



Core Case Study

Saving Energy and Money and Reducing Our Environmental Impact

Do you like to burn dollar bills? Do you like wasting 15–30% of the money you spend on electricity, gasoline, and heating and cooling bills? About 43% of the money that Americans spend each year on energy is unnecessarily wasted and provides no useful energy. In addition to burning up mountains of \$100 bills, this waste of energy increases our harmful environmental impact.

Some do this by driving cars with engines that waste 80% of the money they spend on gasoline. Only about 20% of the money we spend on gasoline, on average, gets us somewhere. Many also waste energy and money by living in leaky houses and buildings. The left photo in Figure 16.1 is an infrared shot of a home that is poorly insulated and has heat and money leaking out through its doors, windows, walls, and roof. Spending a small amount of money insulating the walls and roof and caulking (sealing) leaks around the windows and doors can drastically reduce this loss of heat and money, as shown in the photo on the right. Many homes 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 having a large, window-sized hole in a wall of the house.

Would you like to have an investment that will earn 25% a year without any risk or taxes, compared to a bank savings account with a 0.1% annual return? Do what the owner of the house in Figure 16.1 did. If you live in a typical home and you could invest \$2,000 in insulation and \$25 in caulking all the air leaks around doors and windows and in your ceiling and roof, you could reduce

your heating and cooling bill by 15–30%. The caulking immediately would start earning you a 100% return on your investment. It would take about 4 years to earn back the money you spent on insulation. After that, you would be earning a 25% annual return on your investment as long as you lived in the house. (Interest rate = 100%/ payback period = 100/4 = 25%.) As an added bonus, you could reduce your input of climate-changing CO_2 by about 2.1 metric tons (2.4 tons) a year.

Investing in insulating a house and sealing air leaks is not exciting. But the

money you can save is, and you can also reduce your harmful environmental impacts from heating and cooling your house. It is a win-win deal for you and the environment.

In this chapter, we consider the importance of using energy more efficiently and wasting less energy. We also explore ways to make the transition to a more sustainable energy future during this century by shifting from nonrenewable fossil fuels to renewable energy resources such as solar energy, wind power, flowing water, and the earth's internal heat.



FIGURE 16.1 A thermogram, or infrared photo, of a house that is poorly insulated and poorly sealed and thus loses heat (reddish areas) and wastes money. *Critical thinking:* How do you think the place where you live would compare to this house in terms of heat loss?

16.1 WHY DO WE NEED A NEW ENERGY TRANSITION?

CONCEPT 16.1 The world is in the early stages of a transition from relying on fossil fuels to greater reliance on energy efficiency and renewable energy.

Establishing New Energy Priorities

Shifting to new energy resources is not new. The world has shifted from primary dependence on wood to coal, then from coal to oil, and then to our current dependence on oil, natural gas, and coal as new technologies made these resources more available and affordable. Each of these shifts in key energy resources took about 50 to 60 years. As in the past, it takes an enormous investment in science and engineering, research, technology, and infrastructure to develop and spread the use of new energy resources.

Currently, the world and the United States get about 90% of the commercial energy they use from three carbon-containing fossil fuels—oil, coal, and natural gas (Figure 15.2, p. 383). They have supported tremendous economic growth and improved the lives of many people.

However, we are awakening to the fact that burning fossil fuels, especially coal, is largely responsible for the world's three most serious environmental problems: air pollution, climate change, and ocean acidification. Fossil fuels are affordable because their market prices do not include these and other harmful health and environmental effects.

According to many scientists, energy experts, and energy economists, over the next 50 to 60 years and beyond, we need to make a new energy transition by (1) improving energy efficiency and reducing energy waste, (2) decreasing our dependence on nonrenewable fossil fuels, and (3) relying more on a mix of renewable energy from the sun, wind, the earth's interior heat (geothermal energy), flowing water (hydropower), and biomass (wood and biofuels). We also need to modernize the electrical grids used to transmit electricity produced at fossil fuel and solar power plants and wind farms (see chapter-opening photo).

We can reduce fossil fuel use, but fossil fuels are not going to disappear. In 2065, fossil fuels are projected to provide at least 50% of the world's energy, compared to 90% today, according to the International Energy Agency. The use of coal is likely to decline the most because of its harmful environmental effects and its key role in accelerating climate change and ocean acidification.

Supporters of this restructuring of the global energy system and economy over the next 50 to 60 years and beyond project that it will save money, create profitable business and investment opportunities, and provide jobs. They also project that it will save lives by sharply reducing air pollution, help keep climate change from spiraling out of control and creating ecological and economic chaos, and

slow the increase in ocean acidity. Finally, supporters project that this shift will increase our positive environmental impact, and pass the world on to future generations in better shape than we found it.

For four decades, fossil fuel industries and utility companies have been using their economic and political power to slow this energy shift, especially in the United States. Eventually, however, economists expect fossil fuel businesses to fade as cheaper and cleaner energy alternatives emerge, which is how creative capitalism works.

This energy shift is being driven by the availability of perpetual supplies of clean and increasingly cheaper solar and wind energy throughout the world and advances in solar cell and wind turbine technology. This is in contrast to fossil fuels, which are dependent on finite supplies of oil, coal, and natural gas that are not widely distributed, are controlled by a few countries, and are subject to fluctuating prices based on supply and demand.

In this new technology-driven energy economy, an increasing percentage the world's electricity will be produced locally from available sun and wind and regionally from solar cell power plants and wind farms and transmitted to consumers by a modern, interactive, smart electrical grid. Homeowners and businesses with solar panels on their roofs or land will become independent electricity producers. They will be able to heat and cool their homes and businesses, run electrical devices, charge hybrid or electric cars, and sell any excess electricity they produce. The United States will benefit economically, because making such a market-based shift will set off an explosion of increased energy efficiency and renewable energy and battery technological innovations by tapping into the country's renowned ability to innovate.

Like any major societal change, this shift will not be easy. However, to many analysts the harmful environmental, health, and economic effects of not making this shift far outweigh the environmental, health, and economic benefits of making this shift.

This shift is underway and gaining momentum as the cost of electricity produced from the sun and wind continues its rapid fall and investors see a way to make money on two of the world's fastest growing businesses. Between 2009 and 2015, the cost of generating electricity with solar energy fell by 82% and with wind by 61%. Germany (see the Case Study that follows), Sweden, Denmark, and Costa Rica have made the most progress in this shift, and Japan leads the world in reducing energy waste. For example, Costa Rica gets more than 90% of its electricity from renewable resources, mostly hydropower, geothermal energy, and wind. It aims to generate all of its electricity from renewable sources by 2021, mostly by increasing its use of geothermal energy.

In the United States, solar and wind power use is increasing and coal use has dropped slightly, mostly because of increased use of affordable domestic supplies of natural gas to produce electricity. However, the United States has

yet to commit to making the new energy shift, partly because of almost four decades of opposition by politically and economically powerful fossil fuel and electric utility companies. In addition, increased reliance on using cheap natural gas to produce electricity hinders the shift to wind, solar, and other renewable energy resources.

CASE STUDY

Germany Is a Renewable Energy Superpower

Germany is phasing out nuclear power and between 2006 and 2014, increased the percentage of its electricity produced by renewable energy, mostly from the sun and wind, from 6% to 28%. Its goals for 2050 are to get 60% of its electricity from renewable energy, increase electricity efficiency by 50%, reduce its current emissions of climate-changing $\rm CO_2$ by 80% to 95%, and sharply reduce its use of coal, which currently provides 40% of its electricity, as a backup energy resource for solar and wind power.

The biggest factor in this shift is Germany's use of a **feed-in-tariff** (also used by Great Britain and 47 other countries). Under a long-term contract, it requires utilities to buy electricity produced by homeowners and businesses from renewable energy resources at a price that guarantees a good return and to feed it into the electrical grid.

German households now own and make money from roughly 80% of the country's solar cell installations. The feed-in-tariff program is financed by all electricity users and costs less than \$5 a month per household. It has also created more than 370,000 new renewable energy jobs. In addition, the German government and private investors have subsidized research on technological improvements in solar and wind power and backup energy storage systems that can further lower costs. However, political opposition by Germany's coal industry and some electrical utility companies and the need for costly backup power may slow the country's shift to greater dependence on solar and wind power.

16.2 WHY IS IMPROVING ENERGY EFFICIENCY AND REDUCING ENERGY WASTE AN IMPORTANT ENERGY RESOURCE?

CONCEPT 16.2A Improvements in energy efficiency and reducing energy waste could save at least a third of the energy used in the world and up to 43% of the energy used in the United States.

CONCEPT 16.2B We have a variety of technologies for sharply increasing the energy efficiency of industrial operations, motor vehicles, appliances, and buildings.

We Waste a Lot of Energy and Money

Improving energy efficiency and conserving energy are key strategies in using energy more sustainability. **Energy efficiency** is a measure of how much useful work we can get from each unit of energy we use. Improving energy efficiency means using less energy to provide the same amount of work. No energy-using device operates at 100% efficiency; some energy is always lost as heat, as required by the second law of thermodynamics (p. 42). However, there are ways to improve energy efficiency and waste less energy by using of more fuel-efficient cars, lights, appliances, computers, and industrial process.

We can also cut energy waste by changing our behavior. **Energy conservation** means reducing or eliminating the unnecessary wasting of energy. If you ride your bicycle to school or work rather than driving a car, you are practicing energy conservation. Another way to conserve energy is to turn off lights and electronic devices when you are done using them.

You may be surprised to learn that roughly 84% of all commercial energy used in the United States is wasted (Figure 16.2). About 41% of this energy unavoidably ends up as low-quality waste heat in the environment because of the degradation of energy quality imposed by the second law of thermodynamics. The other 43% is wasted unnecessarily, mostly due to the inefficiency of industrial motors,

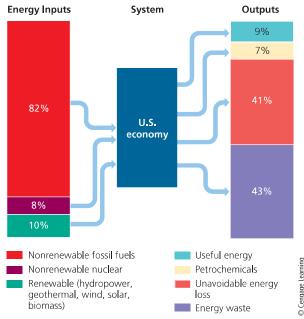


FIGURE 16.2 Flow of commercial energy through the U.S. economy. Only 16% of the country's high-quality energy ends up performing useful tasks. *Critical thinking:* What are two examples of unnecessary energy waste?

(Compiled by the authors using data from U.S. Department of Energy.)

motor vehicles, power plants, light bulbs, and numerous other devices (**Concept 16.2A**).

Percentage of energy used in the United States that is unnecessarily wasted

Another reason for our costly and wasteful use of energy is that many people live and work in poorly insulated, leaky houses and buildings that require excessive heating during cold weather and excessive cooling during hot weather (see Figure 16.1). In addition, many Americans (and people in other parts of the world) live in everexpanding suburban areas around large cities where they must depend on cars for getting around. Three of every four Americans commute to work, mostly alone in energy-inefficient vehicles, and only 5% rely on more energy-efficient mass transit. In addition, many people waste energy and money by buying inefficient appliances.

Much of this loss of energy and money is due to heavy reliance on three widely used energy-inefficient technologies:

- Huge data centers, filled with racks of electronic servers
 that process all online information and provide cloudbased data storage for users. Typically, they use only
 10% of the electrical energy they consume. The other
 90% is lost as heat. Most data centers run 24 hours a
 day at their maximum capacities, regardless of the
 demand. They also require large amounts of energy
 for cooling to keep the servers from overheating.
- The *internal combustion engine*, which propels most motor vehicles, wastes about 80% of the high-quality energy in its gasoline fuel. Thus, only about 20% of the money people spend on gasoline provides them with transportation. The other 80% of the energy released by burning gasoline ends up as waste heat in the atmosphere.
- Nuclear, coal, and natural gas power plants, which turn
 their fuel into one-third electricity and two-thirds
 waste heat that flows into the atmosphere or into
 waterways. Typically, only about a third of your
 electricity bill is actually for electricity.

Improvements in energy efficiency and conservation have numerous economic, health, and environmental benefits (Figure 16.3). To most energy analysts, they are the quickest, cleanest, and usually the cheapest ways to provide more energy, reduce pollution and environmental degradation, and slow climate change and ocean acidification.

Improving Energy Efficiency in Industries and Utilities

The industrial sector includes all facilities and equipment used to produce, process, or assemble goods. Industries

Solutions

Improving Energy Efficiency

- Prolongs fossil fuel supplies
- Reduces oil imports and improves energy security
- Very high net energy
- Low cost
- Reduces pollution and environmental degradation
- Buys time to phase in renewable energy
- Creates local jobs







engage Learning

FIGURE 16.3 Improving energy efficiency and conserving energy can have important benefits. *Critical thinking:* Which two of these benefits do you think are the most important? Why?

 $Top: Dmitriy\ Raykin/Shutterstock.com.\ Center:\ V.\ J.\ Matthew/Shutterstock.com.\ Bottom:\ andrea\ lehmkuhl/Shutterstock.com.$

that use the most energy are those that produce petroleum, chemicals, cement, steel, aluminum, and paper and wood products.

One way for industries and utility companies to save energy is to use **cogeneration** to produce two useful forms of energy—electricity and heat—from the same fuel source. For example, the steam used for generating electricity in a power or industrial plant can be captured and used again to heat the plant or other nearby buildings, rather than being released into the environment as waste heat. The energy efficiency of these systems is 60–80%, compared to 25–35% for coal-fired and nuclear power plants. Denmark leads the world by using cogeneration to produce 53% of its electricity compared to 12% in the United States.

Inefficient motors account for 60% of the electricity used in U.S. industry. Industries can save energy and money by using more energy-efficient variable-speed electric motors that run at the minimum speed needed for each job. In contrast, standard electric motors run at full speed with their output throttled to match the task. This is somewhat like using one foot to push the gas pedal to the floorboard of your car and putting your other foot on the brake pedal to control its speed.

Recycling materials such as steel and other metals can also help industries save energy and money. For example, producing steel from recycled scrap iron uses 75% less high-quality energy than does producing steel from virgin iron ore and emits 40% less CO₂.

Industries can also save energy by using energy-efficient LED lighting; installing smart meters to monitor energy use; and shutting off computers, printers, and nonessential lights at the end of the work day.

A growing number of major corporations are saving money by improving energy efficiency. For example, between 1990 and 2014, Dow Chemical Company, which operates 165 manufacturing plants in 37 countries, saved \$27 billion in a comprehensive program to improve energy efficiency. Ford Motor Company saves \$1 million a year by turning off unused computers.

Building a Smarter and More Energy-Efficient Electrical Grid

In the United States, electricity is delivered to consumers through an electrical grid. This network of transmission and distribution lines carries electricity from power plants, wind farms, and other electricity producers to homes, schools, offices, and other end users.

The U.S. electrical grid system, designed more than 100 years ago, is inefficient and outdated. According to former U.S. energy secretary Bill Richardson, "We're a major superpower with a third-world electrical grid system."

Work is underway to convert and expand the outdated U.S. electrical grid system into a *smart grid*. The new grid would be a digitally controlled, ultra-high-voltage (UHV), and high-capacity system with superefficient transmission lines. It will be less vulnerable to power outages, connect to wind farms and solar power plants throughout the country, be more energy efficient, and help save consumers money.

Such a grid could quickly adjust for a major power loss in one area by automatically rerouting electricity from other parts of the country. It would also enable power companies and consumers to buy electricity produced from wind, solar, and other renewable forms of energy in areas where they are not directly available.

According to the U.S. Department of Energy (DOE), building such a grid would cost the United States up to \$800 billion over the next 20 years. However, it would save the U.S. economy \$2 trillion during that period. Much of these savings would go to consumers with smart electricity meters that would enable them to track how much electricity they use, when they use it, and what its cost is. They could use this information to limit electricity use during times when rates are higher.

The two fastest growing energy resources in the world and in the United States are solar and wind energy used to produce electricity. However, this growth will be limited unless wind farms and solar cell power plants built in sparsely populated areas or at sea can be connected to a smart grid. A national network of wind farms and solar cell power plants would make the sun and wind reliable sources of electricity around the clock. Without such a grid, the United States will not reap the environmental and economic advantages of relying on the sun and wind to produce much of its electricity.

Making Transportation More Energy-Efficient

In 1975, the U.S. Congress established Corporate Average Fuel Economy (CAFE) standards to improve the average fuel economy of new cars and light trucks, vans, and sport utility vehicles (SUVs) in the United States. Between 1973 and 2013, these standards increased the average fuel economy for such vehicles in the United States from 5 kilometers per liter, or *kpl* (11.9 miles per gallon, or *mpg*) to 10.6 kpl (24.9 mpg). The government goal is for such vehicles to get 23.3 kpl (54.5 mpg) by 2025. Existing fuel economy standards for new vehicles in Europe, Japan, China, and Canada are much higher than this proposed 2025 U.S. standard.

Energy experts project that by 2040, all new cars and light trucks sold in the United States could get more than 43 kpl (100 mpg) using available technology. They call for such government standards as an important way reduce energy waste, cut air pollution, and slow climate change and ocean acidification.

Governments may be pushing for more fuel-efficient vehicles, but consumers do not always buy such vehicles, especially when gasoline prices fall. Most consumers are unaware that gasoline costs them much more than the price they pay at the pump. A number of hidden gasoline costs not included in the price of gasoline include government subsidies and tax breaks for oil companies, car manufacturers, and road builders; defense spending to secure access to Middle East oil supplies; costs of pollution control and cleanup; and higher medical bills and health insurance premiums resulting from illnesses caused by air and water pollution from the production and use of motor vehicles. The International Center for Technology Assessment estimated that the hidden costs of gasoline for U.S. consumers amount to \$3.18 per liter (\$12.00 per gallon).

One way to include more of these hidden costs in the market price is through higher gasoline taxes. This would implement the full-cost pricing **principle of sustainability**. However, higher gas taxes are politically unpopular in the United States. Some analysts call for increasing U.S. gasoline taxes and reducing payroll and income taxes to balance such increases, thereby relieving consumers of any additional financial burden. Another way for governments to encourage higher energy efficiency

in transportation is to give consumers significant tax breaks or other economic incentives to encourage them to buy more fuel-efficient vehicles.

Other ways to save energy and money in transportation include building or expanding mass transit systems within cities, constructing high-speed rail lines between cities (as is done in Japan, much of Europe, and China), and carrying more freight by rail instead of in heavy trucks. Another approach is to encourage bicycle use by building bike lanes along highways and city streets.

Switching to Energy-Efficient Vehicles

Energy-efficient vehicles are available. One such vehicle is the gasoline–electric *hybrid car* (Figure 16.4, left). These cars have a small gasoline-powered engine and a battery-powered electric motor used to provide the energy needed for acceleration and hill climbing. The most efficient current models of these cars get a combined city/highway mileage of up to 23 kpl (55 mpg) and emit about 65% less CO₂ per kilometer driven than do comparable conventional cars.

Another option is the *plug-in hybrid electric vehicle* (Figure 16.4, right). These cars can travel 48–97 kilometers (30–60 miles) on electricity alone. Then a small gasoline-powered motor kicks in, recharges the battery, and extends the driving range to 600 kilometers (370 miles) or more. The battery can be plugged into a conventional 110-volt outlet and fully charged in 6 to 8 hours or a much shorter time using a 220-volt outlet. Another option is an all-electric vehicle that runs on a battery only.

According to a DOE study, replacing most of the current U.S. vehicle fleet with plug-in hybrid vehicles over

3 decades would cut U.S. oil consumption by 70–90%, eliminate the need for costly oil imports, save consumers money, and reduce CO_2 emissions by 27%. Recharging the batteries in these cars mostly by electricity generated by clean renewable energy resources such as wind turbines, solar cells, or hydroelectric power would cut U.S. emissions of CO_2 80–90%. This would slow climate change and ocean acidification and save thousands of lives by reducing air pollution from motor vehicles and coal-burning power plants.

The problem for the average consumer is that the prices of hybrid, plug-in hybrid, and all-electric cars are high because of the high cost of their batteries, which have to be replaced every few years. Thus, the key to greatly increasing the use of hybrid, plug-in hybrid, and all-electric motor vehicles is to ramp up research and development of suitable batteries (Science Focus 16.1). Another important factor will be to build a network of recharging stations throughout the country. Israel, Denmark, and several other countries are pioneering the use of stations where motorists can swap dead batteries for fully charged ones in less time than it takes to fill a gas tank. **GREEN CAREER: Plug-in hybrid and all-electric car technology**

Another potential alternative fuel resource is the **hydrogen fuel cell**, which could be used to power electric vehicles. This device uses hydrogen gas (H_2) as a fuel to produce electricity when it reacts with oxygen gas (O_2) in the atmosphere and emits harmless water vapor into the atmosphere. A fuel cell is more efficient than an internal combustion engine, has no moving parts, and requires little maintenance. Their H_2 fuel is usually produced by passing electricity through water or produced from methane stored in a vehicle. Two major problems with fuel cells

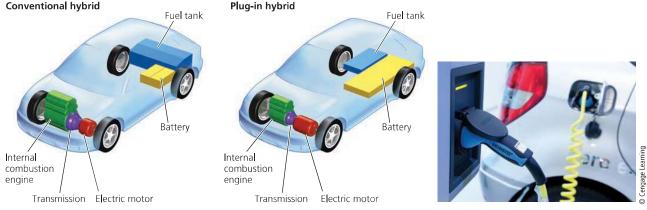


FIGURE 16.4 Solutions: A conventional gasoline—electric hybrid vehicle (left) is powered mostly by a small internal combustion engine with an assist from a strong battery. A plug-in hybrid electric vehicle (right) has a smaller internal combustion engine with a second and more powerful battery that can be plugged into a 110-volt or 220-volt outlet and recharged (see photo). An all-electric vehicle (not shown) runs completely on a rechargeable battery. **Question:** Would you buy one of these vehicles? Explain.

Photo: Gyuszko/Dreamstime.com

SCIENCEFOCUS 16.1

The Search for Better Batteries

The major obstacle standing in the way of wider use of plug-in hybrid-electric and all-electric vehicles is the need for an affordable, small, lightweight, and easily rechargeable car battery that can store enough energy for long-distances trips.

Lithium-ion batteries are light (because lithium is the lightest solid chemical element) and can pack a lot of energy into a small volume. Many of them are hooked together and used to power hybrid, plug-in hybrid, and all-electric motor vehicles. However, they are expensive, take a long time to recharge, lose their charge even when they are idle, must be replaced every few years, and can catch fire. Lithium-ion batteries are expensive but prices dropped by 50% between 2010 and 2015.

Researchers at the Massachusetts Institute of Technology (MIT) have developed a new type of lithium-ion battery using nanotechnology (Science Focus 14.1, p. 370). It is less expensive and can be charged 40 times faster. In 2014, researchers Joseph DeSimone and Nitash Balsara created a prototype of a nonflammable lithium-ion battery.

Scientists have also developed supercapacitors, which are small mechanical batteries consisting of two metal surfaces separated by an electric insulator. They quickly store and release large amounts of electrical energy, thus providing the power needed for quick acceleration. They can be recharged in minutes, can hold a charge much longer than conventional chemical batteries, and do not have to be replaced as frequently as conventional batteries.

If any one or a combination of these or other new battery technologies can be mass-produced at an affordable cost, plug-in hybrid and all-electric vehicles could take over the car and truck market within a few decades, which would greatly reduce air pollution, climate-changing CO₂ emissions, and ocean acidification. **GREEN CAREER: Battery engineer**

CRITICAL THINKING

How might your life change if one or more of the new battery technologies discussed above become a reality?

CONSIDER THIS . . .

LEARNING FROM NATURE

Blue-green algae use sunlight and an enzyme to produce hydrogen from water. Scientists are evaluating this as a way to produce hydrogen fuel for cars and for home heating without the use of costly high-temperature processes or electricity to produce this fuel. If successful, this would sharply reduce emissions of CO_2 and other air pollutants.

are that they are expensive and that H_2 has a negative net energy, which means that it takes more energy to produce it than it can provide, as discussed later in this chapter.

Reducing the weight of a vehicle is another way to improve fuel efficiency. Car bodies can be made of *ultralight* and *ultrastrong* composite materials such as fiberglass, carbon fiber, hemp fiber, and graphene (see Case Study, p. 369). The current cost of making such car bodies is high, but technological innovations and mass production would likely bring these costs down.

Energy conservation can also play a role. Since cars are the biggest energy user for most Americans, shifting to a more fuel-efficient car that gets at least 17 kpl (45 mpg) is one of the best ways to save money and reduce one's harmful environmental impact.

Designing Buildings That Save Energy and Money

Green architecture can help us make a transition to more energy-efficient, resource-efficient, and money-saving buildings over the next few decades. Green architecture makes use of technology such as natural lighting, direct solar heating, insulated windows, and energy-efficient appliances and lighting. It often makes use of solar hot water heaters, electricity from solar cells, and windows that darken automatically to deflect heat from the sun.

Some homes and urban buildings also have *living roofs*, or *green roofs*, covered with specially formulated soil and selected vegetation (Figure 16.5). Green roofs can reduce the costs of cooling and heating a building by absorbing heat from the summer sun, insulating the structure, and retaining heat in the winter. **GREEN CAREER: Sustainable environmental design and architecture**

Superinsulation is important in energy-efficient building design. A house can be so heavily insulated and airtight that heat from direct sunlight, appliances, and human bodies can warm a superinsulated house with little or no need for a backup heating system, even in extremely cold climates.

Superinsulated houses in Sweden use 90% less energy for heating and cooling than do typical American homes of



FIGURE 16.5 Green roof on Chicago's City Hall.

the same size. One example of superinsulation is strawbale construction, in which a house's walls are built of straw bales that are covered inside and out with mudbased adobe bricks (Figure 16.6). Such walls have insulating values of 2–6 times those of conventional walls.

The World Green Building Council and the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) have developed standards for certifying that a building meets certain energy efficiency and environmental standards. GREEN CAREERS: Sustainable environmental design and architecture

CONSIDER THIS...

THINKING ABOUT Energy-Efficient Building Design

What are three ways in which the building in which you live or work could have been designed to cut its waste of energy and money?

Saving Energy and Money in Existing Buildings

Here are ways to reduce energy use in existing buildings and to cut energy and save money on electricity and heating and cooling bills (see **Core Case Study**):

- Get a home energy audit.
- Insulate the building and plug leaks (Figure 16.1).
- Use energy-efficient windows.
- Seal leaky heating and cooling ducts in attics and unheated basements.
- Heat interior spaces more efficiently. In order, the most energy-efficient ways to heat indoor space are superinsulation (including plugging leaks); a geothermal heat pump that transfers heat stored from underground into a home; passive solar heating; a high-efficiency, conventional heat pump (in warm





FIGURE 16.6 Solutions: Energy-efficient, Victorian-style straw-bale house in Crested Butte, Colorado, during construction (left) and after it was completed (right). **Question:** Would you like to live in such a house? Explain.

climates only); and a high-efficiency natural gas furnace

- Heat water more efficiently. One option is a roof-mounted solar hot water heater. Another option is a *tankless instant water heater*. It uses natural gas or liquefied petroleum gas (but not an electric heater, which is inefficient) to deliver hot water only when it is needed rather than keeping water in a large tank hot all the time.
- Use energy-efficient appliances. A refrigerator with its freezer in a drawer on the bottom uses about half as much energy as one with the freezer on the top or on the side, which allows dense cold air to flow out quickly when the door is opened. Microwave ovens use 25–50% less electricity than electric stoves do for cooking and 66% less energy than conventional ovens. Front-loading clothes washers use 55% less energy and 30% less water than top-loading models use and cut operating costs in half.
- Use energy-efficient computers. According to the EPA, if all computers sold in the United States met its Energy Star requirements, consumers would save \$1.8 billion a year in energy costs and reduce greenhouse gas emissions by an amount equal to that of taking about 2 million cars off the road.
- Use energy-efficient lighting. The DOE estimates that by switching to LED bulbs over the next 20 years, U.S. consumers could save money and reduce the demand for electricity by an amount equal to the output of 40 new power plants.
- Stop using the standby mode. Consumers can reduce their energy use and their monthly power bills by plugging their standby electronic devices into smart power strips that cut off power to a device when it detects that the device has been turned off.

Figure 16.7 lists ways in which you can cut your energy use and save money in your home.

Why Are We Wasting So Much Energy and Money?

Considering its impressive array of economic and environmental benefits (Figure 16.3), why is there so little emphasis on improving energy efficiency and conserving energy? One reason is that energy resources such as fossil fuels and nuclear power are artificially cheap. This is primarily because of the government subsidies and tax breaks they receive and because their market prices do not include the harmful environmental and health costs of producing and using them. This distortion of the energy marketplace violates the full-cost pricing **principle of sustainability**.

Another reason is that there are too few significant government tax breaks, rebates, low-interest and long-term loans, and other economic incentives for consumers and businesses to invest in improving energy efficiency and reducing energy waste. A third reason is that most governments and utility companies have not put a high priority on educating the public about the environmental and economic advantages of improving energy efficiency and conserving energy.

Some critics say an emphasis on improving energy efficiency does not work because of the *rebound effect* in which some people tend to use more energy when they buy energy-efficient devices. For example, some people who buy a more efficient car tend to drive more, which offsets some of their energy and money savings and their reduced environmental impact.

Instead of downplaying efforts to improve energy efficiency, energy experts call for a major program to educate people about the rebound effect and its waste of money and long-lasting harmful health and environmental effects.



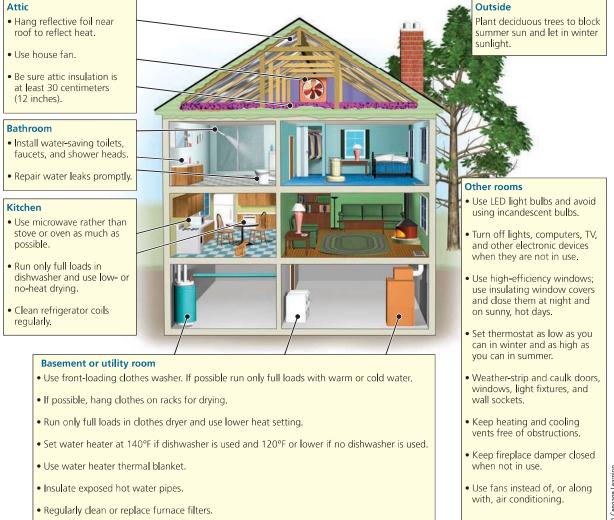


FIGURE 16.7 Individuals matter: You can save energy and money where you live and reduce your harmful environmental impact. Critical thinking: Which of these things do you already do? Which additional ones might you do?

Relying More on Renewable Energy

The lesson from one of nature's three scientific principles of **sustainability** is to *rely mostly on solar energy*. Most forms of zrenewable energy can be traced to the sun, because wind, flowing water, and biomass would not exist, were it not for solar energy. Another form of renewable energy is geothermal energy, or heat from the earth's interior. All of these sources of renewable energy are constantly replenished at no cost to us.

Studies show that with increased and consistent government backing in the form of research and development funds and subsidies and tax breaks, renewable energy could provide 20% of the world's electricity by 2025 and 50% by 2050. In 2012, the National Renewable Energy Laboratory (NREL) projected that, with a crash program,

the United States could get 50% of its electricity from renewable energy sources by 2050.

In 2014, 13 countries got more than 30% of their electricity from renewable energy, compared to 13% in the United States. Germany is phasing out nuclear power, gets 14% of its electricity from renewable energy, and plans to increase that to 50% by 2050 (see Case Study, p. 410). In 2015, California legislators approved a plan that would require the state to produce half of its electric power from renewable energy by 2030. And San Diego, California, adopted a legally binding pledge in 2015 to get all of its electricity from renewable energy by 2035.

If renewable energy is so great, why does it provide only 8% of the world's energy (Figure 15.2, left, p. 383) and 5% of the energy used in the United States (Figure 15.2,

right p. 383)? There are several reasons. *First*, there are the myths that solar and wind energy are too diffuse, too intermittent and unreliable, and too expensive to use on a large scale. Experience has shown that these perceptions are out of date. *Second*, 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 and nuclear power.

Third, while government subsidies and tax breaks for renewable have been increasing, Congress must renew them every few years. In contrast, subsidies and tax breaks for fossil fuels and nuclear power have essentially been guaranteed for many decades thanks in large part to political pressure from the fossil fuel and nuclear industries.

Fourth, the prices we pay for nonrenewable energy from fossil fuels and nuclear power do not include most of the harmful environmental and human health costs of producing and using them. This helps to shield them from free-market competition with renewable sources of energy.

Fifth, history shows that it typically takes 50 to 60 years to make a shift in energy resources (**Core Case Study**). Renewable wind and solar energy are the world's fastest growing sources of energy, but it will likely take decades for them to supply 25% or more of the world's electricity.

16.3 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING SOLAR ENERGY?

CONCEPT 16.3 Passive and active solar heating systems can heat water and buildings effectively, and the cost of using sunlight to produce electricity is falling rapidly.

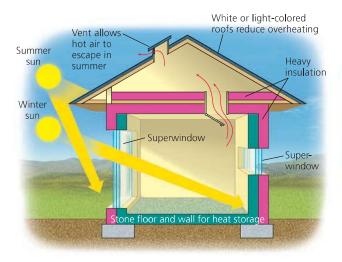
Heating Buildings and Water with Solar Energy

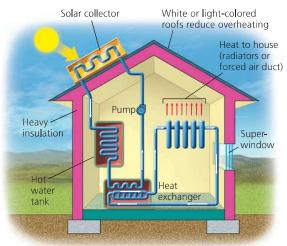
A building that has enough access to sunlight can get all or most of its heat through a **passive solar heating system** (Figure 16.8, left, and Figure 16.9). Such a system absorbs and stores heat from the sun directly within a well-insulated, airtight structure. Water tanks and walls and floors made of concrete, adobe, brick, or stone can store much of the collected solar energy as heat that is slowly released.

Use of passive solar energy is not new. For thousands of years, people have intuitively followed this **principle of sustainability** by orienting their dwellings to take advantage of the sun's heat and light. They also built thick walls of adobe and stone that collect heat, store it, and release it slowly. In hot climates, people have used light colors on their roofs and walls to reflect incoming solar energy and keep their houses cool. Now we are rediscovering this ancient solar wisdom.

An **active solar heating system** (Figure 16.8, right) captures 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 that face the sun. 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, and used as needed.

Rooftop active solar collectors are used to heat water in many homes and apartment buildings. One in ten houses and apartment buildings in China uses the sun to provide hot water with systems that cost the equivalent of \$200. Once the initial cost is paid, the hot water is heated for free. In Spain and Israel, builders are required to put rooftop solar water heaters on all new buildings. According to the





ACTIVE

PASSIVE

FIGURE 16.8 Solutions: Passive (left) and active (right) solar home heating systems.





FIGURE 16.9 This passive solar home (right) in Golden, Colorado, collects and stores incoming solar energy to provide much of its heat in a climate with cold winters. Notice the solar hot water heating panels in the yard. Some passive solar houses have sunrooms (see inset photo) to help collect incoming solar energy.

UN Development Programme, solar water heaters could be used to provide half of the world's hot water.

Passive and active solar systems can heat new homes in areas with adequate sunlight, as long as trees or other buildings do not block solar access. (See Figures 20 and 21, pp. S33 and S34, in Supplement 4 for maps showing solar energy availability throughout the world and in the United States, respectively.) Figure 16.10 lists the major advantages and disadvantages of using passive or active solar heating systems for heating buildings.

Cooling Buildings Naturally

Direct solar energy works against us when we want to keep a building cool, but we can use indirect solar energy (mainly wind) to help cool buildings. We can open windows to take advantage of breezes and use fans to keep the air moving. When there is no breeze, superinsulation and high-efficiency windows keep hot air outside.

Other ways to keep buildings cool include blocking the sun with shade trees, broad overhanging eaves, window awnings, or shades. A light-colored roof can reflect up to 90% of the sun's heat (compared to only 10–15% for a dark-colored roof), while a green roof can absorb extra heat. Geothermal heat pumps can pump cool air from underground into a building during summer to cool it as well.

CONSIDER THIS...

LEARNING FROM NATURE

Some species of African termites stay cool in a hot climate by building giant mounds that allow air to circulate through them. Engineers have used this design lesson from nature to cool buildings naturally, reduce energy use, and save money.

Trade-Offs Passive or Active Solar Heating **Advantages Disadvantages** Medium net Need access to sun 60% of time during energy daylight Very low Sun can be blocked emissions of COby trees and other and other air structures pollutants High installation and Very low land maintenance costs disturbance for active systems Moderate cost Need backup system (passive) for cloudy days

FIGURE 16.10 Heating a house with passive or active solar energy system has advantages and disadvantages (**Concept 16.3**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using these technologies outweigh their disadvantages?

Concentrating Sunlight to Produce High-Temperature Heat and Electricity

One of the problems with direct solar energy is that it is dispersed. **Solar thermal systems,** also known as *concentrated solar power (CSP)*, use different methods to collect and concentrate solar energy to boil water and produce steam

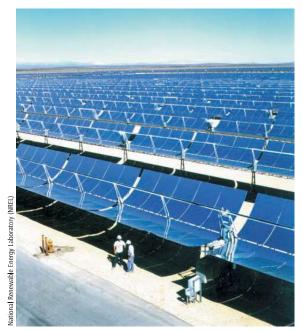


FIGURE 16.11 Solar thermal power: This solar power plant in California's Mojave Desert uses curved (parabolic) solar collectors to concentrate solar energy to provide enough heat to boil water and produce steam for generating electricity.

for generating electricity. These systems can be used in deserts and other open areas with ample sunlight.

One such system uses rows of curved mirrors, called parabolic troughs, to collect and concentrate sunlight. Each trough focuses incoming sunlight on a pipe that runs through its center and is filled with synthetic oil (Figure 16.11). The oil heats to temperatures as high as 400°C (750°F). That heat is used to boil water and produce steam, which in turn powers a turbine that drives a generator to produce electricity.

Another solar thermal system (Figure 16.12) uses an array of computer-controlled mirrors to track the sun and focus its energy on a central power tower to provide enough heat to boil water that is used to produce electricity. The heat produced by either of these systems can also be used to melt a certain kind of salt stored in a large insulated container. The heat stored in this molten salt system can then be released as needed to produce electricity at night or on cloudy days.

Some analysts see solar thermal power as a growing and important source of the world's electricity. However, because solar thermal systems have a low net energy, they need large government subsidies or tax breaks to be competitive in the marketplace. These systems also require large volumes of cooling water for condensing the steam back to water and for washing the surfaces of the mirrors and parabolic troughs. However, they are usually built in sunny, arid desert areas where water is scarce. Figure 16.13 summarizes the major advantages and disadvantages of using these solar thermal systems.

Solar energy can also be concentrated on a smaller scale. In some sunny areas, people use inexpensive *solar cookers* to



FIGURE 16.12 Solar thermal power: In this system in California an array of mirrors tracks the sun and focuses reflected sunlight on a central receiver to boil the water for producing electricity.

Trade-Offs

Solar Thermal Systems

Advantages

High potential for growth

No direct emissions of CO₂ and other air pollutants

Lower costs with natural gas turbine backup

Source of new jobs



Disadvantages

Low net energy and high costs

Needs backup or storage system on cloudy days

+

Requires high water use

Can disrupt desert ecosystems

FIGURE 16.13 Using solar energy to generate high-temperature heat and electricity has advantages and disadvantages (**Concept 16.3**). **Critical thinking:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using these technologies outweigh their disadvantages?

Top: Sandia National Laboratories/National Renewable Energy Laboratory. Bottom: National Renewable Energy Laboratory. Cengage Learnii



FIGURE 16.14 Solutions: Solar cooker (left) in Costa Rica and simple solar oven (right).



focus and concentrate sunlight for boiling and sterilizing water (Figure 16.14, left) and cooking food (Figure 16.14, right). Inventor Jon Boehner has developed a \$6 solar cooker made from a cardboard box. Solar cookers can replace wood and charcoal fires and reduce indoor air pollution, a major killer of many of the world's poor people. They also help to reduce deforestation by decreasing the need for firewood and charcoal (Figure 10.16, p. 234) made from firewood.

Using Solar Cells to Produce Electricity

In 1931, Thomas Edison (inventor of the electric light bulb) told Henry Ford, "I'd put my money on the sun and solar energy. ... I hope we don't have to wait until oil and coal run out before we tackle that." Edison's dream is now a reality.

We can convert solar energy directly into electrical energy using **photovoltaic** (**PV**) **cells**, commonly called **solar cells**. Most solar cells are thin transparent wafers of purified silicon (Si) or polycrystalline silicon with trace amounts of metals that allow them to conduct electricity.

Solar cells have no moving parts and they operate safely and quietly with no emissions of greenhouse gases and other air pollutants. A typical solar cell has a thickness ranging from less than that of a human hair to that of a sheet of paper. When sunlight strikes solar cells, they produce electricity (a flow of electrons). Many cells wired together in a panel and many panels can be connected to produce electricity for a house or a large solar power plant (Figure 16.15). Such systems can be connected to existing electrical grids or to batteries that store the electrical energy until it is needed.

People can mount arrays of solar cells on rooftops and incorporate them into almost any type of roofing material. Nanotechnology and other emerging technologies will likely allow the manufacturing of solar cells in paper-thin, rigid or flexible sheets (see Figure 14.14, p. 371) that can be printed like newspapers and attached to or embedded

in other surfaces such as outdoor walls, windows, drapes, and clothing. Engineers are also developing dirt- and water-repellent coatings to keep solar panels and collectors clean without having to use water. Solar power providers are putting floating arrays of solar cell panels on the surfaces of lakes, reservoirs, ponds, and canals. GREEN CAREER: Solarcell technology

Solar cells have great potential for providing electricity in less-developed countries. Worldwide, 1.3 billion people, most of them in rural villages in such countries, do not have access to electricity. A growing number of these individuals and villages are using rooftop solar panels (Figure 16.16) to power energy-efficient LED lamps (Figure 16.17), which can replace costly and inefficient kerosene lamps that pollute indoor air.

India has more than 300 million mostly rural poor people who are not connected to an electrical grid. Private entrepreneurs in India and Africa are setting up standalone *solar-powered microgrids* where a centralized group of solar cell panels are connected by cable to a few dozen homes and local businesses. Customers use cell phones to connect to village smart meters and purchase a certain amount of electricity. The smart meters cut off the power when a user's payment runs out.

Solar cells emit no greenhouse gases, although they are not a carbon-free option, because fossil fuels are used to produce and transport the panels. However, the emissions per unit of electricity produced are much smaller than those generated by using fossil fuels and nuclear power to produce electricity. Conventional solar cells also contain toxic materials that must be recovered when the cells wear out after 20–25 years of use, or when they are replaced by new systems.

One problem with current solar cells is their low energy efficiency. They typically convert only 15–20% of the incoming solar energy into electricity. However, scientists and engineers are rapidly improving the efficiency of solar cells. In 2014, researchers at Germany's Fraunhofer



FIGURE 16.15 Solar cell power plant: Huge arrays of solar cells can be connected to produce electricity.

Institute for Solar Energy Systems developed a solar cell with an efficiency of 45%—compared to an efficiency of 35% for fossil fuel and nuclear electric power plants. They plan to scale up this prototype cell for commercial use within a few years. Figure 16.18 lists the major advantages and disadvantages of using solar cells to produce electricity (**Concept 16.3**).

Because of government subsidies and tax breaks for solar cell producers and users and rapidly declining prices, solar cells have become the world's fastest growing way to produce electricity (Figure 16.19). Between 2001 and 2015, the cost per watt of electricity produced by solar cells fell by 83%, and this cost is expected to keep falling.

Some businesses and homeowners are spreading the cost of rooftop solar power systems over decades by including them in their mortgages. Others are leasing solar-cell systems from companies that install and maintain them.

Some communities and neighborhoods are using community solar or shared solar systems to provide electricity for individuals who rent or live in condominiums, or whose access to sunlight is blocked by buildings or trees. Customers buy the power from a centrally located small solar cell power plant. The power is delivered by the local

FIGURE 16.16 Solutions: A solar-cell panel provides electricity for lighting this hut in rural West Bengal, India. *Critical thinking:* Do you think your government should provide aid to poor countries for obtaining solar-cell systems? Explain.

utility and customers share deductions on their monthly bills for any excess power the project sells back to the grid.

Producing electricity from solar cells is expected to grow because solar energy is unlimited and available throughout the world. It is also a technology, not a fuel

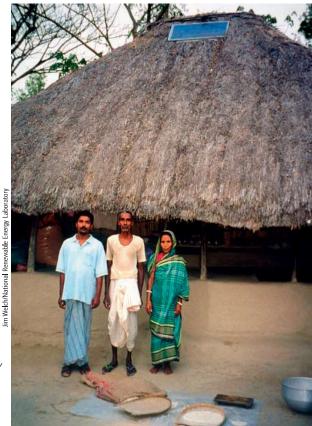




FIGURE 16.17 Solar powered LED lantern in Mexico.



FIGURE 16.18 Using solar cells to produce electricity has advantages and disadvantages (**Concept 16.3**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using this technology outweigh its disadvantages? Why?

 $\label{top:martin D. Vonka/Shutterstock.com. Bottom: pedrosala/Shutterstock.com.} \\$

such as coal or natural gas, the prices of which are controlled by available supplies. Prices for solar cell systems are likely to continue dropping because of technological advances, mass production, and decreased installation costs.

Solar cells cannot produce electricity at night, and storing energy in large batteries for use at night and on cloudy

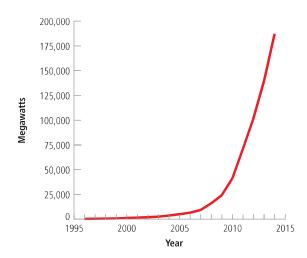


FIGURE 16.19 Global installed electricity capacity of solar cells, 1996–2014. *Data analysis:* By what factor and percent did the capacity of installed solar cell increase between 1996 and 2015?

(Compiled by the authors using data from U.S. Energy Information Administration, International Energy Agency, Worldwatch Institute, and Earth Policy Institute.)

days is expensive. However, researchers at Ohio State University have developed a solar cell panel with a built-in battery that is 25% less expensive and 20% more efficient than conventional batteries. If it can be mass produced, this invention could revolutionize the use of solar energy to produce electricity.

In 2015, solar energy provided only 0.6% of U.S. electricity. However, this new technology is growing exponentially at a rapid rate (Figure 16.19) and prices continue to drop. If pushed hard and supported with government subsidies equivalent to or greater than fossil fuel subsidies, solar energy could supply 5% of U.S. electricity by 2020 and as much as 23% by 2050, according to projections by the NREL.

After 2050, continuing exponential growth and doubling of the large base of solar electricity would allow it to become one of the top sources of electricity for the United States and much of the world. If that happens, it will represent global application of the solar energy **principle of sustainability**. **GREEN CAREER: Solar-cell technology**

16.4 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING WIND POWER?

CONCEPT 16.4 Wind is one of the fastest growing, least expensive, and cleanest ways to produce electricity.

Using Wind to Produce Electricity

Simply put, *wind* is air in motion. Land near the earth's Equator absorbs more solar energy than does land near its



Poles. This uneven heating of the earth's surface and its atmosphere, combined with the earth's rotation, causes winds to blow (Figure 7.9, p. 146). Because wind is an indirect form of solar energy, using it is a way to apply the solar energy **principle of sustainability**.

The kinetic energy from blowing winds can be captured and converted to electrical energy by devices called *wind turbines*. As a turbine's blades spin, they turn a drive shaft that connects to the blades. The drive shaft then turns an electric generator, which produces electricity (Figure 16.20, left). Groups of wind turbines called *wind farms* transmit electrical energy to electrical grids. Wind farms can operate both on land (chapter-opening photo) and at sea (Figure 16.20, right).

Today's wind turbine towers can be as tall as a 60-story building and have blades as long as 70 meters (230 feet)—the combined length of six school buses. This height allows them to tap into the strong and more constant winds found at higher altitudes on land and at sea (Figure 16.20, right) and to produce more electricity at a lower cost. A typical wind turbine can generate enough electricity to power more than 1,000 homes.

Harvard University researcher Xi Lu estimates that wind power has the potential to produce 40 times the world's current use for electricity. Most of world's wind farms have been built on land in parts of Europe, China, and the United States. However, the frontier for wind energy is offshore wind farms (Figure 16.20, right) because

winds are generally much stronger and steadier over coastal waters than over land. When located far enough offshore, wind farms are not visible from the land. Building offshore also avoids the need for negotiations among multiple landowners over the locations of turbines and electrical transmission lines. Offshore wind farms have been built off the coasts of 10 European countries, as well as China and Japan. Researchers at the Sandia National Laboratories—with funding from the DOE—are developing towering hurricane-resistant wind turbines for use at sea with blades that are 200 meters (650 feet) long. This is roughly the length of two football fields or seven blue whales.

Since 1990, wind power has been the world's second-fastest-growing source of electricity after solar cells (Figure 16.21). In 2014, the United States led the world in producing electricity from wind, followed by China and Germany.

In 2013, wind farms in more than 85 countries produced about 3.5% of the world's electricity—enough to provide electricity for more than 500 million people. Experts project that by 2050, this number could grow to 31%. Around the world, more than 400,000 people are employed in the production, installation, and maintenance of wind turbines and such job numbers will grow as wind power continues its rapid expansion (Figure 16.21).

In 2015, wind power produced 45% of Denmark's electricity and the country plans to increase this to 50% by

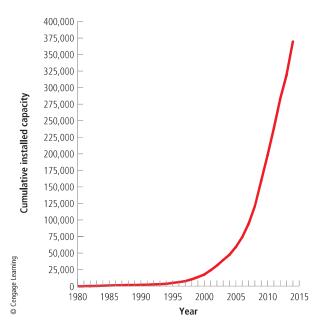


FIGURE 16.21 Global installed capacity for generation of electricity by wind energy, 1980–2014. **Data analysis:** In 2014, the world's installed capacity for generating electricity by wind power was about how many times more than it was in 2005?

(Compiled by the authors using data from Global Wind Energy Council, European Wind Energy Association, American Wind Energy Association, Worldwatch Institute, World Wind Energy Association, and Earth Policy Institute.)

2020 and to 85% by 2035. By 2015, wind turbines in the United States were producing 4.7% of the country's electricity, an amount equal to that produced by 64 large nuclear power reactors.

A study published in the *Proceedings of the U.S. National Academy of Sciences* estimated that the United States has enough wind potential to meet 16 to 22 times its current electricity needs. The DOE estimates that wind farms at favorable sites in three states—North Dakota, Kansas, and Texas—could more than meet the electricity needs of the lower 48 states if a modern electrical grid is available to distribute the electricity. In addition, the NREL estimates that winds off the Atlantic and Pacific coasts and the shores of the Great Lakes could generate 4 times the electricity currently used in the lower 48 states—more than enough electricity to replace all of the country's coal-fired power plants. Many states in these regions plan to tap into this vast source of energy and boost their economies.

According to a 2015 study by the DOE, with the continuation of government subsidies, the United States could get 30% of its electricity from wind by 2030. This would create up to 600,000 jobs and lower energy bills. It would also reduce air pollution and slow climate change and ocean acidification by reducing the use of coal to produce electricity.

Wind is abundant, widely distributed, and inexhaustible, and wind power is mostly carbon-free and pollution-free. A wind farm can be built within 9 to 12 months and expanded as needed. And although wind farms can cover large areas of land, the turbines themselves occupy only a small portion of the land.

Many U.S. landowners in favorable wind areas are investing in wind farms. Landowners typically receive \$3,000 to \$10,000 a year in royalties for each wind turbine placed on their land. The land can still be used for activities such as growing crops or grazing cattle (Figure 16.20, left, and chapter-opening photo). An acre of land in northern Iowa planted in corn can produce about \$1,000 worth of ethanol car fuel. The same site used for a single wind turbine can produce \$300,000 worth of electricity per year

Since 1990, prices for electricity produced by wind in the United States (and other countries) have been falling sharply. Wind farms in Texas generate so much electricity that some utility companies are offering free electricity at night. Prices are expected to keep falling because of technological improvements in wind turbine design that increase their energy efficiency and reduce mass-production and maintenance costs. The DOE and the Worldwatch Institute estimate that, if we were to apply the **full-cost pricing principle of sustainability** by including the harmful environmental and health costs of various energy resources in comparative cost estimates, wind energy would be the least costly way to produce electricity.

Like any energy source, wind power has some draw-backs. Land areas with the greatest wind power potential are often sparsely populated and located far from cities. Thus, to take advantage of its huge potential for using wind energy, the United States will have to invest in replacing and expanding its outdated electrical grid with a smart grid system to connect with the country's wind farms.

Because winds can die down, a backup source of power such as natural gas is needed. However, a large number of wind farms in different areas connected to a smart grid could take up the slack when winds die down in any one area without the need for a backup source of energy. This could make wind power a more stable and reliable source of electricity than fossil fuel and nuclear power plants.

Wind turbines can also kill birds and bats—a problem that scientists and wind power developers are working on (Science Focus 16.2).

Figure 16.22 lists the major advantages and disadvantages of using wind to produce electricity. According to many energy analysts, wind power has more benefits and fewer serious drawbacks than any other energy resource, except for reducing energy waste (Figure 16.2) and increasing energy efficiency (Figure 16.3). **GREEN CAREER:** Wind-energy engineering

SCIENCEFOCUS 16.2

Making Wind Turbines Safer for Birds and Bats

Wildlife ecologists and bird experts estimate that collisions with wind turbines kill as many as 234,000 birds and 600,000 bats each year in the United States. Such deaths are a legitimate concern.

However, according to studies by the Defenders of Wildlife, the U.S. Fish and Wildlife Service, and the Smithsonian Conservation Biology Institute wind turbines are a minor source of bird and bat deaths compared to other human-related sources and account for only about 0.003% of such deaths. Each year, domestic and feral cats kill 1.4 billion to 3.7 billion birds; collisions with windows 1 billion; cars and trucks 89 million to

340 million; high-tension wires 174 million; and pesticides 72 million. Most of the wind turbines involved in bird and bat deaths were built years ago using outdated designs, and some were built in bird migration corridors.

Developers of new wind farms avoid bird migration corridors, as well as areas with large bat colonies. Newer turbine designs reduce bird and bat deaths considerably by using slower blade rotation speeds along with several other innovations. For example, researchers are also evaluating the use of ultraviolet light to deter birds and bats from turbines. Ultrasonic devices attached to turbine blades scare bats away by emitting

high-frequency sounds that we cannot hear. Another approach is to use radar to track large incoming flocks of migrating birds and to shut down the turbines until they pass. In addition, many older wind turbines are being replaced with new designs that sharply reduce bird and bat deaths by providing no perching or nesting surfaces.

CRITICAL THINKING

What would you say to someone who tells you that we should not depend on wind power because wind turbines can kill birds and bats?

Trade-Offs Wind Power **Advantages** Disadvantages High net energy Needs backup or storage system when winds die down unless connected in a Widely available national electrical grid Low electricity Visual pollution for cost some people Little or no direct emissions of CO2 Low-level noise and other air bothers some people pollutants Can kill birds if not Easy to build and properly designed

FIGURE 16.22 Using wind to produce electricity has advantages and disadvantages (**Concept 16.4**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why? Do you think the advantages outweigh the disadvantages? Why?

Top: TebNad/Shutterstock.com. Bottom: Yegor Korzh/Shutterstock.com.

16.5 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING GEOTHERMAL ENERGY?

CONCEPT 16.5 Geothermal energy can supply many areas with heat and electricity, and has a generally low environmental impact, but sites where it can be produced economically are limited.

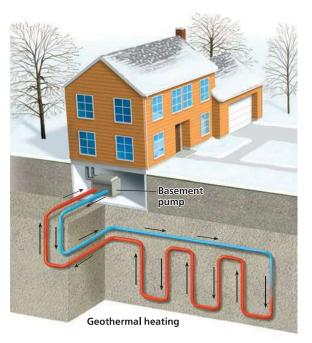
Tapping into the Earth's Internal Heat

Geothermal energy is heat stored in soil, underground rocks, and fluids in the earth's mantle. Geothermal energy is used to heat and cool buildings, and to heat water to produce electricity.

A *geothermal heat pump* system (Figure 16.23) can heat and cool a house almost anywhere in the world. This system makes use of the temperature difference between the earth's surface and underground at a depth of 3–6 meters (10–20 feet), where the temperature typically is 10–20°C (50–60°F) year-round. In winter, a closed loop of buried pipes circulates a fluid, which extracts heat from the ground and carries it to a heat pump, which transfers the heat to a home's heat distribution system. In summer, this system works in reverse, removing heat from a home's interior and storing it below ground.

expand

and located



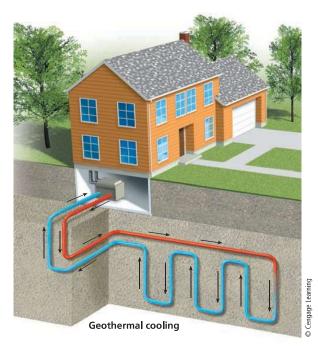


FIGURE 16.23 Natural capital: A geothermal heat pump system can heat or cool a house almost anywhere.

According to the EPA, a geothermal heat pump system is the most energy-efficient, reliable, environmentally clean, and cost-effective way to heat or cool a space. Installation costs can be high but are recouped within 3 to 5 years, after which these systems save energy and money for their owners. Initial costs can be added to a home mortgage to spread the financial burden over two or more decades.

We can also tap into deeper, more concentrated *hydro-thermal reservoirs* of geothermal energy (Figure 16.24). Wells are drilled into the reservoirs to extract their dry steam (with a low water content), wet steam (with a high water content), or hot water. The steam or hot water can be used to heat homes and buildings, provide hot water, grow vegetables in greenhouses, raise fish in aquaculture ponds, and spin turbines to produce electricity.

Drilling geothermal wells, like drilling oil and natural gas wells, is expensive and requires a major investment. It is also a risky investment because drilling projects do not always succeed in tapping into concentrated deposits of geothermal energy. Once a successful deposit is found, it can supply geothermal energy for heat or to produce electricity around the clock, as long as heat is not removed from the deposit faster than the earth replaces it—usually at a slow rate. When this happens geothermal energy becomes a nonrenewable resource.

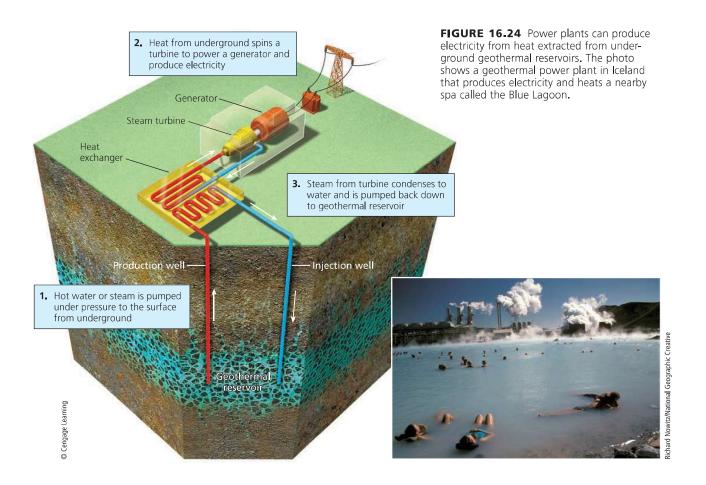
Geothermal energy is used in 24 countries, including the United States, the world's largest producer of geothermal

electricity from hydrothermal reservoirs. Most of it is produced in California, Nevada, Utah, and Hawaii (see Figure 25, p. S38, in Supplement 4 for a map of the best geothermal sites in the continental United States). In 2015, there were 134 new geothermal power plants under construction or in development in the United States. When completed, they could triple the country's electrical output from geothermal energy. The U.S. Geothermal Energy Association (GEO) estimates that 90% of the available geothermal energy for producing electricity in the United States and 60% of the potential supply in California has not been tapped.

Figure 16.25 shows the global growth in installed geothermal electricity-generating capacity between 1950 and 2014. Iceland gets almost all of its electricity from renewable hydroelectric (69%) and geothermal (29%) power plants (Figure 16.25, photo) and nearly 95% of its demand for heat and hot water from geothermal energy.

In Peru, a National Geographic Explorer is carrying out research to develop that country's geothermal resources (Individuals Matter 16.1).

Another source of geothermal energy is *hot, dry rock* found 5 kilometers or more (3 miles or more) underground almost everywhere. Water can be injected through deep wells drilled into this rock. Some of this water becomes steam that is brought to the surface and used to spin turbines to generate electricity. According to the U.S. Geological Survey, tapping just 2% of this source of geothermal



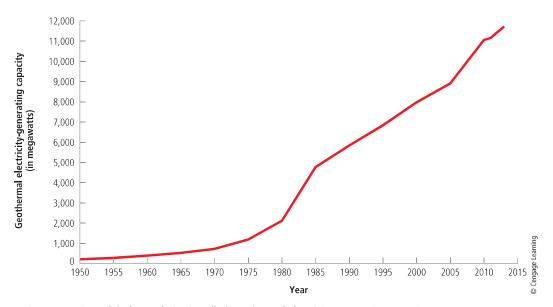


FIGURE 16.25 Global cumulative installed geothermal electricity-generating capacity, 1950–2013. *Data analysis:* About how many times more geothermal electricity-generating capacity was available in 2013 than in 1980?

(Compiled by the authors using data from International Energy Agency, Worldwatch Institute, Earth Policy Institute, and BP.)

INDIVIDUALS MATTER 16.1

Andrés Ruzo—Geothermal Energy Sleuth and National Geographic Explorer

Andrés Ruzo is a geophysicist with a driving passion to learn about geothermal energy and to show how this renewable and clean energy source can help us to solve some of the world's energy problems. As a boy, he spent his summers on the family farm in Nicaragua. Because the farm rests on top of the Casita Volcano, he was able to experience firsthand the power of the earth's heat.

As an undergraduate student at Southern Methodist University (SMU) in Dallas, Texas (USA), because of his boyhood experience, he took a course in volcanology. The course awakened his passion for geology along with a desire to learn more about the earth's heat as a source of energy. This led him to pursue a PhD in geophysics at SMU's Geothermal Laboratory.

O Andres Ruzo

Since 2009, Ruzo and his wife and field assistant, Sofia, have been gathering data across Peru to develop the country's first detailed heat flow map—which will help identify areas of geothermal energy potential. Their field work involves lowering temperature measuring equipment down into oil, gas, mining, or water wells. Much of this work was done in the Talara Desert in northwestern Peru, where surface temperatures can exceed 54°C (130°F). Other wells were temperature logged deep in the Amazon rainforest. These data illustrate how thermal energy flows through the upper crust of the earth, and highlights areas where earth's heat can potentially be tapped as a source of energy.

Ruzo believes that geothermal energy is a "sleeping giant" that, if properly harnessed, can be an important renewable source of heat and electricity. He says that his goal in life is "to be a force of positive change in the world."

energy in the United States could produce more than 2,000 times the amount of electricity currently used in the country. The limiting factor is its high cost. **GREEN CAREER: Geothermal engineer**

Figure 16.26 lists the major advantages and disadvantages of using geothermal energy (**Concept 16.5**). The two biggest factors limiting the widespread use of geothermal

energy are the lack of hydrothermal sites with concentrations of heat high enough to make it affordable and the high cost of drilling the wells and building the plants.

16.6 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING BIOMASS AS AN ENERGY SOURCE?

CONCEPT 16.6A Solid biomass is a potentially renewable resource, but it requires large areas of land and burning it faster than it is replenished produces a net gain in emissions of greenhouse gases.

CONCEPT 16.6B Liquid biofuels derived from biomass can lessen dependence on oil, but devoting large areas of land to biofuel crops can degrade soil and biodiversity and increase greenhouse gas emissions.

Producing Energy by Burning Solid Biomass

Energy can be produced by burning the solid biomass or organic matter found in plants or plant-related material or by converting it to gaseous or liquid biofuels. Examples of biomass fuels include wood, wood pellets, wood wastes, charcoal made from wood, and agricultural wastes such as sugarcane stalks, rice husks, and corncobs.

Trade-Offs

Geothermal Energy

Advantages

Medium net energy and high efficiency at accessible sites

Lower CO₂ emissions than fossil fuels

Low operating costs at favorable sites

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Disadvantages

High cost except at concentrated and accessible sources

Scarcity of suitable sites

Noise and some CO₂ emissions

FIGURE 16.26 Using geothermal energy for space heating and for producing electricity or high-temperature heat for industrial processes has advantages and disadvantages (**Concept 16.5**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why? Do you think the advantages of this energy resource outweigh its disadvantages? Why?

Photo: N. Minton/Shutterstock.com

Biomass is burned mostly for heating and cooking, but can also be used for industrial processes and generating electricity. Biomass used for heating and cooking supply 10% of the world's energy, 35% of the energy used in less-developed countries, and 95% of the energy used in the poorest countries.

Wood is a renewable resource only if it is not harvested faster than it is replenished. The problem is that 2.7 billion people in 77 less-developed countries face a *fuelwood crisis*. They often are forced to meet their fuel needs by harvesting trees faster than new ones can replace them.

One solution is to plant fast-growing trees, shrubs, or perennial grasses in *biomass plantations*. However, repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. It can also allow for the spread of nonnative tree species that become invasive. Clearing forests and grasslands to provide fuel also reduces biodiversity and the amount of vegetation that would otherwise capture climate-changing CO₂.

In the southeastern and northwestern United States, virgin and second-growth hardwood forests are being cleared to make wood pellets for fuel. They are mostly exported to European Union countries for use in heating factories and producing electricity. Critics call this an unsustainable practice. The pellet industry denies that they are removing whole trees and says they are using only tree branches and other wood wastes to make the pellets. However, as the volume of wood pellet production has increased, observers are seeing the destruction of large forested areas.

There is also controversy over burning forestry and crop wastes to provide heat and electricity. The supply of such wastes is not as large as some have estimated, and collecting and transporting these widely dispersed wastes to factories and utilities is difficult and expensive. In addition, crop wastes left on fields are valuable soil nutrients, and many argue they should be used as such.

Burning wood and other forms of biomass produces CO_2 and other pollutants such as fine particulates in smoke. In 2014, the EPA proposed phasing in stricter regulations to curb such pollution from new residential woodburning stoves in the United States, beginning in 2015. Figure 16.27 lists the major advantages and disadvantages of burning solid biomass as a fuel (**Concept 16.6A**).

Using Liquid Biofuels to Power Vehicles

Biomass can also be converted into liquid biofuels for use in motor vehicles. The two most common liquid biofuels are *ethanol* (ethyl alcohol produced from plants and plant wastes) and *biodiesel* (produced from vegetable oils). The biggest producers of liquid biofuel are, in order, the United States (producing ethanol from corn), Brazil (producing ethanol from sugarcane residues), the European Union (producing biodiesel from vegetable oils), and China (producing ethanol from nongrain plant sources).

Trade-Offs

Solid Biomass

Advantages

Widely available in some areas

Moderate costs

Medium net energy

No net CO₂ increase if harvested, burned, and replanted sustainably

Plantations can help restore degraded lands

Disadvantages

Contributes to deforestation

Clear-cutting can cause soil erosion, water pollution, and loss of wildlife habitat

Can open ecosystems to invasive species

Increases CO₂ emissions if harvested and burned unsustainably

FIGURE 16.27 Burning solid biomass as a fuel has advantages and disadvantages (**Concept 16.6A**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why? Do you think the advantages outweigh the disadvantages? Why?

Top: Fir4ik/Shutterstock.com. Bottom: Eppic/Dreamstime.com.

Biofuels have three major advantages over gasoline and diesel fuel produced from oil. *First,* biofuel crops can be grown throughout much of the world, which can help more countries reduce their dependence on imported oil. *Second,* if growing new biofuel crops keeps pace with harvesting them, there is no net increase in CO₂ emissions, unless existing grasslands or forests are cleared to plant biofuel crops. *Third,* biofuels are easy to store and transport through existing fuel networks and can be used in motor vehicles at little additional cost.

Since 1975, global ethanol production has increased rapidly, especially in the United States and Brazil. Brazil makes ethanol from *bagasse*, a residue produced when sugarcane is crushed. This sugarcane ethanol has a medium net energy that is 8 times higher than that of ethanol produced from corn. About 45% of Brazil's motor vehicles run on ethanol or ethanol–gasoline mixtures produced from sugarcane grown on only 1% of the country's arable land. This has greatly reduced Brazil's dependence on imported oil.

About 43% of the corn produced in the United States in 2014 was used to make ethanol, which is mixed with gasoline to fuel cars. Studies indicate that corn-based ethanol has a low net energy because of the large-scale use of fossil fuels to produce fertilizers, grow the corn, and convert it to ethanol.

According to a 2015 report by the Environmental Working Group (EWG), producing and burning combased ethanol adds at least 20% more greenhouse gases to

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the atmosphere per unit of energy than does producing and burning gasoline. Growing corn also requires a great deal of water, and ethanol distilleries produce large volumes of wastewater. Another EWG study concluded that the heavily government-subsidized corn-based ethanol program in the United States has taken more than 2 million hectares (5 million acres) of land out of the soil conservation reserve (p. 310), an important topsoil preservation program.

As a result, a number of scientists and energy economists call for withdrawing all government subsidies for corn-based ethanol production and sharply reducing the large amount of ethanol required in U.S. gasoline as mandated by the Energy Independence and Security Act of 2007. Corn producers and ethanol distillers claim that the harmful environmental effects of corn-based ethanol are overblown and that it has many environmental and economic benefits

An alternative to corn-based ethanol is *cellulosic ethanol*, which is produced from the inedible cellulose that makes up most of the biomass of plants in the form of leaves, stalks, and wood chips. Cellulosic ethanol can be produced from tall and rapidly growing grasses such as switchgrass and miscanthus that do not require nitrogen fertilizers and pesticides. They also do not have to be replanted because they are perennial plants, and they can be grown on degraded and abandoned farmlands.

Ecologist David Tilman (Individuals Matter 12.1, p. 314) estimates that the net energy of cellulosic ethanol is about 5 times that of corn-based ethanol. However, producing cellulosic ethanol is not yet affordable, and growing switchgrass requires even more land than corn. More research is also needed to determine possible environmental impacts.

In Malaysia and Indonesia, large areas of tropical rain forests are being cleared and replaced with plantations of oil palm trees (Figure 10.4, p. 225), which produce a fruit that contains palm oil. After the oil is extracted, about a third of it is exported to Europe to make biodiesel fuel and the rest goes into processed food and cosmetics. The clearing and burning of tropical forests to make space for these palm oil plantations eliminates the vital biodiversity of the forests. It also adds CO_2 to the atmosphere, and the resulting plantations remove far less CO_2 than do the forests they replace.

In a United Nations report on bioenergy, and in another study by R. Zahn and his colleagues, scientists warned that large-scale biofuel crop farming could reduce biodiversity by eliminating more forests, grasslands, and wetlands and increasing soil degradation and erosion. It would also lead to higher food prices if it becomes more profitable to grow corn for biofuel rather than for feeding livestock and people.

Another approach involves using certain strains of algae to produce biofuels. Algae can grow year-round in various aquatic environments. The algae store their energy as natural oils within their cells. This oil can be extracted

Trade-Offs

Liquid Biofuels

Advantages

Reduced CO₂ emissions for some crops

Medium net energy for biodiesel from oil palms

Medium net energy for ethanol from sugarcane

Disadvantages

Fuel crops can compete with food crops for land and raise food prices

Fuel crops can be invasive species

Low net energy for corn ethanol and for biodiesel from soybeans

Higher CO₂ emissions from corn ethanol

FIGURE 16.28 Ethanol and biodiesel biofuels have advantages and disadvantages (**Concept 16.6B**). *Critical thinking:* Which single advantage and which single disadvantage do you think are the most important? Why?

and refined to make a product very much like gasoline or biodiesel. Researchers estimate that algae can produce 10 times more energy per area of land than plants used to produce cellulosic ethanol can produce. Currently, extracting and refining the oil from algae is too costly. More research is also needed on which types of algae are most suitable and which ways of growing them are the most successful.

Figure 16.28 compares the advantages and disadvantages of using biodiesel and ethanol liquid biofuels.

16.7 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING HYDROPOWER?

CONCEPT 16.7 We can use water flowing over dams, tidal flows, and ocean waves to generate electricity, but environmental concerns and limited availability of suitable sites may limit the use of these energy resources.

Producing Electricity from Falling and Flowing Water

Hydropower is any technology that uses the kinetic energy of flowing and falling water to produce electricity. It is an indirect form of solar energy because it depends on heat from the sun evaporating surface water. The water is deposited as rain or snow at higher elevations. Through

gravity, the water can flow to lower elevations in rivers as part of the earth's solar-powered water cycle (Figure 3.19, p. 63).

The most common approach to harnessing renewable hydropower is to build a high dam across a large river to create a reservoir (see photo on pp. 322–323). Some of the water stored in the reservoir is allowed to flow through large pipes at controlled rates. The flowing water causes blades on a turbine to turn and spin a generator to produce electricity. Electric lines then carry the electricity to where it is needed.

Hydropower is the world's leading renewable energy source and produces about 16% of the world's electricity in 2015. In order, the world's top three producers of hydropower are China, Brazil, and the United States. In 2014, hydropower supplied about 7% of the electricity used in the United States and about half of the electricity used on the West Coast, mostly in Washington and California. Electricity from hydropower has been growing (Figure 16.29).

According to the United Nations, only 13% of the world's potential for hydropower has been developed. Countries with the greatest potential include China, India, and South America, as well as countries in Central Africa and Asia. China has plans to more than double its hydropower output during the next decade and is also building or funding more than 200 hydropower dams around the world

Hydropower is the least expensive renewable energy resource. Once a dam is up and running, its source of energy—flowing water—is free and is annually renewed by snow and rainfall. Despite their potential, some analysts expect that the use of large-scale hydropower plants will fall slowly over the next several decades, as many

existing reservoirs fill with silt and become useless faster than new systems are built. There is also growing concern over emissions of methane, a potent greenhouse gas, from the decomposition of submerged vegetation in hydropower plant reservoirs, especially in warm climates. Scientists at Brazil's National Institute for Space Research estimate that the world's largest dams altogether are the single largest human-caused source of climate-changing methane. The electricity output of hydropower plants may also drop if atmospheric temperatures continue to rise. This will cause melting of mountain glaciers, a primary source of water for these plants.

It is unlikely that large new hydroelectric dams will be built in the United States because most of the best sites already have dams and because of controversy and the high costs involved with building new dams. However, the turbines at many existing U.S. hydropower dams could be modernized and upgraded to increase their output of electricity. Figure 16.30 lists the major advantages and disadvantages of using large-scale hydropower plants to produce electricity (**Concept 16.7**).

Using Tides and Waves to Produce Electricity

Another way to produce electricity from flowing water is to tap 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 can be built across the mouths of such bays and estuaries to capture the energy in these flows for hydropower, but sites with large tidal flows are rare. The only three large tidal energy dams currently operating are in France, Nova Scotia, and South Korea. According to energy

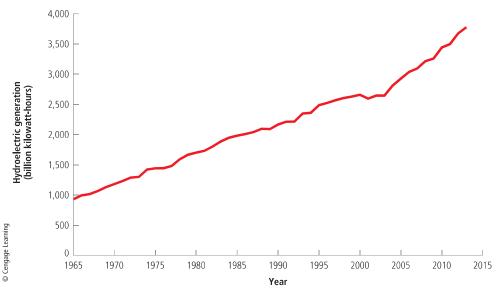


FIGURE 16.29 World hydroelectric generation, 1965–2013. **Data analysis:** After 1965, how many years did it take the world to double its hydroelectric capacity?

(Compiled by the authors using data from International Energy Agency, British Petroleum, Worldwatch Institute, and Earth Policy Institute.)

Trade-Offs Large-Scale Hydropower **Advantages** Disadvantages High net energy Large land disturbance and Large untapped displacement of potential people Low-cost High CH₄ emissions electricity from rapid biomass decay in shallow Low emissions of tropical reservoirs CO2 and other air pollutants in temperate Disrupts downstream areas aquatic ecosystems

FIGURE 16.30 Using large dams and reservoirs to produce electricity has advantages and disadvantages (**Concept 16.7**). **Critical thinking:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of this technology outweigh its disadvantages? Why?

Photo: Andrew Zarivny/Shutterstock.com

experts, tidal power will make only a minor contribution to the world's electricity production because of the rarity of suitable sites.

For decades, scientists and engineers have been trying to produce electricity by tapping wave energy along seacoasts where there are almost continuous waves. However, production of electricity from tidal and wave systems is limited because of a lack of suitable sites, citizen opposition at some sites, high costs, and equipment damage from saltwater corrosion and storms.

16.8 WHAT ARE THE ADVANTAGES AND DISADVANTAGES OF USING HYDROGEN AS AN ENERGY SOURCE?

CONCEPT 16.8 Hydrogen is a clean energy source as long as it is not produced with the use of fossil fuels, but it has a negative net energy.

Will Hydrogen Save Us?

Hydrogen (H) is the simplest and most abundant chemical element in the universe. The sun produces its energy, which sustains life on the earth, through the nuclear fusion of hydrogen atoms (Figure 15.27, p. 402).

Some scientists say that the fuel of the future is hydrogen gas (H₂). Most of their research has been focused on

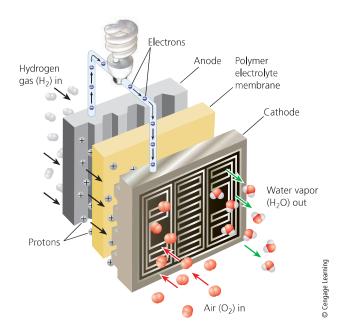


FIGURE 16.31 A fuel cell takes in hydrogen gas and separates the hydrogen atoms' electrons from their protons. The electrons flow through wires to provide electricity, while the protons pass through a membrane and combine with oxygen gas to form water vapor. Note that this process is the reverse of electrolysis, the process of passing electricity through water to produce hydrogen fuel.

using fuel cells (Figure 16.31) that combine H_2 and oxygen gas (O_2) to produce electricity and water vapor ($2 H_2 + O_2 \rightarrow 2 H_2O + energy$), a harmless chemical that is emitted into the atmosphere.

Widespread use of hydrogen as a fuel for running motor vehicles, heating buildings, and producing electricity would eliminate most of the outdoor air pollution that comes from burning fossil fuels. It would also greatly slow climate change and ocean acidification, because production and use of hydrogen do not increase CO_2 emissions unless the H_2 is produced with the use of fossil fuels or nuclear power.

However, there are four major challenges in turning the vision of hydrogen as a major fuel into reality. *First*, there is hardly any hydrogen gas (H₂) in the earth's atmosphere. We can produce H₂ by heating water or passing electricity through it; by stripping it from the methane (CH₄) found in natural gas and from gasoline molecules; and through a chemical reaction involving coal, oxygen, and steam. *Second*, hydrogen has a negative net energy because it takes more high-quality energy to produce H₂ using these methods than we get by burning it. *Third*, although fuel cells are the best way to use H₂, current versions of fuel cells are expensive. However, progress in the development of nanotechnology (see Science Focus 14.1, p. 370) and mass production could lead to less expensive fuel cells.

Fourth, whether or not a hydrogen-based energy system produces less outdoor air pollution and CO_2 than a fossil fuel system depends on how the H_2 fuel is produced. Electricity from coal-burning and nuclear power plants can be used to decompose water into H_2 and O_2 . But this approach does not avoid the harmful environmental effects associated with using coal and the nuclear fuel cycle. In addition, research indicates that making H_2 from coal or stripping it from methane or gasoline adds much more CO_2 to the atmosphere per unit of heat generated than does burning the coal or methane directly.

Hydrogen's negative net energy is a serious limitation. It means that this fuel will have to be heavily subsidized in order for it to compete in the open marketplace. However, this could change. Chemist Daniel Nocera has been learning from nature by studying how a leaf uses photosynthesis to produce the chemical energy used by plants and he has developed an "artificial leaf." This credit-card-sized silicon wafer produces H₂ and O₂ when placed in a glass of tap water and exposed to sunlight. The hydrogen can be extracted and used to power fuel cells. Scaling up this or similar processes to produce large amounts of H₂ at an affordable price with an acceptable net energy over the next several decades could represent a tipping point for use of solar energy and hydrogen fuel. Doing so would help implement the solar energy **principle of sustainability** on a global scale. GREEN CAREER: Fuel cell technology

Figure 16.32 lists the major advantages and disadvantages of using hydrogen as an energy resource (**Concept 16.8**).

Trade-Offs

Hydrogen

Advantages

Can be produced from plentiful water at some sites

No CO₂ emissions if produced with use of renewables

Good substitute for oil

High efficiency in fuel cells



Disadvantages

Negative net energy

CO₂ emissions if produced from carbon-containing compounds

High costs create need for subsidies

Needs H₂ storage and distribution system

FIGURE 16.32 Using hydrogen as a fuel for vehicles and for providing heat and electricity has advantages and disadvantages (**Concept 16.8**). **Critical thinking:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of hydrogen fuel outweigh its disadvantages? Why?

Photo: LovelaceMedia/Shutterstock.com

16.9 HOW CAN WE MAKE THE TRANSITION TO A MORE SUSTAINABLE ENERGY FUTURE?

CONCEPT 16.9 We can make the transition to a more sustainable energy future by reducing energy waste, improving energy efficiency, using a mix of renewable energy resources, and including the environmental and health costs of energy resources in their market prices.

Shifting to a New Energy Economy

According to its proponents, shifting to a new set of energy resources over the next 50 to 60 years would have numerous environmental, health, and economic benefits.

China (which uses 20% of the world's energy) and the United States (which uses 19% of the world's energy) are the key players in making this shift. China has a long way to go in reducing its heavy dependence on coal and leads the world in climate-changing CO₂ emissions. However, it has launched efforts to make its economy more energy efficient, build a modern smart electrical grid, and install solar hot water heaters on a large scale. China is also building wind farms and solar power plants, supporting research on better batteries and improved solar and wind technologies, and building and selling all-electric cars. It is also making money by producing and selling more wind turbines and solar cell panels than any other country.

The United States is also making efforts to shift to a new energy economy. However, it is falling behind China's efforts and those of countries such as Germany, Sweden, and Denmark. This is mostly because of more than 40 years of successful efforts by powerful fossil fuel and electric utility companies to stop or slow down this shift because it threatens their profits.

This energy and economic transition is underway and is accelerating because it is increasingly driven by market forces. This is the result of the rapidly falling prices of electricity produced by the sun and wind, new energy technologies, and strong and growing public opposition to coal and nuclear power. Investors are moving rapidly into clean energy technologies. According to many scientists and energy economists, the shift to a new energy economy could be further accelerated if citizens, the leaders of emerging renewable energy companies, and energy investors demanded the following from their elected officials:

- Use **full-cost pricing** to include the harmful health and environmental costs of using fossil fuels and all other energy resources in their market prices.
- Tax carbon emissions. This is supported by most economists and many business leaders, and is now done in 40 countries. Use the revenue to reduce taxes on income and wealth and to promote investments and

- research in new energy-efficient and renewable energy technologies. (We discuss this further in Chapter 19.)
- Sharply decrease and eventually eliminate government subsidies for fossil fuel industries, which are wellestablished and profitable businesses.
- Establish a national feed-in-tariff system that guarantees owners of wind farms, solar power plants, and home solar systems a long-term price for energy that they feed into their electrical grids (as is being done in more than 50 countries, many of them in Europe).
- Mandate that a certain percentage (typically 20–40%) of the electricity generated by utility companies be

- from renewable resources (as is done in 24 countries and in 29 U.S. states).
- Increase government fuel efficiency (CAFE) standards for new vehicles to 43 kilometers per liter (100 miles per gallon) by 2040.

We have the creativity, wealth, and most of the technology to make the transition to a safer, more energy-efficient, and cleaner energy economy within your lifetime. With such a shift, we could greatly increase our beneficial environmental impact. Figure 16.33 lists ways in which you can take part in the transition toward such a future.

What Can You Do?

Shifting to More Sustainable Energy Use

- Walk, bike, or use mass transit or a car pool to get to work or school
- Drive only vehicles that get at least 17 kpl (40 mpg)
- Have an energy audit done in the place where you live
- Superinsulate the place where you live and plug all air leaks
- Use passive solar heating
- For cooling, open windows and use fans
- Use a programmable thermostat and energy-efficient heating and cooling systems, lights, and appliances
- Turn down your water heater's thermostat to 43–49°C (110–120°F) and insulate hot water pipes
- Turn off lights, TVs, computers, and other electronics when they are not in use
- Wash laundry in cold water and air dry it on racks

FIGURE 16.33 Individuals matter: You can make a shift in your own life toward using energy more sustainably. *Critical thinking:* Which three of these measures do you think are the most important ones to take? Why? Which of these steps have you already taken and which do you plan to take?

IG IDEAS

- To make our economies more sustainable, we need to reduce our use of fossil fuels, especially coal, and greatly increase energy efficiency, reduce energy waste, and use a mix of renewable energy resources, especially the sun and wind.
- Making this energy shift will have important economic and environmental benefits.
- Making the transition to a more sustainable energy future will require including the harmful environmental and health costs of all energy resources in their market prices, taxing carbon emissions, and greatly increasing government subsidies and research and development for improving energy efficiency and developing renewable energy resources.

Tying It All Together

Saving Energy and Money and Reducing Our Environmental Impact

In the Core Case Study, we learned that by wasting energy, we waste money and increase our harmful environmental impact. The world and the United States waste so much energy that reducing this waste by increasing energy efficiency and saving energy is the quickest, cleanest, and usually the cheapest way to provide more energy. In doing so, we would also reduce pollution and environmental degradation and slow climate change and ocean acidification.

Over the next 50 to 60 years, we could choose to rely less on fossil fuels, especially coal, and more on increasing energy efficiency and using a mix of solar, wind, and other renewable energy resources. Making this energy shift would have enormous economic, environmental, and health benefits.

Relying more on energy from the sun and wind helps us to implement the solar energy **principle of sustainability**. It also follows the chemical cycling **principle of sustainability** by reducing our excess inputs of CO₂ into the atmosphere, which disrupt the earth's carbon cycle. This energy shift also mimics the earth's biodiversity **principle of sustainability** by reducing the environmental degradation that degrades biodiversity.

Making this chiff. ""

Making this shift will require implementing the full-cost pricing **principle of sustainability** by including the harmful health and environmental costs of all energy resources in their market prices. It will also require compromise and trade-offs in the political arena, in keeping with the win-win **principle of sustainability**. By making this energy shift,

we would also by implementing the ethical **principle of sustainability** that calls for us to honor future generations by increasing our beneficial environmental impact.



Chapter Review

Core Case Study

1. What are two ways in which we waste energy? What are the benefits of reducing this waste?

Section 16.1

2. What is the key concept for this section? Why do we need to make a new energy transition over the next 50 to 60 years? What are the two key components of this energy resource shift? What are the economic and environmental advantages of making this energy transition? List three factors that are driving this shift. How would the United States benefit from it? Describe Germany's progress in making this energy shift.

Section 16.2

3. What are the two concepts for this section? Define and give an example of **energy efficiency**. Explain why improving energy efficiency and reducing energy waste is a major energy resource. What percentage of the energy used in the United States is

unnecessarily wasted? Why is so much energy wasted? List three widely used energy-inefficient technologies. What are the major advantages of reducing energy waste? List four ways to save energy and money in industry. What is cogeneration? What is a smart electric grid and why is it important? What are U.S. CAFE standards? What are the hidden costs of using gasoline? List four ways to save energy and money in transportation. Distinguish between hybrid, plug-in hybrid, and all-electric vehicles. Explain the importance of developing better and cheaper batteries and list some advances in this area. What are fuel cells and what are their major advantages and disadvantages? What are some green architecture technologies? What is superinsulation? What are 10 ways to improve energy efficiency in existing buildings? List six ways in which you can save energy where you live. What is the rebound effect and how can it be reduced? Give five reasons why we are not making greater use of renewable energy.

Section 16.3

4. What is the key concept for this section? Distinguish between a passive solar heating system and an active solar heating system and list the major advantages and disadvantages of using such systems for heating buildings. What are three ways to cool houses naturally? What are solar thermal systems, how are they used, and what are the major advantages and disadvantages of using them? What is a solar cell (photovoltaic or PV cell) and what are the major advantages and disadvantages of using such devices to produce electricity?

Section 16.4

5. What is the key concept for this section? What are the advantages of using taller wind turbines? Summarize the global and U.S. potential for wind power. What are the major advantages and disadvantages of using wind to produce electricity?

Section 16.5

6. What is the key concept for this section? 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?

Section 16.6

7. What are the two key concepts for this section? What is **biomass** and what are the major advantages and disadvantages of using wood to provide heat and electricity? What are the major advantages and

disadvantages of using biodiesel and ethanol to power motor vehicles? Explain how algae and bacteria could be used to produce fuels nearly identical to gasoline and diesel fuel.

Section 16.7

8. What is the key concept for this section? Define **hydropower** and summarize the potential for expanding it. What are the major advantages and disadvantages of using hydropower? What is the potential for using tides and waves to produce electricity?

Section 16.8

9. What is the key concept for this section? What are the major advantages and disadvantages of using hydrogen as a fuel to use in producing electricity and powering vehicles?

Section 16.9

10. What is the key concept for this section? Describe efforts by China and the United States to make the shift to a new energy economy. List six strategies suggested by scientists and energy economists for making the transition to a more sustainable energy future. List five ways you can participate in making the transition to a new energy future. What are this chapter's *three big ideas*? Explain how we would be applying the six **principles of sustainability** by improving energy capacity and shifting to renewable energy resources.

Note: Key terms are in bold type.

Critical Thinking

- 1. List five ways in which you unnecessarily waste energy during a typical day, and explain how each of these actions violates the three scientific principle of sustainability.
- 2. Congratulations! You have won enough money 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?
- **3.** Suppose that 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 (p. 42) and net

- energy (Figure 15.3, p. 384) to evaluate this claim. Write a response to the homebuilder summarizing your findings.
- **4.** 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 to accomplish this if payroll taxes and income taxes were reduced to balance gasoline tax increases, with no net additional cost to consumers? Explain.
- 5. Suppose that a wind power developer has proposed building a wind farm near where you live. Would you be in favor of the project or opposed to it? Write a letter to your local newspaper or a blog for a website explaining your position and your reasoning. As part of your research, determine how the electricity you use now is generated and where the nearest power plant is located, and include this information in your arguments.

- **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 resources can compete on a level playing field in the marketplace.
 - 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 eliminated. They should be replaced with subsidies and tax breaks for improving energy efficiency and developing renewable energy alternatives.
 - **c.** Development of renewable energy alternatives should be left to private enterprise and should receive little or no help from the federal government, but the nuclear power and fossil fuels

- industries should continue to receive large federal government subsidies.
- 7. What percentages of the U.S. Department of Energy research and development budget would you devote to fossil fuels, nuclear power, renewable energy, and improving energy efficiency? How would you distribute your funds among the various renewable energy options? Explain your thinking.
- 8. How important is it to make the transition to a new energy future? Do you think it can be done? Explain. How would making such a transition affect your life and the lives of any children or grandchildren that you might have? How would not making such a transition affect your life and the lives of any children or grandchildren that you might have?

Doing Environmental Science

Do a survey of energy use at your school, based on the following questions: How is the electricity generated? How are most of the buildings heated? How is water heated? How are most of the vehicles powered? How is the computer network powered? How could energy efficiency be improved, if at all, in each of these areas? How

could your school make use of solar, wind, biomass, and other forms of renewable energy if it does not already do so? Write up a proposal for using energy more efficiently and sustainably at your school and submit it to school officials.

Global Environment Watch Exercise

Go to your MindTap course to access the GREENR database. Starting on the home page, under "Browse Issues and Topics", click on *Energy*, then select *Renewable Energy*. Use this portal to search for information on the renewable energy policy in Germany (you may also use the World Map). What are some of the challenges the German government is facing, and how are they being addressed?

What challenges would arise if a U.S. government mandate required a similar transition to renewable energies? Write a report answering these questions and discussing the effects of the "German Experiment" on the United States as it looks to revise its energy policy and address climate change.

Data Analysis

Study the table below and then answer the questions that follow it by filling in the blank columns in the table.

Model	Miles per Gallon (mpg)	Kilometers per Liter (kpl)	Annual Liters (Gallons) of Gasoline	Annual CO ₂ Emissions
Toyota Prius Hybrid	55			
Honda CR-Z AV-S7	37			
Chevrolet Cruze A-S6	30			
Ford Fusion AS6	29			
Ford F150 2WD-6 Pickup Truck	20			
Chevrolet Silverado DC15 2WD Pickup Truck	20			
Toyota Tundra Pickup Truck A-S6	16			
Ferrari AM7	13			

- 1. Using Supplement 1 (Measurement Units, p. S1), convert the miles per gallon figures in the table to kilometers per liter (kpl).
- **2.** How many liters (and how many gallons) of gasoline would each car use annually if it was driven 19,300 kilometers (12,000 miles) per year?
- **3.** How many kilograms (and how many pounds) of carbon dioxide would be released into the atmosphere each year by each car, based on the fuel consumption calculated in question 2, assuming that the combustion of gasoline releases 2.3 kilograms of CO₂ per liter (19 pounds per gallon)?