce electricity? Cast your vote online at **academic.cengage.com/biology/miller**.

We Can Convert Plants and Plant Wastes to Liquid Biofuels

Liquid biofuels such as *biodiesel* and *ethanol* (ethyl alcohol), which are produced from plants and plant wastes, can be used in place of petroleum-based diesel fuel and gasoline (see Case Study at right and second Case Study, p. 424). The biggest producers of biofuels—Brazil, the United States, the European Union, and China—plan to double their production by 2020. Brazil already runs 45% of its cars on ethanol, and within a decade, could run all of its vehicles on this biofuel and eliminate its oil imports. U.S. government agencies estimate that biodiesel and ethanol could fuel 25–50% of U.S. motor vehicles by 2030.

Biofuels have some major advantages over gasoline and diesel fuel produced from oil. *First,* while oil resources are concentrated in a small number of countries, biofuel crops can be grown almost anywhere. This means that most countries can improve their energy and economic security by reducing their dependence on imported oil.

Second, if these crops are not used faster than they are replenished by new plant growth, there is no net increase in CO_2 emissions, unless existing grasslands or forests are cleared to plant biofuel crops. *Third,* biofuels are available now, are easy to store and transport, can be distributed through existing fuel networks, and can be used in vehicles at little or no additional cost.

However, in a 2007 U.N. report on bioenergy and in another study by R. Zahn and his colleagues, scientists warned that the benefits of biofuels could be outweighed by resulting problems. These reports noted that large-scale biofuel-crop farming could do the following: decrease biodiversity by clearing more natural forests and grasslands; increase soil degradation, erosion, and nutrient leaching; push small farmers off their land; and raise food prices (**Concept 16-6B**). A number of ecologists warn that crops used to produce biofuels should be grown only on land that is already degraded. They argue against clearing existing forests and grasslands and filling in wetlands that support biodiversity and store enormous amounts of carbon.

A 2007 paper published by Nobel Prize–winning chemist Paul Crutzen warned that intensive farming of crops to make biofuels could also speed up global warming by producing more greenhouse gases than are produced by burning conventional diesel fuel and gasoline. This would happen if nitrogen fertilizers were used to grow such crops. Such fertilizers, when applied to the soil, release large amounts of nitrous oxide (N_2O), a greenhouse gas 300 times more potent per molecule than CO_2.

■ CASE STUDY

Is Biodiesel the Answer?

Biodiesel is produced from vegetable oil extracted from soybeans, rapeseeds, sunflowers, oil palms, and jatropha shrubs, and fats such as used vegetable oils from restaurants. European Union countries (primarily Germany, France, and Italy) produce about 95% of the world's biodiesel, mostly from rapeseeds and sunflower seeds, and these countries hope to get 20% of their diesel fuel from this source by 2020. In Europe, where government taxes on vehicle fuel are high, almost half of all cars run on conventional diesel or biodiesel, mostly because they are as much as 40% more efficient than conventional gasoline engines.

In the United States, biodiesel production is growing rapidly, aided by government subsidies. Biodiesel provides only 1% of U.S. diesel consumption and the Department of Energy estimates that biodiesel at best could supply only 10% of the country's diesel fuel needs. This is because soybean and canola crops grown in the United States for biodiesel production require huge areas of land and have low yields. And using industrialized agriculture to produce these crops results in topsoil loss, fertilizer runoff, and increased emissions of the greenhouse gas nitrous oxide.

Brazil, Malaysia, and Indonesia produce biodiesel from palm oil extracted from large oil palm plantations, and they export much of it to Europe. The oil yield for biodiesel from oil palm is five times that from rapeseeds used in Europe and eight to nine times that from soybeans used in the United States. But increased burning and clearing of tropical forests to plant oil palm plantations in these countries poses a serious threat to their biodiversity. This also increases net emissions of CO_2 by replacing rain forests that store lots of carbon with crops that store much less carbon, according to a 2006 study by scientist Alexander Farrell at the University of California, Berkeley.

Another promising source of biodiesel is the *jatropha shrub,* a plant found in tropical areas of Africa, India, and Brazil. The plentiful oil in its golf-ball size fruit can be burned without being refined, and the plant grows in hot, dry, tropical areas. Jatropha crops are unlikely to threaten rain forests, displace food crops, or require extensive use of nitrogen fertilizers. In its natural state,

TRADE-OFFS

Biodiesel

Advantages

- Reduced CO emissions
- Reduced CO_2 emissions (78%)
- High net energy yield for oil palm crops
- Moderate net energy yield for rapeseed crops
- Reduced hydrocarbon emissions
- Better gas mileage (40%)
- Potentially renewable

Disadvantages

- Increased NO_x emissions and more smog
- Higher cost than regular diesel
- Environmental costs not included in market price
- Low net energy yield for soybean crops
- May compete with growing food on cropland and raise food prices
- Loss and degradation of biodiversity from crop plantations
- Can make engines hard to start in cold weather

Figure 16-25 General advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

the jatropha shrub needs little water and no fertilizer, although this is not the case if it is grown as a monoculture crop in large plantations. One problem is that the jatropha is an invasive species that could threaten native plants in some areas.

Some scientists are looking for ways to produce biodiesel from various types of oil-rich algae. Algae grow rapidly at any time of the year and can be cultivated in seawater or wastewater ponds. The algae remove CO_2 from the atmosphere and convert it to oil, proteins, and other useful products and require much less land than growing crops requires. The challenge is to cut the very high cost of producing oil by this method.

Figure 16-25 lists the advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline.

■ CASE STUDY
Is Ethanol the Answer?

Ethanol can be made through the fermentation and distillation of sugars in plants such as sugarcane, corn, and switchgrass, and from agricultural, forestry, and municipal wastes. This process involves converting starch in plant material to simple sugars that are fermented by yeast into a slurry that is distilled to remove its ethanol.

Gasoline mixed with 10–23% pure ethanol makes *gasohol,* which can be burned in conventional gasoline engines. Pure ethanol or E85 (a mixture of 85% ethanol and 15% gasoline) can be burned in *flexible-fuel cars,* which have engines designed to run on a variety of fuels.

Brazil, the Saudi Arabia of sugarcane, is the world's second largest ethanol producer after the United States. When burned, ethanol made from *bagasse,* a residue produced when sugarcane is crushed, yields 8 times the amount of energy used to produce it. That compares with a net energy yield of 4.1 for gasoline (Figure 15-A, p. 374). About 45% of Brazil's motor vehicles run on ethanol or ethanol-gasoline mixtures produced from a residue of sugar cane grown on only 1% of the country's arable land.

Since the 1970s, Brazil has saved almost $50 billion in imported oil costs—nearly ten times the government's investment in ethanol production subsidies, which are no longer needed. In addition, ethanol production has created about 1 million rural jobs. Within a decade, Brazil could expand its sugarcane production, eliminate all oil imports, and greatly increase ethanol exports to other countries.

Brazil plans to greatly expand its production of sugarcane to produce ethanol and to grow more soybeans to produce biodiesel and cattle feed. However, this could threaten some of the country's biodiversity. To do this, Brazil plans to clear larger areas of its rapidly disappearing wooded savanna Cerrado region—one of the world's biodiversity hotspots (Figure 10-26, p 241). This area—three times the size of the U.S. state of Texas—is the world's most biodiverse savanna, with 10,000 plant species, nearly half of them found nowhere else.

In the United States, most ethanol is made from corn. U.S. farmers profit from growing corn to produce ethanol because they receive generous government subsidies as part of the nation's energy policy. But studies indicate that using fossil fuel–dependent industrialized agriculture to grow corn and then using more fossil fuel to convert the corn to ethanol provides a net energy yield of only about 1.1–1.5 units of energy per unit of fossil fuel input (Figure 15-A, p. 374).

A growing number of analysts warn that producing ethanol from corn will not significantly reduce the country's oil imports or help to slow global warming. According to environmental economist Stephen Polansky, processing all of the corn grown in the United States into ethanol each year, with high government subsidies, would cover only about 12% (or about 30 days worth) of the country's current demand for gasoline, at an extremely high cost to taxpayers.

A 2008 study by Tim Searchinger at Princeton University and other researchers estimated that clearing and planting grasslands and forests to grow corn for producing ethanol would increase CO_2 emissions by 93% over those from burning conventional gasoline over a

Figure 16-26 **Natural capital:** the cellulose in this rapidly growing switchgrass in Manhattan, Kansas (USA) can be converted into ethanol. This perennial plant can also help to reduce global warming by removing carbon dioxide from the atmosphere and storing it as organic compounds in the soil.

30-year period. And extensive use of nitrogen fertilizers to grow corn releases large amounts of the greenhouse gas nitrous oxide into the atmosphere. If these estimates are correct, switching from gasoline to biofuels such as ethanol produced from corn will increase global warming and the resulting climate change.

Ethanol production also requires large amounts of water and releases about the same amount of carbon dioxide and much higher levels of nitrous oxide than gasoline production releases, and it offers little if any reduction in air pollution. In addition, fewer than 2% of U.S. gas stations offer ethanol, and most U.S. vehicles do not have flex-fuel engines that can burn ethanol.

Driven by U.S. ethanol production, the price of corn has risen sharply, as have the prices of corn-based foods—including bread, pasta, tortilla flour, poultry, beef, pork, and dairy products. This in turn is increasing the number of hungry and malnourished people who can no longer afford to buy enough food, and this has led to social unrest. In 2007, there were protests in Mexico because of an almost 60% increase in the price of corn meal, followed by pasta protests in Italy. In 2008, environmental expert Lester Brown estimated that filling a 95-liter (25-gallon) tank of an SUV with ethanol would use enough corn grain to feed the average person for a year.

An alternative to corn ethanol is *cellulosic ethanol,* which is produced from inedible cellulose that makes up most of the biomass of plants (see *The Habitable Planet,* Video 10, at **www.learner.org/resources/series209.html**). In this process, acids or other processes are used to isolate cellulose and lignin from material. Then various enzymes convert the cellulose to a variety of sugars that can be fermented and distilled to produce ethanol. A possible plant that could be used for cellulosic ethanol production is *switchgrass* (Figure 16-26), a tall perennial grass native to North American prairies. It grows faster than corn, is disease resistant and drought tolerant, and can be grown on land unfit for crops without the use of nitrogen fertilizers. According to a 2008 article by U.S. Department of Agriculture scientist Ken Vogel and his colleagues, using switchgrass to produce ethanol yields about 5.4 times more energy than it takes to grow it—a yield much greater than the 1.1–1.5 net energy yield for corn.

While most corn-based ethanol producers burn fossil fuels to provide heat for fermentation, cellulosic ethanol producers can reduce such energy inputs by burning plant wastes. This and other aspects of cellulosic ethanol production and use could reduce net greenhouse gas emissions below current levels.

However, researchers have also found that large areas of land would be needed to produce enough cellulosic ethanol to make a significant dent in gasoline consumption and that clearing and planting large areas of land with switchgrass would likely increase greenhouse gas emissions. Thus scientists differ on how much of a net reduction in greenhouse gas emissions would result from extensive cellulosic ethanol production.

Other sources for producing cellulosic ethanol include crop residues, such as leaves and stalks, and municipal wastes such as sawdust, cardboard, waste paper, and sewage. But cellulose has properties that make it difficult to break down, and affordable chemical processes for converting cellulosic material to ethanol are still being developed (see *The Habitable Planet,* Video 10,

TRADE-OFFS

Ethanol Fuel

Advantages	Disadvantages
High octane	Lower driving range
Some reduction in CO_2 emissions (sugarcane bagasse)	Low net energy yield (corn)
High net energy yield (bagasse and switchgrass)	Higher CO_2 emissions (corn)
Reduced CO emissions	Much higher cost
Can be sold as E85 or pure ethanol	Environmental costs not included in market price
Potentially renewable	May compete with growing food and raise food prices
	Higher NO_x emissions and more smog
	Corrosive
	Can make engines hard to start in cold weather

Figure 16-27 General advantages and disadvantages of using ethanol as a vehicle fuel, compared to gasoline. (**Concept 16-6B**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

at **www.learner.org/resources/series209.html**) and are probably at least a decade away.

Figure 16-27 lists the advantages and disadvantages of using ethanol as a vehicle fuel, compared to gasoline.

Some scientists are studying the genetic makeup of bacteria living in the guts of termites that use enzymes to break down the cellulose in wood for their food. And California-based Amyris Biotechnologies and several other companies are carrying out research to bypass some of the problems associated with using plants to produce biofuels such as ethanol and biodiesel. These scientists are trying to use genetic engineering to develop bacteria that can turn sugar directly into hydrocarbon fuels like gasoline, jet fuel, and diesel fuel, which, unlike ethanol and biodiesel, can easily be sent through existing oil pipelines and burned in any motor vehicle. Stay tuned to see if we can learn how to turn bacteria into tiny fuel factories.

HOW WOULD YOU VOTE?

Do the advantages of using liquid ethanol as a fuel outweigh its disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

RESEARCH FRONTIER

Developing more energy-efficient, cheaper, and more sustainable ways to produce liquid biofuels. See **academic.cengage.com/biology/miller**.

16-7 What Are the Advantages and Disadvantages of Geothermal Energy?

CONCEPT 16-7 Geothermal energy has great potential for supplying many areas with heat and electricity and generally has a low environmental impact, but locations where it can be exploited economically are limited.

Getting Energy from the Earth's Internal Heat

Geothermal energy is heat stored in soil, underground rocks, and fluids in the earth's mantle (Figure 14-3, p. 346, and Figure 15-2, p. 372). We can tap into this stored energy to heat and cool buildings and to produce electricity. Scientists estimate that using just 1% of the heat stored in the uppermost 5 kilometers (8 miles) of the earth's crust would provide 250 times more energy than that stored in all the earth's oil and natural gas reserves.

A *geothermal heat pump* system (Figure 16-28) can heat and cool a house by exploiting the temperature differences between the earth's surface and underground, almost anywhere in the world at a depth of 3–6 meters (10–20 feet). In winter, a closed loop of buried pipes circulates a fluid (usually water or an antifreeze solution), which extracts heat from the ground and carries it to a heat pump, which transfers the heat to a home's heat distribution system (usually a blower and air ducts). In summer, this system works in reverse, removing heat from a home's interior and storing it in the ground. These systems can also be modified to provide hot water.

According to the EPA, after superinsulation, a well-designed geothermal heat pump system is the most energy-efficient, reliable, environmentally clean, and cost-effective way to heat or cool a space. It produces no air pollutants and emits no CO_2. For more information, see **www.ghpc.org** and **www.econar.com**. Installation costs are recouped after 3–5 years, and then such systems save their owners money.

We have also learned to tap into deeper, more concentrated *hydrothermal reservoirs* of geothermal energy, as Iceland has done for decades (Figure 16-1, **Core Case Study**). Wells are drilled into these reservoirs to extract their dry steam, wet steam, or hot water, which are used to heat buildings, provide hot water, grow vegetables in greenhouses, raise fish in aquaculture ponds, and spin turbines to produce electricity. Cool water left over can be pumped back into the reservoirs to be reheated.

CORE CASE STUDY

In France, some 70 district geothermal heating facilities provide both heat and hot water for about 200,000 residences. China, Turkey, and Japan also have a number of district heating systems that use geothermal energy. Currently, about 40 countries (most of them in the developing world) extract enough energy from hydrothermal reservoirs to produce about 1% of the world's electricity, enough to meet the needs of 60 million people and equal to the electrical output of all 104 nuclear power plants in the United States. (See Figure 17, p. S69, in Supplement 10 for a map of the global reserves of usable hydrothermal geothermal energy.)

The United States and the Philippines account for half of the world's electricity produced from geothermal energy; the Philippines gets one-fourth of its electricity from this energy resource. Other countries with a high potential for using geothermal energy to produce electricity are Japan, Indonesia, China, Canada, Mexico, and Russia (Figure 17, p. S69, in Supplement 10).

The United States is the world's largest producer of geothermal electricity from hydrothermal reservoirs. Most of it is produced in California, Nevada, Utah, and Hawaii (see Figure 18, p. S70, in Supplement 10) and meets the electricity needs of about 6 million Americans. The largest operation, called The Geysers, powers about 1 million homes near San Francisco, California. California gets about 6% of its electricity from geothermal energy and 15 new projects are under development.

Using geothermal energy generally has a much lower environmental impact than using fossil fuel energy. At concentrated and accessible hydrothermal sites, electricity can be produced at a low cost compared to other alternatives (Table 16-1). On average, a geothermal power plant releases about one-sixth as much CO_2 as a power plant burning natural gas emits, and one-tenth the amount emitted by a coal-burning power plant. China has a large potential for geothermal power, which could help to reduce its dependence on coal-fired power plants.

Geothermal energy has two main problems. One is that the current cost of tapping large-scale hydrothermal reservoirs is too high for all but the most concentrated and accessible sources, although new drilling and extraction technologies may bring these costs down. The other is that some dry- or wet-steam geothermal reservoirs could be depleted if their heat is removed faster than natural processes can renew it. Recirculating the water back into the underground reservoirs for reheating could slow such depletion.

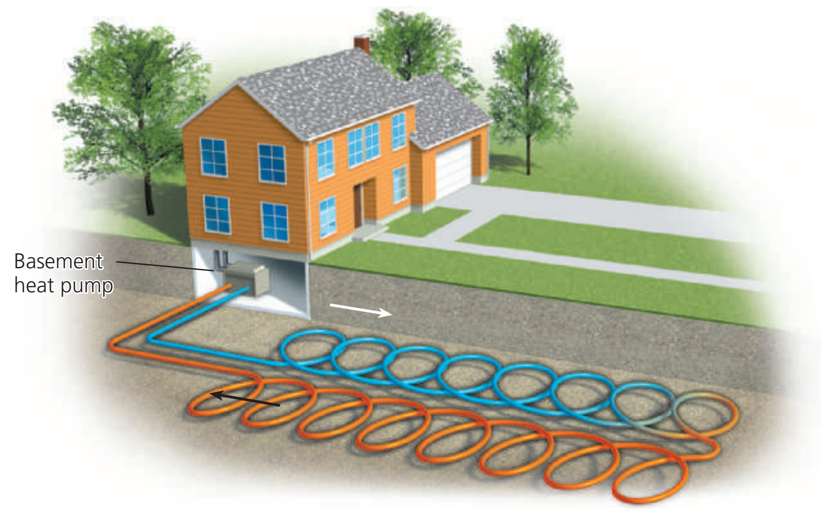


Figure 16-28 **Natural capital:** a geothermal heat pump system can heat or cool a house almost anywhere. It heats the house in winter by transferring heat from the ground into the house (shown here). In the summer, it cools the house by transferring heat from the house to the ground.

Another potential source of geothermal energy is *hot, dry rock* that lies 5 or more kilometers (3 or more miles) underground almost everywhere. Deep drilling and seismic exploration techniques developed by the oil industry might be used to tap this source. Water could be injected into a deep well and pressurized to create fractures in the intensely hot rock and to form a reservoir of very hot geothermal fluid. Then other wells would be drilled to bring the boiling water and steam to the surface for use in generating electricity.

According to the U.S. Geological Survey, tapping just 2% of this hot, dry rock geothermal energy in the United States could produce more than 2,000 times the country's current annual use of electricity. The limiting factor is cost. Estimates range from 3 to 30 times the cost of electricity produced from suitable hydrothermal sites. More research and improved technology could bring this cost down. Iceland (**Core Case Study**) is drilling deep wells to evaluate this source of the earth's internal heat.

CORE CASE STUDY

RESEARCH FRONTIER

Finding better and affordable ways to tap different sources of geothermal energy. See **academic.cengage.com/biology/miller**.

Figure 16-29 (p. 428) lists the advantages and disadvantages of using geothermal energy (**Concept 16-7**).

Some analysts see geothermal energy, coupled with improvements in energy efficiency and electricity produced by solar cells and wind farms, as keys to a more sustainable energy future.

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on geothermal energy to provide heat and to produce electricity? Cast your vote online at **academic.cengage .com/biology/miller**.

TRADE-OFFS

Geothermal Energy

Advantages	Disadvantages
Very high efficiency	Scarcity of suitable sites
Moderate net energy at accessible sites	Can be depleted if used too rapidly
Lower CO_2 emissions than fossil fuels	Environmental costs not included in market price
Low cost at favorable sites	CO_2 emissions
Low land use and disturbance	Moderate to high local air pollution
Moderate environmental impact	Noise and odor (H_2S)
	High cost except at the most concentrated and accessible sources

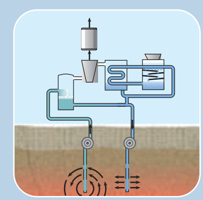


Figure 16-29 Advantages and disadvantages of using geothermal energy for space heating and for producing electricity or high-temperature heat for industrial processes (**Concept 16-7**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

16-8 What Are the Advantages and Disadvantages of Hydrogen as an Energy Source?

▶ **CONCEPT 16-8 Hydrogen fuel holds great promise for powering cars and generating electricity, but to be environmentally beneficial, it would have to be produced without the use of fossil fuels.**

Hydrogen Is a Promising Fuel but There Are Challenges

Many scientists and executives of major oil and automobile companies say the fuel of the future is hydrogen gas (H_2)—first envisioned as a fuel in 1874 by science fiction writer Jules Verne in his book, *The Mysterious Island.* Iceland (**Core Case Study**) envisions hydrogen as an important component of the renewable energy economy it hopes to develop by 2050–2060.

CORE CASE STUDY

Most attention has been focused on fuel cells (Figure 16-30) that combine hydrogen gas (H_2) and oxygen gas (O_2) to produce electricity and emit water vapor into the atmosphere.

Widespread use of hydrogen as a fuel would eliminate most of the air pollution problems we face today. It would also greatly reduce the threats of global warming and climate change, because using it emits no CO_2—as long as the hydrogen is not produced with the use of fossil fuels or other carbon-containing compounds. Hydrogen also provides more energy per gram than does any other fuel, making it the ideal aviation fuel.

So what is the catch? There are three challenges in turning the vision of widespread use of hydrogen as a fuel into reality. *First,* hydrogen is chemically locked up in water and in organic compounds such as methane and gasoline, so it takes energy and money to produce hydrogen from these compounds. In other words, hydrogen is not an energy resource like coal or oil. It is a fuel produced by using energy, and thus its net energy yield will always be negative. *Second,* fuel cells are the best way to use hydrogen to produce electricity, but current versions of such cells are expensive. However, progress in the development of nanotechnology (Science Focus, p. 362) could lead to improved membranes and catalysts that would make fuel cells more efficient and cheaper.

Third, whether a hydrogen-based energy system produces less air pollution and CO_2 than a fossil fuel system depends on how the hydrogen is produced. We could use electricity from coal-burning and conven-

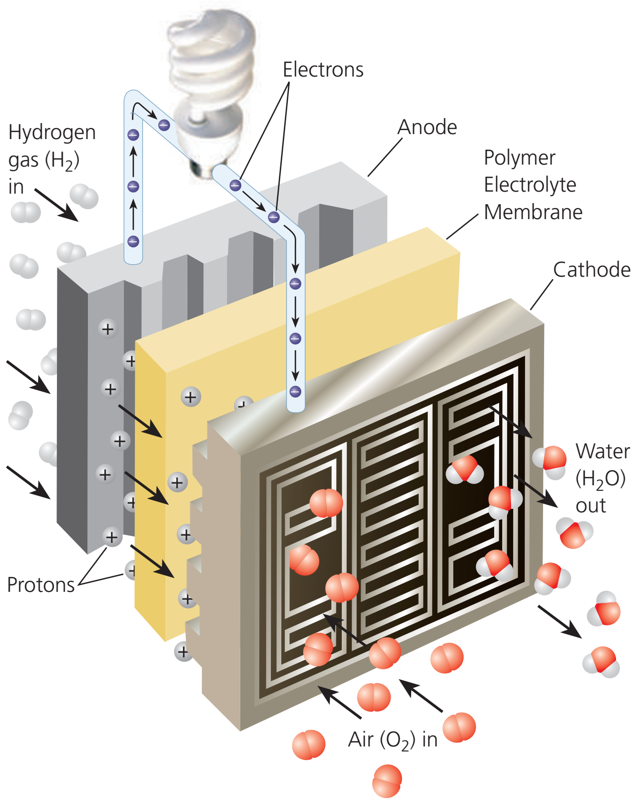


Figure 16-30 A *fuel cell* takes in hydrogen gas and separates the hydrogen atoms' electrons from their protons. The electrons flow through wires to provide electricity, while the protons pass through a membrane and combine with oxygen gas to form water vapor ($2H_2 + O_2 \rightarrow 2H_2O$ + energy). Note that this process is the reverse of electrolysis, which is used to produce hydrogen fuel ($2H_2O$ + energy $\rightarrow 2H_2 + O_2$).

tional nuclear power plants to decompose water into hydrogen and oxygen gas. But this approach does not avoid the harmful environmental effects associated with using these fuels (Figure 15-15, p. 385, and Figure 15-21, p. 391) (**Concept 16-8**). We can also make hydrogen from coal and strip it from organic compounds found in fuels such as gasoline or natural gas. However, according to a 2002 study by a team of scientists, producing hydrogen from coal and organic compounds will add much more CO_2 to the atmosphere per unit of heat generated than does burning these carbon-containing fuels directly.

Most proponents of hydrogen believe that if we are to receive its very low pollution and low CO_2 emission benefits, the energy used to produce H_2 must come from low-polluting, renewable sources that emit little or no CO_2, such as solar cell power plants (Figure 16-19), wind farms (Figure 16-22, middle and right), geothermal energy (Figure 16-1), and micro-hydropower plants. Also, some naturally occurring bacteria and algae can produce hydrogen by biodegrading almost any organic material in a microbiological fuel cell.

Once produced, hydrogen can be stored in a pressurized tank as liquid hydrogen or in solid metal hydride compounds and sodium borohydride, which when heated release hydrogen gas. Scientists are also evaluating ways to store H_2 by absorbing it onto the surfaces of activated charcoal or carbon nanofibers, which release hydrogen gas when heated. Another possibility is to store it inside nano-size glass microspheres that can easily be filled and refilled. More research is needed to convert these possibilities into reality.

Metal hydrides, sodium borohydride, charcoal powders, ammonia borane, carbon nanotubes, and glass microspheres containing hydrogen will not explode or burn if a vehicle's fuel tank or system is ruptured in an accident. Also, use of ultralight car bodies made of composites and energy-efficient aerodynamic design would improve fuel efficiency so that large hydrogen fuel tanks would not be needed.

This makes hydrogen stored in such ways a much safer fuel than gasoline, diesel fuel, natural gas, and concentrated ethanol. Indeed, gasoline is 22 times more explosive than hydrogen, and if hydrogen burns, the heat produced dissipates much more rapidly than it does from gasoline or diesel fires. For 30 years, liquefied hydrogen has been shipped all over the United States with no fires reported.

Most automobile companies have developed prototype hydrogen-powered cars, trucks, and buses (such as those used in Iceland, **Core Case Study**). More than 500 such vehicles are on the road today and the number is expected to increase rapidly. Currently, hydrogen can be produced from natural gas at a cost equivalent to $2.50 per gallon of gasoline—less than what consumers are paying now. Some analysts project that a variety of fuel-cell cars running on affordable hydrogen produced from natural gas could be introduced between 2010 and 2020 and take over the market by 2030.

CORE CASE STUDY

In 2007, engineering professor Jerry Woodall invented a new way to produce hydrogen on demand by exposing pellets of an aluminum-gallium alloy to water, without producing toxic fumes. If this process is perfected and proves economically feasible, hydrogen could be generated as needed inside a tank about the same size as an average gasoline tank, and thus would not have to be transported or stored. Merely replacing the gasoline fuel injector with a hydrogen injector would allow current internal combustion engines to run on hydrogen. The engine would then be 25% more fuel efficient than it was when burning gasoline, and it would emit no pollutants. Stay tuned while this possibility is evaluated.

Larger stationary fuel cells can provide electricity and heat for commercial and industrial users. A 45-story office building in New York City gets much of its heat from two large fuel-cell stacks. And Japan has built a large fuel cell that produces enough electricity to run a small town.

Canada's Toronto-based Stuart Energy is developing a home fueling unit about the size of a dishwasher that will allow homeowners to use electricity to produce their own hydrogen from tap water. The

TRADE-OFFS

Hydrogen

Advantages	Disadvantages
Can be produced from plentiful water	Not found as H_2 in nature
Low environmental impact	Energy is needed to produce fuel
Renewable if produced from renewable energy resources	Negative net energy
No CO_2 emissions if produced from water	CO_2 emissions if produced from carbon-containing compounds
Good substitute for oil	Environmental costs not included in market price
Competitive price if environmental and social costs are included in cost comparisons	Nonrenewable if generated by fossil fuels or nuclear power
Easier to store than electricity	High costs (that may eventually come down)
Safer than gasoline and natural gas	Will take 25 to 50 years to phase in
Nontoxic	Short driving range for current fuel-cell cars
High efficiency (45–65%) in fuel cells	No fuel distribution system in place
	Excessive H_2 leaks may deplete ozone in the atmosphere

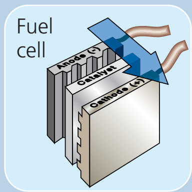


Figure 16-31 Advantages and disadvantages of using hydrogen as a fuel for vehicles and for providing heat and electricity (**Concept 16-8**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

unit could be installed in a garage and used to fuel a hydrogen-powered vehicle overnight, when electricity rates are sometimes lower. In sunny areas, homeowners could install rooftop panels of solar cells to produce and store hydrogen fuel for their cars, especially when solar cells become more affordable or with the help of generous government subsidies for such installations.

Another promising application is in homes, where a fuel-cell stack about the size of a refrigerator could provide heat, hot water, and electricity. The extra cost involved could be included in the purchase price of the home, just as conventional heating and cooling systems are, and spread out over the life of the mortgage. These systems could also be leased to homeowners. Honda has developed a home unit that produces hydrogen from the methane in natural gas. In 2007, about 2,200 Japanese homeowners got their electricity and hot water from such units. Japanese government plans call for using such fuel cell systems for about one-fourth of Japanese households by 2020.

Most current fuel cell units convert natural gas to hydrogen, but this releases CO_2. A better long-term solution would be to produce H_2 using electricity generated by wind farms, large solar-cell farms, and hydroelectric and geothermal power plants, and to distribute it using upgraded natural gas pipelines. **GREEN CAREER:** Hydrogen energy

RESEARCH FRONTIER

Developing better and more affordable ways to produce hydrogen from renewable energy resources and ways to store and distribute it. See **academic.cengage.com/biology/miller**.

Figure 16-31 lists the advantages and disadvantages of using hydrogen as an energy resource (**Concept 16-8**).

HOW WOULD YOU VOTE? ✓

Do the advantages of producing and burning hydrogen as an energy resource outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

16-9 How Can We Make a Transition to a More Sustainable Energy Future?

▶ **CONCEPT 16-9 We can make a transition to a more sustainable energy future if we greatly improve energy efficiency, use a mix of renewable energy resources, and include environmental costs in the market prices of all energy resources.**

Choosing Energy Paths

Energy policies must be developed with the future in mind, because experience shows that it usually takes at least 50 years and huge investments to phase in new energy alternatives. Creating energy policy involves trying to answer the following questions for *each* energy alternative:

- How much of the energy resource is likely to be available in the near future (the next 25 years) and the long term (the next 50 years)?

- What is the estimated net energy yield (Science Focus, p. 374) for the resource?
- How much will it cost to develop, phase in, and use the resource?
- What government research and development subsidies and tax breaks will be used to help develop the resource?
- How will dependence on the resource affect national and global economic and military security?
- How vulnerable is the resource to terrorism?
- How will extracting, transporting, and using the resource affect the environment, human health, and the earth's climate? Can these harmful costs be included in the market price of the resource through mechanisms like taxing and reducing environmentally harmful subsidies?

Our energy future depends primarily on which energy resources the government and private companies decide to promote, coupled with political and economic pressure from citizens and consumers. Energy expert Amory Lovins describes this process as "choosing an energy path."

Fossil fuel and nuclear power interests generally favor a *supply-side* or *hard-path* approach. It is built around scouring a country to find more nonrenewable oil, natural gas, and coal, and building more energy-wasting coal-burning and nuclear power plants.

In contrast, many environmental scientists and economists favor a *demand-side* or *soft-path* approach, described in 1977 by Lovins. (See his Guest Essay at CengageNOW.) This approach emphasizes reducing energy waste and depending more on a mix of renewable resources such as solar, wind, geothermal, and biomass. Proponents see this energy path as more sustainable than relying on nonrenewable fossil energy and nuclear energy resources.

In considering possible energy paths, scientists and energy experts who have evaluated energy alternatives have come to some general conclusions. First, *there will be a gradual shift from large, centralized macropower systems to smaller, decentralized micropower systems* (Figure 16-32) such as wind turbines, fuel cells for cars, household solar panels, rooftop solar water heaters, small natural gas turbines, and stationary fuel cells for houses and commercial buildings.

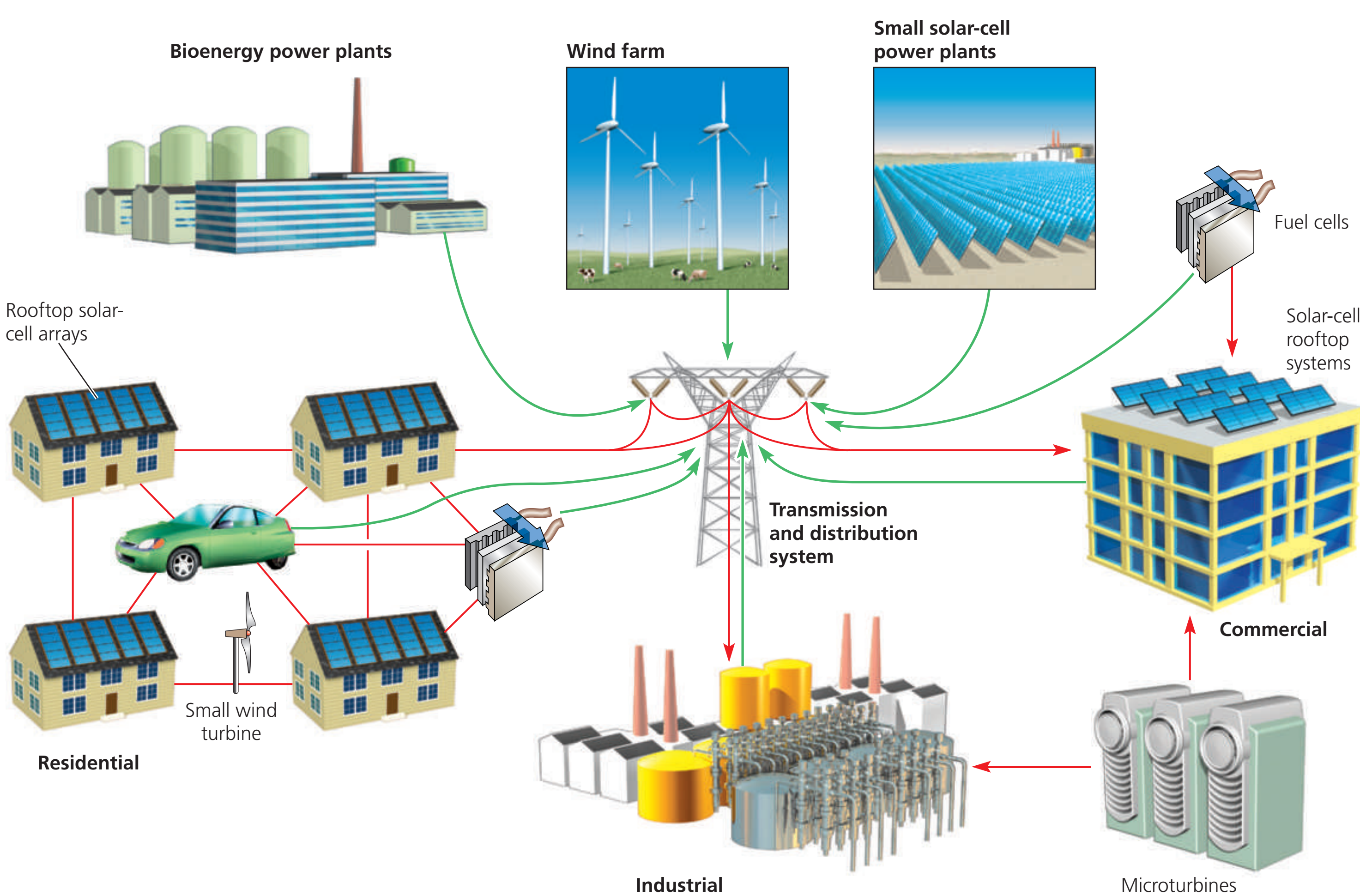


Figure 16-32 **Solutions:** *decentralized power system* in which electricity is produced by a large number of dispersed, small-scale *micropower systems.* Some such systems would produce power on site; others would feed the power they produce into an updated electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system often based on locally available renewable energy resources. **Question:** Can you think of any disadvantages of a decentralized power system?

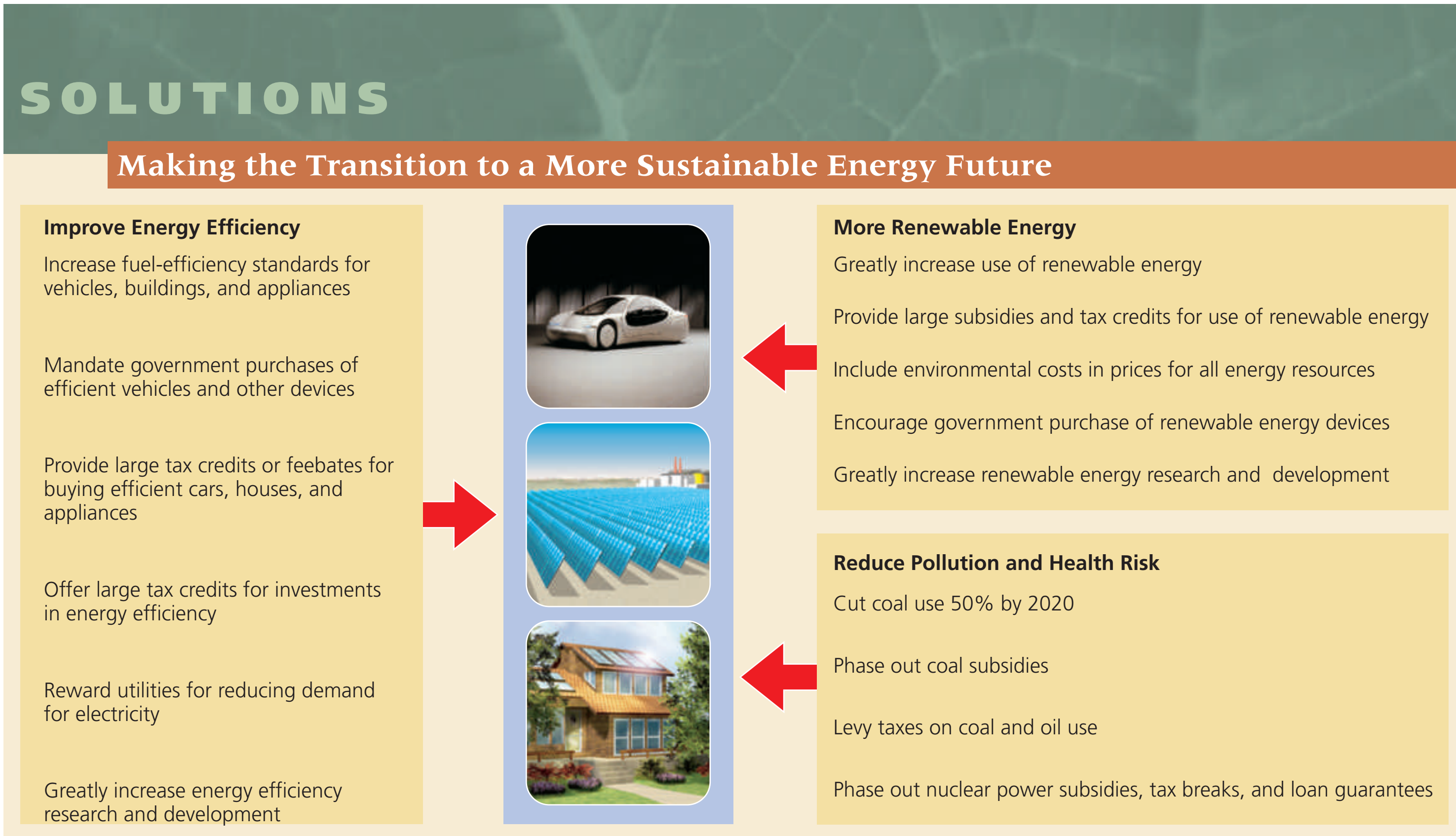


Figure 16-33 Suggestions of various energy analysts for helping us to make the transition to a more sustainable energy future (**Concept 16-9**). **Question:** Which five of these solutions do you think are the most important? Why?

Currently, most countries have a centralized and geographically concentrated system of large power plants, refineries, pipelines, and other infrastructure that is vulnerable to disruption from events such as terrorist attacks and natural disasters. For example, in 2005, Hurricane Katrina crippled about 10% of America's oil and gas producing wells (see Figure 6, bottom, p. S62, in Supplement 10) and oil refineries in the Gulf of Mexico for more than a year.

This shift from centralized macropower to dispersed micropower would be similar to the computer industry's shift from large, centralized mainframe computers to increasingly smaller, widely dispersed PCs, laptops, and handheld computers. It would improve national and economic security, because countries would rely on diverse, dispersed, domestic, and renewable energy resources instead of on a small number of large coal and nuclear power plants, imported oil, and oil refineries that are vulnerable to storm damage and sabotage.

The second general conclusion of experts is that *a combination of greatly improved energy efficiency and the use of natural gas and sustainably produced biofuels will best help us to make the transition to a diverse mix of locally available renewable energy resources* (**Concept 16-9**) *over the next several decades*. Natural gas is the most clean-burning fossil fuel, and it can be used easily in the short term during this transition. Instead of depending mostly on nonrenewable fossil fuels produced elsewhere, people will eventually make use of a variety of often locally available renewable energy resources, applying the diversity **principle of sustainability** by not putting all of their "energy eggs" in one basket.

Third, *because of their supplies and artificially low prices, fossil fuels will continue to be used in large quantities*. The challenge is to find ways to reduce the harmful environmental impacts of widespread fossil fuel use, with special emphasis on reducing air pollution and emissions of greenhouse gases and including their harmful environmental costs in their market prices, as less environmentally harmful alternatives are phased in.

Figure 16-33 summarizes these and other strategies for making the transition to a more sustainable energy future over the next 50 years (**Concept 16-9**).

Economics, Politics, and Education Can Help Us to Shift to More Sustainable Energy Resources

To most analysts, economics, politics, and consumer education hold the key to making a shift to a more sustainable energy future. It will require maintaining consistent and sustained energy policies at the local, state, and national levels so that businesses can make long-range plans. Governments can use three strategies to help stimulate or dampen the short-term and long-term use of particular energy resources.

First, they can *keep the prices of selected energy resources artificially low to encourage use of those resources.* They do this by providing research and development (R&D) subsidies and tax breaks to encourage the development of those resources, and by enacting regulations to favor them. For decades, this approach has been employed to stimulate the development and use of fossil fuels and nuclear power in the United States and in most other developed countries. The U.S. oil industry received almost half of the $600 billion in R&D subsidies provided by taxpayers between 1950 and 2003, according to the U.S. Department of Energy and the Congressional Budget Office.

And in 2007, the Department of Energy allocated $159 million for solar energy R&D. At the same time, it allocated nearly double this amount, $303 million, for nuclear energy R&D and $427 million for coal R&D. For decades, this sort of policy has created an uneven economic playing field that *encourages* energy waste and rapid depletion of nonrenewable energy resources, while it *discourages* improvements in energy efficiency and the development of renewable energy resources.

To many energy analysts, one of the most important steps governments can take to level the economic playing field is to phase out the $250–300 billion in annual subsidies now provided worldwide for fossil fuels and nuclear energy—both mature industries that could be left to stand on their own, economically. These analysts call for greatly increasing subsidies for developing renewable energy and energy-efficiency technologies. If this had been done beginning in 1980, they say, the world probably could have greatly increased its energy sustainability, sharply decreased its dependence on imported oil, avoided two wars in the Middle East, and be well on the way to slowing global warming and projected climate change.

The *second* major strategy that governments can use is to *keep energy prices artificially high for selected resources to discourage their use.* They can do this by eliminating existing tax breaks and other subsidies that favor use of the targeted resource, and by enacting restrictive regulations or taxes on its use. Canada, in 2007 introduced rebates for hybrid vehicles, a tax on gas-guzzlers, and subsidies for development of renewable fuels. China is also taxing gas-guzzlers and raising energy-efficiency requirements for homes and office buildings. Such measures can increase government revenues, encourage improvements in energy efficiency, reduce dependence on imported energy, and decrease use of energy resources that have limited supplies. To make such changes acceptable to the public, analysts suggest that governments can offset energy taxes by reducing income and payroll taxes and providing an energy safety net for low-income users.

HOW WOULD YOU VOTE? ✓

Should the government of the country where you live greatly increase taxes on fossil fuels and offset this by reducing income and payroll taxes and providing an energy safety net for the poor and lower middle class? Cast your vote online at **academic.cengage.com/biology/miller**.

Third, governments can *emphasize consumer education.* Even if governments offer generous financial incentives for energy efficiency and renewable energy use, people will not make such investments if they are uninformed—or misinformed—about the availability, advantages, disadvantages, and relative costs of energy resources (Table 16-1). For example, cloudy Germany has more solar water heaters and solar cell panels than sunny France and Spain, mostly because the German government has made the public aware of the environmental benefits of these technologies. It has also provided consumers with substantial economic incentives for using them.

The good news is that we have the technology, creativity, and wealth to make the transition to a more sustainable energy future within your lifetime, as the state of California is proving (see following Case Study). Making this transition depends primarily on *education* and *politics*—on how well individuals understand ecological and environmental problems, and on how they vote and then influence their elected officials. People can also vote with their pocketbooks by refusing to buy inefficient and environmentally harmful products and by letting company executives know about their choices. Figure 16-34 (p. 434) lists some ways in which you can contribute to making this transition.

■ CASE STUDY

California's Efforts to Improve Energy Efficiency

The U.S. state of California has a population of 37 million people and is the world' sixth largest economy. It uses less energy per person than any other U.S. state. While overall per capita energy use in the United States has grown by half since 1974, California's energy use per person has stayed about even. The state has accomplished this through a mix of state regulations and high electricity prices, and at the same time it has kept its economy growing.

Because California promotes the use of cleaner, renewable sources of power, state residents pay close to the highest rates for electricity anywhere in the United States. This helps reduce energy waste and encourages the use of energy-efficient devices. In the long run, because of increased efficiency, it also saves people money. While the average American uses 12,000 kilowatt-hours (kWh) of electricity in a year, the average California resident uses less than 7,000 kWh. That translates to about $800 in savings for the average

WHAT CAN YOU DO?

Shifting to Sustainable Energy Use

- Get an energy audit done for your house or office
- Drive a car that gets at least 15 kilometers per liter (35 miles per gallon)
- Use a carpool to get to work or to school
- Walk, bike, and use mass transit
- Superinsulate your house and plug all air leaks
- Turn off lights, TV sets, computers, and other electronic equipment when they are not in use
- Wash laundry in warm or cold water
- Use passive solar heating
- For cooling, open windows and use ceiling fans or whole-house attic or window fans
- Turn thermostats down in winter and up in summer
- Buy the most energy-efficient home, lights, and appliances available
- Turn down the thermostat on water heaters to 43–49 °C (110–120 °F) and insulate hot water heaters and pipes

Figure 16-34 **Individuals matter:** ways to reduce your use and waste of energy. **Questions:** Which three of these items do you think are the most important? Why? Which things in this list do you already do or plan to do?

Californian, even with the state's high electricity prices. And while U.S. per capita CO_2 emissions stayed about the same between1974 and 2004, such emissions in California fell by 30%.

Actions taken by the state of California to reduce energy waste include establishing the nation's first and strictest building standards for energy efficiency, setting stringent appliance efficiency standards, and giving rebates for purchases of solar energy equipment. The state has also created a strategy called *decoupling,* in which utility profits were disconnected from the amount of electricity sold, and instead, are now tied into the amount of energy conserved.

> **THINKING ABOUT**
> **California's Strategies for Energy Efficiency**
> Do you think that California would have the lowest per capita energy use in the country if the state government had not acted as it did? Explain.

REVISITING Iceland and Sustainability

CORE CASE STUDY

SUSTAINABILITY

Iceland's attempt to convert completely to renewable resources (**Core Case Study**) shows that it is possible for a society to run at least partly on renewable energy such as geothermal heat (Figure 16-1) and hydropower. It also reveals that it is not easy to make such a conversion, and that all players—government, industry, financial institutions, and citizens—must make a commitment to shifting to a more sustainable energy future.

For example, the use of hydrogen as fuel is neither an easy nor an inexpensive solution. But Iceland is tackling this obstacle and, within a decade or two, could be using hydrogen as the fuel for its transportation sector.

Other countries and cities can follow the lead of Icelanders and make the transition to a more sustainable energy future by applying the four **scientific principles of sustainability**. This means:

- Relying much more on direct and indirect forms of solar energy
- Recycling and reusing materials and thus reducing wasteful and excessive consumption of energy and matter
- Mimicking nature's reliance on biodiversity by using a diverse mix of locally and regionally available renewable energy resources
- Reducing use and waste of energy and other resources by slowing population growth.

A transition to renewable energy is inevitable,
not because fossil fuel supplies will run out—
large reserves of oil, coal, and gas remain in the world—
but because the costs and risks of using these supplies will continue
to increase relative to renewable energy.

MOHAMED EL-ASHRY

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 400. Describe Iceland's attempt to develop a renewable energy economy by 2050.

2. Distinguish between **energy conservation** and **energy efficiency.** Explain why energy efficiency can be thought of as an energy resource. How much of the energy used in the United States is wasted unnecessarily? What are the major advantages of reducing energy waste? List three reasons why this source of energy has been neglected?

3. What is net energy efficiency and why is it important? Describe three ways to save energy and money in **(a)** industry, **(b)** transportation, and **(c)** buildings. What is **cogeneration (combined heat and power or CHP)?** Describe how Dow Chemicals has saved energy and money. Describe the trends in fuel efficiency in the United States since the 1970s. Explain why the price of gasoline is much higher than what consumers pay at the pump. What is a feebate? Distinguish among hybrid, plug-in hybrid, and fuel-cell motor vehicles. Describe five ways to save energy in an existing building.

4. List five advantages of relying more on a variety of renewable sources of energy and describe two factors holding back such a transition.

5. Distinguish between **passive solar heating** and **active solar heating** and discuss the major advantages and disadvantages of such systems. What are three ways to cool houses naturally? Discuss the major advantages and disadvantages of using solar energy to generate high-temperature heat and electricity. What is a **solar cell (photovoltaic** or **PV cell)** and what are the major advantages and disadvantages of using such cells to produce electricity?

6. What are the major advantages and disadvantages of using flowing water to produce electricity in hydropower plants? What is the potential for using tides and waves, to produce electricity?

7. What is a wind turbine? What is a wind farm? What are the major advantages and disadvantages of using wind to produce electricity? What are the major advantages and disadvantages of using wood to provide heat and electricity? What are **biofuels** and what are the major advantages and disadvantages of using **(a)** biodiesel and **(b)** ethanol to power motor vehicles? Evaluate the use of corn, sugar cane, and cellulose plants to produce ethanol.

8. What is **geothermal energy** and what are three sources of such energy? What are the major advantages and disadvantages of using geothermal energy as a source of heat and to produce electricity? What are the major advantages and disadvantages of burning hydrogen gas to provide heat, to produce electricity, and to fuel cars?

9. List three general conclusions of energy experts about possible future energy paths for the world. List five major strategies for making the transition to a more sustainable energy future. Describe three roles that governments play in determining which energy resources we use. Describe what the U.S. state of California has done to improve energy efficiency and rely more on various forms of renewable energy.

10. Describe how Iceland's pursuit of a renewable energy economy (**Core Case Logo**) applies the four **scientific principles of sustainability**. CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. Imagine that the country where you live has completed a transition to using only renewable energy, as Iceland plans to do (**Core Case Study**). Do you think that you would have to give up any of the conveniences you now enjoy? If so, what are they? Describe any adjustments you might have to make in your way of living. CORE CASE STUDY

2. List five ways in which you unnecessarily waste energy during a typical day, and explain how these actions violate any of the four **scientific principles of sustainability** (see back cover). SUSTAINABILITY

3. Congratulations! You have won $500,000 to build a more sustainable house of your choice. With the goal of maximizing energy efficiency, what type of house would you build? How large would it be? Where would you locate it? What types of materials would you use? What types of materials would you *not* use? How would you heat and cool the house? How would you heat water? What types of lighting, stove, refrigerator, washer, and dryer would you use? Which, if any, of these appliances could you do without?

4. A homebuilder installs electric baseboard heat and claims, "It is the cheapest and cleanest way to go." Apply your understanding of the second law of thermodynamics (**Concept 2-4B**, p. 40) and net energy (Figure 16-4), to evaluate this claim.

5. Should buyers of energy-efficient motor vehicles receive large rebates, funded by taxes on gas-guzzlers? Explain.

6. Explain why you agree or disagree with the following proposals made by various energy analysts:

   a. Government subsidies for all energy alternatives should be eliminated so that all energy choices can compete in a true free-market system.

   b. All government tax breaks and other subsidies for conventional fossil fuels (oil, natural gas, and coal), synthetic natural gas and oil, and nuclear power (fission and fusion) should be phased out. They should be replaced with subsidies and tax breaks for improving energy efficiency and developing solar, wind, geothermal, hydrogen, and biomass energy alternatives.

   c. Development of solar, wind, and hydrogen energy should be left to private enterprise and should receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal government subsidies.

7. Imagine that you are in charge of the U.S. Department of Energy (or the energy agency in the country where you live). What percentage of your research and development budget will you devote to fossil fuels, nuclear power, renewable energy, and improving energy efficiency? How would you distribute your funds among the various types of renewable energy (wind, solar, hydropower, geothermal)? Explain your thinking.

8. List three ways in which you could apply **Concept 16-9** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the world. List the five most important features of your energy policy.

10. List three questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Make calculations to fill in the missing data in this table. Show all calculations. (*Note:* 1 liter = 0.265 gallon; 1 kilogram = 2.20 pounds; 1 hectare = 10,000 square meters = 2.47 acres.)

EPA Size Class/ Model	Compact/ Honda Civic Hybrid	Midsize/ Toyota Camry Hybrid	Sports Utility Vehicle (SUV)/ Hummer H3
Combined highway and city fuel efficiency in kilometers per liter (miles per gallon)	17.8 (42.0)	14.4 (34.0)	6.4 (15.0)
Liters (gallons) of gasoline consumed per year, assuming an average mileage of 19,300 kilometers (12,000 miles)			
Kilograms (pounds) of CO_2 produced per year, assuming combustion of gasoline releases 2.3 kilograms per liter (19 pounds per gallon)			
Hectares (acres) of tropical rain forest needed to take up CO_2 produced per year, assuming the annual uptake of an undisturbed forest is 0.5 kilograms of CO_2 per square meter			

1. About how many times as much CO_2 per year is produced by the SUV as is produced by the compact car?
2. About how many times as much CO_2 per year is produced by the SUV as is produced by the midsize car?
3. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million SUVs?
4. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million midsize cars?
5. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million compact cars?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 16 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

AP* Review Questions for Chapter 16

Questions 1–4 refer to the following approximate energy efficiencies

(A) 5%
(B) 15%
(C) 30%
(D) 50%
(E) 100%

1. Coal fired power plant

2. Nuclear power plant

3. Incandescent light bulb

4. Motor vehicle with internal combustion engine

5. The Corporate Average Fuel Economy Standards (CAFE) have
(A) been raised to 35 mpg.
(B) had extreme success in the United States.
(C) increased steadily since 1973.
(D) decreased to about 21 mpg since 1985.
(E) been raised due to hybrid technology.

6. All of the following are ways to help save energy EXCEPT
(A) building straw bale houses.
(B) using living roofs.
(C) using low-efficient windows.
(D) using green architecture.
(E) insulating and plugging leaks.

7. An example of using an active solar heating system would be to
(A) plant a deciduous tree outside a window to keep the sun out.
(B) install a photovoltaic system on the roof.
(C) use super windows.
(D) use heavy blinds on the windows.
(E) use vents to allow hot air to escape in the summer.

Use the following disadvantages to the list of alternative energy sources for questions 8–12.

(A) Interferes with migratory birds
(B) Air pollution
(C) Scarcity of suitable sites
(D) Negative net energy
(E) May raise food prices

8. Geothermal

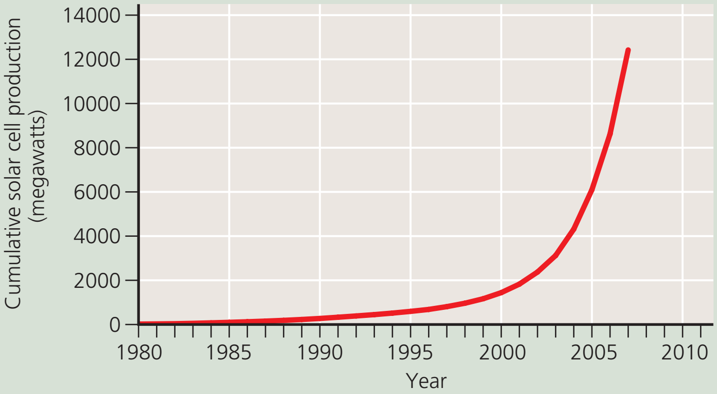
9. Hydrogen fuel cells

10. Biomass

11. Ethanol fuel

12. Wind energy

Questions 13 and 14 refer to the diagram below.



13. How many years did it take to triple the production of solar cells from 1995?
(A) 3
(B) 6
(C) 9
(D) 12
(E) 15

14. What information can be inferred from the graph above?
(A) More people are using solar energy now than in 1980.
(B) Solar energy utilization has surpassed that of wind energy.
(C) By the year 2010 there will be 14,000 megawatts of solar-cell production
(D) The amount of available solar energy is currently increasing exponentially.
(E) There has been a linear increase in solar-cell production since 1995.