Energy Efficiency and Renewable Energy

16

Amory Lovins and the Rocky Mountain Institute

CORE CASE STUDY

In 1984, energy analyst Amory B. Lovins completed construction of a large, solar-heated, solar-powered, superinsulated, partially earth-sheltered home and office in Snowmass, Colorado (USA) (Figure 16-1), an area with extremely cold winters. The building serves as headquarters for the Rocky Mountain Institute (RMI)—a nonprofit, non-partisan, group of scientists and analysts who do research and consulting on energy, resource efficiency, and renewable energy alternatives as well as on finding ways to work toward a more just, prosperous, and life-sustaining world.

This office–home has no conventional heating system. Instead, it makes use of energy from the sun, heavy roof insulation, thick stone walls, energy-efficient windows, and a waste-heat recovery system. Solar energy provides 99% of its hot water, 95% of its daytime lighting, and 90% of its household electricity. The building's heating bill in this very cold climate is less than $50 a year. Such savings are accomplished through the use of energy-efficient lights, refrigerators, computers, and other electrical devices and solar cells, which generate electricity when exposed to sunlight. The savings from these energy-efficiency investments repaid their costs in only 10 months.

GOOD NEWS

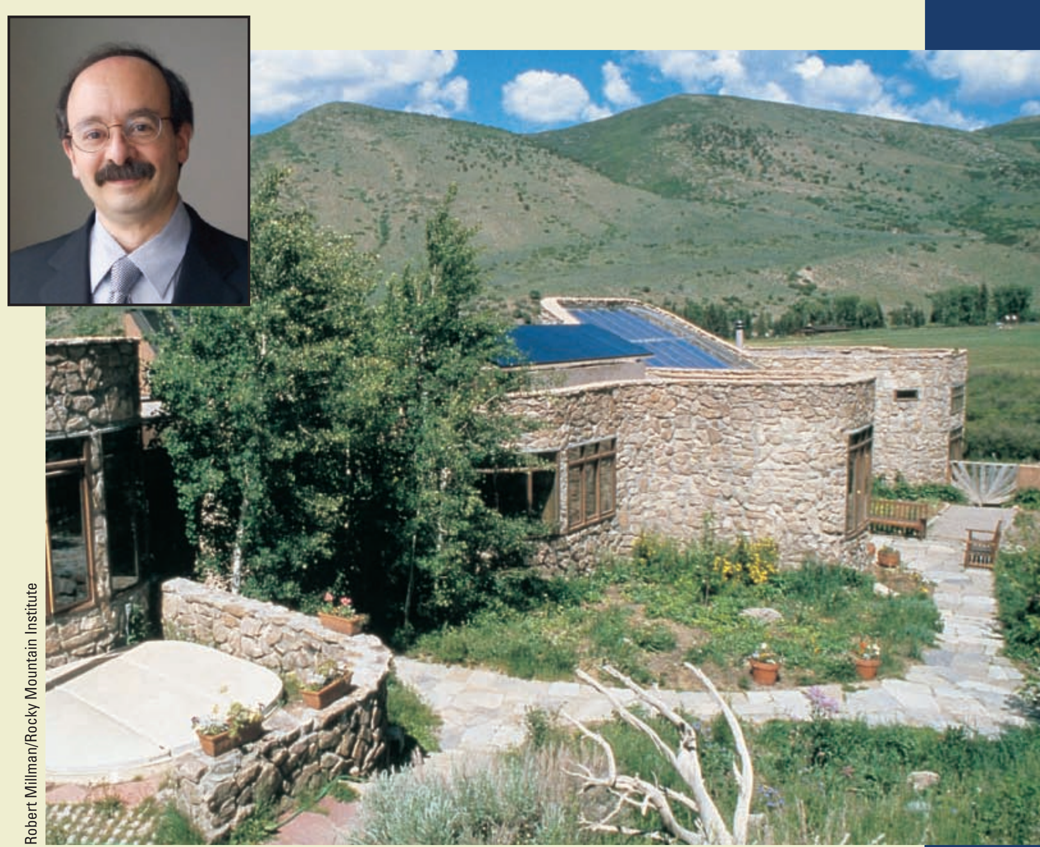
The RMI building is designed to work with nature. It was sited to collect as much sunlight as possible. It contains a central greenhouse that holds a variety of plants, humidifies the building, and helps to heat it and purify its air. Heat from the sun is stored for days in the structure's massive walls and floors. In other words, this building is a shining example of how to apply the solar energy **principle of sustainability**.

SUSTAINABILITY

The work of RMI goes far beyond the walls of this building. Lovins and his staff have consulted with more than 80 major corporations and governments in more than 50 countries, as well as state governments and the U.S. military to help them save energy and money.

In the 1970s, Lovins envisioned humanity making a transition to a more energy-efficient world fueled mostly by an array of renewable energy resources. Since then, he has dedicated his life to showing how such a shift could be made. He is now helping to lead the world into an energy future that is based on cutting energy waste to the bone and getting at least half of our energy from a variety of low- or no-carbon renewable-energy resources. In addition, he has walked his talk by designing, building, and living in his office and home shown in Figure 16-1.

In 2008, Lovins was honored as one of America's Best Leaders by U.S. News Media Group and the Harvard Kennedy School. In this chapter, we will examine the exciting and challenging energy future that he envisioned over three decades ago.



Robert Millman/Rocky Mountain Institute

Figure 16-1 This building houses part of the Rocky Mountain Institute in Snowmass, Colorado (USA), and serves as the home for the Institute's cofounder, Amory B. Lovins (inset photo), who now serves as chairman and chief scientist. The building serves as an outstanding example of energy-efficient passive solar design. For his many contributions to improving energy and resource efficiency and finding alternative solutions to energy problems over the past three decades, Lovins has won essentially every global environmental award. He has also published 29 books and several hundred papers, and still finds time to compose poetry and music, and to play the piano.

Key Questions and Concepts

16-1 **Why is energy efficiency an important energy resource?**

CONCEPT 16-1 Improving energy efficiency can save the world at least a third of the energy it uses, and it can save the United States up to 43% of the energy it uses.

16-2 **How can we cut energy waste?**

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

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 costs of using direct sunlight to produce high-temperature heat and electricity are coming down.

16-4 **What are the advantages and disadvantages of using hydropower?**

CONCEPT 16-4 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 our use of these energy resources.

16-5 **What are the advantages and disadvantages using wind power?**

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

16-6 **What are the advantages and disadvantages of using biomass as an energy resource?**

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

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

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

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

16-8 **What are the advantages and disadvantages of using hydrogen as an energy resource?**

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

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 greatly improving energy efficiency, using a mix of renewable energy resources, and including the environmental costs of energy resources in their market prices.

Note: Supplements 2 (p. S3), 6 (p. S20), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

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

LESTER R. BROWN

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

▶ **CONCEPT 16-1** **Improving energy efficiency can save the world at least a third of the energy it uses, and it can save the United States up to 43% of the energy it uses.**

We Waste Huge Amounts of Energy

Many analysts urge us to make much greater use of a strategy not usually thought of as a source of energy—a decrease in our energy use based primarily on reducing unnecessary waste of energy. This largely untapped source of energy is abundant, clean, cheap, and readily available. In using it, we could save money by lowering our utility and gasoline bills, improve military and economic security by reducing or eliminating dependence

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

on foreign oil, and sharply reduce our greenhouse gas emissions, which contribute to projected climate disruption.

The best way to do reduce our unnecessary waste of energy is to improve **energy efficiency**: the measure of how much work we can get from each unit of energy we use. Each unit of energy saved eliminates the need to produce that energy, and it saves us money. As Amory Lovins (Figure 16-1) puts it, improving energy efficiency means "doing more and better with less energy and money, but with more brains and technology."

The United States has improved its energy-efficiency since 1980. But Japan, Germany, and France are two to three times more energy efficient than the United States is. For that reason, we use the United States as a prime example of how we can improve energy efficiency and save money. Many other countries, including China and India, can make similar improvements.

For example, 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 is unavoidably lost because of the degradation of energy quality imposed by the second law of thermodynamics (see Chapter 2, p. 47). The other 43% is wasted unnecessarily, mostly due to the inefficiency of incandescent lightbulbs, furnaces, industrial motors, most motor vehicles, coal and nuclear power plants, and numerous other energy-consuming devices.

Another reason for this waste is that many people live and work in leaky, poorly insulated, and badly designed buildings that require excessive heating in the winter and cooling in the summer—a fact that has been demonstrated clearly by Amory Lovins and his colleagues at the Rocky Mountain Institute (**Core Case Study**). Unnecessary energy waste costs the United States an average of about $570,000 per minute, according to Lovins (see his Guest Essay at CengageNOW™). How much does this cost the United States in a year?

For years, many Americans have been wasting a lot of money buying larger, gas-guzzling vehicles and building larger houses that require more and more energy to heat and cool. Many live in ever-expanding suburban areas that surround most cities, and they must depend on their cars for getting around. Roughly three of every four Americans commute to work, mostly in energy-inefficient vehicles, and only 5% rely on more energy-efficient mass transit.

The energy that is used to heat and cool homes and other buildings, to provide us with light, and to propel motor vehicles is not free. Thus, saving energy saves us money and also reduces our environmental impact (Figure 16-3). If enough people reduce energy use and waste, then pollution will also be

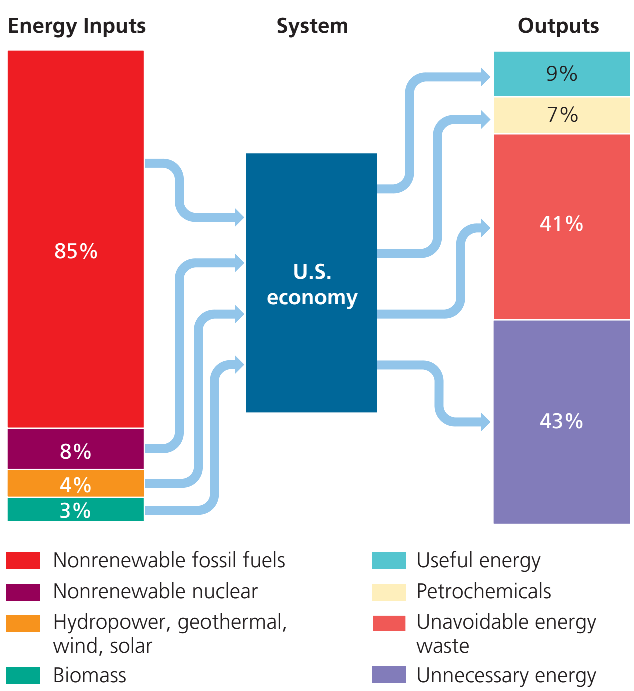


Figure 16-2 This diagram shows how commercial energy flows through the U.S. economy. Only 16% of all commercial energy used in the United States ends up performing useful tasks; the rest of the energy is unavoidably wasted because of the second law of thermodynamics (41%) or is wasted unnecessarily (43%). **Question:** What are two examples of unnecessary energy waste? (Data from U.S. Department of Energy)

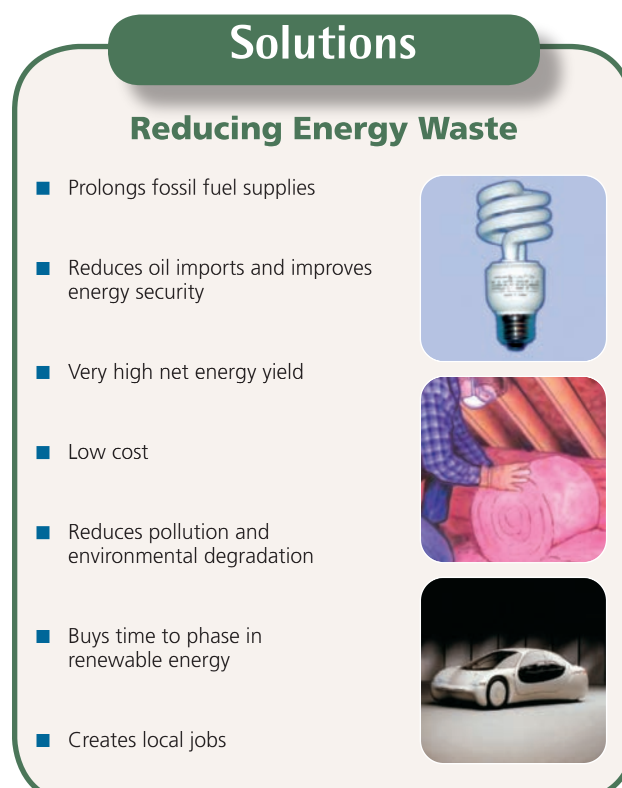


Figure 16-3 Reducing unnecessary energy waste and thereby improving energy efficiency provides several benefits. Amory Lovins estimates that in the United States "we could save at least half the oil and gas and three-fourths of the electricity we use at a cost of only about an eighth of what we're now paying for these forms of energy." **Questions:** Which two of these benefits do you think are the most important? Why?

reduced. This could save us even more money by lowering health care and insurance costs and taxes used for pollution control and cleanup.

We waste large amounts of energy and money by relying heavily on four widely used devices:

- The *incandescent lightbulb* (see Figure 2-16, right, p. 48), which uses only 5–10% of the electricity it draws to produce light, while the other 90–95% is wasted as heat. It is really a *heat bulb* and is gradually being replaced by more energy-efficient compact fluorescent bulbs (see Figure 2-16, left) and even more efficient light-emitting diodes (LEDs).
- The *internal combustion engine* (see Figure 2-16, right), which propels most motor vehicles and wastes about 80% of the energy in its fuel.
- A nuclear *power plant* (see Figure 15-20, p. 387), which produces electricity for space heating or water heating. It wastes about 75% of the energy in its nuclear fuel and probably closer to 92% when we include the additional energy used in the nuclear fuel cycle (see Figure 15-21, p. 388).
- A *coal-fired power plant* (see Figure 15-15, p. 382), which wastes about 66% of the energy that is released by burning coal to produce electricity, and probably 75–80% if we include the energy used to dig up the coal and transport it to the plant, and to transport and store the toxic ash byproduct.

Some energy efficiency experts consider these technologies to be energy-wasting dinosaurs, and they call for us to use our scientific and engineering brainpower to replace them with more energy-efficient and less environmentally harmful alternatives over the next few decades.

16-2 How Can We Cut Energy Waste?

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

We Can Save Energy and Money in Industry and Utilities

Industry accounts for about 30% of the world's energy consumption and 33% of U.S. energy consumption, mostly for production of metals, chemicals, petrochemicals, cement, and paper. There are many ways for industries to cut energy waste (**Concept 16-2**).

GOOD NEWS

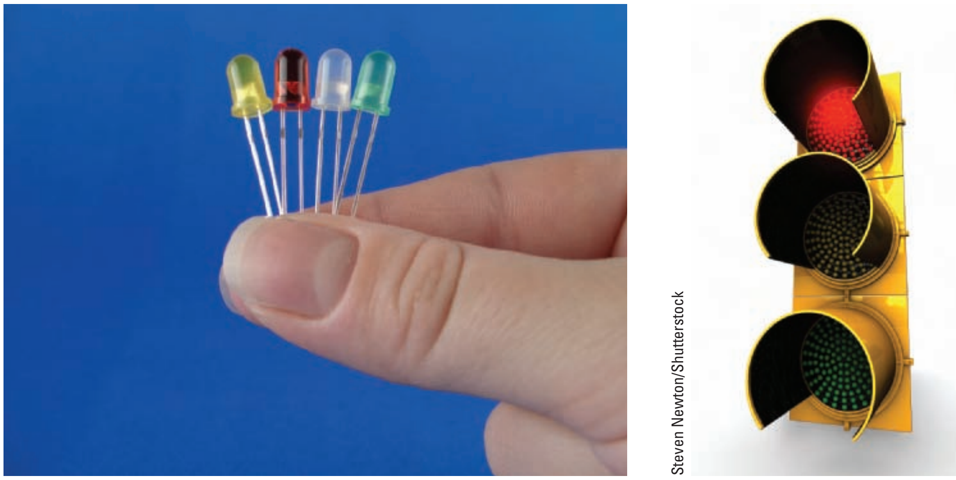
Some industries save energy and money by using **cogeneration**, which involves using a **combined heat and power (CHP)** system. In such a system, two useful forms of energy (such as steam and electricity) are produced from the same fuel source. For example, the steam produced in generating electricity in a CHP system can be used to heat the power plant or other nearby buildings, rather than released into the environment and wasted. The energy efficiency of these systems is 75–90% (compared to 30–40% for coal-fired boilers and nuclear power plants), and they emit one-third as much CO_2 per unit of energy produced as do conventional coal-fired boilers. Denmark leads the world by getting 82% of its electricity from CHP systems. The United States gets only 8% of its electricity from CHP. China does better by getting 13% of its electricity and 60% of its urban central heating from CHP.

Another way to save energy and money in industry is to *replace energy-wasting electric motors*, which use one-fourth of the electricity produced in the United States and 65% of the electricity used in U.S. industry. Most of these motors are inefficient because they run only at full speed with their output throttled to match the task—somewhat like keeping one foot on the gas pedal of your car and the other on the brake pedal to control its speed. Replacing them with variable speed motors, which run at the minimum rate needed for each job, saves energy and reduces the environmental impact of electric motor use.

Recycling materials such as steel and other metals is a third way for industry to save energy and money. For example, producing steel from recycled scrap iron uses 75% less energy than producing steel from virgin iron ore and emits 40% less CO_2. Switching three-fourths of the world's steel production to such furnaces would cut energy use in the global steel industry by almost 40% and sharply reduce its CO_2 emissions.

A fourth way for industry to save energy is to *switch from low-efficiency incandescent lighting* to higher-efficiency fluorescent lighting (see Figure 2-16, left, p. 48) and light-emitting diodes (LEDs) (Figure 16-4). A compact fluorescent bulb uses one-fourth as much electricity as an incandescent bulb, typically lasts ten times as long, and saves at least $30 in replacement costs during its lifetime. Even better, LEDs use about one-seventh of the electricity required by an incandescent bulb and can last about 100 times longer.

A growing number of major corporations are now boasting about the money they save by wasting less energy. For example, the CEO of Dow Chemical Company, which operates 165 manufacturing plants in 37 countries, estimates that between 1996 and 2006, energy efficiency improvements cost Dow about $1 billion, but resulted in savings of about $8.6 billion.



Zholudov Serhij/Shutterstock

Steven Newton/Shutterstock

Figure 16-4 These small, light-emitting diodes (LEDs) come in different colors (left) and contain no toxic elements. They are being used for industrial and household lighting, and also in Christmas tree lights, traffic lights (right), street lights, and hotel conference and dining room lighting. LEDs last so long (about 100,000 hours) that users can install them and forget about them. LED bulbs are expensive but prices are projected to drop because of newer designs and mass production. Shifting to energy-efficient fluorescent lighting in homes, office buildings, stores, and factories and to LEDs in all traffic lights would save enough energy to close more than 700 of the world's coal-burning electric power plants.

There is also a great deal of energy waste in the generation and transmission of electricity to industries and communities (see Case Study below). Part of the reason is that utility companies have historically encouraged electricity use instead of efficiency. According to Amory Lovins (Figure 16-1), the best way to improve energy efficiency in utilities would be for state utility commissions to reward utilities for cutting our bills by helping us to save energy, instead of rewarding them for selling us more electricity.

CORE CASE STUDY

The utility commissions in six U.S. states have adopted this approach and nine more states may soon follow. In 2009, the American Council for an Energy Efficient Economy estimated that making this efficiency focus a national policy would eliminate the need for building 450 new coal-fired or nuclear power plants by 2050. The state of California has had great success in using such a "save-a-watt" approach and in encouraging energy efficiency in a number of other ways. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about California's efforts to improve energy efficiency.

■ **CASE STUDY**

Saving Energy and Money with a Smarter Electrical Grid

Grid systems of high-voltage transmission lines carry electricity from power plants, wind turbines, and other electricity producers to users. Many energy experts place top priority on converting and expanding the outdated U.S. electrical grid system into what they call a *smart grid*. This more energy-efficient, digitally controlled, ultra-high-voltage grid with superefficient transmission lines would be responsive to local and regional changes in demand and supply (see Figure 20, p. S51, in Supplement 8 for a map of the proposed new grid in the United States).

China plans to build an efficient and reliable ultra-high voltage (UHV) electricity grid network by 2020 and to become the global leader in manufacturing and selling such technology and equipment. In 2009 alone, it committed $45 billion to this vital project.

A smarter electrical grid involves a two-way flow of energy and information between producers and users of electricity. Such a system would use smart meters to monitor the amount of electricity used and the patterns of use for each customer. It would then use this information to deliver electricity as efficiently as possible.

Smart meters would also show consumers how much energy they are using by the minute and for each appliance. This information would help them to reduce their power consumption and power bills. Smart appliances such as clothes washers and dryers could be programmed to perform their tasks during off-peak hours when electricity is cheaper. A smart grid could allow individuals to run their air conditioners remotely so that they could leave them off when they are not at home and turn them on before they return. With such a system, customers who use solar cells, wind turbines, or other devices to generate some of their own electricity could cut their bills by selling their excess electricity to utility companies.

According to the U.S. Department of Energy (DOE), building such a grid would cost the United States from $200 billion to $800 billion, but would pay for itself in a few years by saving the U.S. economy more than $100 billion a year.

We Can Save Energy and Money in Transportation

There is a lot of room for reducing energy waste in transportation, which accounts for about 28% of the energy consumption and two-thirds of the oil consumption in the United States. One reason for this waste is that U.S. government fuel efficiency standards for motor vehicles have been generally low for many years. Between 1973 and 1985, average fuel efficiency for new vehicles sold in the United States rose sharply because of government-mandated *corporate average fuel economy (CAFE)* standards. However, since 1985, the average fuel efficiency for new

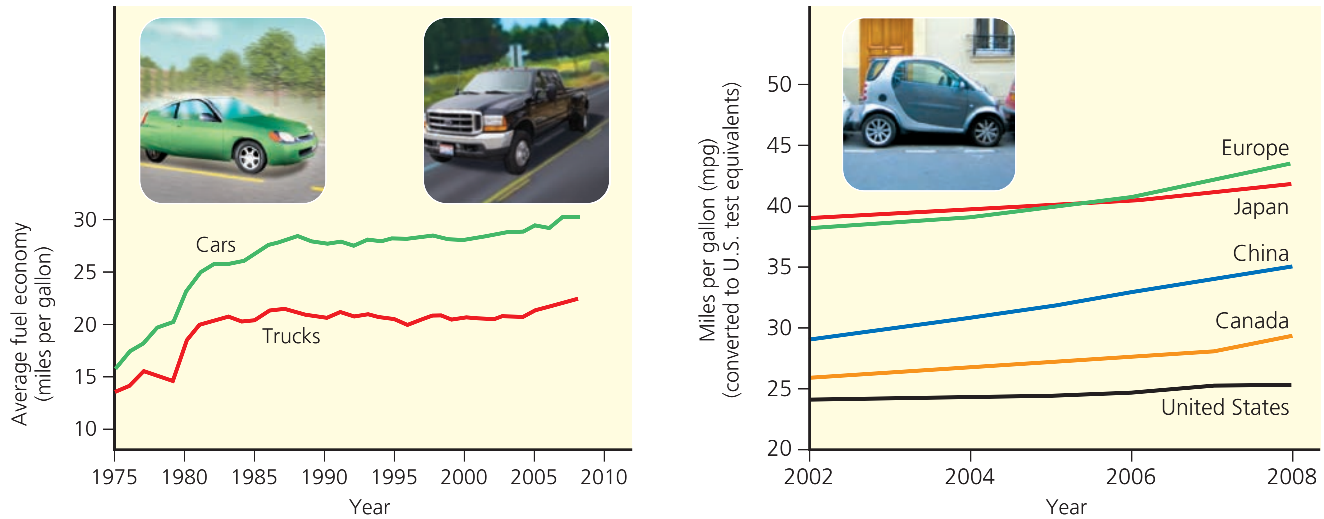


Figure 16-5 This diagram shows changes in the average fuel economy of new vehicles sold in the United States, 1975–2008 (left) and the fuel economy standards in other countries, 2002–2008 (right). (Data from U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, and International Council on Clean Transportation)

vehicles decreased to about 9 kilometers per liter (kpl), or 21 miles per gallon (mpg) (Figure 16-5, left).

This occurred mostly because there was no increase in the CAFE standards until 2008 and because mileage standards for popular trucks and SUVs are not as high as are those for cars. Indeed, a 2008 study by the University of Michigan Transportation Institute showed that the average fuel efficiency of U.S cars has improved by only about 1.3 kpl (3 mpg) since 1908, back in the days of the Ford Model T.

Fuel economy standards for new vehicles in Europe, Japan, China, and Canada are much higher than are those in the United States (Figure 16-5, right). A 2008 law raised U.S. CAFE standards to 15 kpl (35 mpg), to be attained by 2016. However, this future standard will still be much lower than current standards in China and many other countries. Energy experts such as Joseph Romm call for the government to require all new cars sold in the United States to get more than 43 kpl (100 mpg) by 2040.

Partly because of low CAFE standards, in 2010, more than half of all U.S. consumers owned SUVs, pickup trucks, minivans, and other large, inefficient vehicles. One reason for this is that many Americans want to have vehicles that are big and powerful. Another reason is that most U.S. consumers do not realize that gasoline costs them much more than the price they pay at the pump. According to a 2005 study by the International Center for Technology Assessment, the hidden costs of gasoline for U.S. consumers were about $3.18 per liter ($12 per gallon).

These hidden costs include government *subsidies* (payments intended to help businesses survive and thrive) and tax breaks for oil companies, car manufacturers, and road builders; costs of pollution control and cleanup; costs of military protection of oil supplies in the Middle East (not including the two Iraq wars); time wasted idling in traffic jams; and costs of illness from air and water pollution in the form of higher medical bills and health insurance premiums. Consumers pay for these hidden costs, but not at the gas pump.

One way to include more of the real cost of gasoline in its market price is through gasoline taxes, which are widely used in Europe but are politically unpopular in the United States. To help deal with such opposition, some economists and other analysts call for reducing payroll and income taxes to balance increases in gas taxes, thereby relieving consumers of any additional financial burden. So far, oil and car companies have been able to prevent such a solution by influencing elected representatives to keep gasoline taxes low, thereby keeping the true costs of gasoline hidden from consumers.

THINKING ABOUT

The Real Cost of Gasoline

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

Another way for governments to encourage higher efficiency in transportation is to give consumers tax breaks or other economic incentives to encourage them to buy more fuel-efficient vehicles. Energy expert Amory Lovins (**Core Case Study**) has proposed a *fee-bate* program in which buyers of fuel-inefficient vehicles would pay a high fee, and the resulting revenues would be given to buyers of efficient vehicles as rebates. For example, the fee on a gas-guzzling, $57,000 Hummer H2, which averages about 5 kpl (12 mpg), might be $10,000. The government would then give that amount as a rebate to the buyer of a hybrid

CORE CASE STUDY

or other fuel-efficient car that averages 20 kpl (46 mpg) or more.

Within a short time, such a program—endorsed by the U.S. National Academy of Sciences—would greatly increase sales of gas-sipping vehicles. It would also focus carmakers on producing and making their profits from such vehicles, and it would cost the government (taxpayers) nothing. So far, the U.S. Congress has not implemented such a program.

Other ways to save energy in transportation include shifting from diesel-powered to electrified rail systems, building accessible mass transit systems within cities, constructing high-speed rail lines between cities as is done in Japan, China, and much of Europe, and carrying more freight by train instead of by truck.

Another method is to encourage bicycle use by building bike lanes along highways and city streets. Amory Lovins estimates that the United States could cut its oil imports by half if each American driver biked to work just one day a week. To reduce car use, greenhouse gas emissions, and parking congestion, the University of New England in Maine and Ripon College in Wisconsin give free, high-quality bikes to new students who agree to leave their cars at home.

More Energy Efficient Vehicles Are on the Way

There is growing interest in developing modern, super-efficient, ultralight, and ultrastrong cars that could get up to 130 kilometers per liter (300 miles per gallon) using existing technology—a concept that Amory Lovins (Figure 16-1) invented in 1991. (See Amory Lovins's Guest Essay at CengageNOW).

GOOD NEWS

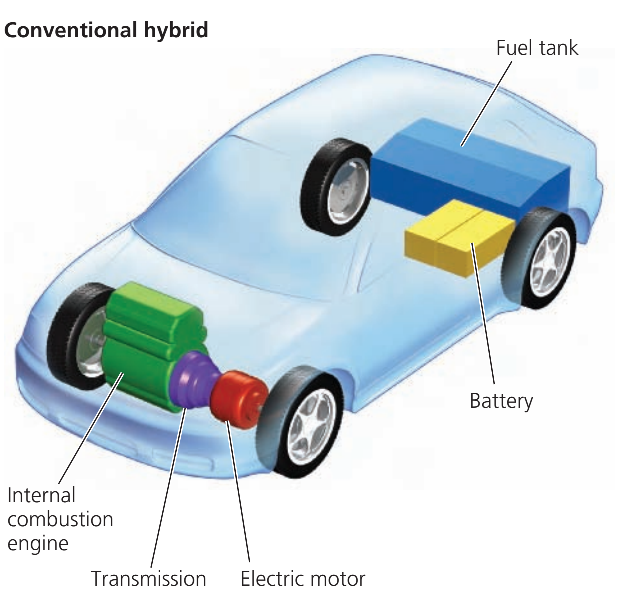
CORE CASE STUDY

One of these vehicles is the energy-efficient, gasoline–electric *hybrid car* (Figure 16-6, left). A primitive form of it was patented in 1909 by Belgium inventor Henri Pieper. Today's version has a small, traditional gasoline-powered engine and a battery-powered electric motor used to provide the energy needed for acceleration and hill climbing. The most efficient models of these cars, such as the Toyota Prius, get a combined city/highway mileage of up to 21 kpl (50 mpg) and emit about 65% less CO_2 per kilometer driven than a comparable conventional car emits.

The next step will probably be the *plug-in hybrid electric vehicle*—a hybrid with a second and more powerful battery that can be plugged into an electrical outlet and recharged (Figure 16-6, right). By running primarily on electricity, plug-in hybrids could easily get the equivalent of at least 43 kpl (100 mpg) for ordinary driving and up to 430 kpl (1,000 mpg), if used only for trips of less than 32 kilometers (40 miles) before recharging.

American manufacturers plan to have a variety of plug-in hybrids available by 2012. However, a Chinese car company (BYD) is already mass-producing and selling the world's first plug-in hybrid, called the Build Your Dreams (BYD) car. It can reach a speed of 100 kilometers per hour (60 miles per hour) and can travel 190 kilometers (120 miles) between battery charges. General Motors plans to introduce the Volt plug-in hybrid in 2011, at a cost of around $40,000. It will travel 64 kilometers (40 miles) on a fully charged battery.

The Chinese company BYD is selling its cars in China and plans to start selling them in Europe for around $22,000. The company, with 5,000 auto engineers and 5,000 battery engineers, aims to become the top-selling carmaker in China by 2015. Using the BYDs widely could help China to reduce urban pollution and greenhouse gas emissions, provide a large number of jobs, and greatly reduce its dependence on oil imported from the Middle East. Another option for drivers is the Indian-made Reva, the world's most successful plug-in



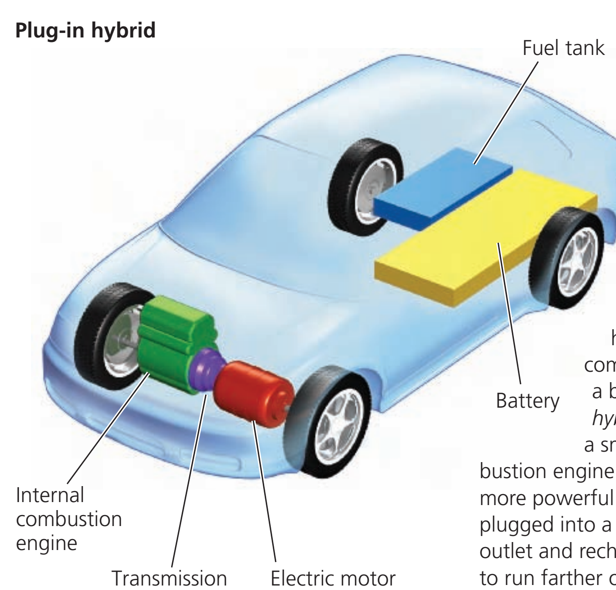


Figure 16-6 **Solutions:** A *conventional gasoline–electric hybrid* vehicle (left) has a small internal combustion engine and a battery. A *plug-in hybrid* vehicle (right) has a smaller internal combustion engine with a second and more powerful battery that can be plugged into a 110-volt or 220-volt outlet and recharged. This allows it to run farther on electricity alone.

hybrid electric vehicle, which is used in a number of European cities and costs around $14,500.

Some analysts project that plug-in hybrids could dominate the motor vehicle market by 2020, partly because most urban and suburban drivers travel less than 64 kilometers (40 miles) a day, and running a car on electricity costs about one-fifth as much per kilometer as running it on gasoline. In addition to this, electricity is less vulnerable to large price hikes than gasoline is. The key is to develop a durable, dependable, safe, and affordable battery (Science Focus below). Another important factor will be to have a network of recharging stations in many convenient locations within and between communities and in home garages.

According to a 2006 DOE study, replacing most of the current U.S. vehicle fleet of 220 million vehicles with highly efficient plug-in hybrid vehicles over 2 decades, would cut U.S. oil consumption by 70–90%, eliminate the need for oil imports, save consumers money, and reduce CO_2 emissions by 27%. If the batteries in these cars were recharged mostly by electricity generated by renewable resources such as wind, U.S. emissions of CO_2 would drop by 80–90%, which would help to slow projected climate change. **GREEN CAREER:** plug-in hybrid car and bus technology

GOOD NEWS

Another option is an *energy-efficient diesel car*, which accounts for 45% of new passenger car sales in Europe. Diesel cars emit more nitrogen oxides and particulates than comparable conventional and hybrid vehicles. However, new diesel engines have very low emissions, are quiet, and are about 30% more fuel efficient than comparable internal combustion engines. Running these vehicles on a fuel called *biodiesel*, discussed later in this chapter, would reduce their air pollution emissions and increase energy efficiency. For SUVs and for most trucks and trains, because of their heavier weights, diesel is a better fuel than gasoline or electricity.

An electric vehicle that uses a *fuel cell* may be the next stage in the development of superefficient cars. Fuel cells are at least twice as efficient as internal combustion engines, have no moving parts, require little maintenance, and use hydrogen gas as fuel to produce electricity. This would essentially eliminate emissions of CO_2 and other air pollutants if the hydrogen was produced from noncarbon or low-carbon renewable sources of electricity such as wind turbines and solar cells. But such cars are unlikely to be widely available until 2020 or later and will probably be very expensive because they have a negative net energy yield. **GREEN CAREER:** fuel-cell technology

The fuel efficiency for all types of cars could nearly double if car bodies were to be made of *ultralight* and *ultrastrong* composite materials such as fiberglass and the carbon-fiber composites (Figure 16-7) used in bicycle helmets and in some racing cars.

RESEARCH FRONTIER

Developing better and more affordable hybrid and fuel cell vehicles; see **www.cengage.com/login**.

SCIENCE FOCUS

The Search for Better Batteries

Thomas Edison invented the first rechargeable, nickel-based battery in 1890. Since then, scientists have created the rechargeable lead-acid batteries used in most cars, the nickel-cadmium batteries used in toys and until recently in laptop computers, and the nickel-metal-hydride batteries that power the Prius and other hybrid vehicles. New battery technology is difficult to develop because it is based on chemical reactions that are governed by the laws of thermodynamics.

The major obstacle standing in the way of mass-market, plug-in, hybrid electric vehicles is the difficulty in making an affordable battery that can store enough energy to power a vehicle over long distances without overheating. One promising type of battery is a *lithium-ion battery*, commonly used in laptop computers and cell phones. These batteries are light and can pack a lot of energy into a small space.

But there are two problems with current lithium-ion batteries. *First*, they have an occasional tendency to overheat, release oxygen, and in rare cases burst into flames. *Second*, they cost twice as much as the nickel-metal-hydride batteries currently used in hybrid cars.

In 2009, researchers at the Massachusetts Institute of Technology (MIT) developed a new type of lithium battery that charges more rapidly, is less likely to heat up to dangerous levels, and is cheaper than the batteries used to power today's hybrid vehicles. One battery manufacturer is using nanotechnology (see Chapter 14, Science Focus, p. 365) to make electrodes out of a nanophosphate material that will lengthen battery life and will not heat up and release flammable oxygen.

In the quest for lightweight, inexpensive batteries, Anela Belcher, a materials scientist and bioengineer at MIT, is working on an entirely new type of battery. She has genetically engineered a virus that can coat itself with electricity-conducting materials to form a miniscule nanowire. She is trying to find ways to link these tiny wires up to form the components of a battery far more compact and powerful than any yet developed. Such viral batteries would essentially grow themselves without producing the often-toxic wastes now produced in the manufacturing of other types of batteries. **GREEN CAREER:** battery engineer

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

U.S. battery makers are far behind those of Japan, China, and South Korea in developing and producing batteries for cars and other uses. Some analysts warn that in a future that depends on electric vehicles, the United States may end up substituting dependence on batteries built in Asia (mostly South Korea and China) for dependence on imported oil—much of it from the Middle East.

Critical Thinking

Would you buy a plug-in hybrid vehicle? Why or why not?

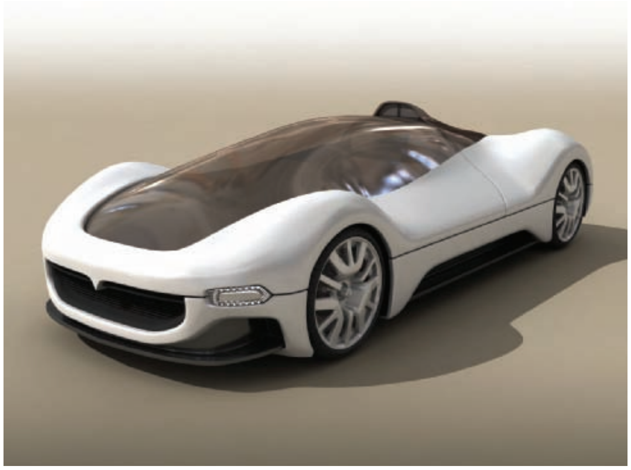

AND Inc./Shutterstock

Figure 16-7 The body on this concept car, made of carbon-fiber composite, is much safer and stronger than a traditional car body and the car gets better mileage because of its greatly reduced weight. Such car bodies are expensive but further research and mass production could bring their prices down.

We Can Design Buildings That Save Energy and Money

According to a 2007 UN study, better architecture and energy savings in buildings could save 30–40% of the energy used globally. For example, orienting a building to face the sun so it can get more of its heat from solar energy can save up to 20% of heating costs and as much as 75% of such costs when the building is well insulated and airtight (Figure 16-1). This is a simple application of the solar energy **principle of sustainability** (see back cover).

GOOD NEWS

SUSTAINABILITY

The 24-story Georgia Power Company building in the U.S. city of Atlanta, Georgia, uses 60% less energy than conventional office buildings of the same size. The largest surface of this building faces south to capture as much solar energy as possible. Each floor extends out over the one below it. This blocks out the higher summer sun on each floor to reduce air conditioning costs but allows the lower winter sun to help light and heat each floor during the day. In the building's offices, energy-efficient compact fluorescent lights focus on work areas instead of illuminating entire rooms. Such *green buildings* have been widely used in Europe for almost 2 decades, especially in Germany and the Netherlands, and are beginning to catch on in the United States.

Green architecture, based on energy-efficient and money-saving designs, makes use of natural lighting, passive solar heating, solar cells, solar hot water heaters, recycled wastewater, and energy-efficient appliances and lighting. Some also use *living roofs*, or *green roofs*, covered with soil and vegetation (Figure 16-8 and Photo 10 in the Detailed Contents). Others use white or light-colored roofs that help reduce cooling costs by reflecting incoming solar radiation especially in hotter climates—a strategy for working with nature that people have used for centuries.

Superinsulation is very important in energy-efficient design. As the Rocky Mountain Institute's headquarters (Figure 16-1) demonstrates, a house can be so heavily insulated and airtight that heat from direct sunlight, appliances, and human bodies can warm it with little or no need for a backup heating system, even in extremely cold climates. Superinsulated houses in Sweden use 90% less energy for heating and cooling than typical American homes of the same size use. Such houses can be ventilated with little energy loss to bring in fresh air. Another example of a superinsulated houses is one with thick walls of straw bales that are covered on the inside and outside with adobe (see Photos 8 and 9 in the Detailed Contents). (See the Guest Essay about straw bale construction and solar energy houses by Nancy Wicks at CengageNOW.)

CORE CASE STUDY

Green building certification standards now exist in 21 countries, thanks to the efforts of the World Green Building Council. Since 1999, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program has awarded silver, gold, and platinum standard certificates to nearly 9,000 U.S. buildings that meet certain standards. Between 1999 and 2009, these buildings saved $1.6 billion in electricity costs. **GREEN CAREERS:** environmental design and green architecture

We Can Save Money and Energy in Existing Buildings

There are many ways to save energy and money in existing buildings. A good first step is to have an expert make an *energy survey* of a house or building

GOOD NEWS


City of Chicago—Mark Farina

Figure 16-8 City Hall in Chicago, Illinois (USA), has a *green* or *living roof*—an important part of the city's efforts to become a more sustainable green city. Such a roof can save energy used to heat and cool the building. It absorbs heat from the summer sun, which would otherwise go into the building, and it helps to insulate the structure and retain heat in the winter. In addition, it absorbs precipitation, which would normally become part of the city's storm water runoff and add to pollution of its waterways.

to suggest ways to improve energy efficiency and save money. Such a survey might result in some or all of the following recommendations:

- *Insulate the building and plug leaks.* About one-third of the heated air in typical U.S. homes and buildings escapes through holes, cracks, and closed, single-pane windows (Figure 16-9). During hot weather, these windows and cracks let heat in, increasing the use of air conditioning. Adding insulation to walls and attics, plugging air leaks, and sealing heating and cooling ducts are three of the quickest, cheapest, and best ways to save money and energy in any building.
- *Use energy-efficient windows.* Replacing energy-wasting single-pane windows with energy-efficient double-pane windows or highly efficient *superwindows* that have the insulating effect of a window with 3 to 20 panes can cut expensive heat losses from a house or other building by two-thirds, lessen cooling costs in the summer, and reduce heating system CO_2 emissions.
- *Stop other heating and cooling losses.* Leaky heating and cooling ducts in attics and unheated basements allow 20–30% of a home's heating and cooling energy to escape and draw unwanted moisture and heat into the home. Careful sealing of duct joints can reduce this loss and save money. Also, using white or light-colored roofing or living roofs (Figure 16-8) can cut electricity use for air conditioning and reduce CO_2 emissions in warmer climates. Engineers are working on roofs that can change colors—being white and reflecting solar energy in hot weather and turning dark in order to absorb solar energy during cold weather.
- *Heat houses more efficiently.* In order, the most energy-efficient ways to improve efficiency and save money for heating a space are to use: superinsulation (which would include plugging leaks); a geothermal heat pump that transfers heat stored in the earth to a home (discussed later in this chapter); passive solar heating (Figure 16-1); a high-efficiency, conventional heat pump (in warm climates only); small, cogenerating microturbines fueled by natural gas; and a high-efficiency (92–98%) natural gas furnace. The most wasteful and expensive way to heat a space is to use electric resistance heating with electricity produced by a coal-fired or nuclear power plant (Figure 15-3, p. 373).

CORE CASE STUDY

- *Heat water more efficiently.* One approach is to use a roof-mounted solar hot water heater. These are widely used in China, Israel, and a number of other countries. Another option is a *tankless instant water heater* fired by natural gas or LPG. (Using electricity for this purpose is not efficient.) These suitcase-size devices, widely used in many parts of Europe, heat water instantly as it flows through a small burner chamber, providing hot water only when it is needed. They cost up to 60% less to operate than a standard electric unit costs. And they work. One of the authors (Miller) used them along with passive and active solar hot water heaters in an office and living space for 12 years.
- *Use energy-efficient appliances.* According to the EPA, if all U.S. households used the most efficient frost-free refrigerator available, 18 large coal or nuclear power plants could close. Microwave ovens use 25–50% less electricity than electric stoves do for

VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 16-9 This *thermogram*, or infrared photo, shows heat losses (red, white, and orange) around the windows, doors, roofs, and foundations of houses and stores in Plymouth, Michigan (USA). Many homes and buildings in the United States and other countries are so full of leaks that their heat loss in cold weather and heat gain in hot weather are equivalent to what would be lost through a large, window-sized hole in a wall of the house. **Question:** How do you think the place where you live would compare to these buildings in terms of heat loss and the resulting waste of money spent on heating and cooling bills?

cooking and 20% less than convection ovens use. Clothes dryers with moisture sensors cut energy use by 15%. Refrigerators with a freezer on the bottom cut electricity use and operating costs in half, compared to models with the freezer on top. Front-loading clothes washers use 55% less energy and 30% less water than top-loading models use and cut operating costs in half. Plasma televisions use about 20% more energy than LCD sets of the same size. Keeping TVs, computers, and other appliances on standby can require up to 5% of all residential electricity used. Consumers can reduce this energy use and save money by plugging such electronic devices into a smart power strip that cuts off power when it detects that the device has been turned off.

- *Use energy-efficient lighting.* The best compact fluorescent lightbulbs (CFLs, see Figure 2-16, left, p. 48) produce light of the same brightness and quality as that of incandescent bulbs. They are four times more efficient and last up to ten times longer than incandescent bulbs, which waste 90–95% of their energy input. According to the DOE, replacing 30 incandescent bulbs with CFLs can save a consumer more than $1,000 in electricity costs over the life of the bulbs. Australia, Canada, Brazil, China, and the European Union plan to phase out sales of incandescent bulbs over the next 5–10 years. Over the next 2 decades, most bulbs may be replaced by even more efficient, pea-sized LEDs (Figure 16-4) if LED prices come down. They last 60 times longer than incandescent bulbs and 10 times longer than CFLs. According to a 2008 study by professors E. Fred Shubert and Jong Kyu Kim at Renssalaer Polytechnic Institute, replacing all of the world's lightbulbs with LEDs for a decade would reduce CO_2 emissions and save enough electricity to close 280 coal-fired power plants.

GOOD NEWS

Figure 16-10 summarizes ways in which you can save energy in the place where you live.

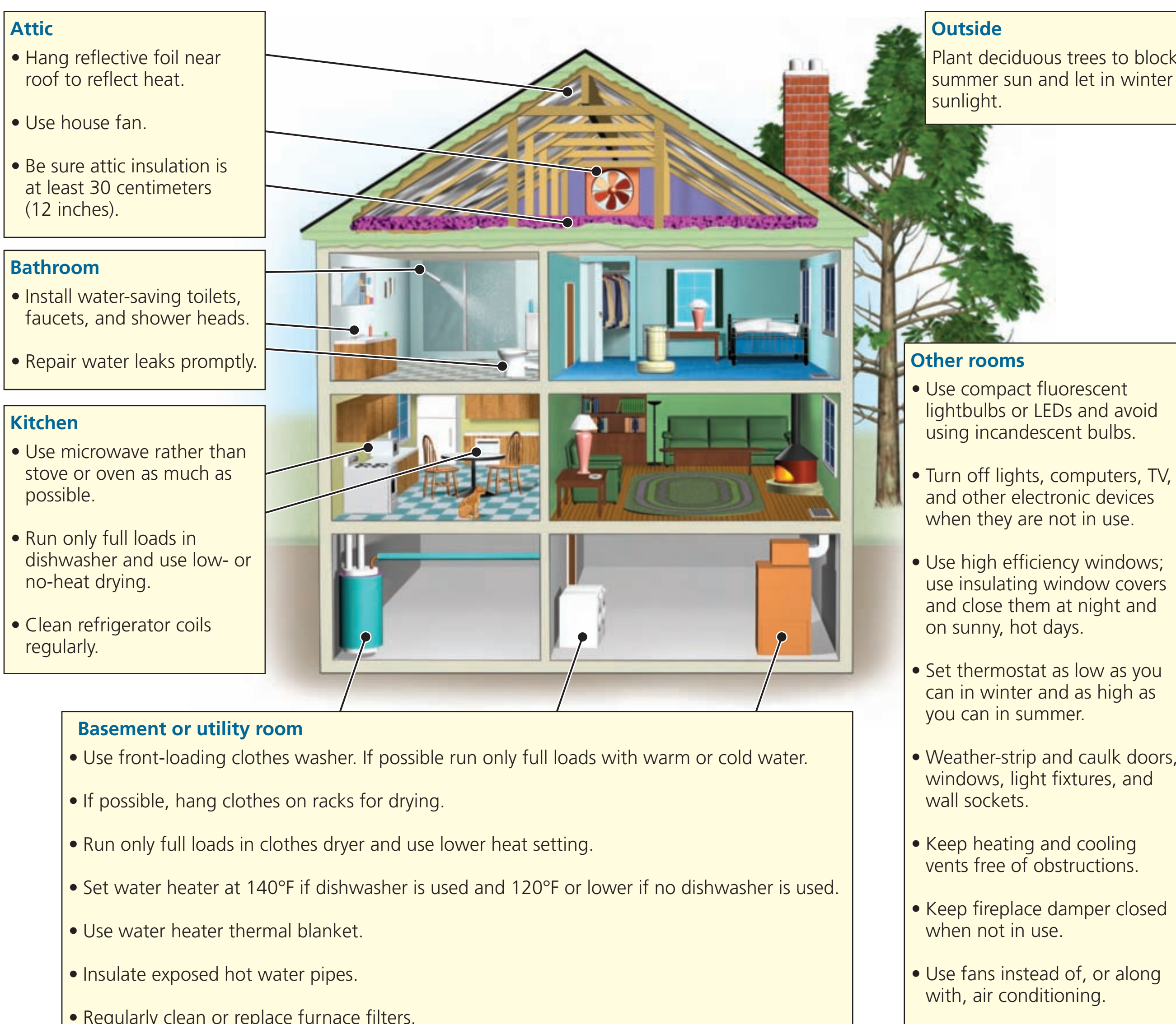


Figure 16-10 **Individuals matter:** You can save energy where you live. **Question:** Which of these things do you do?

CONNECTIONS

Using Compact Fluorescent Bulbs Reduces Mercury Pollution

GOOD NEWS

The typical compact fluorescent lightbulb (CFL) contains a small amount of toxic mercury—roughly the amount that would fit on the tip of a ballpoint pen—and newer bulbs will have only half this amount. The mercury cannot be released to the environment unless the bulb gets broken. The total amount of mercury in all of the country's CFLs is a tiny fraction of the amount of mercury released every year by coal-fired power plants that produce the electricity that lights many energy-wasting incandescent bulbs. While the mercury in CFLs can be recycled (see **www.epa.gov/bulbreycling**), the mercury continuously spewed into the atmosphere by coal-burning power plants cannot be retrieved. Instead, it pollutes air and water, and some of it can end up in our lungs and in our food, especially in fish. Thus, shifting to CFLs helps to reduce the amount of mercury released into the atmosphere.

Why Are We Still Wasting So Much Energy and Money?

Cutting energy waste will not solve our energy problems, but it is an important first step. Considering its impressive array of benefits (Figure 16-3), why is there so little emphasis on improving energy efficiency?

One reason is that fossil fuels, nuclear power, and other widely used energy resources are artificially cheap, 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 their production and use. Without such market price feedback, people are more likely to waste energy and less likely to invest in improving energy efficiency.

Another reason is that there are few 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 the U.S. federal government has done a poor job of encouraging fuel efficiency in motor vehicles (Figure 16-5) and educating the public about the environmental and economic advantages of cutting energy waste.

Also, people tend to resist change even when it saves them money. Pilot studies have shown that many people begin saving energy when they use devices that continuously display household or vehicle energy consumption and when their utility bills show comparisons of their energy use with that of similar households. With such feedback, people in some neighborhoods compete to see who can get the lowest heating and electricity bills.

We Can Use Renewable Energy to Provide Heat and Electricity

One of nature's three **principles of sustainability** (see back cover) is to *rely mostly on solar energy*—by far the earth's most abundant and virtually unlimited source of energy. We can get renewable solar energy directly from the sun or indirectly from wind and moving water, as well as from wood and other forms of biomass, none of which would exist without direct solar energy. Another form of renewable energy is geothermal energy from the earth's interior.

SUSTAINABILITY

GOOD NEWS

Studies show that with increased and consistent government subsidies, tax breaks, and funding for research and development, renewable energy could provide 20% of the world's electricity by 2025 and 50% by 2050. Denmark already gets 20% of its electricity from wind and has plans to increase this to 50% by 2030. Brazil gets 45% of its automotive fuel from ethanol made from sugarcane residue, and could phase out its use of gasoline within a decade. Costa Rica gets more than 95% of its electric power from renewable hydroelectric, wind, and geothermal energy. Studies show that with a crash program, the United States could get 20% of its energy and at least 25% of its electricity from renewable sources by 2020.

China is rapidly becoming the world's leader in producing renewable energy and in making and selling wind turbines and solar cells to other countries. By 2009, China had created 1.2 billion jobs in its rapidly growing renewable energy industries and was adding new jobs at a rate of 100,000 per year. China plans to get 15% of its energy from renewable sources by 2020 and 33% by 2050. If China reaches these goals it will reduce its dependence on coal and lower its emissions of CO_2 and other air pollutants.

Making a major shift toward a variety of locally available renewable energy resources over the next few decades would result in more decentralized and energy-efficient national economies that are less vulnerable to supply cutoffs and natural disasters. It would also improve economic and national security for the United States, China, and many other countries by reducing their dependence on imported crude oil and liquefied natural gas. And it would greatly reduce air and water pollution, slow projected climate disruption, create large numbers of jobs, and save consumers money.

If renewable energy is so great, why does it provide only 8% of the world's energy and 7% of the energy used in the United States? There are three major reasons. *First*, since 1950, government tax breaks, subsidies, and funding for research and development of renewable energy resources have been much lower than those for fossil fuels (especially oil) and nuclear power, although subsidies and tax breaks for renewables have increased in recent years.

Second, although subsidies and tax breaks for fossil fuels and nuclear power have essentially been guaranteed for many decades, those for renewable energy in the United States have to be renewed by Congress every few years. This makes it risky for companies to invest in renewable energy.

Third, the prices we pay for nonrenewable fossil fuels and nuclear power do not include 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. And it does not provide consumers with the price information they need to make better financial choices.

Energy analysts such as Amory Lovins (Figure 16-1) say that if these economic handicaps— CORE CASE STUDY *unbalanced and intermittent subsidies* and *inaccurate pricing*—were eliminated, many forms of renewable energy would be cheaper than fossil fuels and nuclear energy, and would quickly take over the energy marketplace.

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

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 costs of using direct sunlight to produce high-temperature heat and electricity are coming down.

We Can Heat Buildings and Water with Solar Energy

We can provide some homes and other buildings with most of the heat they need by using **passive solar heating systems** (Figures 16-1, 16-11, left, and 16-12, p. 410). CORE CASE STUDY Such a system absorbs and stores heat from the sun directly within a well-insulated structure. Walls and floors of concrete, adobe, brick, or stone, and water tanks can be used to store much of the collected solar energy as heat and to release it slowly throughout the day and night. A small backup heating system such as a vented natural gas or propane heater can be used, if necessary (see the Guest Essay by Nancy Wicks at CengageNOW).

Using passive solar energy is not new. For thousands of years, people have intuitively followed this basic principle of sustainability. They have oriented their dwellings to take advantage of the sun's heat and light, built thick stone walls that collect and store heat during the day and gradually release it at night, and used light colors on their roofs and walls in hot climates to reflect more sunlight and keep their houses cool. Now some of us are rediscovering this ancient earth wisdom.

An **active solar heating system** (Figure 16-11, 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 to face the sun. Some of the collected heat can be used directly. The rest can be stored in a

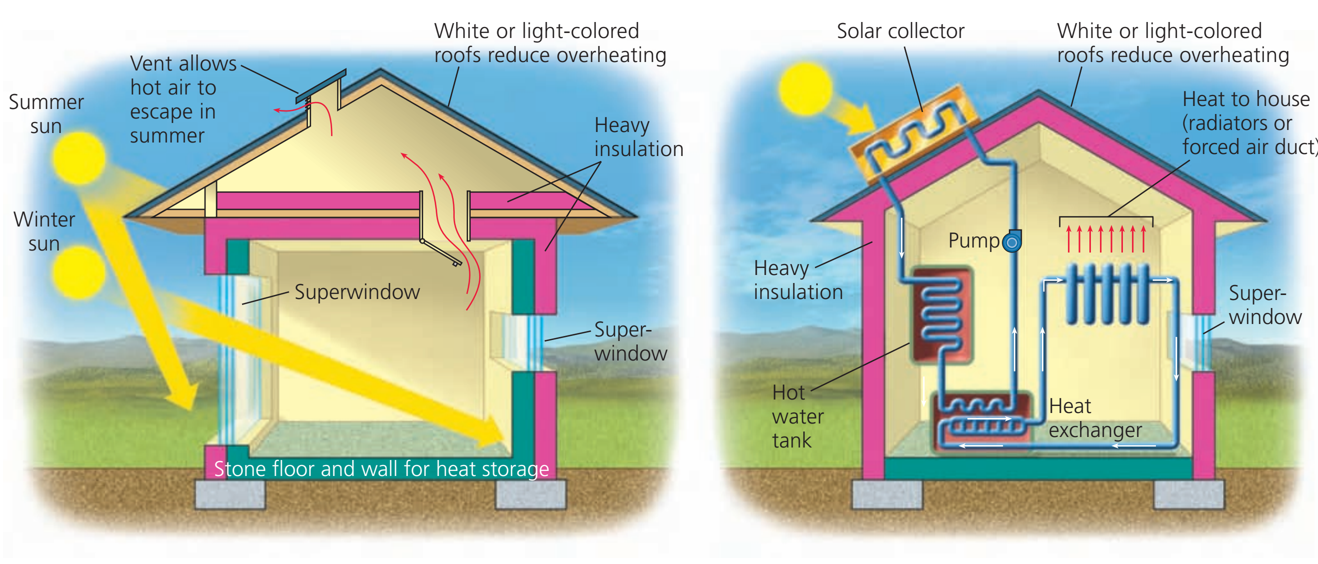


Figure 16-11 **Solutions:** Homes can be heated with passive or active solar systems.

Steven Sargent/National Renewable Energy Laboratory

Alan Ford/National Renewable Energy Laboratory

Figure 16-12 This passive solar home (left) in Golden, Colorado (USA), collects and stores incoming solar energy which provides much of its heat in a climate with cold winters. Such homes also have the best available insulation in their walls and ceilings, and energy-efficient windows to slow the loss of stored solar energy. Notice the solar hot water heating panels in the yard. Some passive solar houses like this one (see photo on right) in Dublin, New Hampshire (USA), have attached sunrooms that collect incoming solar energy.

large insulated container, filled with gravel, water, clay, or a heat-absorbing chemical, for release as needed. Active solar collectors (Figure 16-12, center) are also used to heat water in many homes.

With systems that cost the equivalent of as little as $200, about one in ten houses and apartment buildings in China (Figure 16-13) currently use the sun to provide hot water. By 2030, half of all households in China may get their hot water in this way—an excellent example of applying the solar energy **principle of sustainability** (see back cover). Once the fairly low initial cost is paid, the hot water is essentially free. Such systems are also widely used in Germany, Japan, Greece, Austria, and Turkey. In Spain and Israel, all new buildings must have rooftop systems for heating water and space. Soon millions of households in less-developed countries such as India and Brazil could be using this simple and inexpensive way to heat water.

National Renewable Energy Laboratory

Figure 16-13 Rooftop solar hot water heaters, such as those shown here on apartment buildings in the Chinese city of Kunming in the province of Yunnan, are now required on all new buildings in China, and their use is growing rapidly in urban and rural areas.

Figure 16-14 lists the major advantages and disadvantages of using passive or active solar heating systems. They can be used to heat new homes in areas with adequate sunlight. (See the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8.) But solar energy cannot be used to heat existing homes and buildings that are not oriented to receive sunlight or that are blocked from sunlight by other buildings or trees.

We Can Cool Buildings Naturally

Direct solar energy actually works against us when we want to keep a building cool, but we can use indirect solar energy (mainly wind) and other natural services to help cool buildings. For example, we can open windows to take advantage of breezes and use fans to keep the air moving. A living roof (Figure 16-8) can also make a huge difference in keeping a building cool. When there is no breeze, superinsulation and high-efficiency win-

Trade-Offs

Passive or Active Solar Heating

Advantages	Disadvantages
Net energy is moderate (active) to high (passive)	Need access to sun 60% of time during daylight
Very low emissions of CO_2 and other air pollutants	Sun can be blocked by trees and other structures
Very low land disturbance	High installation and maintenance costs for active systems
Moderate cost (passive)	Need backup system for cloudy days

Figure 16-14 Heating a house with a passive or active solar energy system has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

dows help to keep hot air outside. Here are some other ways to keep cool:

- Block the high summer sun with window overhangs, awnings, or shades.
- In warm climates, use a light-colored roof to reflect as much as 90% of the sun's heat (compared to only 10–15% for a dark-colored roof).
- Use geothermal heat pumps for cooling (and for heating in winter).

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

Solar thermal systems use different methods to collect and concentrate solar energy in order to boil water and produce steam for generating electricity (Figure 16-15). These systems are used mostly in desert areas with ample sunlight (see the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8).

A 2009 study by environmental and industry groups estimated that solar thermal power plants could meet up to 25% of the world's projected electricity needs by 2050. These plants would not emit CO_2 into the atmosphere, and building and maintaining them

GOOD NEWS

National Renewable Energy Laboratory

Sandia National Laboratories/National Renewable Energy Laboratory

Figure 16-15 *Solar thermal power:* In this desert solar power plant (left) near Kramer Junction, California (USA), curved (parabolic) solar collectors concentrate solar energy and use it to produce electricity. The concentrated solar energy heats a fluid-filled pipe that runs through the center of each trough. The concentrated heat in the fluid is used to produce steam that powers a turbine that generates electricity. Such plants also exist in desert areas of southern Spain, Australia, and Israel. In another approach (right), an array of computer-controlled mirrors tracks the sun and focuses reflected sunlight on a central receiver, sometimes called a *power tower*. This tower near Daggett, California (USA), can collect enough heat to boil water and produce steam for generating electricity. Excess heat in both systems can be released to the atmosphere by cooling towers. The heat 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. Such plants also exist in desert areas of southern Spain and North Africa. Because a power tower heats water to higher temperatures, it can have a higher net energy ratio than a parabolic trough system has.

would create thousands of jobs. Researchers at the German Aerospace Center estimate that coupling an array of solar thermal power plants in North Africa with a new high-voltage electricity transmission system could meet all of Europe's electricity needs.

In addition, scientists estimate that, by using a global high-voltage smart electrical distribution system (Case Study, p. 401) along with solar thermal power plants built in less than 1% of the world's deserts—an area roughly the size of Austria or the U.S. state of South Carolina—we could meet all of the world's electricity needs. One drawback is that solar thermal systems have a low net energy yield of only about 3%. Researchers are working to raise it to at least 20%, which will make this approach economically feasible on a large scale.

Water is the factor that may limit the production of electricity from solar thermal power plants. There are two problems. *First*, these power plants require large volumes of cooling water for condensing the steam back to water for reuse and for washing off the surfaces of mirrors and parabolic troughs (Figure 16-15). *Second*, thermal power plants are built in sunny, arid deserts where water is scarce.

In a *wet cooling* system, some of the water must be replenished constantly because it evaporates and is released into the atmosphere by giant cooling towers (see Figure 15-15, p. 382). An alternative that requires much less water is *dry cooling*, which uses fans and heat exchangers to transfer the excess heat to the atmosphere. But running these machines takes energy, which lowers the net energy yield of the whole system and raises the cost of electricity. The U.S state of California has banned the use of wet cooling systems for solar thermal power plants in its water-short desert areas.

GOOD NEWS

Today's solar thermal power plants (without a molten salt storage system) can produce electricity when the sun is out at a much lower cost than that of nuclear power plants, taking into account the nuclear fuel cycle (Figure 15-21, p. 388), and at about the same cost as that of a coal-burning power plant. Adding a molten salt storage system allows these plants to produce power around the clock. Such storage systems make the electricity much more expensive, but experts expect these costs to drop with improved technology and mass production (**Concept 16-3**).

Figure 16-16 summarizes the major advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

GOOD NEWS

We can use concentrated solar energy on a smaller scale, as well. In some sunny rural areas, people use inexpensive *solar cookers* to focus and concentrate sunlight for cooking food and sterilizing water (Figure 16-17). In 2009, inventor Jon Boehner received a $75,000 prize for developing a $6 solar cooker made from a cardboard box. Solar cookers can replace wood and charcoal fires, which helps to reduce deforestation by decreasing the need for firewood.

Trade-Offs

Solar Energy for High-Temperature Heat and Electricity

Advantages	Disadvantages
Moderate environmental impact	Low net energy and high costs
No direct emissions of CO_2 and other air pollutants	Needs backup or storage system on cloudy days
Lower costs with natural gas turbine backup	High water use for cooling

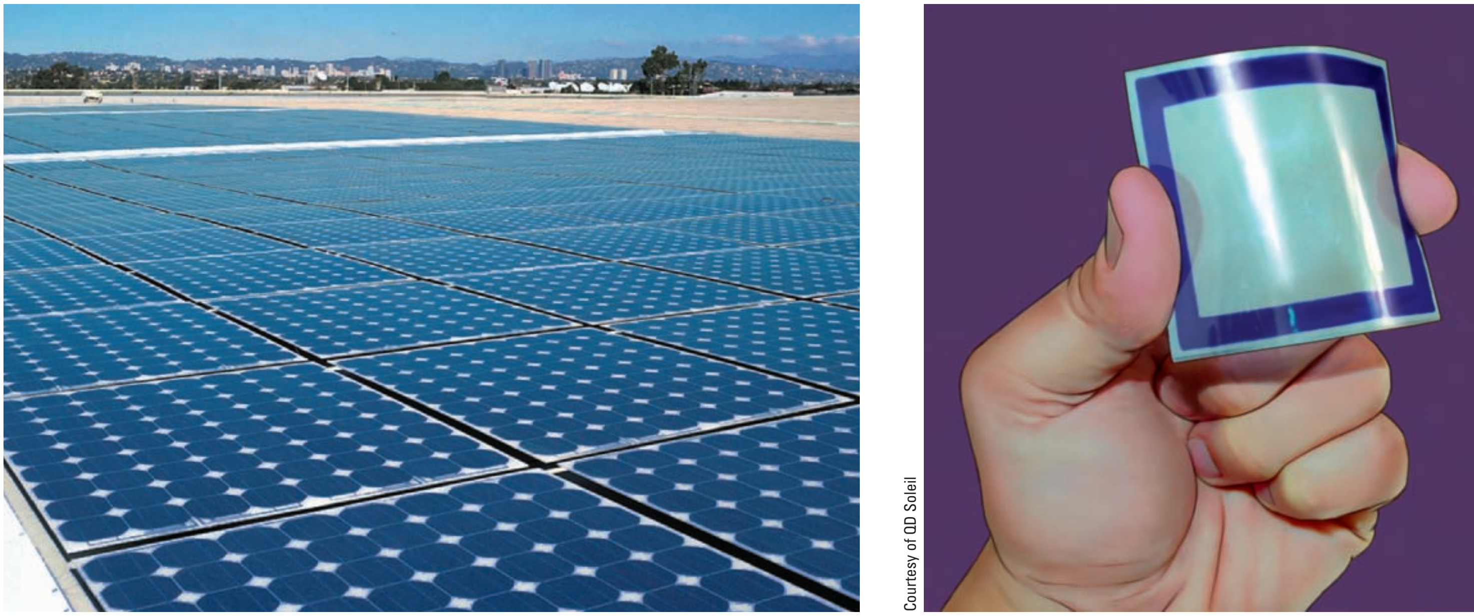
Figure 16-16 Using solar energy to generate high-temperature heat and electricity has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using these technologies outweigh their disadvantages?

We Can Use Sunlight to Produce Electricity

We can convert solar energy directly into electrical energy using **photovoltaic** (**PV**) **cells**, commonly called **solar cells**. Most solar cells are thin wafers of purified

Mark Edwards/Peter Arnold, Inc.

Figure 16-17 **Solutions:** This woman in India is using a solar cooker to prepare a meal for her family.



Sunpower (previously known as, PowerLight Corporation)/National Renewable Energy Laboratories

Courtesy of QD Soleil

Figure 16-18 **Solutions:** Photovoltaic (PV) or solar cells can provide electricity for a house or building using conventional solar panels such as those shown here (left) on the roof of a U.S. Postal Service processing and distribution center in Inglewood, California. They can also be incorporated into metal roofing materials that can simulate the look of ceramic roof tiles, as well as slate, wooden shake, or asphalt shingles in a wide variety of colors. A new plug-and-play light-weight modular rooftop solar cell system can be snapped together and installed in a few hours. In addition, new, flexible, thin-film solar cells (right) or even more efficient tiny silicon nanorods (made with the use of nanotechnology) can be applied to roofs, windows, building walls, bridges—almost any surface, even T-shirts.

silicon (Si) or polycrystalline silicon with trace amounts of metals that allow them to produce electricity. 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 these transparent cells, they emit electrons, and many cells wired together in a panel can produce electrical power. The cells can be connected to existing electrical grid systems or to batteries that store the electrical energy until it is needed.

We can mount solar cells on rooftops (Figure 16-18, left), incorporate them into almost any type of roofing material in different colors and shapes, or produce them in flexible sheets (Figure 16-18, right) that can be installed on roofs, the sides of buildings, or almost any surface. New, flexible, and extremely thin-film solar cells that are printed on metal foil use much less silicon, can be mass produced, and allow almost any surface to become a power plant. **GREEN CAREER:** solar-cell technology

The Rocky Mountain Institute headquarters (**Core Case Study**) uses photovoltaic panels on the building's roof (Figure 16-1) to generate electricity. The system includes a tracking mechanism and small electric motors to keep the panels pointed toward the sun during daylight hours. With this mechanism, these panels collect about 30–40% more energy than stationary panels can.

Nearly 1.6 billion people, or one of every four people in the world, live in less-developed countries in rural villages that are not connected to an electrical grid. With easily expandable banks of solar cells, these people could now get electrical service (Figure 16-19). Eventually, new solar cells based on nanotechnology (Figure 16-18, right) will drastically lower the cost of providing electricity to less-developed areas.

Large solar-cell power plants are in operation in Portugal, southern Spain, Germany, South Korea, and the southwestern United States (Figure 16-20, p. 414). Excess energy from such plants can be stored for use at

Jorgen Schytte/Peter Arnold, Inc.

Figure 16-19 **Solutions:** This system of solar cells provides electricity for a remote village in Niger, Africa. **Question:** Do you think your government should provide aid to help poor countries obtain solar-cell systems? Explain.

Figure 16-20 This solar-cell power plant in the U.S. state of Arizona near the city of Springerville has been in operation since 2000 and is the world's largest solar-cell power plant. Analysis shows that the plant, which is connected to the area's electrical grid, paid back the energy needed to build it in less than 3 years.

Figure 16-21 Using solar cells to produce electricity has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

night or on cloudy days by using the excess electricity to run pumps that compress air into underground caverns. This stored pressure is released as needed to drive turbines and produce electricity. Such a system has been used for decades in Germany and in the U.S. state of Alabama. Excess energy from solar cells could also be stored by using the electricity to decompose water and produce hydrogen gas, which can be used as a fuel, as we discuss later in this chapter.

In 2010, the three largest producers of solar-cell electricity were Japan, China, and Germany. Figure 16-21 lists the major advantages and disadvantages of using solar cells (**Concept 16-3**).

Solar thermal power systems (Figure 16-15) and centralized solar-cell power plants (Figure 16-20) must be concentrated in sunny deserts, and they require an expensive modernized regional or national grid system to transfer the power they produce to users (see the map in Figure 20, p. S51, in Supplement 8). By contrast, smaller solar-cell systems for homes and businesses can be used in any sunny part of the world (see the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8), and they produce the energy where it is needed.

Solar cells emit no greenhouse gases, although they are not carbon-free, because fossil fuels are used to produce and transport the panels. But these emissions are small compared to those of fossil fuels and the nuclear power fuel cycle. 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 with new systems.

Until recently, the main problem with using solar cells to produce electricity has been their high cost. Despite this drawback, their production has soared in recent years and solar cells have become the world's fastest growing way to produce electricity (see the graph in Figure 11, p. S62, in Supplement 9.) This is because of their advantages (Figure 16-21, left) and because of increased government subsidies and tax breaks for solar cell producers and users. Production is likely to grow much more as new, thin-film nanotechnology solar cells (Figure 16-18, right) become cheap enough to compete with fossil fuels and to make more expensive conventional solar-cell panels obsolete. **GREEN CAREER:** solar-cell technology

RESEARCH FRONTIER

Developing more efficient and affordable solar cells; see **www.cengage.com/login**.

Energy analysts say that with increased research and development, plus much greater and more consistent government tax breaks and other subsidies, solar cells could provide 16% of the world's electricity by 2040. In 2007, Jim Lyons, chief engineer for General Electric, projected that solar cells will be the world's number-one source of electricity by the end of this century. If that happens, it will represent a huge global application of the solar energy **principle of sustainability** (see back cover).

HOW WOULD YOU VOTE?

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

16-4 What Are the Advantages and Disadvantages of Using Hydropower?

▶ CONCEPT 16-4 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 our use of these energy resources.

We Can Produce Electricity from Falling and Flowing Water

Hydropower uses the kinetic energy of flowing and falling water to produce electricity. It is an indirect form of solar energy because it is based on the evaporation of water, which is deposited at higher elevations where it can flow to lower elevations in rivers as part of the earth's solar-powered water cycle (see Figure 3-16, p. 67).

The most common approach to harnessing hydropower is to build a high dam across a large river to create a reservoir. Some of the water stored in the reservoir is allowed to flow through large pipes at controlled rates to spin turbines that produce electricity (see Figure 13-13, p. 328).

Hydropower is the world's leading renewable energy source used to produce electricity. In order, the world's top five producers of hydropower are Canada, China, Brazil, the United States, and Russia. In 2007, hydropower supplied about 20% of the world's electricity, including 99% of Norway's, 75% of New Zealand's, 59% of Canada's, and 21% of China's electricity. Hydropower supplied about 6% of the electricity used in the United States, (but about 50% of that used on the West Coast).

According to the United Nations, only about 13% of the world's potential for hydropower has been developed. Much of this untapped potential is in China, India, South America, Central Africa, and parts of the former Soviet Union. China has plans to more than double its hydropower output by 2020 and is also building or funding more than 200 dams around the world. Brazil has four large dams in its Amazon Basin and plans to build as many as 70 more. If completed, current and planned hydropower projects around the world would have the electrical output of several thousand large coal-burning power plants without the high emissions of CO_2 and other air pollutants.

But some analysts expect that 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. Also, there is growing concern over emissions of methane, a potent greenhouse gas, from the decomposition of submerged vegetation in hydropower plant reservoirs, especially in warm climates. In fact, 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 methane. In addition, eventually, projected climate change is likely to reduce the electrical output of many of the world's large dams as mountain glaciers, a primary source of their water, continue to melt.

Figure 13-13 (p. 328) lists the major advantages and disadvantages of large dams and reservoirs, and Figure 16-22 lists the major advantages and disadvantages of using large-scale hydropower plants to produce electricity (**Concept 16-4**).

HOW WOULD YOU VOTE? ✓

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

The use of *microhydropower generators* may become an increasingly important way to produce electricity. These are floating turbines, each about the size of an overnight suitcase. They use the power of flowing water to turn rotor blades, which spin a turbine to produce electric current. They can be placed in any

GOOD NEWS

Trade-Offs

Large-Scale Hydropower

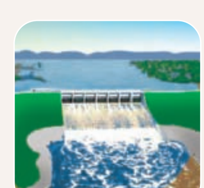
Advantages

Moderate to high net energy

Large untapped potential

Low-cost electricity

Low emissions of CO_2 and other air pollutants in temperate areas



Disadvantages

Large land disturbance and displacement of people

High CH_4 emissions from rapid biomass decay in shallow tropical reservoirs

Disrupts downstream aquatic ecosystems

Figure 16-22 Using large dams and reservoirs to produce electricity has advantages and disadvantages (**Concept 16-4**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

stream or river without altering its course to provide electricity at a very low cost with a very low environmental impact.

We Can Use Tides and Waves to Produce Electricity

We can also produce electricity from flowing water by tapping into the energy from *ocean tides* and *waves*. In some coastal bays and estuaries, water levels can rise or fall by 6 meters (20 feet) or more between daily high and low tides. Dams have been built across the mouths of some bays and estuaries to capture the energy in these flows for hydropower. Only two large tidal energy dams are currently operating, one at La Rance on the northern coast of France, and the other in Nova Scotia's Bay of Fundy. Several countries plan to build some sort of tidal flow system, but costs are high and globally, suitable sites are limited.

Between 2006 and 2008, Verdant Power built and installed six underwater turbines to tap the tidal flow of the East River near New York City. The turbines resemble underwater wind turbines as they swivel to face the incoming and outgoing tides, and they have produced electricity efficiently. The next phase of this project involves installing 30 turbines. If the project is successful, as many as 300 turbines may be used in the river. Such a system powers a town in Norway. However, these systems are limited to the small number of rivers that have adequate tidal flows.

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

Wave power facilities are being developed in northern California, Ireland, and Great Britain. However, production is limited because there are few suitable sites for such systems, the costs are high, and the equipment is vulnerable to corrosion from saltwater and storm damage (**Concept 16-4**). However, improved technology could greatly increase the production of electricity from waves sometime during this century.

16-5 What Are the Advantages and Disadvantages of Using Wind Power?

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

Using Wind to Produce Electricity Is an Important Step toward Sustainability

The differences in the angles of the sun's rays hitting the earth between the equator and the poles create different amounts of solar heating; together with the earth's rotation, this creates flows of air called *wind* (see Figure 7-3, p. 149). We can capture this indirect form of solar energy with wind turbines on land and at sea that convert it into electrical energy (Figure 16-23). Such wind turbines are being erected in large numbers at some sites to create *wind farms*. Because today's wind turbines can be as tall as 22 stories and have blades as long as the height of 7-story building, they can tap into the stronger, more reliable, and less turbulent winds found at higher altitudes.

GOOD NEWS

In recent years, wind power has been the world's second-fastest-growing source of energy (see the graph in Figure 12, p. S62, in Supplement 9), after solar cells. In order, the largest wind-power producers in 2009 were China, the United States (see Case Study, p. 418), Germany, Spain, and India. The rapidly increasing use of wind power in China will help to reduce its use of coal and its emissions of CO_2 and other air pollutants. By 2020, China plans to be the world's largest manufacturer and seller of wind turbines.

Denmark, the world's most energy-efficient country, gets 20% of its electricity from wind and is aiming for 50%. Danish companies also control at least one-third of the global wind turbine market. Around the world, more than 400,000 people are employed in the production, installation, and maintenance (Figure 16-24) of wind turbines. These job numbers are likely to rise rapidly in coming years.

GOOD NEWS

In 2009, a Harvard University study led by Xi Lu estimated that wind power has the potential to produce 40 times the world's current use of electricity. The study used data on wind flows and strengths from thousands of meteorological measuring stations to determine that most electricity needs could be met by a series of large wind farms. Most of the land-based

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

Figure 16-23 **Solutions:** A single wind turbine (left) can produce electricity. Increasingly, they are interconnected in arrays of tens to hundreds of turbines. These *wind farms* or *wind parks* can be located on land (middle) or offshore (right). The land beneath these turbines can still be used to grow crops or to raise cattle. **Questions:** Would you object to having a wind farm located near where you live? Why or why not?

wind farms would be located in remote and sparsely populated areas of countries such as China, the United States, and Canada.

Even though offshore wind farms are more costly to install, analysts expect to see increasing use of them (Figure 16-23, right) because wind speeds over water are often stronger and steadier than those over land, and any noise that they make is muffled by surf sounds. Locating them offshore eliminates the need for negotiations among multiple landowners over the locations of turbines and electrical transmission lines. Also, there are more suitable sites at sea, and the turbines could be anchored on floating platforms far enough from shore to be out of sight for coastal residents while taking advantage of stronger and more constant offshore winds. Siting them offshore would avoid complaints about noise that have been voiced by some people living near land-based wind farms.

A 2009 study published in the Proceedings of the U.S. National Academy of Sciences estimated that the world's top CO_2-emitting countries have more than enough land-based and offshore wind potential to more than meet their current electricity needs. The U.S. has enough wind potential to meet an estimated 16 to 22 times its current electricity needs, and China has enough wind potential to meet 15 times its current electricity consumption. Canada has enough wind power to generate 39 times its electrical needs, and Russia could use wind power to meet its electrical needs 170 times over.

Unlike oil and coal, wind is 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. The DOE and the Worldwatch Society estimate that, when we include the harmful environmental and health costs of various energy resources in comparative cost estimates, wind energy is the cheapest way to produce electricity (**Concept 16-5**).

Like any energy source, wind power has some drawbacks. Areas with the greatest wind power potential are often sparsely populated and located far from cities. Thus, to take advantage of the potential for using wind energy, countries such as the United States will have to invest in a long overdue upgrading and expansion of their outdated electrical grid systems. The resulting large increase in the number of transmission towers and lines will cause controversy in some areas and could result in lawsuits challenging such changes. One way to

Suzlon Energy Ltd.

Figure 16-24 Maintenance workers get a long-distance view from atop a wind turbine, somewhere in North America, built by Suzlon Energy, a company established in India in 1995.

deal with this problem could be to run many of the new lines along state-owned interstate highway corridors to avoid legal conflicts. Wind power proponents argue that continuing to rely mostly on the use of polluting and climate-changing coal and oil and the costly nuclear power fuel cycle is a far worse alternative.

Another problem is that winds can die down and thus require a backup source of power, such as natural gas, for generating electricity. However, analysts calculate that a large number of wind farms in different areas connected to an updated electrical grid could usually take up the slack when winds die down in any one area.

Scientists are working on ways to store wind energy. Electricity produced by wind can be passed through water and used to produce hydrogen fuel, which could be thought of as "stored" wind power. Another option is to use wind-generated electricity to pump pressurized air deep underground into aquifers, caverns, and abandoned natural gas wells. The energy stored in the compressed air could then be released as needed to spin turbines and generate electricity when wind power is not available. This process is being used in Germany and in the U.S. state of Alabama.

CONNECTIONS

Bird Deaths and Wind Turbines

Wildlife ecologists and ornithologists have estimated that that wind turbines kill as many as 440,000 birds each year in the United States, although other more recent estimates put the figure at 7,000 to 100,000. (Compare this to much larger numbers reported by Defenders of Wildlife: housecats and feral cats kill 100 million birds a year; hunters, more than 100 million; cars and trucks, about 80 million; and pesticide poisoning, 67 million.) Most of the wind turbines involved in bird deaths were built with the use of outdated designs, and some were built in bird migration corridors. Wind power developers now make sophisticated studies of these corridors in order to avoid them when building wind farms. Newer turbine designs use slower blade rotation speeds and do not provide places for birds to perch or nest, which also reduces bird casualties. Some wind power critics point out that many birds are killed by collisions with electrical transmission towers and lines. But this is a problem that will occur with or without wind power, and researchers will keep trying to find ways to minimize it. The bottom line is: wind power is much less of a threat to birds than other hazards are.

Some people in populated areas and in coastal areas oppose wind farms as being unsightly and noisy. But in windy parts of the U.S. Midwest and in Canada, many farmers and ranchers welcome them and some have become wind power producers themselves. For each wind turbine located on a farmer's land, the landowner typically receives $3,000 to $10,000 a year in royalties. And that farmer can still use the land for growing crops or grazing cattle.

Figure 16-25 lists the major advantages and disadvantages of using wind to produce electricity. According to energy analysts, wind power has more benefits and fewer serious drawbacks than any other energy resource, except for energy efficiency. **GREEN CAREER:** wind-energy engineering

Trade-Offs

Wind Power

Advantages	Disadvantages
Moderate to high net energy yield	Needs backup or storage system when winds die down
Widely available	Visual pollution for some people
Low electricity cost	Low-level noise bothers some people
Little or no direct emissions of CO_2 and other air pollutants	Can kill birds if not properly designed and located
Easy to build and expand	

Figure 16-25 Using wind to produce electricity has advantages and disadvantages (**Concept 16-5**). With sufficient and consistent government incentives, wind power could supply more than 10% of the world's electricity and 20% of the electricity used in the United States by 2030. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

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

CASE STUDY

The Astounding Potential for Wind Power in the United States

The map in Figure 24, p. S54, in Supplement 8 shows the land and offshore areas with the most potential for generating wind power in the United States. The DOE calls the four Great Plains states of North Dakota, South Dakota, Kansas, and Texas the "Saudi Arabia of wind power." The DOE estimates that wind farms in favorable sites in these four states could more than meet the electricity needs of the lower 48 states. In addition, offshore wind resources—off the Atlantic and Pacific coasts, and off the shores of the Great Lakes—could also supply all of the country's electricity. Wind power proponents call for developing more land-based and offshore wind farms instead of building more offshore oil-drilling rigs and more coal-fired and nuclear power plants.

GOOD NEWS

In 2009, wind farms generated enough electricity (30% of it in Texas) to replace the burning of enough coal to fill a coal train that would stretch 3,200 kilometers (2,000 miles). According to a 2009 study by the U.S. Department of the Interior, with expanded and sustained subsidies, wind farms off of the Atlantic and Gulf coasts could generate enough electricity to more than replace all of the country's coal-fired power plants.

In 2008, the DOE estimated that with sufficient and sustained government incentives, wind power could provide at least 20% of the country's electricity by 2030. This would reduce greenhouse gas emissions by an amount equal to the total emissions of 140 million motor vehicles. It would also create hundreds of thousands of jobs if the United States began building most of its own turbines instead of importing them from other countries.

CONNECTIONS

Wind Turbines and U.S. Jobs

GOOD NEWS

Greatly expanding the wind turbine industry in the United States would support about 500,000 jobs, by DOE estimates. It would also restore some of the shrinking U.S. manufacturing base. For example, according to the American Wind Energy Association, the country could use old manufacturing plants that once made gears for automobiles to make gears for wind turbines. Since 2007, more than 42 wind turbine manufacturing plants have been built or expanded in the United States. Each turbine manufacturer needs about 400 component suppliers. At one time, about 70% of the wind power equipment used in the United States was imported from Europe. Today that figure has been reduced to 50% and wind power proponents want it to keep dropping.

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

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

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

We Can Produce Energy by Burning Solid Biomass

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

Solid biomass is burned mostly for heating and cooking, but also for industrial processes and for generating electricity. Wood, wood wastes, charcoal made from wood, and other forms of 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. In agricultural areas, *crop residues* (such as sugarcane and cotton stalks, rice husks, straw, corn cobs, and coconut shells) and *animal manure* (see Photo 11 in the Detailed Contents) can be collected and burned.

Wood is a renewable fuel only if it is harvested no faster than it is replenished. The problem is, about 2.7 billion people in 77 less-developed countries face a *fuelwood crisis* and are often forced to meet their fuel needs by harvesting wood faster than it can be replenished. One way to deal with this problem is to produce solid biomass fuel by planting fast-growing trees such as cottonwoods, willows, and poplars, and by growing shrubs, perennial grasses such as switchgrass, and water hyacinths in *biomass plantations*. But repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. Clearing forests and grasslands for such plantations destroys or degrades biodiversity. And plantation tree species such as European poplar and American mesquite are invasive species that can spread from plantations to takeover nearby ecosytems.

CONNECTIONS

Middlebury College and More Sustainable Biomass Burning

GOOD NEWS

Middlebury College in the U.S. state of Vermont is a leader among educational institutions in the quest to become more sustainable. Recently, it switched from burning oil to heat its buildings to burning wood chips in a state-of-the-art boiler that is part of a cogeneration system. The system heats about 100 college buildings and spins a turbine to generate about 20% of the electricity used by the college. The college has also planted an experimental patch of already-cleared land with fast-growing willow trees as a source of some of the wood chips for the new system. This demonstrates to students that it is preferable to establish biomass plantations only on land that has already been cleared. The college uses its tree-growing experiment and its wood-chip system to help its students learn more about environmental sustainability.

Another problem with depending on solid biomass as a fuel is that clearing forests to provide the fuel reduces the amount of vegetation that would otherwise capture CO_2, and burning biomass produces CO_2. However, if the rate of use of biomass does not exceed the rate at which it is replenished by new plant growth, there is no net increase in CO_2 emissions. But monitoring and managing this balance, globally or throughout any one country, is very difficult.

Still another problem is that burning solid biomass to produce electricity is only about 30-40% efficient. However, using a cogeneration system (Connections, p. 419) in which the excess heat produced by burning the biomass is used to heat water and nearby buildings raises the net energy yield to 60% or higher. Denmark, for example, gets almost half of its electricity by burning wood and agricultural wastes such as straw for cogeneration.

Figure 16-26 lists the general advantages and disadvantages of burning solid biomass as a fuel (**Concept 16-6A**).

HOW WOULD YOU VOTE?

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

We Can Convert Plants and Plant Wastes to Liquid Biofuels

Liquid biofuels such as *biodiesel* (produced from vegetable oils) and *ethanol* (ethyl alcohol produced from plants and plant wastes) are being used in place of petroleum-based diesel fuel and gasoline. By 2009, about 1.7% of the world's liquid fuels were biofuels (mostly ethanol and biodiesel). The biggest producers of liquid biofuels are, in order, the United States (mostly ethanol from corn), Brazil (mostly ethanol from sugarcane residues), the European Union (mostly biodiesel from vegetable oils), and China (mostly producing ethanol from nongrain plant sources to avoid diverting grains from its food supply).

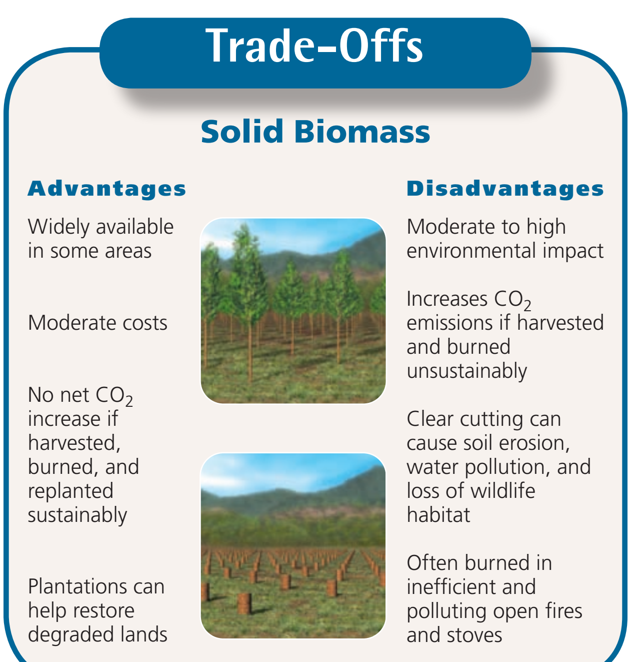


Figure 16-26 Burning solid biomass as a fuel has advantages and disadvantages (**Concept 16-6A**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

Biofuels have three major advantages over gasoline and diesel fuel produced from oil. *First*, while oil resources are concentrated in a small number of countries, biofuel crops can be grown almost anywhere, and thus they help countries to reduce their dependence on imported oil. *Second*, if these crops are not used faster than they are replenished by new plant growth, there is no net increase in CO_2 emissions, unless existing grasslands or forests are cleared to plant biofuel crops. *Third*, biofuels are available now, are easy to store and transport, can be distributed through existing fuel networks, and can be used in motor vehicles at little or no additional cost.

However, in a 2007 UN report on bioenergy, and in another study by R. Zahn and his colleagues, scientists warned that large-scale biofuel-crop farming could decrease biodiversity by increasing the clearing of natural forests and grasslands; increase soil degradation, erosion, and nutrient leaching; push small farmers off their land; and raise food prices if farmers can make more money by growing corn and other crops to fuel cars rather than to feed livestock and people (**Concept 16-6B**).

CONNECTIONS

Biofuels and Climate Change

In 2007, Nobel Prize–winning chemist Paul Crutzen warned that intensive farming of biofuel crops could speed up atmospheric warming and projected climate change by producing more greenhouse gases than would be produced by burning fossil fuels instead of biofuels. This would happen if nitrogen fertilizers were used to grow corn and other biofuel crops. Such fertilizers, when applied to the soil, release large amounts of the potent greenhouse gas nitrous oxide. A 2008 study by Finn Danielsen and a team of other scientists concluded that keeping tropical rain forests intact is a better way to slow projected climate change than burning and clearing such forests and replacing them with biofuel plantations.

Another problem with biofuels production is that growing corn and soybeans in climates that require irrigation could reduce water supplies in these arid regions. In fact, the two most water-intensive ways to produce a unit of energy are irrigating soybean crops to produce biodiesel fuel and irrigating corn to produce ethanol.

The challenge is to grow crops for food and biofuels by using more sustainable agriculture (see Figure 12-34, p. 310) with less irrigation, land degradation, air and water pollution, greenhouse gas emissions, and degradation of biodiversity. Also, any system for producing a biofuel should have a favorable net energy yield so that it can compete in the energy marketplace without large government subsidies.

In the remainder of this section we use three case studies to evaluate the usefulness of biofuels as energy resources. The first evaluates the current production of biodiesel, the second the current production of ethanol, and the third the potential for using algae and bacteria to produce biofuels.

■ CASE STUDY

Is Biodiesel the Answer?

If a truck or bus whizzing by you leaves a scent of fast food, it is probably running on *biodiesel*. This diesel biofuel is produced from vegetable oil extracted from soybeans, rapeseed (a type of mustard seed), sunflowers, oil palms, jatropha shrubs, and coffee grounds. It can also be made from used vegetable oils from restaurants. European Union countries (primarily Germany, France, and Italy) produce about 95% of the world's biodiesel, mostly from rapeseeds and sunflower seeds, and these countries hope to get 20% of their diesel fuel from this source by 2020. In Europe, more than half of all cars run on diesel, primarily because they are as much as 40% more efficient than gasoline engines.

Aided by government subsidies, biodiesel production is growing rapidly in the United States. But soybean and rapeseed crops grown for biodiesel production require huge areas of land and have low yields. Also, using industrialized agriculture to produce these crops results in topsoil loss and fertilizer runoff. Biodiesel production also requires energy (mostly from crude oil and natural gas), which reduces its net energy yield and increases emissions of greenhouse gases.

Brazil, Malaysia, and Indonesia produce biodiesel from palm oil, extracted from large plantations of African oil palm (see Figure 12-5, p. 282), and export much of it to Europe. The net energy yield for biodiesel from oil palm is five times that from rapeseeds used in Europe and about eight to nine times higher than the yield from soybeans used to produce biodiesel in the United States. But increased burning and clearing of tropical forests and other wooded lands to establish oil palm plantations in these countries poses a serious threat to their biodiversity.

Clearing such land also reduces CO_2 uptake by eliminating rain forests that store large amounts of carbon in order to grow crops that store much less carbon. Two studies in 2009 estimated that cutting down Brazilian rain forests to grow soybeans for biodiesel fuel would create a loss of carbon uptake that would take more than 300 years to replace. Also, African oil palm is an invasive plant that has taken over adjacent farms and forest areas in parts of Brazil. Figure 16-27 lists the major advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline.

Trade-Offs

Biodiesel

Advantages	Disadvantages
Reduced CO and CO_2 emissions	Increased NO_x emissions and smog
High net energy yield for oil palm crops	Low net energy yield for soybean crops
Reduced hydrocarbon emissions	Competes with food for cropland
Better mileage (up to 40%)	Clearing natural areas for plantations reduces biodiversity and increases atmospheric CO_2 levels

Figure 16-27 Using biodiesel as a vehicle fuel has advantages and disadvantages compared to gasoline. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of biodiesel fuel outweigh its disadvantages?

■ CASE STUDY

Is Ethanol the Answer?

Ethanol can be made from plants such as sugarcane, corn, and switchgrass, and from agricultural, forestry, and municipal wastes. This process involves converting plant starches into simple sugars, which are processed to produce ethanol.

Brazil, the Saudi Arabia of sugarcane, is the world's second largest ethanol producer after the United States. Brazil makes its ethanol from *bagasse* (Figure 16-28), a residue produced when sugarcane is crushed. This ethanol yields 8 times the amount of energy used to

National Renewable Energy Laboratory

Figure 16-28 Bagasse is a sugarcane residue that can be used to make ethanol.

produce it—compared with a net energy yield of 5 for gasoline. 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.

Within a decade, Brazil could expand its sugarcane production, eliminate all oil imports, and greatly increase ethanol exports to other countries. To do this, Brazil plans to clear and replace larger areas of its rapidly disappearing Cerrado, a wooded savanna region—one of the world's biodiversity hot spots (see Figure 10-27, p. 243)—with sugarcane plantations. This would increase the harmful environmental costs of this otherwise sustainable resource.

Environmental scientists David Pimentel and Tad Patzek warn that producing ethanol from sugarcane has a number of other harmful environmental effects. They include the CO_2 emissions from the burning of oil and gasoline to produce sugarcane, very high soil erosion after sugarcane plantations are harvested, and stresses on water supplies. Producing 1 liter (0.27 gallons) of ethanol from sugarcane requires the equivalent of about 174 bathtubs of water. The water that runs off of sugarcane plantations also contains significant amounts of the fertilizers, herbicides, and pesticides that are often applied at high levels to help increase crop yields.

In the United States, most ethanol is made from corn. (See Figure 13, p. S63, in Supplement 9 for a graph showing the rapid increase in ethanol production in the United States, Brazil, and the world since 1975.) U.S. farmers profit from growing corn to produce ethanol because they receive generous government subsidies as part of the nation's energy policy.

But studies indicate that using fossil fuel–dependent industrialized agriculture to grow corn and then using more fossil fuel to convert the corn to ethanol provides a net energy yield of only about 1.1–1.5 units of energy per unit of fossil fuel input. This low net energy yield explains why the U.S. government (taxpayers) must subsidize corn ethanol production to help it compete in the energy markets with other types of ethanol production that have higher net energy yields. It also helps to explain why Brazil, achieving a net energy yield of 8 from bagasse, can produce ethanol from sugarcane at about half the cost of producing it from corn in the United States. To make matters worse, cars running on E85 fuel (containing 85% ethanol and 15% gasoline) get about 30% lower gas mileage than comparable cars running on just gasoline.

CONNECTIONS

Corn, Ethanol, and Tortilla Riots in Mexico

Traditionally, the United States has supplied approximately 75% of the world's corn. Mexico imports 80% of its corn from the United States. Since 2005, when America began using much of its corn crop to produce ethanol, the prices of food items such as corn tortillas in Mexico have risen sharply. This has drastically affected the 53 million people living in poverty in Mexico and has led to food riots and massive citizen protests.

According to a 2007 study by environmental economist Stephen Polansky, processing all of the corn grown in the United States into ethanol each year would meet only about 30 days worth of the country's current demand for gasoline. This would leave no corn for other uses and would cause sharp increases in the prices of corn-based foods such as cereals, tortillas, poultry, beef, pork, and dairy products as well as prices of the thousands of food products that use corn syrup as a sweetener. This would increase the number of hungry and malnourished people who depend on these foods but could no longer afford to buy them. Energy expert Vaclav Smil has calculated that using ethanol produced from corn to replace conventional gasoline in the United States would require growing corn on six times the country's total area of farmable land, or 75% of the world's cultivated land.

There are conflicting analyses on how using corn to produce ethanol affects CO_2 emissions compared to burning gasoline. A 2008 study by Tim Searchinger at Princeton University and other researchers estimated that clearing and planting grasslands and forests to grow corn for producing ethanol would increase the net amount of CO_2 in the atmosphere by 93% compared to burning conventional gasoline over a 30-year period. But a 2007 EPA study estimated that using corn ethanol would reduce greenhouse gas emissions by about 22% compared to burning gasoline. More research is needed to resolve this issue.

An alternative to corn ethanol is *cellulosic ethanol*, which is produced from inedible cellulose that makes up most of the biomass of plants (see *The Habitable Planet*, Video 10, at **www.learner.org/resources/series209.html**). In this process, cellulose from plant material such as leaves, stalks, husks, and wood chips is isolated, and then enzymes convert the cellulose to sugars that can be processed to produce ethanol. By using these widely available inedible cellulose materials to produce ethanol, producers could dodge the food vs. biofuels dilemma.

A plant that could be used for cellulosic ethanol production is *switchgrass* (Figure 16-29), a tall perennial grass native to North American prairies that grows faster than corn. It is disease resistant and drought tolerant, can be grown without the use of nitrogen fertilizers on land unfit for other crops, and doesn't need to be replanted each year. According to a 2008 article by U.S. Department of Agriculture scientist Ken Vogel and his colleagues, using switchgrass to produce ethanol yields about 5.4 times as much energy as it takes to grow it—a yield much greater than the 1.1–1.5 net energy yield for corn ethanol. According to the U.S. Department of Agriculture, within a decade or two, we could produce much more ethanol than we could from corn by using cellulose from plants such as switchgrass, woodchips from forestry operations, and trash.

GOOD NEWS

However, one drawback is reported by cellulosic ethanol expert Robert Ranier, who estimates that replacing half of U.S. gasoline consumption with cellulosic

National Renewable Energy Laboratory

Figure 16-29 **Natural capital:** The cellulose in this rapidly growing switchgrass can be converted into ethanol, but further research is needed to develop affordable production methods. This perennial plant can also help to slow projected climate change by removing carbon dioxide from the atmosphere and storing it as organic compounds in the soil.

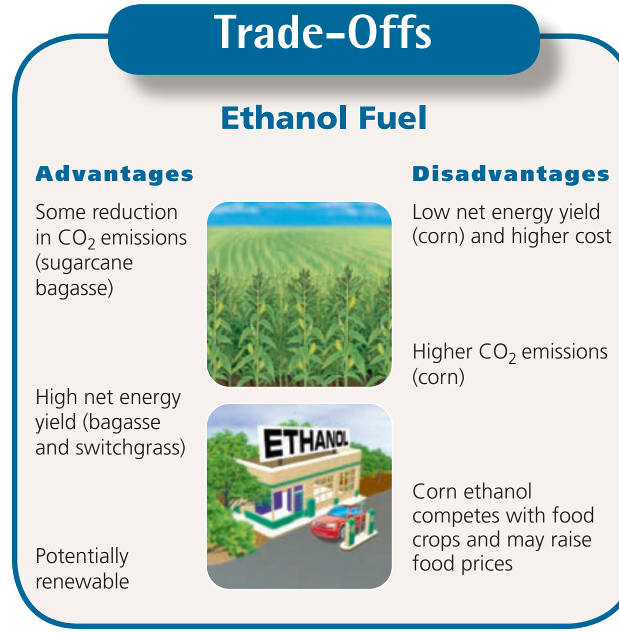


Figure 16-30 Using ethanol as a vehicle fuel has advantages and disadvantages compared to using gasoline (**Concept 16-6B**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

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

ethanol would require about seven times the land area currently used for all corn production. We also do not know how using cellulosic ethanol would affect CO_2 emissions. According to Daniel Kammen of the Berkeley Institute of the Environment, substituting cellulosic ethanol for gasoline would cut motor vehicle greenhouse gas emissions by 90% or more. But a 2009 study led by Tim Searchinger found that clearing and planting large areas of land to grow switchgrass for producing ethanol would increase the net amount of greenhouse gases in the atmosphere by 50% compared to burning gasoline instead of switchgrass ethanol.

Another problem is that it is difficult and costly to break down the cellulose and extract the glucose needed to make ethanol. As a result, affordable chemical processes for converting cellulosic material to ethanol are still being developed and are probably at least a decade away.

Figure 16-30 lists the major advantages and disadvantages of using ethanol as a vehicle fuel, compared to using gasoline.

CASE STUDY
Getting Gasoline and Diesel Fuel from Algae and Bacteria

Scientists are looking for ways to produce biofuels almost identical to gasoline and biodiesel from various types of existing or genetically engineered oil-rich algae (**www.oilgae.com**). Algae grow rapidly at any time of the year and can be cultivated in various aquatic environments.

As they grow, the algae remove CO_2 from the atmosphere and convert it to oil, proteins, and other useful products. They also require much less land, water, and other resources than biofuel plantations do and would not affect food prices by competing for cropland. The algae could be grown in wastewater from sewage treatment plants where they would help to clean up the wastewater while producing biofuel.

Another possibility would be to transfer carbon dioxide produced by coal-burning power plants into nearby algae ponds or bioreactors for use in making biofuel. This would be an application of the solar energy and nutrient recycling **principles of sustainability**.

There are four major challenges in converting such technological dreams into reality: cutting the very high cost of producing oil by such methods; learning whether it is economically better to grow the algae in open ponds or in enclosed bioreactors; finding an affordable way get the oil out of the algae (for example, by drying and crushing the algae or removing it with a solvent); and progressing from small-scale pilot projects to large-scale production systems.

A different approach is to make gasoline or diesel fuel from rapidly multiplying bacteria by using techniques developed in the new field of synthetic biology. One start-up company has a pilot plant near sugarcane fields in Louisiana that uses genetically engineered bacteria to convert the sugar in sugarcane juice into fatty acids that can be used as biodiesel fuel. But some environmental scientists warn that producing useful quantities of biodiesel from such organisms would require converting large areas of the world's land to much less diverse sugarcane plantations.

Making gasoline and diesel fuel from algae and bacteria probably will not wean the United States and other countries from crude oil because we use so much of it. But these emerging technologies could put a good dent in the world's dependence on conventional crude oil and heavy oil from tar sand (see Chapter 15, p. 379), which would reduce the severe environmental impacts of using these fuels.

Producing gasoline and diesel fuels from algae and bacteria could be done almost anywhere. The resulting fuels could be distributed by the world's current gasoline and diesel fuel distribution systems. Thus, it is not surprising that some of the major oil companies are investing heavily in research on producing oil-like compounds from algae and bacteria, hoping to lock in numerous patents for such processes. Stay tuned for new developments in these research ventures.

RESEARCH FRONTIER

Developing more energy-efficient, cheaper, and more sustainable ways to produce liquid biofuels; see **www.cengage .com/login**.

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

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

We Can Get Energy by Tapping the Earth's Internal Heat

Geothermal energy is heat stored in soil, underground rocks, and fluids in the earth's mantle (see Figure 14-2, p. 348). We can tap into this stored energy to heat and cool buildings and to produce electricity. Scientists estimate that using just 1% of the heat stored in the uppermost 5 kilometers (8 miles) of the earth's crust would provide 250 times more energy than that stored in all the earth's crude oil and natural gas reserves.

GOOD NEWS

One way to capture geothermal energy is by using a *geothermal heat pump* system (Figure 16-31). It can heat and cool a house by exploiting the temperature difference, almost anywhere in the world, between the earth's surface and underground at a depth of 3–6 meters (10–20 feet), where the earth's temperature typically is 10–20ºC (50–60ºF) 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 in the ground.

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

We can also tap into deeper, more concentrated *hydrothermal reservoirs* of geothermal energy. This is done by drilling wells into the reservoirs to extract their dry steam (with a low water content), wet steam (with a high water content), or hot water, which are then used to heat homes and buildings, provide hot water, grow vegetables in greenhouses, raise fish in aquaculture ponds, and spin turbines to produce electricity.

The United States is the world's largest producer of geothermal electricity from hydrothermal reservoirs. Most of it is produced in California, Nevada, Utah, and Hawaii (see Figure 26, p. S55, in Supplement 8 for a map of the best geothermal sites in the continental United States). It meets the electricity needs of about 6 million Americans—a number roughly equal to the

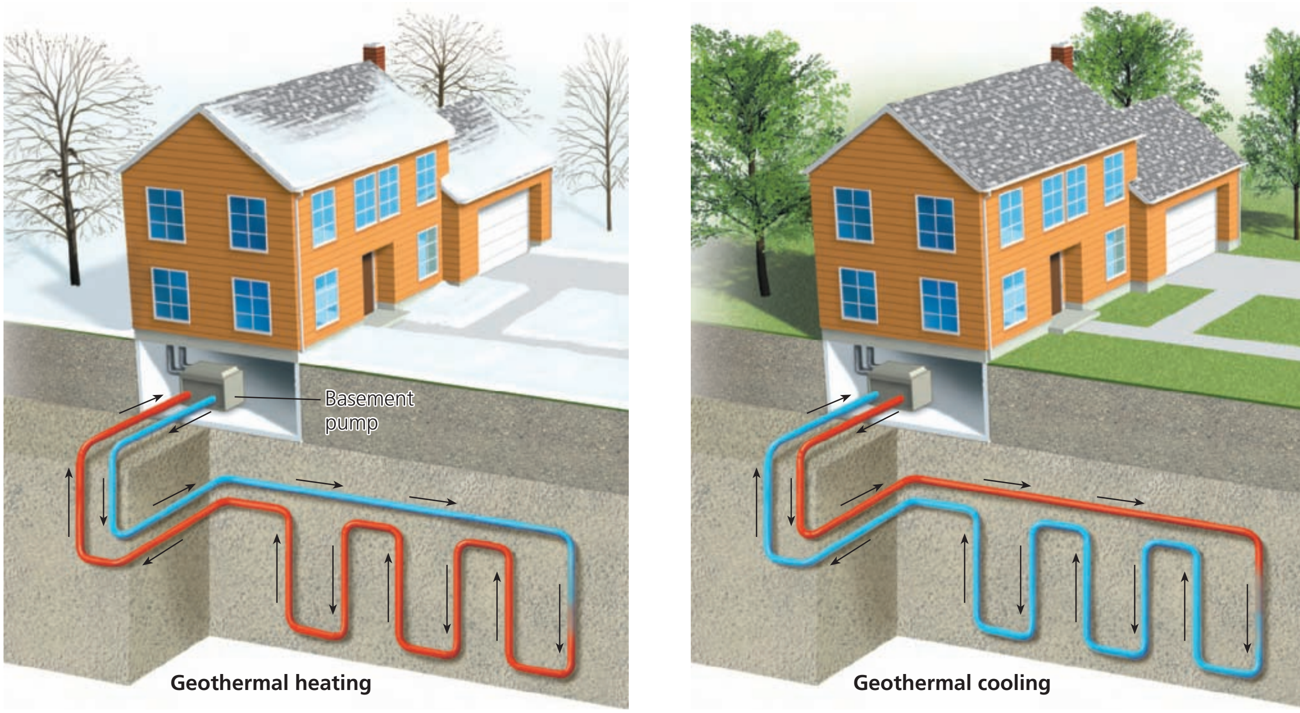


Figure 16-31 **Natural capital:** A geothermal heat pump system can heat or cool a house almost anywhere. It heats the house in winter by transferring heat from the ground into the house (shown here). In the summer, it cools the house by transferring heat from the house to the ground.

combined populations of Los Angeles, California, and Houston, Texas—and supplies almost 6% of California's electricity. But there is a lot of room for growth, because geothermal energy generates just 0.4% of the electricity used in the United States.

Iceland gets almost all of its electricity from hydroelectric and geothermal energy power plants (Figure 16-32). In the Philippines, geothermal plants provide electricity for 19 million people. China has a large potential for geothermal power, which could help the country to reduce its dependence on coal-fired power plants (see Figure 25, p. S54, in Supplement 8 for a map of the world's best geothermal sites).

Geothermal heat storage sites not far below the surface can be tapped by pumping water into them. Then the hot water is pumped to the surface and used to heat

Biophoto/Grenet M. & Soumillard A. PHONE-Auteurs/Peter Arnold, Inc.

Figure 16-32 This geothermal power plant in Iceland produces electricity and heats a nearby spa called the Blue Lagoon.

fluids with low boiling points. This releases vapor that can spin a turbine to generate electricity. So far, such systems are inefficient but scientists are working on ways to improve their efficiency.

Another source of geothermal energy is *hot, dry rock* found 5 or more kilometers (3 or more miles) underground almost everywhere. Water can be injected through wells drilled into this rock. After it absorbs some of the heat, the water is pumped to the surface, used to generate electricity, and then injected back into the earth. According to the U.S. Geological Survey, tapping just 2% of this source of geothermal energy in the United States could produce more than 2,000 times the country's current annual use of electricity.

But digging so deep into the earth's crust is costly. It may also carry the risk of triggering small earthquakes. This possibility led to the cancelling of a major hot rock project in Switzerland in 2009. The high cost could be brought down by more research and improved technology. **GREEN CAREER:** geothermal engineer

Figure 16-33 lists the major advantages and disadvantages of using geothermal energy (**Concept 16-7**). Some analysts see geothermal energy, combined with improvements in energy efficiency, the use of solar cells and wind farms to produce electricity, and the use of natural gas as a temporary bridge fuel, as keys to a more sustainable energy future.

Trade-Offs

Geothermal Energy

Advantages	Disadvantages
Moderate net energy and high efficiency at accessible sites	High cost and low efficiency except at concentrated and accessible sites
Lower CO_2 emissions than fossil fuels	Scarcity of suitable sites
Low cost at favorable sites	Noise and some CO_2 emissions

Figure 16-33 Using geothermal energy for space heating and for producing electricity or high-temperature heat for industrial processes has advantages and disadvantages (**Concept 16-7**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

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

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

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

Will Hydrogen Save Us?

Hydrogen 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 (see Figure 2-9, bottom, p. 43).

Some scientists say that the fuel of the future is hydrogen gas (H_2). In the quest to make it so, most research has been focused on using fuel cells (Figure 16-34) 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), which is emitted into the atmosphere.

Widespread use of hydrogen as a fuel would eliminate most outdoor air pollution problems that we face today. It would also greatly reduce the threat of projected climate disruption, because using it emits no CO_2—as long as the H_2 is not produced with the use of fossil fuels or nuclear power. Hydrogen also provides more energy per gram than does any other fuel, making it a lightweight fuel ideal for aviation.

GOOD NEWS

So what is the catch? There are three challenges in turning the vision of hydrogen as a fuel into reality. *First*, there is hardly any hydrogen gas (H_2) in the earth's atmosphere, so it must be produced from elemental hydrogen (H), which is chemically locked up in water and in organic compounds such as methane and gasoline. We can produce H_2 by heating water or passing electricity through it; by stripping it from the methane (CH_4) found in natural gas and from gasoline molecules; and through a chemical reaction involving coal, oxygen, and steam. The problem is that it takes energy and money to produce H_2 using these methods. In other words, hydrogen gas is not an energy resource like coal or oil. It is a fuel produced by using other forms of energy, and thus *has a negative net energy yield.* Therefore, it will always take more energy to make it from these sources than the energy we get by burning it as a fuel.

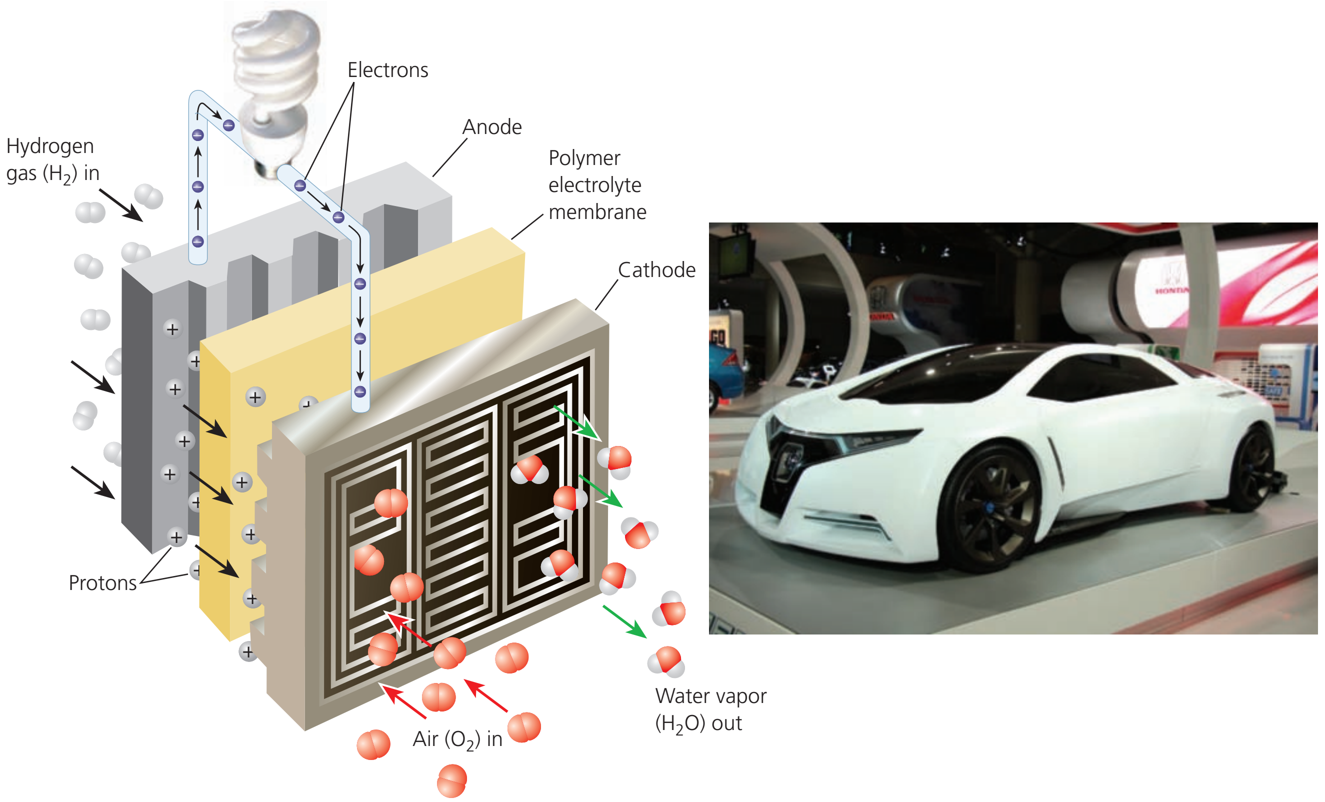


Figure 16-34 A *fuel cell* takes in hydrogen gas and separates the hydrogen atoms' electrons from their protons. The electrons flow through wires to provide electricity, while the protons pass through a membrane and combine with oxygen gas to form water vapor. Note that this process is the reverse of *electrolysis*, the process of passing electricity through water to produce hydrogen fuel. The photo (right) shows a fuel-cell concept car introduced by Honda Motor Company in 2009 at an international car show in Toronto, Canada. All of the exhaust from this car is water vapor.

Second, fuel cells are the best way to use H_2 to produce electricity, but current versions of fuel cells are expensive. However, progress in the development of nanotechnology (see Chapter 14, Science Focus, p. 365, and Supplement 4, p. S16) could lead to cheaper and more efficient fuel cells.

Third, 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 is produced. We could use electricity from coal-burning and nuclear power plants 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. We can also make H_2 from coal and strip it from organic compounds found in fuels such as gasoline. However, according to a 2002 study, using these methods to produce H_2 would add much more CO_2 to the atmosphere per unit of heat generated than does burning carbon-containing fuels directly. If renewable energy sources were used to make H_2, these CO_2 emissions would be avoided.

Hydrogen's negative net energy yield is a serious limitation and means that this fuel will have to be subsidized in order for it to compete in the open marketplace with fuels that have moderate to high net energy yields. However, because hydrogen is such a clean burning fuel, it may eventually be widely used.

For example, in the 1990s, Amory Lovins (**Core Case Study**) and his colleagues at the Rocky Mountain Institute designed a very light, safe, extremely efficient hydrogen-powered car. It is the basis of most prototype hydrogen fuel-cell cars now being tested by major automobile companies (Figure 16-34, right). Some analysts project that fuel-cell cars, running on affordable H_2 produced from natural gas, could be in widespread use by 2030 to 2050. However, in 2009, the U.S. government reduced its research and development support for hydrogen fuel and put more emphasis on wind, direct solar energy, cleaner coal, and nuclear power.

CORE CASE STUDY

Larger, stationary fuel cells could provide electricity and heat for commercial and industrial users. In 2010, Bloom Energy in California began selling fuel-cell stacks, each about the size of a trash dumpster, to power buildings. They use natural gas to provide the hydrogren gas, and the company depends on significant state and federal subsidies to be competitive with producers of electricity from coal-burning plants. In addition, Japan has built a large fuel cell that produces enough electricity to run a small town.

Canada's Toronto-based Stuart Energy is developing a fueling unit about the size of a dishwasher that will allow consumers to use electricity to produce their own H_2 from tap water. The unit could be installed in a garage and used to fuel a hydrogen-powered vehicle overnight. In sunny areas, people could install rooftop panels of solar cells to produce and store H_2 for their cars.

Another promising application is in homes, where a fuel-cell stack about the size of a refrigerator could provide heat, hot water, and electricity. Some Japanese homeowners get their electricity and hot water from such fuel cell units, which produce H_2 from the methane in natural gas. **GREEN CAREER:** hydrogen energy

With all of these possibilities, using taxpayer funds to subsidize H_2 production may still be a good investment, but only if the H_2 is made with electricity produced by low-polluting, renewable sources that emit little or no CO_2 (Science Focus, below).

RESEARCH FRONTIER

Developing better and more affordable ways to produce hydrogen from renewable energy resources and practical ways to store and distribute it; see **www.cengage.com/login**.

Figure 16-35 lists the major advantages and disadvantages of using hydrogen as an energy resource (**Concept 16-8**).

Trade-Offs

Hydrogen

Advantages	Disadvantages
Can be produced from plentiful water at some sites	Negative net energy yield
No direct CO_2 emissions if produced from water	CO_2 emissions if produced from carbon-containing compounds
Good substitute for oil	High costs require subsidies
High efficiency (45–65%) in fuel cells	Needs H_2 storage and distribution system

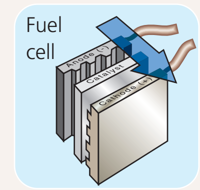


Figure 16-35 Using hydrogen as a fuel for vehicles and for providing heat and electricity has advantages and disadvantages (**Concept 16-8**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

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

SCIENCE FOCUS

The Quest to Make Hydrogen Workable

Scientists are proposing various schemes for producing and storing hydrogen gas (H_2) as fuel. For example, naturally occurring bacteria and algae can produce H_2 by biodegrading almost any organic material in a microbiological fuel cell.

The most likely H_2 production methods will use electricity generated by solar cell power plants, wind farms, and geothermal energy. In 2008, MIT scientists Daniel Nocera and Matthew Kanan developed a catalyst made from inexpensive cobalt and phosphate salts that can split water into hydrogen and oxygen using a fairly small amount of electricity. This could make it affordable to use electricity produced by wind turbines or solar cells to produce H_2 and thus to store in H_2 the energy produced by the wind and sun.

Once produced, H_2 can be stored in a pressurized tank as liquid hydrogen. It can also be stored in solid metal hydride compounds and in sodium borohydride, both of which release H_2 when heated. Scientists are also evaluating ways to store H_2 by coating the surfaces of activated charcoal or carbon nanofibers with it; when heated the coated surfaces release the H_2. Another possibility is to store H_2 inside nanosize glass microspheres that can easily be filled and refilled.

H_2 could also be stored in the hollow tubes of chicken feathers. In 2009, a team of scientists led by chemical engineer Richard Wool estimated that a hydrogen storage tank using chicken feathers could be mass-produced for about $200 per tank. This would also make use of the almost 3 billion tons of chicken feather waste produced each year in the United States. Yet another possibility is the development of *ultracapacitors* that could quickly store large amounts of electrical energy, which would then be used to propel cars or to produce H_2 on demand.

Metal hydrides, sodium borohydride, carbon nanotubes, and glass microspheres containing H_2 will not explode or burn if a vehicle's fuel tank is ruptured in an accident. Thus, H_2 stored in such ways is a much safer fuel than gasoline, diesel fuel, natural gas, and concentrated ethanol. Also, the use of ultralight car bodies would improve fuel efficiency so that large hydrogen fuel tanks would not be needed.

In 2007, engineering professor Jerry Woodall invented a new way to produce hydrogen by exposing pellets of an aluminum-gallium alloy to water. If this process is perfected and proves economically feasible, H_2 could be generated as needed inside a tank about the same size as an average car's gasoline tank.

Critical Thinking

Do you think that governments should subsidize research and development of these and other technologies in order to help make H_2 a workable fuel? Explain.

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 greatly improving energy efficiency, using a mix of renewable energy resources, and including the environmental costs of energy resources in their market prices.**

Choosing Energy Paths

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

- How much of the energy resource is likely to be available in the near future (the next 25 years) and in the long term (the next 50 years)?
- What is the estimated net energy yield (see Chapter 15, Science Focus, pp. 371–373) for the resource?
- What are the estimated costs for developing, phasing in, and using the resource?
- What government research and development subsidies and tax breaks will be needed to help develop the resource?
- How will dependence on the resource affect national and global economic and military security?
- How vulnerable is the resource to terrorism?
- How will extracting, transporting, and using the resource affect the environment, the earth's climate, and human health? Should we include these harmful costs in the market price of the resource through mechanisms like taxing and reducing environmentally harmful subsidies?
- Does use of the resource produce hazardous, toxic, or radioactive substances that we must safely store for very long periods of time?

In 1977, Amory Lovins (**Core Case Study**) CORE CASE STUDY published his pioneering book, *Soft Energy Paths*. In it, he compared what he called *hard energy paths*—based on increasing use of nonrenewable coal, oil, natural gas, and nuclear energy—to what he called *soft energy paths*—based on improving energy efficiency and increasing the use of various renewable energy resources. At that time, many energy experts criticized Lovins as being unrealistic and not really understanding the energy business. Today, he is one of the world's most prominent energy experts and is helping the world make the transition to the soft energy path that he proposed over three decades ago.

Our energy future—the energy path we choose—depends primarily on what energy resources governments and private companies decide to *promote*, which will be influenced partly by political and economic pressure from citizens and consumers. In considering possible energy futures, scientists and energy experts who have evaluated energy alternatives have come to three general conclusions. First, *there will likely be a gradual shift from large, centralized macropower systems to smaller, decentralized micropower systems* (Figure 16-36, p. 430) such as wind turbines, household solar-cell panels, rooftop solar water heaters, small natural gas turbines, and eventually fuel cells for cars and stationary fuel cells for houses and commercial buildings.

Currently, most countries have a system of centralized, large power plants, refineries, pipelines, and other infrastructure that are vulnerable to disruption from events such as terrorist attacks and natural disasters. For example, in 2005, Hurricane Katrina crippled about 10% of America's oil- and gas-producing wells (see the map in Figure 18, bottom, p. S49, in Supplement 8) and oil refineries in the Gulf of Mexico for more than a year.

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

The second general conclusion of experts is that *a combination of greatly improved energy efficiency and the temporary use of natural gas will be the best way to make the transition to a diverse mix of locally available renewable energy resources over the next several decades* (**Concept 16-9**). By using a variety of often locally available renewable energy resources, we would be applying the diversity **principle of sustainability** and not putting all of our "energy eggs" in only one or two baskets. SUSTAINABILITY

The third general conclusion is that *because of their still-abundant supplies and artificially low prices, fossil fuels will continue to be used in large quantities*. This presents two major challenges. One is to find ways to reduce the harmful environmental impacts of widespread fossil fuel use, with special emphasis on reducing outdoor emissions of greenhouse gases and other air pollutants. The other is to find ways to include more of the harmful environmental costs of using fossil fuels

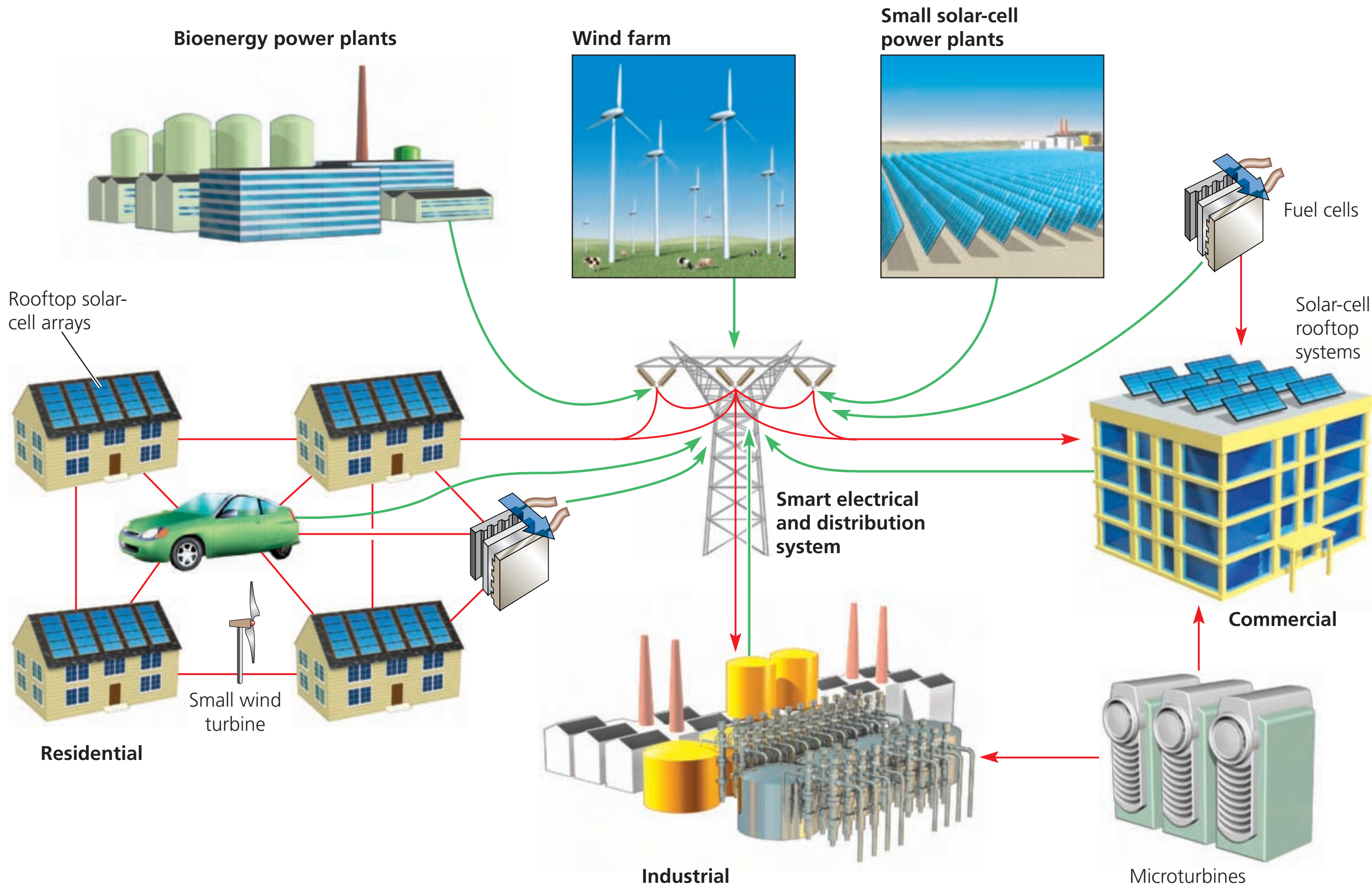


Figure 16-36 **Solutions:** During the next few decades, we will probably shift from dependence on a *centralized macropower system*, based on a few hundred large coal-burning and nuclear power plants to a *decentralized micropower system*, in which electricity is produced by a large number of dispersed, small-scale, local power generating systems. Some of the smaller systems would produce power on site; others would feed the power they produce into a modern electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system, largely based on locally available renewable energy resources. **Question:** Can you think of any disadvantages of a decentralized power system?

in their market prices, as less environmentally harmful alternatives are phased in.

Figure 16-37 summarizes these and other strategies for making the transition to a more sustainable energy future over the next 50 years (**Concept 16-9**). GOOD NEWS

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

To most analysts, economics, politics, and consumer education hold the keys to making a shift to more sustainable energy resources. Governments can use three strategies to help stimulate or reduce the short-term and long-term use of a particular energy resource.

First, they can *keep the prices of selected energy resources artificially low to encourage use of those resources*. They do this by providing research and development subsidies, tax breaks, and loan guarantees to encourage the development of those resources, and by enacting regulations that favor them. For decades, this approach has been employed to stimulate the development and use of fossil fuels and nuclear power in the United States as well as in most other more-developed countries. This has created an uneven economic playing field that *encourages* energy waste and rapid depletion of nonrenewable energy resources, while it *discourages* improvements in energy efficiency and the development of a variety of renewable energy resources.

Many energy analysts argue that one of the most important steps that governments can take to level the economic playing field is to phase out the $250–300 billion in annual subsidies and tax breaks now provided worldwide for fossil fuels and nuclear energy—both of which are mature industries that could be left to stand on their own economically. These analysts call for greatly increasing subsidies and tax breaks for developing and using renewable energy and energy-efficiency technologies.

Solutions

Making the Transition to a More Sustainable Energy Future

Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

Provide large tax credits or feebates for buying efficient cars, houses, and appliances

Reward utilities for reducing demand for electricity

Greatly increase energy efficiency research and development

More Renewable Energy

Greatly increase use of renewable energy

Provide large subsidies and tax credits for use of renewable energy

Greatly increase renewable energy research and development

Reduce Pollution and Health Risk

Phase out coal subsidies and tax breaks

Levy taxes on coal and oil use

Phase out nuclear power subsidies, tax breaks, and loan guarantees

Figure 16-37 Energy analysts have made a number of suggestions for helping us make the transition to a more sustainable energy future (**Concept 16-9**). **Questions:** Which five of these solutions do you think are the most important? Why?

However, making such a shift in energy subsidies is difficult because of the immense political and financial power of the fossil fuel and nuclear power industries. They vigorously oppose the loss of their subsidies and tax breaks, as well as any significant increase in subsidies and tax breaks for energy efficiency, which reduces the use of fossil fuels and nuclear power. They also oppose subsidies for competing renewable energy sources.

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

Third, governments can *emphasize consumer education*. Even if governments offer generous financial incentives for energy efficiency and renewable energy use, people will not make such investments if they are uninformed—or misinformed—about the availability, advantages, disadvantages, and hidden environmental costs of various energy resources.

An excellent example of what a government can do to bring about a more sustainable energy mix is the case of Germany. It is the world's most solar-powered nation, with half of the world's installed capacity. Why does cloudy Germany have more solar water heaters and solar cell panels than sunny France and Spain have? There are two main reasons. One is that the German government made the public aware of the environmental benefits of these technologies. The other is that the government provided consumers with substantial economic incentives for using the technologies.

The government did not accomplish this by raising taxes. Instead, it allowed utilities to raise electricity rates slightly on all users to subsidize those who installed solar systems. This arrangement was based on a direct subsidy called a *feed-in tariff*: users installing solar panels get a guaranteed payment for 20 years for each kilowatt of excess energy that they feed into the grid. As a result, when German homeowners and businesses install solar cell systems, they get a guaranteed 8% return on their investments for 20 years. This is a key reason why the German city of Freiburg in the sunnier southern part of Germany relies more on solar energy than most other communities in the world. Seventeen other European nations and more than 20 other nations around the world, including China, have adopted feed-in tariffs.

We have the creativity, wealth, and most of the technology needed to make the transition to a more sustainable energy future within your lifetime. GOOD NEWS Making this transition depends primarily on *education*, *economics*, and *politics*—on how well individuals understand environmental and energy problems and their possible solutions, and on how they vote and then influence their elected officials. People can also vote with their wallets by refusing to buy energy-inefficient and environmentally harmful products and services, and by letting company executives know about their choices. Figure 16-38 (p. 432) lists some ways in which you can contribute to making the transition to a more sustainable energy future.

What Can You Do?

Shifting to More Sustainable Energy Use

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

Figure 16-38 **Individuals matter:** you can reduce your use and waste of energy. **Questions:** Which three of these items do you think are the most important? Why? Which things in this list do you already do or plan to do?

Here are this chapter's *three big ideas*:

- We should evaluate energy resources on the basis of their potential supplies, how much net useful energy they provide, and the environmental impacts of using them.
- Using a mix of renewable energy sources—especially solar, wind, flowing water, sustainable biofuels, and geothermal energy—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.
- Making the transition to a more sustainable energy future will require sharply reducing energy waste, using a mix of environmentally friendly renewable energy resources, and including the harmful environmental costs of energy resources in their market prices.

REVISITING The Rocky Mountain Institute and Sustainability

CORE CASE STUDY

SUSTAINABILITY

By relying mostly on nonrenewable fossil fuels, we violate the three **principles of sustainability** (see back cover), and this has become a serious long-term problem. We depend mostly on nonrenewable energy resources such as oil and coal and not on direct and indirect forms of renewable solar energy. The technologies we use to obtain energy from these nonrenewable resources disrupt the earth's chemical cycles by diverting huge amounts of water, degrading or destroying terrestrial and aquatic ecosystems, and emitting large quantities of greenhouse gases and other air pollutants. Using these technologies also destroys and degrades biodiversity and ecosystem services.

The work of Amory Lovins and the Rocky Mountain Institute, described in the **Core Case Study** that opens this chapter, is all about sustainability. For more than 25 years, the research and consulting done by the institute around the world has helped businesses, governments, and individuals to make the transition to a more sustainable energy future. In choosing soft energy paths as recommended by Lovins, we would be applying the three **principles of sustainability**. This means

- relying much more on direct and indirect forms of solar energy for our electricity, heating and cooling, and other needs,
- recycling and reusing materials and thus reducing wasteful and excessive consumption of energy and matter, and
- mimicking nature's reliance on biodiversity by using a diverse mix of locally and regionally available renewable energy resources.

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

MOHAMED EL-ASHRY

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 398. Describe the work of Amory Lovins at the Rocky Mountain Institute.

2. What is **energy efficiency**? Explain why we can think of energy efficiency as an energy resource. What percentage of the energy used in the United States is unnecessarily wasted? List four widely used energy-wasting technologies. What are the major advantages of reducing energy waste? List three reasons why this source of energy has been neglected.

3. Describe three ways to save energy and money in **(a)** industry, **(b)** transportation, **(c)** new buildings, and **(d)** existing buildings. What is **cogeneration (combined heat and power** or **CHP)**? How could we encourage electric utility companies to reduce their energy waste? What is a smart grid and why is it important?

4. Describe the trends in fuel efficiency in the United States since the 1970s. Explain why the price of gasoline is much higher than what consumers pay at the pump. What is a fee-bate? Distinguish among hybrid, plug-in hybrid, and fuel-cell motor vehicles. Describe the possible connection between wind farms and plug-in hybrid cars. Summarize the search for better batteries and describe two promising developments. What is a living roof? What is the importance of a white or light-colored roof? What is a superinsulated house? Compare the energy efficiency of incandescent, compact fluorescent, and LED lightbulbs. Explain how using compact fluorescent lightbulbs can reduce overall air pollution from toxic mercury. What are green buildings and why are they important? List six ways in which you can save energy where you live. Give three reasons why we waste so much energy.

5. List five advantages of relying more on a variety of renewable energy sources and describe two factors holding back such a transition. Distinguish between a **passive solar heating system** and an **active solar heating system** and discuss the major advantages and disadvantages of such systems for heating buildings. What are three ways to cool houses naturally? Discuss the major advantages and disadvantages of concentrating solar energy to generate high-temperature heat and electricity. What is a **solar cell (photovoltaic** or **PV cell)** and what are the major advantages and disadvantages of using such devices to produce electricity?

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

7. What is a wind turbine? What is a wind farm? What are the major advantages and disadvantages of using wind to produce electricity? Explain why the United States is the "Saudi Arabia of wind energy." What are the major advantages and disadvantages of burning wood to provide heat and electricity? What are biofuels and what are the major advantages and disadvantages of using biodiesel and ethanol to power motor vehicles? Evaluate the use of corn, sugarcane, and cellulose plants to produce ethanol. Describe the potential for using algae and bacteria to produce gasoline and diesel fuel.

8. What is **geothermal energy** and what are three sources of such energy? What are the major advantages and disadvantages of using geothermal energy as a source of heat and to produce electricity? What are the major advantages and disadvantages of using hydrogen as a fuel to produce electricity and to power motor vehicles?

9. List three general conclusions of energy experts about possible future energy paths for the world. List five major strategies for making the transition to a more sustainable energy future. Describe three roles that governments play in determining which energy resources we use.

10. What are this chapter's *three big ideas*? Describe how the Rocky Mountain Institute applies the three **principles of sustainability** to evaluating and using energy resources.

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

CRITICAL THINKING

1. Imagine that you live in the Rocky Mountain Institute's building (Figure 16-1), powered mostly by the sun (**Core Case Study**). Do you think that you would have to give up any of the conveniences you now enjoy? If so, what are they? Describe any adjustments you might have to make in your way of living.

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

3. Congratulations! You have won $500,000 to build a more sustainable house of your choice. With the goal of maximizing energy efficiency, what type of house would you build? How large would it be? Where would you locate it? What types of materials would you use? What types of materials would you *not* use? How would you

heat and cool the house? How would you heat water? What types of lighting, stove, refrigerator, washer, and dryer would you use? Which, if any, of these appliances could you do without?

4. A homebuilder installs electric baseboard heat and claims, "It is the cheapest and cleanest way to go." Apply your understanding of the second law of thermodynamics (see Chapter 2, p. 47) and net energy (see Figure 15-3, p. 373) to evaluate this claim.

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

6. Explain why you agree or disagree with the following proposals made by various energy analysts:
   a. We should eliminate government subsidies for all energy alternatives so that all energy providers can compete in a true free-market system.
   b. We should phase out 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). We should replace them with subsidies and tax breaks for improving energy efficiency and developing solar, wind, geothermal, hydrogen, and biomass energy alternatives.
   c. We should leave development of solar, wind, and hydrogen energy to private enterprise and it should receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal government subsidies.

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

8. China is investing 10 times as much as the United States is spending (as a percentage of its gross domestic product) in new, cleaner energy technologies such as electric cars, wind power, and solar energy. Chinese leaders understand that these technologies represent one of the biggest money-making opportunities of this century, and they plan to sell these technologies to the world. Energy analysts and economists call for the United States to launch a massive research and development program to join China in becoming a technological and economic leader in the area of clean energy. Do you agree with this proposal? Explain.

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

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

ECOLOGICAL FOOTPRINT ANALYSIS

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

EPA Size Class/ Model	Compact Honda Civic Hybrid	Midsize Car Toyota Camry Hybrid	Sports Utility Vehicle (SUV) Hummer H3
Combined highway and city fuel efficiency in kpl (mpg)	17.8 (42.0)	14.4 (34.0)	6.40 (15.0)
Liters (gallons) of gasoline consumed per year, assuming an average mileage of 19,300 kilometers (12,000 miles)			
Kilograms (pounds) of CO_2 produced per year, assuming that the combustion of gasoline releases 2.3 kilograms per liter (19 pounds per gallon)			
Hectares (acres) of tropical rain forest needed to take up the CO_2 produced per year, assuming that the uptake of an undisturbed forest is 0.5 kilograms of CO_2 per square meter			

Source: www.fueleconomy.gov/feg/findacar.htm

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

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AP* Review Questions for Chapter 16

Questions 1–4 refer to the following approximate energy efficiencies.

(A) 1%
(B) 5%
(C) 8%
(D) 20%
(E) 33%

1. Coal fired power plant including the energy used to dig up the coal

2. Nuclear power plant including the nuclear fuel cycle

3. Incandescent light bulb

4. Internal combustion engine used to power most motor vehicles

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

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

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

Questions 8–11 refer to the following disadvantages of alternative energy sources.

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

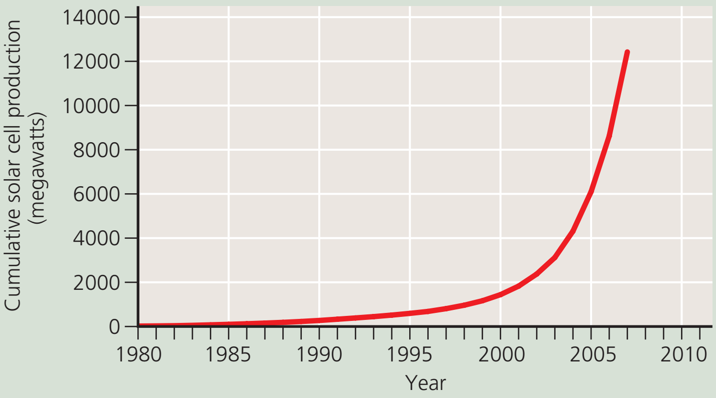
8. Geothermal

9. Hydrogen fuel cells

10. Ethanol fuel

11. Wind energy

Questions 12 and 13 refer to the diagram below.



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

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