Michael Reynolds is a maverick in the construction industry. Based in Taos, New Mexico, Reynolds builds homes that embody many of the principles of sustainability. The walls, for example, are constructed of used automobile tires that otherwise would have ended up in landfills. The recycled tires are packed with dirt from the construction site, using a local resource. They’re laid on top of one another like bricks to build thick walls. Cement
stucco or earthen plaster is then applied to the tire walls, creating an appealing design (FIGURE 15-1a). Reynolds’s houses, called Earthships, are generally built into the sides of hills, taking advantage of the Earth to shelter the house from summer heat and winter cold. With their thick walls and well-insulated ceilings, Earthships are heated by the sun and are extremely energy efficient. They stay cool in the summer and warm in the winter.

Reynolds’s homes are designed with interior planters that line the south wall, permitting residents to grow a variety of vegetables year round (FIGURE 15-1b). The plants are watered with wastewater from sinks and showers—commonly called gray water. In his most recent designs, Reynolds has devised a system to capture nutrients from toilet water. The waste is fed into specially lined outdoor planters, where it is broken down by bacteria and other microorganisms. The nutrients are used by plants growing in the planters.

Besides being heated by the sun, Reynolds’s homes generate their own electricity from sunlight and are equipped with efficient lighting systems and appliances. His homes even capture and purify rainwater and snowmelt off the roof for cooking, drinking, bathing, washing dishes, and other uses.

Earthships are designed for self-sufficiency and environmental responsibility. They are unlike conventional homes, which Reynolds likens to patients in intensive care units that depend on outside support in the form of food, water, and energy.

CRITICAL THINKING
Exercise
An internationally known expert from the oil industry argues to a group of congressional representatives that solar energy is not an economically sound option. It’s a great idea, he says, but the economics of solar energy aren’t good enough to merit widespread use in the United States. He argues that the conventional fuels such as oil, coal, and nuclear energy are more economical and, therefore, more desirable options. If you were one of the senators on the panel listening to this testimony, what questions would you ask? How would you evaluate this advice? What critical thinking rules does this examination require?
Without these inputs, a patient could not survive. Homes are equally as vulnerable. In many ways, the typical modern home is a microcosm of cities and towns. Cut off from oil, food, and water, a city or town would face serious difficulties.

Reynolds and a handful of other builders are part of a growing legion of citizens working to help make the transition to a sustainable society, one that supplies human needs while protecting and even enhancing the Earth's life-support systems. A key element of his design is the use of sunlight, a form of renewable energy. Conservation is also vital to the success of his design. This chapter examines two major “sources” of energy needed to create a sustainable global energy system: conservation and renewable energy. The final section of the chapter shows how these alternative and environmentally sustainable forms of energy could eventually replace what many consider to be unsustainable fuel sources: oil, coal, natural gas, and nuclear energy.

**15.1 Energy Conservation: Foundation of a Sustainable Energy System**

We humans need energy, and we need it badly. Yet at least half—perhaps as much as three-quarters—of the energy consumed in the world is wasted, largely because of inefficient technologies and wasteful practices. The second law of thermodynamics states that when energy is converted from one form to another, some energy is lost as heat. In other words, no energy conversion is 100% efficient; some waste is inevitable. The amount of energy wasted in the United States, however, far exceeds the inevitable loss.

Given our heavy dependence on nonrenewable energy supplies—and given their economic and environmental costs and eventual depletion—waste is economically, environmentally, and socially unacceptable. It is also ultimately unsustainable. Writer Bruce Hannon put it best when he said, “A country that runs on energy cannot afford to waste it.” Lest we forget, waste is lost opportunity. Reducing waste opens up new opportunities.

**Economic and Environmental Benefits of Energy Conservation**

Conservation is one of the biological principles of sustainability discussed in Chapter 2 and is essential to the sustainable transition now under way. As noted in that chapter, conservation is used here to include frugality (using what you need) and efficiency (using it efficiently). Energy conservation offers numerous social, economic, and environmental benefits. In industry, energy conservation can reduce the cost of producing goods, giving companies a decided economic advantage in the marketplace. An Alcoa plant in Iowa, for example, found that with a minimum investment in energy-efficiency measures it could cut its $6 million annual energy bill by 25%, thus reducing energy costs by $1.5 million a year—a tidy sum that makes them more competitive and more profitable. Energy conservation also results in substantial reductions in pollution. Many factories, for example, produce their own electricity by burning coal. To reduce pollution, they’ve installed pollution control devices such as smoke-stack scrubbers on their power plants. These devices capture pollutants but produce a considerable amount of hazardous solid waste. By using energy more efficiently, companies can reduce the energy they need. Energy savings reduce fuel costs. They also result in economic savings by reducing the amount of hazardous waste that must be disposed of.

The economic savings from energy efficiency can be illustrated by comparing the cost of this strategy with the cost of supplying energy from conventional sources. For example, measures that improve the efficiency of machines and appliances cost about 1 cent per kilowatt-hour of energy saved, according to energy expert Amory Lovins. In contrast, electricity from coal-fired power plants costs 8 cents per kilowatt-hour (kWh). What this means is that for every penny a company invests in energy efficiency it will save 7 cents in electrical bills, if they’re paying 8 cents per kWh. Similar calculations can be made for other fuels. Not surprisingly, the most energy-efficient companies and nations are also the most successful economically.

Besides saving money, energy efficiency addresses a number of environmental problems simultaneously. For example, reducing the combustion of fossil fuels reduces acid deposition, global warming, and urban air pollution. Cutting our demand for oil reduces the number of oil spills, thus saving aquatic species as well as the birds and mammals that depend on clean water. In addition, using less fossil fuel reduces the destruction of wildlife habitat by decreasing the extraction of fossil fuels. Besides saving money, efficiency measures can be rapidly deployed, so they begin saving individuals and businesses money very quickly. Finally, energy efficiency can help us stretch limited supplies of fossil fuel, giving us more time to make a transition to a more sustainable system of energy.
Energy Conservation Options

The range of energy conservation options available to businesses and homeowners is enormous. In some cases, efficiency can be achieved through minor changes in our actions. The Denver Marriott hotel, for instance, made substantial cuts in energy demand by asking its cleaning staff to raise the temperature setting in unoccupied rooms during the summer (so the air conditioning system didn’t have to work so hard) and to lower it during the winter (to reduce heating costs). Around the home, shutting off lights, turning off televisions when they’re not in use, and lowering the thermostat a little in the winter and raising it in the summer can result in significant reductions in energy demand.

Every degree you raise the temperature in the summer reduces your cooling costs approximately 8%. For commuters, driving within the speed limit, keeping cars tuned up, and being sure that tires are properly inflated could translate into millions of gallons of gasoline saved each year. Such measures require little or no initial investment and can save individuals a lot of money. When millions of people contribute to the cause, savings can be enormous.

Many devices that save energy are readily available for homes, businesses, and factories. Water-saving devices—especially showerheads, dishwashers, and washing machines—can save substantial amounts of energy in homes by reducing demand for hot water. High-efficiency lighting systems can cut electrical demand for lighting in homes and businesses by three-fourths. The compact fluorescent lightbulb (CFL), available in many stores today, can be substituted for standard incandescent bulbs and uses only one-fourth as much energy to produce the same amount of light (FIGURE 15-2). Although high-quality compact fluorescents cost more initially (about $1 to $8), they outlast 9 or 10 ordinary bulbs and save $30 to $50 over their lifetimes in reduced electrical demand. They also reduce carbon dioxide pollution by about one ton and reduce summer cooling costs because they produce little waste heat, unlike incandescent bulbs. Homeowners are recommended to install them in high-use areas.

Even more efficient lightbulbs, known as LEDs, are now available (FIGURE 15-3). LED stands for light-emitting diode. These bulbs use even less energy than standard CFLs, about one-third as much. Although they are still costly, they also outlast the long-lasting CFLs. An LED could last as many as 50,000 to 60,000 hours, saving several hundred of dollars over its lifetime. LEDs are now often used in taillights of trucks and cars, and even stoplights. The City of Denver replaced all of its stoplights with LEDs, which saves them $1 million a year in electric costs. LEDs can be used to replace outdoor floodlights and are also available for indoor use.

Some of the most substantial savings come from some of the easiest and least expensive measures. Caulking leaks in the building envelope—that is, the walls, foundation, and ceiling—of homes and businesses can dramatically reduce heat gain in the summer and heat loss in the winter. Applying weatherstripping around doors and windows can also reduce heat gain and loss. Sealing the leaks in a building saves lots of energy, slashes fuel costs, and dramatically increases comfort levels.

Substantial energy savings can also be achieved by installing a lot more insulation in homes, businesses, and factories. Doubling the insulation in a new home, for example, adds about 5% to the cost but pays for itself in 5 years in reduced energy costs.

Planting shade trees around homes can reduce summer cooling costs. One study showed that three trees planted near light-colored houses in a residential neighborhood in Phoenix could cut cooling costs by 18%. In Sacramento and Los Angeles, the savings are even greater—34 and 44%, respectively. Planting conifers on the north and west sides of homes can cut wind and reduce winter heating costs. Tree planting
near homes and businesses in the United States could cut energy demand by nearly 1 quad, or about 1/100th of our total energy demand. Although it is not a lot, individual savings can be substantial.

Conservation does not mean freezing in the dark, as some would have you believe. For homeowners, adding attic insulation or installing storm windows reduces heat loss in the winter and retains cool air in the summer, resulting in a significant savings on utility bills and a more comfortable life. Both insulation and storm windows require small investments that are paid back in short periods by reduced energy bills. (For additional suggestions, see Table 15-1 Individual Actions Count!)

One extraordinary means of reducing energy waste is cogeneration. In industrial cogeneration, waste heat from one process is captured and used in another, thus reducing waste and improving the energy efficiency of a plant. For example, for years, many American industries produced their own steam on site for use in various processes. Steam generation requires natural gas or oil, which companies purchased along with electricity from local utilities. Steam generation in factories was 50 to 70% efficient. Today, many companies use waste heat from steam generation to produce electricity, thus boosting the efficiency of the system to 80 or 90%—and driving down the cost of electricity.

Because of its favorable economics, cogeneration is an emerging source of energy. Growth in generating capacity has increased dramatically in the past 25 years—and continues to rise. In Germany, the United States, and other developed countries, small cogeneration technologies are being installed in restaurants, hotels, and apartment buildings. They supply space heat, hot water, and electricity at a much lower cost than conventional systems. In Chula Vista, California, a McDonald’s restaurant produces its own electricity and hot water using a small cogeneration system.

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Table 15-1

Individual Actions Count!

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>• Turn down thermostat on water heater to 120°F.</td>
<td>• Lower thermostat setting at night and when away from your residence.</td>
<td>• Increase thermostat setting at night or when away from your residence.</td>
</tr>
<tr>
<td>• Use less hot water (dishwashing, laundry, showers).</td>
<td>• Insulate ceilings and walls.</td>
<td>• Use fans.</td>
</tr>
<tr>
<td>• Install water efficient showerhead.</td>
<td>• Install storm windows, curtains, or window quilts.</td>
<td>• Cook at night or outside.</td>
</tr>
<tr>
<td>• Install faucet aerators.</td>
<td>• Caulk cracks and use weatherstripping.</td>
<td>• Dehumidify air.</td>
</tr>
<tr>
<td>• Coordinate and concentrate time hot water is used.</td>
<td>• Use fans to distribute heat.</td>
<td>• Close drapes during the day.</td>
</tr>
<tr>
<td>• Install an insulated water heater blanket.</td>
<td>• Dress more warmly.</td>
<td>• Open windows at night.</td>
</tr>
<tr>
<td>• Do full loads of laundry and use cooler water.</td>
<td>• Heat only used areas.</td>
<td>4. Cooking</td>
</tr>
<tr>
<td>• Hang clothes outside to dry.</td>
<td>• Humidify the air.</td>
<td>• Cut the wattage of bulbs.</td>
</tr>
<tr>
<td>• Periodically drain 3 to 4 gallons from water heater.</td>
<td>• Install an electronic ignition system in furnace.</td>
<td>• Turn off lights when not in use.</td>
</tr>
<tr>
<td>• Repair leaky faucets.</td>
<td>• Replace or clean air filters in furnace.</td>
<td>• Use compact fluorescent bulbs whenever possible.</td>
</tr>
</tbody>
</table>

5. Lighting

- Use fans.
- Cut the wattage of bulbs.
- Turn off lights when not in use.
- Use natural lighting whenever possible.

6. Transportation

- Carpool, walk, ride a bike, or take the bus to work.
- Use your car only when necessary.
- Group your trips with the car.
- Keep your car tuned and tire pressure at the recommended level.
- Buy energy-efficient cars.
- Recycle gas guzzlers.
- On long trips, take the train or bus (not a jet).
- Drive the speed limit.

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1One quad is a quadrillion BTUs—about 170 million barrels of oil.
Resource Issues: Solutions for a Sustainable Society

KEY CONCEPTS

The Potential of Energy Efficiency

The United States and other industrial nations have made tremendous improvements in energy conservation, but the conservation potential has hardly begun to be tapped. The World Resources Institute, in fact, estimates that the world could meet 90% of its new energy needs between 1987 and 2020 simply by making more efficient use of the energy we now generate. Even though the world population is expected to double between 1980 and 2020, the Institute says, only a 10% increase in energy production would be needed if existing energy-efficiency technologies were put in place. Unfortunately, they’re not. Most experts agree: Although fossil fuels will run out and renewable energy supplies will take up the slack, energy efficiency could play a huge role in our future.

KEY CONCEPTS

Saving Energy in the Transportation Sector

Over one-fourth (28% in 2008) of the energy consumed in the United States is used in transportation. Energy consumption in the U.S. transportation sector has grown steadily since the 1960s and shows no sign of declining, a trend that many experts believe bodes poorly for our nation’s prospects for creating a sustainable future (FIGURE 15-4).

Fortunately, dramatic improvements in the efficiency of vehicles are possible. Automobiles, the single largest source of energy consumption in this sector, represent the greatest potential for reductions.

Worldwide there are over 110 car models that get over 40 miles per gallon, 70% of which are made by U.S. companies. Only three of these vehicles are sold in the United States, however. Three of the most efficient vehicles on the road in the United States are hybrid gas-electric vehicles, the Toyota Prius, the Honda Civic hybrid, and the Honda Insight. Numerous other auto manufacturers have recently begun selling hybrids. For a discussion of this new breed of energy-efficient car, see Spotlight on Sustainable Development 15-2.

The Toyota Prius gets around 50 miles per gallon. In contrast, the average gas mileage of new cars and light trucks on the road in the United States (both domestic and imported) in 2009 was 22.4 mpg, one of the lowest averages in the more developed nations. By increasing the average mileage to 60 miles per gallon, Americans could reduce automobile emissions by nearly half. This goal could be met by improving gas mileage of all vehicles, wider adoption of hybrids, and by an even more efficient option, the plug-in hybrid, also discussed in Spotlight on Sustainable Development 15-2. The plug-in hybrid is a gas-electric vehicle with a larger battery bank and a larger electric motor. The batteries are charged to reduce their emissions of greenhouse gas emissions by 20% on international flights from 2005 to 2012 and by 5% for domestic routes.

To achieve this goal, Air France announced that it will replace its entire fleet of 18 Boeing 747 jets with the more fuel-efficient Boeing 777-300ER wide-body aircraft. Air France is also replacing its less efficient, early-generation Airbus A320 aircraft with 30 more efficient A320s and A321s.

Air France Pledges Cuts in Carbon Emissions

In 2008, one of Europe’s leading international airlines, Air France, announced plans to spend almost $3 billion a year through 2020 modernizing its fleet of aircraft and pursuing other measures that will reduce the company’s environmental footprint.

Air France hopes to reduce average fuel consumption per passenger 15 to 20% by 2012, according to the company’s chairman Jean-Cyril Spinetta. In doing so, they hope to reduce their emissions of greenhouse gas emissions by 20% on international flights from 2005 to 2012 and by 5% for domestic routes.

To achieve this goal, Air France announced that it will replace its entire fleet of 18 Boeing 747 jets with the more fuel-efficient Boeing 777-300ER wide-body aircraft. Air France is also replacing its less efficient, early-generation Airbus A320 aircraft with 30 more efficient A320s and A321s.

Because energy is used so inefficiently, huge cuts in energy demand can be made by applying efficiency measures. This should not affect the level of services we receive. Much of our future energy demand can be met by freeing up energy currently wasted in three areas: transportation, buildings, and industry/business.
Imagine a car that gets 150, maybe 200 miles per gallon, and can travel from the West Coast to the East Coast on one tank of gas. Imagine a car that comfortably seats five passengers but weighs only about 400 kilograms (900 pounds)—one-half to one-fourth the weight of a typical vehicle. Imagine also that this superefficient, lightweight car is also just as safe as a conventional vehicle and consists of a body and chassis that contain only 6 to 20 parts, compared with 250 or so in a conventional automobile.

Is this some creation of a science fiction writer? No. Far from it. This car is the brainchild of Amory Lovins of the Rocky Mountain Institute (RMI). Renowned for his work on energy efficiency, Lovins received funds from several foundations to develop designs for a superefficient car of the future to help drastically reduce the world’s demand for fossil fuels and cut pollution.

Shown in FIGURE 1, this vehicle, called a hypercar, has a smooth underbody, and an incredibly aerodynamic form. These and other features could dramatically increase the car’s efficiency without sacrificing either interior space, safety, or performance.

Lightweight composites (mixtures of materials) and other space-age materials would be used to construct the car. These materials are stronger and much lighter than those currently used by car manufacturers. Because composites absorb a lot more energy in crashes than the steel used in the bodies of a typical car, the lightweight hypercar would actually be safer. The vehicle’s small engine, discussed shortly, provides for an efficient performance and also leaves more “crumple zone”—area for the car to cave in during an accident. Force is absorbed by the materials, not the occupants.

The hypercar is a hybrid of sorts. Its propulsive unit, its engine, might consist of a small, fossil fuel-powered engine—only 20 horsepower or so—that is used to generate electricity. Other electricity-producing engines are also possible, for example, fuel cells (described in this chapter). Whatever the source, the electricity is sent to four small electric motors in the wheels. During braking, electric motors that drive the wheels function as small generators. They could theoretically capture up to 70% of the braking energy—energy that is lost in a typical automobile. This energy is stored in the battery for later use.

Further adding to the car’s efficiency are special tires made of materials that reduce the friction on the road surface. This could, according to Lovins and his team at RMI, reduce the rolling drag by 65 to 80%. Together, the ultralightweight design, superb aerodynamics, and efficient hybrid propulsion system could translate into a 150 to 200 miles per gallon fuel rating—considerably higher than the 22.4 miles per gallon average achieved by cars and light trucks on the road in the United States. Air emissions from the vehicle would be 100 times lower than today’s cars. In other words, 100 hypercars would produce as much pollution as one conventional vehicle.

Is this a wild dream? Apparently one student at Western Washington University didn’t think so. He built a Corvette-sized two-seater light hybrid. In April 1994, the vehicle was tested by the Department of Energy and found to get 202 miles per gallon. In October 1994, a Swiss-built car that seats four achieved 150 miles per gallon.

As noted in the chapter, virtually all automobile manufacturers are now producing hybrid gas-electric cars that begin to resemble the hypercar with gas mileage between 40 and 70 miles per gallon. Toyota was the first to sell its car (Prius) in Japan, starting in 1999, and then in the United States in 2000. Honda came next with a model known as the Insight. It was first sold in the United States in 2000, but was discontinued in 2006. Numerous American manufacturers are now offering hybrid cars, trucks, SUVs, and vans. And all major U.S. auto manufacturers also have developed diesel hybrid cars that get 60 to 80 miles per gallon (at this writing, there are no plans to manufacture and sell these models).

How does a hybrid work? Hybrids have an electric motor and a small gas engine. In some models, like Toyota’s Prius, the car initially operates on electric power; that is, when the car is turned on and begins to move, its electric motor provides the main propulsion. The gas engine kicks in at around 7 to 10 miles per hour. On the highway, however, the gas engine provides much of the thrust. The electric motor provides additional boost to pass or climb hills. When slowing down or going down a hill, however, the vehicle uses very little power at all. In fact, the gas engine may shut off entirely. The instantaneous gas mileage readout in the Prius,

FIGURE 1 The hypercar.
located on a computer screen in the center of the dashboard, records gas mileages of 100 miles per gallon, indicating that the car is coasting.

When the vehicle comes to a stop at a stoplight, the engine shuts off. When the operator presses on the gas pedal, however, the electric motor kicks in, followed by the gas motor. The car is off and running without hesitation.

Honda’s hybrid Civic is similar to the Toyota Prius in many respects; that is, they contain a gas engine and an electric motor, but the electric motor is much smaller than that of the Prius. As a result, it can’t be used to start the car from a standstill.

When a Honda Civic hybrid is turned on, the gas engine starts up and provides the power needed to move the car and most of the propulsion from that point on. The electric motor kicks in when additional power is needed, for example, when climbing a hill or passing another vehicle.

What about the batteries of a hybrid car? Do they need to be charged each night? No, they’re charged continuously by the car during normal operation through an alternator, a device that provides electricity for lights and radios and the battery bank. As in the hypercar, batteries are also charged during braking. Electricity flows smoothly in and out of the lightweight battery bank (usually located behind the back seat) during various modes of operation, giving one a clean, energy-efficient ride! Like other functions in the car, it is all computer controlled. You drive; the car figures all of this out automatically.

Hybrids cost $2,000 to $3,000 more than nonhybrids. However, federal and state incentives have helped reduce the costs to consumers. Savings on fuel will help offset costs. Expect to see a lot of hybrids on the road in coming years. Sales are going extremely well. The cars are pretty attractive. They’re fast and relatively inexpensive, too. Although not reaching the full potential of the hypercar, they represent a dramatic shift in automobile technology with enormous benefit to the environment.

Another vehicle that holds promise is the plug-in hybrid electric vehicle, now under development. What’s a plug-in hybrid?

Plug-in hybrid electric vehicles are hybrids, much like those just discussed, with a couple differences. First, they contain a larger battery bank. Unlike the hybrids just discussed, these cars are plugged in at night into a 120 or 220-volt outlet (like a dryer outlet). This charges the batteries. The electrical charge, in turn, powers the vehicle in most situations. According to the Institute for Analysis of Global Security, which researches transportation options that could help us free our dependence on foreign oil, “Plug-ins run on the stored (electrical) energy for much of a typical day’s driving—depending on the size of the battery up to 60 miles per charge, far beyond the commute of an average American.” They go on to say that when the electrical charge is used up, the car “automatically keeps running on the fuel in the fuel tank. A person who drives every day a distance shorter than the car’s electric range would never have to dip into the fuel tank.

That of course leads to the second difference. Such cars need larger electric engines than hybrids currently on the market.

Because most of the energy used by plug-ins comes from electricity and not from gasoline and because electricity can be generated efficiently and cleanly from America’s abundant renewable energy resources, especially solar and wind power, hybrid electrics may help us combat the coming shortages of oil without increasing global warming and a host of other environmental problems associated with fossil fuel use.

According to the Institute for the Analysis of Global Security, “The plug-in hybrid drive system is compatible with all vehicle models and does not entail any sacrifice of vehicle performance or driver amenities. A mid size plug-in can accelerate from 0 to 60 miles per hour at less than 9 seconds, sustain a top speed of 97 mph and maintain 120 mph for about 2 minutes even with a low battery.”

Another interesting development is the Chevy Volt (FIGURE 2). This car has a small engine that can run on gasoline, biodiesel, or E-85 (an 85% mixture of ethanol and gasoline). The engine generates electricity that is used to power an electric motor. This car can achieve very high gas mileage. If you drove under 20 miles per day you could run entirely on electricity. If you drove 60 miles per day, you’d get an estimated 150 equivalent miles per gallon. For long trips the car is expected to get around 40 miles per gallon.

Electric cars may also become a major player in transportation throughout the world. Electric cars can be fast,
powerful, and economical. Current models have a limited range, of 30 to 120 miles, making them ideal for commuting back and forth to work or school. (In the U.S., 90% of all automobile trips in a day are under 60 miles.)

Electric cars are powered by electric motors. Electricity is stored in a battery bank that must be charged after use. Numerous models are slated to appear in 2010–2012, including the Nissan Leaf which made its debut late in 2010 (FIGURE 3).

Electric motors are extremely efficient, and even when they use electricity generated at coal-fired power plants, they result in a substantial decrease in energy use and pollution.

The Rocky Mountain Institute thinks you may see a true hypercar on the road very soon. They’ve even spun off a for-profit business to help develop this vehicle. RMI predicts that the hypercar will dominate the market by around 2020. The technology to produce them is currently available. Creating a prototype and gearing up for production would, RMI says, take less time than a conventional automobile because of the simpler design and fewer parts.

RMI admits that the hypercar won’t solve all of the world’s transportation problems. If it became a popular alternative to conventional automobiles, it could drastically reduce fossil fuel consumption and air pollution, both impediments to the goal of creating a sustainable future. The hypercar will not, however, solve such problems as urban sprawl and highway congestion during all hours of the day—and especially that time we mistakenly call “rush hour.” Chapter 17 describes options to get people out of their cars to help ease these other transportation problems.

![Nissan Leaf](image)

Go Green

When the time comes to buy a car, purchase the most energy-efficient model you can afford.

Key Concepts

- **Saving Energy in Buildings**
  - About 40% of the energy consumed in the United States is used in buildings—office buildings, factories, and homes. The modern home and office building make many demands on the energy system. They require lighting, heating, and cooling. Many also contain various machines, appliances, and electronic equipment. Fortunately, very impressive savings can be made in all areas.
  - Unfortunately, efficiency improvements in buildings in the United States and many other more developed countries have lagged behind other areas until recently. There are many reasons for this lack of progress. For example, new houses and commercial buildings are built by contractors who often seek to minimize initial expenses. To do this, they often select less costly and less energy-efficient appliances, heating, and lighting systems. They may also not install much insulation or seal a home as tightly as possible either. In doing so, they inadvertently strap the building owner/operator with a lifetime of high energy bills—all to save a few dollars on the front end. Today, more than 30% of the nation’s housing is occupied by renters, who are often responsible for
saving utility bills. The owner has very little incentive to invest in energy efficiency.

One encouraging development is the emergence of energy conservation companies, which provide innovative financing schemes for building owners who want to invest in energy efficiency. These companies have been successful in Europe for years and are becoming more common in the United States. They advise clients on ways to cut energy consumption and install various devices to achieve their goals. Some companies work out plans to be paid by their clients through energy savings accrued by the latter.

Another very encouraging development is the dramatic increase in green building—creating homes and other buildings that have as little impact on the environment as possible. One key element of green building is efficiency—making homes and other buildings as energy efficient as possible. Green building is discussed in more detail in the next section.

Some experts believe that cost-effective energy-efficiency measures could cut total energy consumption in U.S. buildings by as much as 30% over the next two decades, despite a 15 to 20% increase in the number of buildings.

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**KEY CONCEPTS**

Energy-efficiency measures in buildings can result in substantial energy savings in heating, cooling, lighting, and appliances and electronic equipment. Unfortunately, short-term thinking and economics often prevent investments in measures to cut energy demand in these areas.

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**Saving Energy in Industry** In the United States, industries consume one-third (31.4% in 2008) of the nation’s energy. Over the past 30 years, industrial energy savings have been impressive. Energy required to generate one dollar of economic output has fallen by about 50% (Figure 15-5). Nevertheless, industries have many additional opportunities to cut energy consumption while increasing their economic strength and profitability. Many corporate executives now realize that an investment in energy efficiency is one of the most cost-effective ways of reducing expenses and boosting profits. Energy efficiency is not an impediment but a keystone to economic success.

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Energy can be saved by installing more efficient lighting systems and insulating buildings to reduce heat loss and cooling costs. Energy use can also be cut dramatically by installing more efficient boilers, pumps, and motors. Many pumps, for example, operate at one speed. To control the flow of liquids, valves are used. Installation of variable speed motors has the same effect while dramatically cutting power demand.

Recycling is also an important strategy for reducing industrial energy consumption (Chapter 16). Roughly three-quarters of the energy consumed by industry is used to extract and process raw materials. Making metals from recycled scrap uses a fraction of the energy needed to make them from virgin ore.

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**KEY CONCEPTS**

Industrial energy consumption accounts for a major portion of the world’s energy demand but could be cut substantially, making companies more profitable and competitive.

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**Promoting Energy Efficiency**

Energy efficiency is needed in all sectors of society. How can individuals, businesses, and nations be encouraged or compelled to use energy more efficiently?

Once again, many options are available. This section briefly discusses seven options: (1) education, (2) taxes, (3) feebate systems, (4) government-mandated efficiency standards, (5) voluntary programs, (6) changes in pricing, and (7) least cost planning.

One of the most important steps is education. Educating people about the economic and environmental benefits of energy conservation is vital to the task at hand. Education can occur at many levels, for example, in schools, colleges, and on television. Government agencies such as the U.S. Environmental Protection Agency (EPA) can help educate businesses on the advantages of energy efficiency—and currently take an active role in this arena.

National taxes on fossil fuels—especially oil and coal—could also help promote efficiency. By raising the taxes on fossil fuels, making them more costly to consumers, governments could play an important role in stimulating energy conservation in all sectors of society.

Increased taxes on gasoline and other fuels in the United States and Canada could help cut energy consumption and generate revenues to build mass transit systems, promote conservation, and fund sustainable alternative transportation technologies. Because government currently subsidizes many fossil fuels through tax dollars from general revenues, this step would help it recover the money it already invests in providing us with artificially inexpensive fuel.

Another innovative measure is the feebate system. It consists of a fee (tax) paid by those who buy gas-guzzling cars (which would create a disincentive to consumers), and a rebate given to those who purchase energy-efficient autos. The rebate would be paid by the fees and would be an additional incentive to individuals. The United States had a gas guzzler tax for many years, but President Clinton abolished it in 1999.
On May 4, 2007, one of the most powerful tornados ever witnessed in the United States leveled the town of Greensburg, Kansas, a small community in the western part of the state and home to 1000 people (FIGURE 1). The nearly 2-mile-wide tornado killed 10 residents and destroyed 95% of the town’s buildings. Homes, businesses, schools, and churches were leveled.

Soon after the tragedy, the town’s leaders announced that they were going to rebuild the town, but rebuild green, creating the nation’s first model green town. Their vision of the new Greensburg, now already materializing, calls for super energy-efficient, green-built homes, offices, churches, and schools made from environmentally friendly materials. They also envisioned a town powered entirely by renewable energy, such as wind and solar energy, both abundant resources in this part of Kansas.

Out of tragedy, the town could become an example of the kind of global effort needed to combat climate change, rising fossil fuel prices, war and unrest in the Middle East, and other critical problems facing the world today. City officials envisioned the town as a model of economic prosperity, created in large by the new energy-efficient, renewable-energy economy. Many recognized that the storm that tragically wiped the town off the map could put it back on—this time, as a destination for people all over the world who want to learn how to build green homes and a green community.

Greensburg’s bold new plan caught the eyes of many. Not too long after their announcement, they were contacted by the Discovery channel, which expressed an interest in filming this historic rebuilding. The town’s rebuilding efforts inspired a 13-part series called EcoTown, the first episode of which was aired in May, 2008 on the brand new PlanetGreen Channel (owned by the Discovery Channel).

To facilitate efforts to rebuild their town, several community members formed a nonprofit organization, Greensburg GreenTown (http://www.greensburggreentown.org/). This organization was established to provide the residents with the resources, information, and support they need to create their model green community. To support these goals, Greensburg GreenTown launched an ambitious program to build twelve state-of-the-art green homes in Greensburg, Kansas.

The model green homes will serve two main functions. They will provide tangible examples to the citizens of Greensburg as to what is possible for their own homes as they rebuild their lives. The demonstration homes are also envisioned as demonstration projects for a variety of building construction technologies as well as many green building materials and renewable energy technologies. In addition, each home will serve as a testing site/laboratory with monitoring equipment that provides valuable information on the performance of each type of construction under real world conditions.

The demonstration homes will also serve as lodging and ecotourism destinations to support the new green economy of this region. As lodging for tourists, the homes will provide many individuals and families the experience of living in a super energy-efficient, renewably powered, green home. They can choose a home made with a building material—for example, straw bale or insulating concrete form—that interests them.

To date, one eco-home has been built and construction on another is soon to begin. Since the tornado, businesses, including the John Deere dealership, and the city of Greensburg have constructed eight super energy-efficient very green buildings in Greensburg. The town has also installed several large wind turbines to provide clean, green energy. Numerous homes have been built green by citizens as well.
A fourth means of stimulating conservation is through government-mandated efficiency standards. The National Appliance Conservation Act passed by the U.S. Congress in 1987, for instance, established energy-efficiency standards for all new appliances. It doesn’t spell out what changes need to be made, only the amount of energy that appliances should be consuming. For example, the act required manufacturers of all major household appliances, such as refrigerators, to produce models that consume at least 20% less electricity than 1987 models. California passed a similar law, calling for a 50% cut in electrical usage by new appliances. The results were impressive. Today, homeowners can purchase many appliances that use a fraction of the energy consumed by earlier models. Efficiency standards could be applied to all new homes and factories as well. Automobile mileage standards, already in place, could call for much greater savings. In the United States, however, improvements in gas mileage standards for new cars have been vigorously opposed and have been frozen for over two decades and continue to face opposition. Very significant increases in fuel mileage were enacted under the Bush and Obama Administrations.

Voluntary efforts are also vital. Many governments are starting to take a more active role in promoting energy efficiency in buildings through voluntary programs. In Canada, Natural Resources Canada, the federal agency once called the Department of Energy, Mines, and Resources, launched its Super Energy-Efficient Home program with the Canadian Home Builder’s Association. Their goal is to encourage builders to build homes that use half as much energy as conventional ones. Although slightly higher construction costs and red tape have hindered the program, many builders have adopted the ideas and are now building much more energy-efficient homes. More recently, the Canadian federal government also entered into a program with Home Hardware stores to offer videos and publications on ways to improve the energy efficiency of Canadian homes.

In the United States, the EPA and many states are promoting home energy efficiency through a variety of voluntary programs. EPA has its Energy Star Homes program. This program relies on builders to produce homes that use 30% less energy for heating, cooling, and so on than stipulated in the National Model Energy Code. When this goal has been verified by an independent certifier, the home receives an Energy Star label.

Many cities and states have green building programs that promote energy efficiency. By meeting certain criteria, home builders can apply for a green building certificate. This, in turn, helps builders market a home. A leader in commercial green building is the nonprofit group known as the U.S. Green Building Council. This organization created a commercial building rating system known as LEED—Leadership in Energy and Environmental Design—for new and existing buildings. Architects and builders must meet certain criteria to qualify for LEED certification, which dramatically reduces the energy and environmental impacts of new and existing buildings. They introduced LEED certification for homes in 2007.

Another encouraging development is the National Association of Home Builders’ active role in researching and promoting energy-efficient homes. They released green home building guidelines in 2007. Some lending institutions are also providing loans for energy-efficient homes, although they tend to simply allow the lender to borrow more money, based on the belief that they will have more money in their pockets. Far better, say some critics, would be a program that gives lower interest loans to buyers of green built homes.

Yet another encouraging development is the net zero energy home. Net zero energy homes are designed to produce as much energy as they consume. Builders achieve this difficult goal by building superefficient homes—airtight homes whose walls and ceilings contain three to four times as much insulation as typical energy-efficient homes (FIGURE 15-6). The use of super energy-efficient windows, solar heat gain, and other measures result in homes that use 90% less energy than standard homes. Builders then install solar electric and solar hot water systems to provide for the energy needs of the residents.

The net zero energy movement began in Germany thanks to the efforts of the Passive House (Passiv Haus) Institute. There is now a Passive House Institute headquartered in the United States that is carrying out this effort. The U.S. Department of Energy’s Building America program has also played a very large role in promoting net zero energy buildings.

Conservation can also be stimulated by changes in pricing. For example, some utilities now charge customers more for electricity used during peak hours—times when demand is highest. Why? Meeting peak demand is very costly for utilities. It often requires construction of additional power plants that are needed for only a few hours a day. If utility companies can reduce peak demand through pricing, they won’t have to build expensive new facilities.

Furthermore, efficiency can also be stimulated by a process called least cost planning. In the United States, utilities are regulated by the states. Thus, when a power company decides that it needs to build a new power plant to meet rising demand, it must first receive approval from a
public utility commission. Currently, most states have requirements for least cost planning or integrated resource planning (choosing a variety of technologies, including renewables, and measures such as efficiency to meet energy needs). Least cost planning requires power companies to select the least costly way of providing electricity, which almost always entails energy conservation programs. Some cost-saving options include improvements in generating efficiency, peak-pricing schemes, purchasing electricity from other companies (rather than building new power plants), cogeneration, and promoting energy conservation in homes, factories, and businesses. These steps are not only cheaper for utilities, they save customers money. In general, efficiency measures are two to three times cheaper than building new power plants. Moreover, the payback period of conservation is only 2 or 3 years compared to 20 for a new power plant. Unfortunately, efforts are currently under way in many states to eliminate requirements for least cost planning, and many states are not enforcing their requirements.

Finally, energy conservation can be stimulated by a combination of the measures listed previously here. The Canadian government, for instance, is trying to promote conservation through The Efficiency and Alternative Energy program, which entails 33 different initiatives to improve efficiency in all end-use sectors, including buildings, industry, transportation, and equipment. One of the keys of this program was the 1993 Energy Efficiency Act, which sets minimum efficiency standards for equipment. The Motor Vehicle Safety Act places stringent emissions standards on cars. All of these efforts are part of a strategy aimed at becoming more efficient and reducing greenhouse gas emissions to combat global warming.

**GO GREEN**

*If your home or apartment is equipped with ceiling fans, use them. They help keep a home warmer in the winter and cooler in the summer, greatly reducing energy consumption and fuel bills. Ceiling fans can reduce cooling costs by up to 40% and heating costs by up to 10%.*

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**Roadblocks to Energy Conservation**

Despite the economic and environmental advantages of conservation, it still is not as widely practiced as many would like. Why not? Part of the reason is that Americans, Canadians, and others have been blessed for many years with abundant energy and have had little incentive to use it efficiently.

Another reason is that fossil fuels and nuclear energy are subsidized by federal programs, which reduces the direct cost to the consumer. June 2008 oil was selling at $135 per barrel. If federal subsidies were added the cost would be between $150 to $250 per barrel. Gas would be selling for $4.50 to $7.50 per gallon.

Still another reason is that high-efficiency products such as compact fluorescent lightbulbs often cost more than less energy-efficient ones, and many people neither calculate the long-term savings nor think about the environmental consequences of waste.

In addition, many governments have not been committed to energy conservation programs. The minimal investment is hard to reconcile, say some critics, when the government investment-to-savings ratio for conservation can be as high as 1:1,000—a thousand dollars saved for every dollar invested.

The lack of interest in energy conservation in the United States and other countries can also be attributed to the influence and power of energy companies, which are a dominant force on the political scene. Nonetheless, as Christopher Flavin and Nicholas Lenssen noted in a recent article, “Powerful economic, environmental, and social forces are pushing the world toward a very different energy system.” One of the cornerstones of that system will be energy efficiency. Its potential is great, and many people, businesses, and nations are beginning to recognize that one of the greatest future sources of energy is our waste.

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**KEY CONCEPTS**

Not only are there many ways to use energy much more efficiently, there are also many ways to promote this strategy, including (1) education, (2) taxes on fossil fuels, (3) feebate systems (which levy a tax on those who choose energy-inefficient options and give rebates to those who opt for energy-efficient technologies), (4) government-mandated efficiency programs, (5) voluntary programs, (6) changes in pricing, and (7) least cost planning.

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**15.2 Renewable Energy Sources**

Imagine a world powered by the sun, the winds, and other clean, renewable forms of energy. Although this may sound like a dream, 30 years from now you may well live in a world powered by a diverse mixture of renewable energy resources.

The shift to a renewable energy future has already begun. Brazil, for example, is turning to ethanol produced from sugarcane to power trucks and cars. California is turning to wind and geothermal (the Earth’s heat) energy. Many other states are following suit. Several European nations, including Germany and Spain, are currently generating a substantial portion of their electricity from wind. Great Britain is following suit and Germany is gearing up for a 100% renewable energy future. Israel and other Middle Eastern countries are increasing their dependence on solar energy. Many Pacific Rim nations now get substantial amounts of energy from geothermal sources and plan to obtain substantially more in the future.

As world oil and natural gas reserves decline, as environmental problems caused by fossil fuels intensify, and as population spirals upward, more and more countries will shift to renewable energy resources. Each one will find many different clean and abundant renewable fuels that are locally

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available. By increasing the use of these resources, nations can protect the environment and create more regionally self-reliant economies. By increasing their dependence on clean, affordable, and reliable renewable energy, they create a better future, greater economic and political security, and broader prosperity. This section looks at many of the renewable energy options, discussing the pros and cons of each one.

**KEY CONCEPTS**

Renewable energy will very likely become a major source of energy in the future; the transition to a renewable energy future has already begun in some nations.

### Solar Energy Options

Oil, natural gas, oil shale, and coal all have limits. So does the sun, the origin of solar energy. In the sun’s case, though, the supply of energy is expected to last at least 4 to 5 billion years. Although it is finite, solar energy is typically called a renewable resource.

Each day, about less than one billionth of the sun’s energy strikes the Earth. Although this is a small fraction, it adds up to an impressive total. In fact, if all of the sunlight striking an area the size of Connecticut each year were captured and converted into useful energy, it could power the entire United States, including all homes, factories, and vehicles. Despite its enormous potential, solar energy provides only a fraction of U.S. energy needs. Contrary to popular misconception, this poor showing is not because solar energy is limited to a few areas. In fact, significant sources of solar radiation are available throughout the world, although some are better than others (FIGURE 15-7).

Four major solar technologies are in use worldwide: passive and active solar hot water, photovoltaics, and solar thermal electric. Understanding each one can help us assess the potential of this largely untapped energy source.

**KEY CONCEPTS**

Solar energy is considered a renewable energy source, but it is really finite. Nonetheless, because it is so abundant and clean, it will very likely be a major contributor to future world energy supplies.

#### Passive Solar Heating

FIGURE 15-8 shows a house designed to capture sunlight energy. In this structure, light from the low-angled winter sun streams through south-facing windows and is absorbed by interior walls and floors of brick, tiles, or concrete. The heat stored in material, called thermal mass, radiates into the rooms, heating the air day and night. On cloudy days, passive solar homes are kept warm by residual heat that continues to radiate from thermal mass and by backup systems. This is an example of a passive solar heating system. Properly designed passive solar homes and buildings also require good insulation and insulated curtains or

**FIGURE 15-7** Map of global solar energy availability. The planet is bathed with sunlight energy, although some areas have considerably more than others.
shades to block the outflow of heat at night. Overhangs block out the summer sun.

Passive solar energy is sometimes described as a system with only one moving part, the sun. It can be added to an existing home by building a greenhouse. In addition to supplying winter heat, a greenhouse can provide a source of food most of the year (FIGURE 15-9).

Well-designed passive systems can provide 80 to 90% of a home’s space heating. One passive solar home in Canada, built by the mechanical engineering department of the University of Saskatchewan, for instance, had an annual fuel bill of $40, compared with $1,400 for an average American home at the time of construction. The house was so airtight and well insulated that heat from sunlight, room lights, appliances, and occupants provided sufficient energy to maintain a comfortable interior temperature. The cost of this house was only slightly more than that of a tract home.

As a rule of thumb, solar houses cost 0 to 5% more to build than conventional houses of similar size. Because used home sales are based primarily on square footage, preowned passive solar homes are often a good buy. My previous solar house cost about the same as conventional used homes, with a fraction of the utility bills! My new passive solar home was about 5 to 10% cheaper to build than a conventional home.

Thousands of American homeowners have selected another solar option, the earth-sheltered house. Built partly underground to take advantage of the year-round constant temperature of the soil, properly designed earth-sheltered homes are well lighted, dry, and comfortable. They also require less external maintenance. Because they are sheltered by the earth, they stay warm in the winter and cool in the summer. They can easily be designed for passive solar heating. Combined, passive solar heating and earth sheltering can virtually eliminate the need for conventional heat.

KEY CONCEPTS
Buildings can be designed to capture solar energy to provide space heat. Properly designed structures can derive 80% to 90% of their heat from the sun.

2Actually, the sun is stationary within our system. The Earth rotates around it.

GO GREEN
When shopping for a new apartment or a new home, look for one whose long axis runs east to west and whose south side has plenty of shade-free windows to allow the low-angled winter sun to naturally heat the home. This will cut your annual heating and cooling bill by about 10%.
Active Solar Hot Water Systems  Active heating systems employ solar collectors, generally mounted on rooftops. Most collectors are insulated boxes with a double layer of glass on the sunny side (FIGURE 15-10). These are called flat plate collectors. The inside of the box is painted black to absorb sunlight and convert it into heat. The heat is carried away, by water or some other fluid flowing through pipes in the collector. The heated water is piped to a storage medium, usually water, in a superinsulated water storage tank. After transferring its heat to the storage medium, the water is returned to the collectors to be reheated. This process delivers a large amount of heat to the storage tank during the day, even in the winter so long as the sun is shining. The cycling of the heat transfers fluid from the collectors to the storage tank and back again.

The hot water in the storage tank can be used for showers, baths, and washing dishes and can also be used to heat homes. There are even systems to heat swimming pools and hot tubs. Specially designed active solar systems can be used in industry to provide hot water and steam, a major consumer of energy.

Solar collectors can be expensive to purchase, mount, and maintain (FIGURE 15-11). Leaks in systems can be costly to repair. In fact, a single repair can negate all energy savings for a 6- to 12-month period. Solar collectors are costly to add to a house after it is completed, too. And the extreme temperatures to which they are subjected can be hard on systems. Even so, solar hot water systems are often cost competitive with electric and propane water heating systems. They can even compete with natural gas systems. Solar pool heating systems are much cheaper than gas or electric pool heating systems. However, some new and inexpensive models are available with few moving parts and requiring little maintenance.

KEY CONCEPTS

Active solar systems generally employ rooftop panels that collect heat from sunlight and store it in water or some other medium. This solar energy can then be used to heat domestic hot water or to heat the interior of the building.

Solar electricity: Photovoltaics  Photovoltaics provide a way of generating electricity from sunlight. A photovoltaic (PV) cell consists of a thin wafer of silicon or some other materials that emit electrons when struck by sunlight. Electrons liberated from the material then flow out of the wafer, forming an electrical current (FIGURE 15-12).

PV cells are assembled onto modules, which are mounted on roofs or the ground. Some systems are designed to track the sun across the sky, optimizing electrical production. Solar manufacturers are also making roofing materials, a laminated solar material that is applied to metal roofing. Some manufacturers even apply PV material to glass for windows and skylights—so they perform double duty: they let light in and also produce electricity.

Electricity from photovoltaics currently costs about 24 to 27 cents per kilowatt-hour, or about three to six times more than electricity from conventional sources. Fortunately, costs have fallen rapidly in the last four decades (about 95% since the 1970s) and are expected to decline substantially (around 75%) in the next decade. At this writing (June 2011), the cost of solar electric modules is at an all time low.
predict that improvements in production could soon make photovoltaics competitive with electricity from other sources. New developments, for example, solar cells made from plastic, could dramatically lower costs, making solar electricity cheaper than conventional electricity.

Photovoltaics are already in wide use in remote villages in the less developed nations. In such locations, photovoltaics are far cheaper than building transmission lines that carry electricity from distant power plants. Today, more than 6,000 rural villages in India rely on them. The governments of Sri Lanka and Indonesia have launched ambitious programs to install photovoltaics in remote areas. In the United States, it is often cheaper for a homeowner to install photovoltaics than to pay to string electric lines if the home is more than a few tenths of a mile from a power line. Moreover, several states or utilities in some states, including California, New York, New Jersey, Arizona, Missouri, and Colorado, offer financial incentives that lower the initial cost of PV systems dramatically. The federal government also offers a 30% tax credit on solar electric systems. These incentives often make solar electricity cost competitive with electricity from conventional sources.

Today, photovoltaics provide only a tiny fraction of the world’s electrical power, but sales are growing steadily, averaging a 16 to 17% per year increase in the 1990s. Growth has increased even more in the 2000s. Japan, the United States, and the European Union have all adopted million roof policies, which seek to promote installation of solar electric and solar thermal systems on homes and businesses. For a case study on the use of solar electricity in business, see Spotlight on Sustainable Development 15-4.

Another exciting development is the increase in the efficiency of solar cells. Although they are not yet commercially available, solar cells with efficiencies over 40% have been produced by researchers at the National Renewable Energy Labs in Golden, Colorado. Solar cells currently on the market are one-fifth to one-third as efficient.

**KEY CONCEPTS**

Photovoltaics are thin wafers of material such as silicon that emits electrons when struck by sunlight, creating electricity. Although photovoltaics are costly, prices are falling.

**Solar Thermal Electric** Scientists and engineers have experimented for many years with ways to heat water with sunlight to generate steam that turns a turbine (a special device that drives an electrical generator). Most of their early schemes
were large, costly structures. In southern California, one company has pioneered a less expensive alternative. It consists of a series of aluminum troughs that reflect sunlight onto small oil-filled tubes (FIGURE 15-13). The hot oil heats water, which is turned into steam that drives a turbine to generate electricity. This system produces enough electricity to supply 170,000 homes at a cost of 8 cents per kilowatt-hour—cheaper than nuclear power but more costly than coal (if you ignore the costly environmental impacts of electricity generated from coal). Numerous other companies have installed similar systems.

**KEY CONCEPTS**

**The Pros and Cons of Solar Energy**  One of the most notable advantages of solar energy is that the fuel is free. All we pay for are devices to capture and store it. As a result, solar energy and other renewables will provide a significant help against rising fuel prices (oil, coal, and natural gas prices will continue to rise well into the future). Solar energy is a huge energy resource available as long as the sun continues to shine. While the construction of solar technologies (flat plate collectors and photovoltaics) creates pollution and solid wastes, as does any manufacturing process, once a solar system is operating it is a very clean form of energy. It does not add to global warming, urban air pollution, and other environmental problems. Over their lifetimes, solar systems produce much more energy than is needed to make them. Years of pollution-free operation offset the pollution created by production. In fact, it only takes 1 to 2 years for a PV system to generate all the energy it took to make the entire system. Also, most solar systems can be integrated with building designs and therefore do not take up valuable land.

Solar energy has many applications. It can, for example, be used to meet the low-temperature heat demands of homes or the intermediate- or high-temperature demands...
of factories. Solar energy can be used to cool buildings and generate electricity to power radios, lights, watches, road signs, stream flow monitors, space satellites, automobiles, and industrial motors.

No major technical breakthroughs are required either. Active solar water heating and passive solar space heating are well developed, although some improvements in design and lowered costs could enhance the appeal of others, such as photovoltaics and active solar space heating.

The major limitation of solar energy is that the source, the sun, is intermittent: It goes away at night and is blocked on cloudy days. Consequently, solar energy must be collected and stored. Photovoltaic systems, for example, require storage batteries, although most home owners simply send excess electricity onto the electrical grid during the day. They then draw electricity off at night at no charge. (The electrical grid becomes their storage medium.) Passive solar energy stores heat in thermal mass, but most
solar users must install a backup system to provide heat during long cloudy periods.

Another disadvantage is cost. Although passive solar and solar hot water systems for domestic hot water and pool heating are often cheaper in the long run than conventional systems, a few forms of solar energy do not compete well economically with conventional sources—PVs or solar electricity, for example. (Tax incentives, rebates, and rising energy costs, however, can make these systems cost competitive.) This discussion of costs ignores the massive environmental and economic damage caused by conventional fuels and the huge subsidies that prop them up. When these two factors are taken into account, the economics of solar energy are quite good.

**KEY CONCEPTS**

Solar energy technologies are well developed. Their advantage over other forms of energy production (such as nuclear or coal) is that they rely on a free, abundant fuel (sunlight) and are relatively clean systems to operate. Although some systems are economically competitive, others are still fairly costly. Storing energy from intermittent sunlight remains one of their major drawbacks.

**Wind Energy**

About 2% of the sun’s energy striking the Earth is converted into wind. (Wind is considered another form of solar energy.) Wind can be tapped to generate electricity, pump water, and perform mechanical work (grinding grain, for example). Electricity is produced by generators driven by blades (Figure 15-14). Large wind turbines are used for commercial energy production. Smaller units can be used to power farms and households. Home owners who rely on wind often install photovoltaics to supplement the wind-generated power. My home in Colorado, for instance, is powered by photovoltaics and a small wind generator. My educational center in Missouri, the Evergreen Institute, is powered by two PV systems, a wind turbine, and two solar hot water systems (Figure 15-15).

**KEY CONCEPTS**

Winds are produced by solar energy and can be used to generate electricity or to perform work directly, such as pumping water.

**The Pros and Cons of Wind Energy**

Wind energy offers many of the advantages of solar energy: First, wind energy is an enormous resource. Wind resources are abundant in certain parts of every continent. Tapping the globe’s windiest spots could provide 13 times the electricity now produced worldwide. The Worldwatch Institute estimates that wind energy could easily provide 20 to 30% of the electricity needed by many countries. In the United States, North Dakota, South Dakota, and Texas have enough wind to supply all the electrical demands of the entire country.

Wind energy is clean and renewable, uses only a small amount of land (Table 15-2), and is safe to operate. On a typical wind farm, only 10% of the land is used for roads and windmills; the remaining land can be grazed and even planted (Figure 15-14a). Today, many farmers are leasing small portions of their land to companies to install wind generators. Large, commercial generators net them $3,000 to $5,000 each in rent and royalties, greatly boosting farm income.

Windmill technology is well developed, reliable, and efficient, and the fuel is free. Wind-generated electricity (from large windmills) is cost-competitive with other sources of electricity (Table 15-3). Today, large wind farms are being built all over the world to provide electricity. China, Spain, Germany, Denmark, India, and the United States are leaders in wind power. Despite good wind resources, Canada has lagged behind other nations in developing wind energy. In the United States, new wind energy now costs on average about 5 cents per kilowatt-hour, clearly cost-competitive with coal. When one takes into account the environmental benefits, the economics of wind energy (like solar energy) become even more favorable. These factors, combined with the environmental benefit, make wind the fastest growing
source of energy in the world (FIGURE 15-16). Despite a serious worldwide economic downturn, the global wind industry experienced yet another record year in 2009, increasing cumulative capacity by 31%. By the end of 2009, world wind power capacity was nearly 160,000 megawatts. That's enough electricity to supply the needs of 250 homes. Wind turbines generate electricity in over 70 countries.

There are, of course, disadvantages to wind. Critics argue that the wind does not blow all of the time, so backup systems and storage are needed. Contrary to popular misconception, wind is fairly reliable. Wind farms placed in good locations produce electricity 65 to 85% of the time. According to studies by the U.S. Department of Energy, however, a 1,000-megawatt wind farm requires only about 10 megawatts of backup power. As Mike Bergey of Bergey Windpower notes, “As a power source, wind energy is less predictable than solar energy, but it is also typically available for more hours during a given day.” Another issue is visual impact. Individual wind turbines and wind farms are not visually appealing to everyone. Third, opponents of large-scale wind farms often cite bird kills as a significant concern. As shown in the accompanying viewpoint, bird mortality from commercial wind turbines does occur, but it is minor in comparison to other sources such as pet cats, automobiles, and cell phone towers.

Although winds do not blow all of the time in all locations, wind still could become a major source of electricity. It could supplement solar and hydroelectricity and conventional power sources as well. Surpluses produced in one area could be transferred elsewhere. Consistently windy locations like coastlines and the great plains of North America could also provide a steady stream of electricity to the electrical grid.

Table 15-2
Land Use of Selected Electricity-Generating Technologies, United States

<table>
<thead>
<tr>
<th>Technology</th>
<th>Land Occupied¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal²</td>
<td>3642</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>3561</td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>3237</td>
</tr>
<tr>
<td>Wind³</td>
<td>1335</td>
</tr>
<tr>
<td>Geothermal</td>
<td>404</td>
</tr>
</tbody>
</table>


¹(square meters per gigawatt-hour, for 30 years)
²Includes coal mining.
³Land actually occupied by turbines and service roads.

Table 15-3
Present and Estimated Electrical Generation Costs¹

<table>
<thead>
<tr>
<th>Source</th>
<th>Cents per Kilowatt-Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>8–12</td>
</tr>
<tr>
<td>Coal</td>
<td>5–7</td>
</tr>
<tr>
<td>Gas and oil</td>
<td>6–9</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>3–6</td>
</tr>
<tr>
<td>Wind</td>
<td>5–8</td>
</tr>
<tr>
<td>Geothermal</td>
<td>4.5–5.5</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>22</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>8–12</td>
</tr>
<tr>
<td>Biomass</td>
<td>5</td>
</tr>
</tbody>
</table>


¹Generation costs are costs to companies.

GO GREEN
If you can afford it, buy green power (such as wind-generated electricity) from your local utility.

Figure 15-16 Wind energy. Wind has become the fastest growing source of energy in the world.

Biomass
The organic matter contained in plants is called biomass. The energy found in this organic plant matter comes from sunlight. Useful biomass includes wood, wood residues left over from the timber industry, crops, crop residues, charcoal, manure, urban waste, industrial wastes, and municipal sewage. Some of these fuels can be burned directly. Others are converted to methane (a gas) and ethanol (a liquid). The simplest way to get energy from biomass is to burn it. In some
**VIEWPOINT** Bird Kills from Commercial Wind Farms: Fact or Fiction?

While commercial wind machines do kill birds, the problem has been blown way out of proportion. Studies show that bird kills from wind turbines pale in comparison to bird deaths from several common sources, among them plate glass windows, domestic cats, automobiles and trucks, tall buildings, smokestacks, and communication towers (see Table 1). Worldwide, hundreds of millions of birds—perhaps even billions—are killed each year by these sources. Commercial wind turbines, on the other hand, kill a miniscule number of the birds. So why has wind gotten such a bad rap?

Wind machines got a bad rap from one of America’s oldest and largest wind farms: the Altamont Pass Wind Resource area in California. Located just east of San Francisco, Altamont Pass is home to a mind-boggling 7,000 wind turbines.

<table>
<thead>
<tr>
<th>Activity/Source of Bird Mortality</th>
<th>Estimated Annual Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Killed by cats</td>
<td>270 million or more</td>
</tr>
<tr>
<td>Collisions with and electrocution by electrical transmission wires</td>
<td>130 to 170 million</td>
</tr>
<tr>
<td>Collisions with windows</td>
<td>100 to 900 million</td>
</tr>
<tr>
<td>Poisoning by pesticides</td>
<td>67 million</td>
</tr>
<tr>
<td>Collisions with motor vehicles</td>
<td>60 million</td>
</tr>
<tr>
<td>Collisions with communications towers</td>
<td>40 to 50 million</td>
</tr>
</tbody>
</table>


instances, though, it makes more sense to convert biomass to gaseous and liquid fuels such as ethanol. These can be burned in motor vehicles or used to produce raw materials for the chemical industry to manufacture drugs and plastics as oil and natural gas supplies decline.

Biomass (wood, for instance) supplies about 20% of the world’s energy. In fact, it is the main source of energy for about half of the world’s population, primarily those in the less developed countries. In sub-Saharan Africa, three-fourths of the energy comes from burning wood. In contrast, in the United States and other developed countries, biomass supplies only about 3% of the energy needs. Wood-rich Canada currently supplies about 6% of its total energy demand from biomass, mostly wood.

Certain nonfood crops could also be grown to produce liquid fuel. For example, a desert shrub (*Euphorbia lathyris*) found in Mexico and the southwestern United States produces an oily substance that could be refined to make liquid fuel. In arid climates, the shrub could yield 16 barrels of oil per hectare (6 barrels per acre) on a sustainable basis. The copaiba tree of the Amazon yields a substance that can be substituted for diesel fuel without processing. Vegetable oils can also be used in place of diesel. According to one study, farmers could convert 10% of their cropland to sunflowers to produce all the diesel fuel needed to run their machinery. Eventually, the entire transportation system could be powered by renewable fuels.

Another potential source of energy is manure from livestock operations. Manure is fed into vats where it decomposes, giving off methane, a combustible gas. All over the world, plans are under way to use manure to produce a combustible fuel. This not only helps put a waste to good use, it helps reduce pollution.

**KEY CONCEPTS**

Biomass is organic matter such as wood or crop wastes that can be burned or converted into gaseous or liquid fuels. It is a common fuel source in most developing nations but supplies only a fraction of the needs of people in the developed nations.
to another report. Yet another 10 to 40 million birds perish after flying into communications towers and the guy wires that support them. Pesticides kill an estimated 67 million birds each year.

Cats are a lethal force in the lives of birds. Scientists who have studied bird deaths from cats in Wichita, Kansas, found that a single cat kills, on average, 4.2 birds per year. Other studies suggest even higher numbers. According to one study, a feral cat kills as many birds in 1 week as a large commercial wind turbine does in 1 to 2 years. Declawing a cat doesn’t seem to help much. According to one estimate, the majority of cats (83%) kill birds, even declawed, and well-fed cats prey on wild birds. Neutering or spaying a cat does not seem to cut down on hunting, either. With more than 64 million cats in America alone, what’s the total loss?

No one knows for sure, but if the situation in Wisconsin is indicative of the national toll, America’s bird population is being decimated by our beloved feline companies. In Wisconsin alone, researchers estimate that cats kill approximately 39 million birds per year. Nationwide, the number is estimated to be around 270 million, very likely many many more. Two scientists who studied the issue in one small town in England, estimated that cats kill 20 million birds per year in Great Britain alone. “Even if wind were used to generate 100% of U.S. electricity needs, at the current rate of bird kills, wind would account for only one of every 250 human-related bird deaths,” notes the AWEA. “So, if you want to save birds,” says one wind energy expert who wished to remain anonymous, for reasons that will soon be clear, “put your cat in a blender, then sign up for wind-generated ‘green electricity’ from your utility.”

The Pros and Cons of Biomass  Biomass offers many benefits. It can help less developed nations reduce their dependence on nonrenewable energy resources. It also has a high net energy efficiency when it is collected and burned close to the source of production, and it has a wide range of applications. Unlike fossil fuels, biomass adds very little carbon dioxide to the atmosphere—as long as the amount of plant matter burned equals the amount of plant matter produced each year. Burning some forms of biomass, such as urban refuse, reduces the need for land disposal.

Several recent technological and scientific developments could improve the prospects for biomass. First is the use of high-efficiency gas turbines, similar to those in jet aircraft, to generate electricity from hot gases produced by the combustion of various forms of biomass. Second is the development of an enzymatic process that improves the efficiency of ethanol production from wood wastes—a procedure that has decreased the cost of ethanol from wood from $4 a gallon to $1.35 in the last decade. Further improvements could decrease costs to 60 cents a gallon. Wood wastes now dumped in landfills, urban tree trimmings, and sustainably managed tree farms could eventually form the base of a sustainable ethanol production to meet a portion of our transportation fuel needs.

Biomass is not a panacea, however. Although the world’s reliance on this form of renewable energy will probably increase in coming years, it is doubtful that its use will increase as much as some proponents hope. Why not? Global warming could reduce water supplies and agricultural output in many areas, thus constraining biomass production. Further, some people believe that rising food demand may limit the amount of farmland available to produce biomass fuels. Biomass production could raise food prices, which is especially harmful in less developed countries. Already rising ethanol production has caused an increase in corn prices that has increased the cost of feeding cattle and the cost of feeding people whose main food sources are derived from imported corn. Furthermore, removing crop and forestry
residues may reduce soil nutrient replenishment. Biomass can create large amounts of air pollution—for example, smoke from woodstoves. This smoke contains several toxic air pollutants, such as dioxins, and creosote. Studies show that children living in homes with wood-burning stoves have more respiratory problems than children in homes heated by other means. Finally, transportation costs for biomass are higher than traditional fossil fuels because biomass has a lower energy content per unit of weight.

**KEY CONCEPTS**

Biomass is a major source of energy in many less developed nations and could boost the energy supply of many more developed nations.

### Biodiesel

Another biomass solution that holds great promise is biodiesel. **Biodiesel** is a renewable fuel made from an assortment of vegetable oils—for example, corn oil, canola oil, and soy oil. The liquid is a combustible, clean-burning fuel that could eventually power many of the nation's trucks, cars, buses, vans, ships, and trains, perhaps even jets. (There are already over 1,000 gas stations in the United States that sell biodiesel out of 120,000 stations.) You can locate gas stations at the Alternative Fueling Station Watch on the Internet.

Biodiesel is made by mixing vegetable oil with a solution of methanol containing sodium hydroxide (lye). The oil is usually heated. The methanol-lye mixture is then added to the vegetable oil. This solution is heated some more and then stirred for a period of time, usually about an hour. When the chemical reaction is complete, output comes biodiesel—long chain fatty acids that burn very nicely in diesel engines. The only waste product is glycerol, a dark thin oily substance that can be purified and used to make soap.

**The Pros and Cons of Biodiesel**

Biodiesel is a renewable fuel that could help us meet our needs for transportation fuels as the age of oil winds down. Biodiesel can help stimulate our nation's economy and reduce its reliance on foreign oil. It could also help stimulate rural economies. In the coming years, many farmers will be enlisted to produce “fuel grains” for the biodiesel market. Local biodiesel manufacturers could convert the grains to vegetable oil. Crop production and local manufacturing not only create stronger local and regional economies, they help forge the path to a more decentralized and sustainable system of fuel production.

According to Marc Franke, an Iowa-based proponent of biodiesel, the net energy efficiency of biodiesel production from soy oil is 3.2. The net energy production of biodiesel from canola or rapeseed oil is 4.3. What these figures mean is that for every unit of energy invested in biodiesel production, you get 3.2 units of energy output for soy oil and 4.3 units of energy from canola oil. According to Franke, it would take 7.0 acres of soybeans to supply soybeans to extract the oil needed to make biodiesel for a diesel car that travels 15,000 miles per year and gets 44 miles per gallon. It would take 2.7 acres of canola oil to do the same thing.

Seed crops are not the only potential source of biodiesel, however. Biodiesel can also be produced from vegetable oils discarded by restaurants—reducing disposal costs for them while providing a valuable renewable liquid transportation fuel. U.S. restaurants, including all the fast-food chains, produce an estimated 3 billion gallons of waste vegetable oil per year, according to Franke!

There are a lot of other sources, too. For example, biodiesel can be manufactured from algae grown in ponds associated with sewage treatment plants, helping reduce pollution while generating liquid fuel for North America’s transportation system. Diesel fuel can also be produced from the organic waste such as that generated at turkey farms using a process known as Thermal De-Polymerization (TDP). Agricultural, organic wastes, says Franke, produce enough material to make 4 billion barrels of biodiesel each year!

According to Franke, biodiesel offers the same performance as regular diesel, but dramatically reduces tailpipe emissions. For example, biodiesel contains no sulfur; therefore, combustion of this fuel source eliminates sulfur oxide emissions that contribute to acid rain and snow—a big problem with conventional diesel vehicles.

There’s no black smoke spewing from tailpipes of cars or trucks powered by biodiesel as they pass or power up a hill. Complete cycle carbon dioxide production from the manufacture of the fuel and use of biodiesel cars and trucks is 78% lower than vehicles powered by standard diesel fuel. According to the U.S. Department of Energy, biodiesel is the fastest growing alternative fuel on the market today.

Yet another advantage of biodiesel is that the transition to this fuel won’t require major changes in distribution systems. Biodiesel could be produced locally and sold at area filling stations using the same facilities that are used to dispense diesel fuel made from petroleum.

Biodiesel can also be run in space heaters and oil furnaces, even forklifts, tractors, and electric generators that currently use diesel. Your home someday could be heated with biodiesel. I use biodiesel in my lawn tractor and farm tractor at The Evergreen Institute.

Despite these benefits, biodiesel does have a few disadvantages. For one, it is not yet widely available. Second, in the United States, commercially manufactured biodiesel costs a bit more to produce than standard petroleum-derived diesel. This, of course, is largely due to the fact that biodiesel is only produced by small-scale production facilities. Increasing the scale of production could bring the cost down substantially. As oil prices rise and biodiesel production ramps up, costs could decline, making biodiesel the fuel of the future. Improving matters, starting in January 2004, producers received a federal tax incentive of up to $1 per gallon of biodiesel.

You can also make your own biodiesel at bargain base prices in your basement. Biodiesel Solutions, a company in Fremont, California sells equipment you can set up in your basement or garage to manufacture biodiesel. They claim that it currently costs only about 70 cents per gallon to make, far lower than standard diesel, which is currently running about $3.40 per gallon.
Vegetable Oil as a Fuel

Some people are burning vegetable oil directly in diesel cars, trucks, and buses. Some individuals acquire their fuel from unused vegetable oil. Others salvage vegetable oil from fast-food chains and other restaurants. How can vegetable oil be burned in a diesel car?

It may surprise readers to learn that the German inventor of the diesel engine, Rudolph Diesel, was able to run his engine on peanut oil. Modern diesel engines, however, can’t run directly on vegetable oils. To run a vehicle on straight vegetable oil, which is thicker than biodiesel or conventional diesel fuel, car and truck owners must make some modifications to their vehicles. Several companies now manufacture conversion kits costing $300 to $800. Most of these kits include a separate tank for vegetable oil and heating elements for the tank, the fuel line, and the fuel filter. They heat the vegetable oil, which makes it lighter so it flows more readily.

Vegetable oil is an ideal fuel, but one needs to understand the pros and cons of this approach to compare it with other options, especially biodiesel. Let’s start on the up side.

One of the biggest advantages of vegetable oil is that the fuel is widely available. You can stop and fill up anywhere in North America as long as there’s a restaurant that deep fat fries its food in vegetable oil. (You’ll have to filter the gunk out of the deep fryer oil first, however.)

Not only is the fuel abundant and widely available, so are diesel engine conversion kits. You can purchase them on the Internet.

Like other options discussed in this chapter, the fuel is renewable and can be picked up for free—for example, from fast-food restaurants whose owners are typically pleased to give it away, rather than pay for disposal!

Vegetable oil burns cleanly and thus helps solve another thorny issue—air pollution from conventional fossil fuels. Like biodiesel, vegetable oil use reduces carbon dioxide emissions. The fuel itself is often called carbon neutral but that’s not entirely true. Although the amount produced during combustion equals the amount the plants take up during photosynthesis, it takes energy to make this fuel (gasoline to power a tractor, for instance). The consumption of energy, in turn, produces carbon dioxide. Even so, the fuel is light years ahead of conventional fossil fuels with respect to greenhouse gas production.

Vegetable oil fuels have some disadvantages. The conversion kits and installation of the kits cost money. In addition, the additional fuel tank takes up a considerable amount of trunk space. In many cars, the owner has to start the vehicle with ordinary diesel, then switch to vegetable oil after it has heated up. Five minutes before the car is turned off, the driver has to switch back to petroleum-based diesel to clean the lines of biodiesel. One German company has developed a conversion kit that uses the main fuel tank. Vehicles equipped with this can start on straight vegetable oil.

Hydroelectric Power

Humankind has tapped the power of flowing rivers and streams for thousands of years to run flour mills and, more recently, to produce electricity. River flow is made possible by two factors: sunlight energy, which causes water to evaporate. It is then deposited immediately as rain or sometime later as snow that flow into rivers (Chapter 13). The second factor is gravity, which is responsible for the movement of water in streams.

Hydroelectric power is a renewable resource usually tapped by damming streams and rivers. Water in the reservoirs behind dams is released through special pipes. As it flows out, it turns the vanes of electric generators, producing electricity.

Hydropower supplies about one-fifth of the world’s electrical demand. In Canada, it supplies about 12% of the nation’s total annual energy demand. Hydropower creates no air pollution and is relatively inexpensive. Furthermore, the technology is well developed. Although dams and hydroelectric power plants are expensive to build, they often have lifespans 2 to 10 times greater than coal or nuclear powered plants.

There are some problems associated with hydropower. As noted in Chapter 13, reservoirs behind dams often fill with sediment, shortening the life span of a hydropower facility to 50 to 100 years. However, large projects with enormous reservoirs may last 200 to 300 years. Once a good site is destroyed by sediment, it is gone forever. Dams and reservoirs flood productive land, displace people, destroy stream fisheries, eliminate certain forms of recreation, upset nutrient replenishment in estuaries, and create many additional problems discussed in Chapter 13.

Many countries have a large untapped hydroelectric potential. In South America, for instance, hydroelectric generating potential is estimated at 600,000 megawatts. By comparison, the United States, the world’s leader in hydroelectric production, has a present capacity of about 77,000 megawatts and an additional capacity of about 150,000 to 160,000 megawatts.

As pointed out in Chapter 13, estimates of hydroelectric potential can be deceiving because they include all possible sites, regardless of their economic or environmental costs. For example, half of the U.S. hydroelectric potential is in Alaska, far from places that need power. The potential for additional large projects in the continental United States is small because the most favorable sites have already been developed. Canada faces a similar shortage. Moreover, those developing sites that are available would result in massive...
environmental impacts and might be strongly opposed by the citizenry. In addition, the high cost of constructing large dams and reservoirs has increased the cost of hydroelectric energy by from 3 to 20 times since the early 1970s. Because of these factors, hydropower is projected to increase very slowly in the coming decades.

Two of the most sensible strategies for increasing hydropower may be to (1) increase the capacity of existing hydroelectric facilities—that is, add more turbines—and (2) install turbines on the many dams already built for flood control, recreation, and water supply. In appropriate locations, small dams could provide energy needed by farms, small businesses, and small communities. All projects, however, must be weighed against impacts on wildlife habitat, stream quality, estuarine destruction, and recreational uses.

In LDCs, small-scale hydroelectric generation may fit in well with the demand. In China tens of thousands of medium and small hydroelectric generators account for about one-fourth of the country’s electrical output. Small instream generators that do not impede the flow of water can also provide power to individual homes located near waterways. Water can also be removed, transported downstream in small pipes (to pick up speed), and then run through small generators (FIGURE 15-17). These can provide a remarkable amount of electrical energy 24 hours a day, 365 days a year! However, there aren’t many suitable sites in most parts of the country for small-scale hydros, called microhydro.

**KEY CONCEPTS**

**Geothermal Energy**

The Earth harbors an enormous amount of heat, or geothermal energy, which comes primarily from magma, molten rock beneath the Earth’s surface. Geothermal energy is constantly regenerated, so it is a renewable resource. Geothermal resources fall into three major categories.

Hydrothermal convection zones are places where magma intrudes into the Earth’s crust and heats rock that contains large amounts of groundwater. The heat drives the groundwater to the Earth’s surface through fissures, where it may emerge as steam (geysers) or as a liquid (hot springs).

Geopressurized zones are aquifers that are trapped by impermeable rock strata and heated by underlying magma. This superheated, pressurized water can be tapped by deep wells. Some geopressurized zones also contain methane gas.

Hot-rock zones, the most widespread but also the most expensive geothermal resource, are regions where bedrock is heated by magma. To reap the vast amounts of heat, wells are drilled, and the bedrock is fractured with explosives. Water is pumped into the fractured bedrock, heated, and then pumped out.

Geothermal energy is heavily concentrated in the so-called Ring of Fire encircling the Pacific Ocean and in the great mountain belts stretching from the Alps to China (FIGURE 15-18). It is also prevalent around the Mediterranean Sea and in East Africa’s Great Rift Valley, which extends along the eastern part of the African continent. Within these areas, hydrothermal convection zones are the easiest and least expensive to tap. Hot water or steam from them can heat homes, factories, and greenhouses. In Iceland, for example, 65% of the homes are heated by the Earth’s heat. Iceland’s geothermally heated greenhouses produce nearly all of its vegetables; Russia and Hungary also heat many of their greenhouses in this way.

Geothermal is also being widely used to heat homes and other buildings in the United States and Canada. The heating systems, referred to as ground-source heat pumps, extract heat from the ground through pipe buried 6 to 8 feet below the surface. Using refrigeration technology, these systems commonly referred to as geothermal systems, pump heat from the ground into a building. In the summer, they can be run in reverse. That is, they can extract heat from a building and dump it back into the ground, thus cooling the building. Geothermal systems are about 25% more efficient at heating a building than conventional systems.

Steam from geothermal sources can be used to run turbines that produce electricity. Geothermal plants can produce electricity day and night and can provide electricity when wind or solar systems are not operating. They can also provide electricity in areas without sizable wind or solar resources.
Although still in the early stages of development in most countries, geothermal electric production is growing quickly in the United States, Italy, New Zealand, and Japan. El Salvador in Central America, however, currently generates 40% of its electricity from geothermal sources, and Kenya and Nicaragua acquire 11 and 10%, respectively.

Hydrothermal convection systems have several drawbacks. The steam and hot water they produce are often laden with minerals, salts, toxic metals, and hydrogen sulfide gas. Many of these chemicals corrode pipes and metal. Steam systems may emit an ear-shattering hiss and release large amounts of heat into the air. Pollution control devices are necessary to cut down on air and water pollutants. Engineers have also proposed building closed systems that pump the steam or hot water out and then inject it back into the ground to be reheated. Finally, because heat cannot be transported long distances, industries might have to be built at the source of energy.

**KEY CONCEPTS**

Geothermal energy is a renewable resource created primarily from magma, molten rock beneath the crust. Geothermal energy is used to generate electricity and to heat structures; it is a major source of energy in some countries.

**Hydrogen Fuel**

Hydrogen is another renewable fuel that many believe could be used to help replace oil, gasoline, and natural gas. It could someday be burned in our stoves, water heaters, furnaces, factories, and cars.

Hydrogen gas is produced by heating water to extremely high temperatures or passing electricity through it in the presence of a catalyst (a chemical that facilitates the breakdown of water into oxygen and hydrogen without being changed itself). The device used to generate hydrogen is known as an electrolyzer.

Hydrogen is a relatively clean-burning fuel. In fact, when hydrogen burns it produces only water and small amounts of nitrogen oxide (formed by the combination of atmospheric oxygen and nitrogen). Nitrogen oxides, which contribute to acid deposition, can be minimized by controlling combustion temperature and by installing pollution control devices. Unlike fossil fuels, hydrogen produces no carbon dioxide when burned.

Because hydrogen could be generated from seawater, it is an essentially limitless and renewable energy resource. Hydrogen is also easy to transport and has a wide range of uses. Unfortunately, at the present time it takes considerable energy to produce hydrogen. This low net energy yield makes it an expensive form of energy.

Hydrogen may also serve as a way of storing energy from hydroelectric, wind, solar, and other renewable energy sources. For example, when demand for these sources is low, the electricity they generate could be used to produce hydrogen from water. It would be stored for later use. When renewable sources are not available (say, on a calm day or during the evening), the hydrogen could be burned to produce electricity.

Although the immediate prospects for hydrogen are not spectacular, efforts to produce hydrogen more efficiently could go a long way to make this energy source more cost effective. Some energy analysts predict that one day areas rich in sunlight, wind, and water could become major sources of hydrogen fuel, which could be piped around the world in pipelines.

In 1996, the U.S. Congress passed the Hydrogen Future Act. This law supports research and development of hydrogen fuels and provides approximately $165 million to support these activities.

**Fuel Cells**

Hydrogen can also be used to produce electricity in a fuel cell. Many different types of fuel cells have been developed. **FIGURE 15-19** shows a simplified view of how a fuel cell works. As illustrated, this fuel cell looks a lot like a battery. It consists of an anode and a cathode separated by a membrane. Hydrogen is fed into the cathode where it reacts to form hydrogen ions and electrons. The electrons are drawn off by a wire, forming electricity, which powers lights, electronic equipment, and so on. Oxygen is introduced into the cathode, where it reacts with hydrogen ions that pass through...
the membrane from the anode and electrons returning from the circuit. The product is water.

Electricity produced by a fuel cell can be used to power electric motors in cars. In fact, in 1999 Daimler-Chrysler unveiled a hydrogen-powered car that can travel as fast as 90 miles per hour. It uses hydrogen and oxygen to run a fuel cell, which runs an electric motor to power the car. One company in Canada, Ballard Power Systems, is building hydrogen fuel cell powered buses, which are now being used experimentally in Chicago and British Columbia. During the public ceremony in Chicago, then Mayor Richard Daley, celebrated by drinking a glass of exhaust water collected from the tailpipe of an idling bus to underscore how safe the emissions are. If tests prove successful, Ballard hopes to enter full-scale production of fuel cell bus engines.

Iceland has committed itself to a hydrogen economy and will soon receive all of its energy from hydrogen and geothermal energy.

Although hydrogen-powered cars seem promising, remember that it takes energy (electricity) to make hydrogen. Studies show that it is far more efficient (three to four times) to use electricity directly to power an electric car than it is to use that electricity to generate hydrogen to run a fuel cell to produce electricity to run a car. Fuel cells use hydrogen and oxygen, but both hydrogen and oxygen also burn, so they can be burned directly in cars. For more on the pros and cons of hydrogen, see the Point/Counterpoint on the following pages. Today, a lot of fuel cell work is focused on using hydrogen-containing fuels such as methanol, natural gas, ethanol, or gasoline. The fuels will be fed into an onboard fuel processor that strips the hydrogen from the molecules. The hydrogen is then fed into the fuel cell. Although most fuel cells under development are powered by fossil fuels, the process is reportedly very clean and represents a major improvement over standard gasoline- and diesel-powered motor vehicles. They still produce significant amounts of carbon dioxide. At this writing, Daimler-Chrysler, Toyota, Honda, Ford, and General Motors have fuel cell vehicles that could be brought to market soon.

**KEY CONCEPTS**

Is a Renewable Energy Supply System Possible?

Enormous amounts of renewable energy are available and accessible with current technologies—far more than are available from fossil fuel reserves. This has led some scientists and environmentalists to propose a sustainable energy supply system far different from the one in existence today. They see energy efficiency and renewable energy resources as the cornerstone of this new, environmentally sustainable system. **FIGURE 15-20** shows one scenario for the projected shift in the world’s energy supply system. As illustrated, renewables could take over for all of the nonrenewables. This transition will take many years, and thus, fossil fuels will be around for a long time.

But how will renewable energy supplant the nonrenewables that currently power much of the world? Where will
understand that hydrogen is not a source of energy. Instead, it’s an energy carrier, a way of storing or transporting energy that comes from some other source.

Hydrogen is one of the most abundant elements here on Earth, but nearly all of it is bonded chemically to other elements, primarily in water and hydrocarbon molecules such as methane. These bonds must be broken to obtain the pure hydrogen that can be used as an energy carrier.

Hydrogen in water can be separated using electrolysis. This process can be powered by electricity from any source, including wind, solar, or other renewable power systems. The hydrogen can be burned like other fuels to provide heat or power. But more efficiently, it can be used in a fuel cell that combines hydrogen and oxygen electrochemically, a process that produces electricity, heat, and water. A renewable source of power, an electrolyzer, hydrogen storage tanks, and a fuel cell are all that’s required to create a hydrogen energy system that provides reliable, around-the-clock power. The only emission is pure water.

Turning electricity into hydrogen also addresses another limitation of renewable energy. Hydrogen made using electricity effectively converts this energy into a portable fuel, something electric vehicle makers have struggled for years to do with batteries. Battery-electric cars offer great performance but have a limited driving range, typically less than 50 miles, because of the bulk and weight of the batteries. The average car is driven less than 50 miles a day, but what about longer trips? Hydrogen, used either to power fuel cells or as a clean-burning fuel in hybrid internal combustion/electric drive trains, can extend the driving range of electric cars to hundreds of miles.

Many people wonder why, with all its advantages, hydrogen energy does not yet play a major role in our energy economy. The main hurdles to fuel cell commercialization are high cost and product reliability, but these problems are gradually being resolved by the industry. Another obstacle that hydrogen, like any new fuel, faces is the so-called “chicken and egg” problem. How do you get manufacturers to make and sell fuel cell cars if there are no convenient places to fill them up? At the same time, how do you convince energy companies to build expensive new fueling stations if they’re not convinced there will be vehicles coming in to fill up? This dilemma is also being overcome, mainly by government and large companies investing in mini-fleets of hydrogen vehicles and putting in their own fueling stations.

Vehicles, however, will probably turn out to be the last frontier for hydrogen fuel cell power, because conventional internal combustion engines and their fuels remain relatively inexpensive. In the meantime, we can expect to see fuel cells widely adopted as a replacement for batteries in small power applications, such as laptop computers and other portable devices. Fuel cells are also being used in remote, automated power applications, such as telecommunication repeater stations, and for backup stationary power in buildings.

Some people have made exaggerated claims that hydrogen is a silver bullet that will meet all our future energy needs. The truth is that we will need to use a diverse portfolio of many technologies in the future to generate, transport, and store energy. The special properties of hydrogen and fuel cells ensure they will play key roles among these many solutions. Hydrogen is safer and cleaner than the fuels we use today, and its ability to store energy makes it an ideal complement to the renewable power systems that will some day provide most of our electricity.

(continued)
Hydrogen’s role as a universal energy carrier is both well documented and long awaited. Although hydrogen’s potential to provide clean, renewable electricity via fuel cells—those magical devices that convert chemical energy into electricity—warrants continued research, the same can be said for many other technologies including advanced battery systems. Despite predictions to the contrary, battery technology has advanced rapidly. New, more reliable and efficient batteries are now used to power cell phones, computers, and power tools. They are even being used in the newest generation of electric and plug-in electric hybrid vehicles or PHEVs—the very applications in which hydrogen fuel cells were predicted to dominate but have failed to appear. Likewise, questions about battery materials toxicity are becoming moot: Batteries are self-contained and can be completely recycled (the lead-acid battery industry has practiced recycling for over a century).

Why hasn’t hydrogen enjoyed similar success? Here are a few reasons:

1. Generating, storing, and then producing electricity from hydrogen is a circuitous process. The roundtrip, overall efficiency (electric energy in vs. electric energy out) is seldom better than 25%. Battery systems score much higher with roundtrip efficiencies exceeding 80% in some cases.

2. Hydrogen is difficult to store in quantity, even when compressed under enormous pressure. And while hydrogen gas packs more energy per unit of weight than any other fuel, it fares rather poorly when it comes to energy per unit volume. In an automotive context, fuel cell vehicles running on hydrogen rank about the same, with respect to mileage, as the latest generation of lithium-ion battery electric vehicles.

3. Fuel cell costs, reliability, durability, and standby losses also continue to foil the adoption of hydrogen as a universal energy carrier. In cars and trucks, fuel cell power trains haven fallen short of their goal; battery systems are leaping ahead with vehicles that can be purchased at a fraction of the price of their fuel cell counterparts. Furthermore, battery electric cars can be recharged at home, work, and, increasingly, electric car-friendly businesses. In point of fact, car manufacturers are steering away from fuel cell vehicles and are now concentrating on PHEVs with lithium-ion batteries.

4. Hydrogen safety is still an issue of debatable concern. While the use of hydrogen in open air presents little danger, it can create a serious hazard when used in the home.

Admittedly however, the use of batteries to store electric energy makes sense only up to a maximum of perhaps 100 kilowatt-hours (about as much electricity as a normal household uses in 3 or 4 days). For significantly greater quantities of energy as might be required for air conditioning and heating, the bulk storage and delivery of hydrogen has been offered as a solution. There are, however, less expensive, more practical ways of achieving the same goal:

- The redistribution of renewable electricity to areas (and in forms) as needed is one solution that has failed to receive the attention it deserves. For example, surplus electricity generated from a rooftop solar electric panel in Ohio or from windmills along the Great Lakes, could be delivered to a bookstore parking lot in Michigan to recharge a PHEV while the owner sits inside the store sipping on coffee or socializing with friends.

- Conversely, this same vehicle represents a significant reservoir of readily dispatched electricity back into the grid—a two-way process—to help stabilize the supply of electricity during times of peak demand. This technology—V2G or “Vehicle-to-Grid”—is a variant of “net metering.” As such, it offers possibilities that are not available with hydrogen that is distributed via a universal pipeline (as proposed by hydrogen enthusiasts). To be specific, unlike the existing electric grid that allows for a bidirectional flow of electricity, pipelines are “one way” in operation; one cannot simply create hydrogen at home and send it “back down the pipeline” to other users as is done with net metering.

- Heating and air conditioning represent tremendous energy loads; neither batteries nor hydrogen offer reasonable solutions to this problem. In the case of air conditioning, surplus electricity can be converted directly into ice, circumventing the cost and complexity of a hydrogen fuel cell system. Many large buildings use this cost-saving technique—purchasing power at night when it is cheap and refrigerating a large container of water into ice—to achieve cooling during the day. Likewise, heat can be stored directly.
in the form of chemical or physical changes rather than going through the wasteful processes of generating, storing, and reconverting hydrogen back into electricity.

- Finally, it might make more sense to combine electrolyzed hydrogen with carbon dioxide from the air to manufacture methane. This process, while less efficient than using the hydrogen onsite, offers the compelling benefit of creating a renewable, clean fuel that can be dispatched in our current natural gas (primarily methane) pipeline. (Hydrogen gas cannot be transported in existing pipes that deliver natural gas to homes and businesses.) Furthermore, renewable methane eliminates all the problems associated with storage, energy density, range, availability, and compatibility that are present with hydrogen. Renewable methane is being considered seriously; at three times the energy content per unit volume of hydrogen, it may prove to be the perfect fuel to be used in conjunction with the PHEV.

There is a bit of irony when it comes to the hydrogen economy: because so much has been promised over the years (and so little actually achieved), time, money, and interest that should have been devoted to other ideas has been lost. As a consequence, rather than unshackling us from our energy dependency, talk of a hydrogen economy has lulled us into complacency and inaction. In the meantime, we have become even more dependent on fossil fuels. Certainly, hydrogen will play a part in our energy future, but if we fail to recognize its limitations, if we fail to take a renewed look at other, more practical solutions, we may never get a chance to see hydrogen attain its true potential. Sadly, hydrogen’s ultimate legacy may be the undoing of, rather than the salvation of, humankind.

**Critical Thinking Questions**

1. Summarize each author’s main points and supporting information.
2. Using your critical thinking skills, analyze each viewpoint.
3. After studying the essays, do you think hydrogen will become a major fuel source in the future? Why or why not?

*FIGURE 15-20 Transition to a sustainable energy supply system.* One projection of possible energy resources in the United States. These figures are based on full commitment to renewable resources.
Economic and Employment Potential of the Sustainable Energy Strategy

Numerous studies show that efficiency measures and certain renewable energy technologies “produce” energy more cheaply than conventional sources and eliminate many of the environmental impacts as well. They do this while employing more people than conventional energy supply strategies. The chief reason for this is that efficiency and alternative technologies tend to be more labor-intensive (requiring more people) than oil, coal, and nuclear energy, which are more capital-intensive (requiring huge investments in machines and fuels). Consider some examples.

A California-style wind farm generates electricity for about 5 cents per kilowatt-hour, one-half the cost of electricity from a nuclear power plant and without the serious environmental impacts. In addition, a wind farm that produces the same amount of energy as a nuclear power plant will employ over 540 workers, compared to 100 workers in the nuclear facility (FIGURE 15-21).

Similar gains can be made through energy efficiency. A study in Alaska, for instance, found that state expenditures on weatherization—home energy conservation—would create more jobs per dollar of investment than the construction of hospitals, highways, or new power plants. Conservation spending, for instance, would create three times as many jobs as highway construction.

Weatherization of all homes in the United States would create 6 to 7 million job-years, according to Worldwatch Institute projections. (A job-year is one job for 1 year.) Six million job-years is the equivalent of 300,000 jobs over a period of 20 years! Not all jobs would be low-wage, either. Energy-efficiency companies would be run by well-paid personnel and would employ salespeople, managers, accountants, engineers, and installers.

A wise energy future is economically, environmentally, and socially sustainable. The current system fails on all of these criteria. Nonetheless, great barriers lie on the path to a sustainable system. One of the most significant is that industrial nations have been built on fossil fuels. Billions upon billions of dollars have been spent on the present fossil fuel-based system. Huge investments have been made in mining and drilling equipment, transportation networks, processing facilities, and power plants. Although the system is unsustainable, enormous resistance to change will come from many powerful political and economic interests: legislatures
be able to turn their old skills to similar activities. Petroleum geologists and oil well crews, for example, might use their expertise to drill for geothermal resources.

The transition to a renewable energy system is occurring surely in many parts of the world. Many large corporations are becoming producers and consumers of renewable energy, including General Electric, BP, Shell, Microsoft, Google, and the Philadelphia Eagles football team. Individuals and businesses can help by buying green power, when it is available. Some utilities, for instance, offer electricity from wind sources to customers at a slightly higher cost. Governments can help, too. In 1996, the Canadian government introduced a program to promote renewable energy that includes a variety of measures, including tax breaks, grants for private research, and steps to increase demand for green power in the marketplace. The government is even using more renewable energy in its own facilities. The U.S. government has taken similar steps. The National Renewable Energy Lab, for instance, and many other government labs and facilities are now getting power from solar electricity and wind. Even the White House has been retrofitted with solar electric panels. Many states now have passed laws requiring an increase in renewable energy production (mostly wind) in the next decade. Colorado, for instance, will obtain 20% of its energy from renewable sources by 2020.

The length of the transition to renewable energy resources will depend on our political will and our willingness to change for the sake of the planet’s future.

**KEY CONCEPTS**

Shifting to a sustainable system of energy will take many years. Several renewable energy technologies provide competitively priced electricity while creating more jobs than fossil fuels and nuclear energy.

The great end of living is to harmonize man with the order of things.

—Oliver Wendell Holmes

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**CRITICAL THINKING**

**Exercise Analysis**

Critical thinking warns us that broad statements—generalizations—such as those made by the supposed energy expert often fall apart on closer examination. A careful analysis of the issue reveals a somewhat different picture of reality—one much more favorable for solar energy.

Solar energy, as noted in this chapter, consists of at least four different technologies. One of them, solar thermal electric, is currently cost competitive with nuclear power. Solar thermal electric plants use sunlight to heat water or some other fluid, which is then converted into steam to run an electric turbine.

Another form of solar energy is solar electricity generated from photovoltaics (panels on rooftops that convert sunlight energy into electricity). Photovoltaics are not currently cost competitive with conventional fossil fuel resources in most applications in developed countries. It would cost a fortune for most homeowners, for instance, to add panels to their roofs to supply their homes with electricity.
In rural villages in the developing world, however, photovoltaics are quite cost-competitive because the expense incurred by running power lines to remote sites is astronomical. Even in developed countries such as the United States, though, photovoltaics can make sense. If a house is only half a mile from a power line, it is often more economical to install photovoltaics than to run a power line to the house.

Another solar technology is passive solar heating—that is, heating buildings with sunlight energy that streams in through south-facing windows. Passive solar often costs more, but it can be built economically. The author’s house cost no more than a conventional home and is heated almost entirely by the sun, saving several thousand dollars a year.

This exercise also shows that it is important to define what is meant by various terms, such as 

CRITICAL THINKING AND CONCEPT REVIEW

1. In your view, is it imperative that we change to a sustainable energy system? Why or why not?
2. Describe the types of solar energy technologies available. How does each one operate? What is it used for? Which ones are already cost competitive with current energy technologies?
3. What are the advantages and disadvantages of solar energy? How can the problems with the technologies be solved?
4. A person living in the Pacific Northwest argues that renewable energy is useless. The sun rarely shines in his neck of the woods. How would you answer this?
5. Describe the difference between passive and active solar systems. What features are needed in a home to make passive solar energy work?
6. What are photovoltaic cells? Why are they economical to use in rural villages in the developing nations and in semiremote sites in developed countries?
7. Wind energy is cost competitive with conventional electricity from coal and cheaper than nuclear energy. Should we develop this energy resource in preference to nuclear power, coal, or shale oil? Why or why not?
8. What is biomass? How can useful energy be acquired from biomass?
9. How is geothermal energy formed? How can it be tapped? Describe the benefits and risks of geothermal energy.
10. Using your critical thinking skills, debate the following statement: “Hydroelectric power is an immensely untapped resource in the United States and could provide an enormous amount of energy.”
11. What are the major problems facing hydrogen power? How could these be solved?
12. Using your critical thinking skills, discuss the following statement: “Conservation is our best and cheapest energy resource.”
13. Discuss ways in which you could conserve more energy at home, at work, and in transit. Draw up a reasonable energy conservation plan for yourself and your family.
14. Using your critical thinking skills, debate this statement: “A sustainable energy strategy won’t work. It will cost money and lose jobs.”
15. List and describe the barriers to creating a sustainable energy supply system. How could they be overcome?
KEY TERMS
biodiesel
biomass
cogeneration
conservation
earth-sheltered house
The Efficiency and Alternative Energy program
electrolyzer
Energy Efficiency Act
Energy Star Homes program
Energy Star label
flat plate collectors
fuel cell
geopressurized zones
geothermal energy
green building
green building programs
gross national product (GNP)
hot-rock zones
hybrids
hydroelectric power
hydrogen
Hydrogen Future Act
hydrothermal convection zones
least cost planning
Motor Vehicle Safety Act
National Appliance Conservation Act
National Model Energy Code
Natural Resources Canada
net zero energy
passive solar heating system
second law of thermodynamics
solar collectors
Super Energy-Efficient Home program

REFERENCES AND FURTHER READING
To save on paper and allow for updates, additional reading recommendations and the list of sources for the information discussed in this chapter are available at http://environment.jbpub.com/9e/.

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