CHAPTER 6

RENEWABLE ENERGY

WHAT IS RENEWABLE ENERGY?

Imagine energy sources that use no oil, produce no pollution, create no radioactive waste, cannot be affected by political events and cartels, and yet are economical. Even though this sounds impossible, some experts claim that technological advances could make wide use of renewable energy sources possible within a few decades. They may become substantially better energy sources than fossil fuels and nuclear power.

Renewable energy is naturally regenerated and virtually unlimited. Sources include the sun (solar), wind, water (hydropower), vegetation (biomass), and the heat of the earth (geothermal). Each of these alternative energy sources has advantages and disadvantages, and many observers hope that one or more of them may eventually provide a substantially better energy source than conventional fossil fuels, which are limited (nonrenewable) sources of energy. As the United States and the rest of the world continue to expand their energy needs—putting a strain on the environment and nonrenewable resources—alternative sources of energy continue to be explored.

A HISTORICAL PERSPECTIVE

Before the eighteenth century, most energy came from renewable sources. People burned wood for heat, used sails to harness the wind and propel boats, and installed water wheels on streams to run mills that ground grain. The large-scale shift to nonrenewable energy sources began in the 1700s with the Industrial Revolution, a period marked by the rise of factories, first in Europe and then in North America. As demand for energy grew, coal replaced wood as the main fuel. Coal was the most efficient fuel for the steam engine, which is considered to be one of the most important inventions of the Industrial Revolution.

Until the early 1970s most Americans were not concerned about the sources of the nation's energy. Supplies of coal and oil, which together provided more than 90% of U.S. energy, were believed to be plentiful. The decades preceding the 1970s were characterized by cheap gasoline and little public discussion of energy conservation.

That carefree approach to energy consumption ended in the 1970s. An oil crisis, caused in part by the devaluation of the dollar, but largely by an oil embargo by the Organization of Petroleum Exporting Countries, made Americans acutely aware of their dependence on foreign energy. Throughout the United States, people waited in line to fill their gas tanks—in some places gasoline was rationed—and lower heat settings for offices and homes were encouraged. In a country where mobility and convenience were highly valued, the oil crisis was a shock to the system. Developing alternative sources of energy to supplement and perhaps eventually replace fossil fuels suddenly became important. As a result, President Jimmy Carter (1924–) encouraged federal funding for research into alternative energy sources.

In 1978 Congress passed the Public Utilities Regulatory Policies Act, which was designed to help the struggling alternative energy industry. The act exempted small alternative producers from state and federal utility regulations and required existing local utilities to buy electricity from them. The renewable energy industries grew rapidly, gaining experience, improving technologies, and lowering costs. This law was the single most important factor in the development of the commercial renewable energy market.

In the 1980s President Ronald Reagan (1911–2004) favored private-sector financing, so he proposed the reduction or elimination of federal expenditures for alternative energy sources. Even though federal funds were severely cut, the U.S. Department of Energy continued to support some research and development. President Bill

Clinton (1946–) reemphasized the importance of renewable energy and increased funding in several areas. President George W. Bush (1946–) supported funding for research and development of renewable technologies and tax credits for the purchase of hybrid and alternative-fuel cars.

DOMESTIC RENEWABLE ENERGY USAGE

In 2007 the United States consumed approximately 6.8 quadrillion British thermal units (Btu) of renewable energy, nearly 7% of the nation's total energy consumption. (See Table 6.1 and Figure 6.1.) Biomass sources (wood, biofuels, and waste) contributed 3.6 quadrillion Btu, whereas hydroelectric power provided 2.5 quadrillion Btu. Together, biomass and hydroelectric power provided 89% of renewable energy in 2007. Geothermal energy was the third-largest source, with about 0.4 quadrillion Btu. Wind provided 0.3 quadrillion Btu, and solar power contributed close to 0.1 quadrillion Btu.

BIOMASS ENERGY

The term *biomass* refers to organic material such as plant and animal waste, wood, seaweed and algae, fuel ethanol, and garbage. The use of biomass is not without environmental problems. Deforestation can occur from widespread use of wood, especially if forests are clear-cut, which can result in soil erosion and mudslides. Burning wood, like burning fossil fuels, also pollutes the

TABLE 6.1

Energy consumption by source, selected years 1949–2007

[Quadrillion Btu]

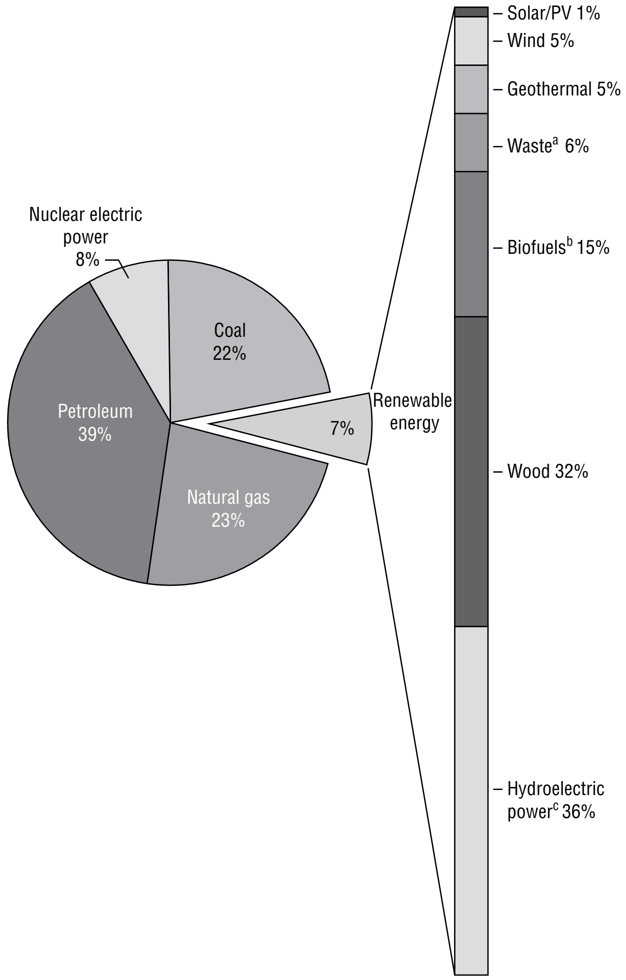
	Fossil fuels						Renewable energy[a]							
Year	Coal	Coal coke net imports[b]	Natural gas[c]	Petroleum[d]	Total	Nuclear electric power	Hydro-electric power[e]	Geothermal	Solar/PV	Wind	Biomass	Total	Electricity net imports[b]	Total
1949	11.981	−0.007	5.145	11.883	29.002	0.000	1.425	NA	NA	NA	1.549	2.974	0.005	31.982
1950	12.347	.001	5.968	13.315	31.632	.000	1.415	NA	NA	NA	1.562	2.978	.006	34.616
1955	11.167	−.010	8.998	17.255	37.410	.000	1.360	NA	NA	NA	1.424	2.784	.014	40.208
1960	9.838	−.006	12.385	19.919	42.137	.006	1.608	.001	NA	NA	1.320	2.929	.015	45.087
1965	11.581	−.018	15.769	23.246	50.577	.043	2.059	.004	NA	NA	1.335	3.398	(s)	54.017
1970	12.265	−.058	21.795	29.521	63.522	.239	2.634	.011	NA	NA	1.431	4.076	.007	67.844
1971	11.598	−.033	22.469	30.561	64.596	.413	2.824	.012	NA	NA	1.432	4.268	.012	69.289
1972	12.077	−.026	22.698	32.947	67.696	.584	2.864	.031	NA	NA	1.503	4.398	.026	72.704
1974	12.663	.056	21.732	33.455	67.906	1.272	3.177	.053	NA	NA	1.540	4.769	.043	73.991
1976	13.584	(s)	20.345	35.175	69.104	2.111	2.976	.078	NA	NA	1.713	4.768	.029	76.012
1978	13.766	.125	20.000	37.965	71.856	3.024	2.937	.064	NA	NA	2.038	5.039	.067	79.986
1980	15.423	−.035	20.235	34.202	69.826	2.739	2.900	.110	NA	NA	2.476	5.485	.071	78.122
1982	15.322	−.022	18.356	30.232	63.888	3.131	3.266	.105	NA	NA	2.664	6.034	.100	73.153
1984	17.071	−.011	18.394	31.051	66.504	3.553	3.386	.165	(s)	(s)	2.971	6.522	.135	76.714
1986	17.260	−.017	16.591	32.196	66.031	4.380	3.071	.219	(s)	(s)	2.932	6.223	.122	76.756
1988	18.846	.040	18.448	34.222	71.556	5.587	2.334	.217	(s)	(s)	3.016	5.568	.108	82.819
1990	19.173	.005	19.603	33.553	72.333	6.104	3.046	.336	.060	.029	2.735	6.206	.008	84.652
1992	19.122	.035	20.714	33.527	73.397	6.479	2.617	.349	.064	.030	2.933	5.993	.087	85.956
1994	19.909	.058	21.728	34.562	76.258	6.694	2.683	.338	.069	.036	3.030	6.155	.153	89.260
1996	21.002	.023	23.085	35.673	79.783	7.087	3.590	.316	.071	.033	3.159	7.168	.137	94.175
1998	21.656	.067	22.830	36.817	81.370	7.068	3.297	.328	.070	.031	2.931	6.657	.088	95.183
2000	22.580	.065	23.824	38.264	84.733	7.862	2.811	.317	.066	.057	3.013	[R]6.356	.075	96.375
2002	21.904	.061	23.558	38.227	83.750	8.143	2.689	.328	.064	.105	2.706	5.893	.072	97.858
2003	22.321	.051	22.897	38.809	84.078	7.959	2.825	.331	.064	.115	2.817	[R]6.150	.022	98.209
2004	22.466	.138	22.931	40.294	85.830	8.222	2.690	.341	.065	.142	3.023	6.261	.039	100.351
2005	[R]22.797	.044	[R]22.583	40.393	[R]85.817	8.160	2.703	.343	.066	.178	[R]3.154	[R]6.444	.084	[R]100.506
2006	[R]22.447	.061	[R]22.191	[R]39.958	[R]84.658	[R]8.214	[R]2.869	[R].343	[R].072	[R].264	[R]3.374	[R]6.922	[R].063	[R]99.856
2007[P]	22.767	.025	23.638	39.818	86.248	8.415	2.463	.353	.080	.319	3.615	6.830	.107	101.600

[a]Most data are estimates.
[b]Net imports equal imports minus exports. Minus sign indicates exports are greater than imports.
[c]Natural gas only; excludes supplemental gaseous fuels.
[d]Petroleum products supplied, including natural gas plant liquids and crude oil burned as fuel. Does not include the fuel ethanol portion of motor gasoline—fuel ethanol is included in "biomass."
[e]Conventional hydroelectric power.
R = Revised.
P = Preliminary.
NA = Not available.
(s) = Less than 0.0005 and greater than −0.0005 quadrillion Btu.
Note: Totals may not equal sum of components due to independent rounding.
Web page: For all data beginning in 1949, see http://www.eia.doe.gov/emeu/aer/overview.html.

SOURCE: Adapted from "Table 1.3. Primary Energy Consumption by Source, Selected Years, 1949–2007 (Quadrillion Btu)," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

FIGURE 6.1

Renewable energy consumption as a share of total energy consumption, 2007



[a]Municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural byproducts, and other biomass. Through 2000, also includes non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
[b]Fuel ethanol and biodiesel consumption, plus losses and co-products from the production of fuel ethanol and biodisel.
[c]Conventional hydroelectric power.

SOURCE: Adapted from "Figure 10.1. Renewable Energy Consumption by Major Sources: Renewable Energy As Share of Total Energy Consumption, 2007," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

environment. Biomass can be burned directly or converted to biofuel by thermochemical and biochemical conversion.

Direct Burning

Direct combustion is the easiest and most commonly used method of using biomass as fuel. Materials such as dry wood or agricultural wastes are chopped and burned to produce steam, electricity, or heat for industries, utilities, and homes. Industrial-sized wood boilers operate throughout the country. The burning of agricultural wastes is also becoming more widespread. In Florida, sugarcane producers use the residue from harvested cane to generate much of their energy. The Energy Information Administration (EIA) reports in *Annual Energy Review 2007* (June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf) that residential use of wood as fuel generated 460 trillion Btu in 2007, about half of the 850 trillion to 1,010 trillion Btu generated in homes in the 1980s.

Thermochemical Conversion

Thermochemical conversion involves heating biomass in an oxygen-free or low-oxygen atmosphere, which transforms the material into simpler substances that can be used as fuels. Products such as charcoal and methanol are produced this way.

Biochemical Conversion

Biochemical conversion uses enzymes, fungi, or other microorganisms to convert high-moisture biomass into either liquid or gaseous fuels. Bacteria convert manure, agricultural wastes, paper, and algae into methane, which is used as fuel. Sewage treatment plants have used anaerobic (oxygen-free) digestion for many years to generate methane gas. Small-scale digesters have been used on farms, primarily in Europe and Asia, for hundreds of years. Biogas pits (a biomass-based technology) are a significant source of energy in China.

Another type of biochemical conversion, fermentation, uses yeast to decompose carbohydrates, yielding ethyl alcohol (ethanol), a colorless, nearly odorless, flammable liquid, and carbon dioxide. Most of the ethanol manufactured for use as fuel in the United States is derived from corn, wood, and sugar. Ethanol is mixed with gasoline to create gasohol, which is sold in three blends: 10% gasohol, which is a mixture of 10% ethanol and 90% gasoline; 7.7% gasohol, which is at least 7.7% ethanol but less than 10%; and 5.7% gasohol, which is at least 5.7% ethanol but less than 7.7%. In "Estimated Use of Gasohol–2004" (April 2006, http://www.fhwa.dot.gov/policy/ohim/hs04/pdf/mf33e.pdf), the Federal Highway Administration estimates that in 2004 Americans used about 25.9 billion gallons (98 billion L) of 10% gasohol and 18.1 billion gallons (68.5 billion L) of less-than-10% gasohol.

The Energy Policy Act of 2005 required fuel suppliers to nearly double their use of ethanol by 2012 to reduce the nation's dependence on foreign fuel sources. Automobiles can be built to run directly on ethanol or on any mixture of gasoline and ethanol, such as ethanol-85 (E-85), which is a blend of 85% ethanol and 15% unleaded gasoline. Dan Hartzell reports in "All Fueled up with No Place to Fuel" (*Morning Call* [Allentown, Pennsylvania], May 23, 2008) that in 2008 there were approximately 6.5 million automobiles on U.S. roads capable of using E-85 as a fuel. Such vehicles are called flex-fuel vehicles because they can run on E-85, gasohol, or gasoline.

Methanol (methyl alcohol) fuels have also been tested successfully. Using methanol instead of diesel fuel virtually eliminates sulfur emissions and reduces other environmental pollutants usually emitted from trucks and buses.

Municipal Waste Recovery

Each year millions of tons of garbage are buried in landfills and city dumps. This method of disposal is becoming increasingly costly, and many landfills across the nation are near capacity. Some communities discovered that they could solve both problems—cost and capacity—by constructing waste-to-energy plants. Not only is the garbage burned and reduced in volume by 90% but also energy in the form of steam or electricity is generated in a cost-effective way.

The use of municipal waste (including landfill gas, sludge waste, tires, and agricultural by-products) as fuel has increased steadily since the 1980s through 2000, when it reached an all-time high of 23.1 billion kilowatt-hours (kWh) of electricity generation. (See Table 6.2.) In 2002 electricity generation from waste dropped to 15 billion kWh but rose again to 16.9 billion kWh in 2007.

MASS BURN SYSTEMS. Most waste-to-energy plants in the United States use the mass burn system (also called direct combustion). Because the waste does not have to be sorted or prepared before burning—except for removing obviously noncombustible, oversized objects—the system eliminates expensive sorting, shredding, and transportation machinery that may be prone to break down. The waste is simply carried to the plant in trash trucks and dropped into a storage pit. Overhead cranes lift the garbage into a hopper that controls the amount of waste that is fed into the furnace. The burning waste produces heat, which is used to produce steam. The steam can be used directly for industrial needs or can be sent through a turbine to power a generator to produce electricity.

REFUSE-DERIVED FUEL SYSTEMS. At refuse-derived fuel plants, waste is first processed to remove noncombustible objects and to create homogeneous and uniformly sized fuel. Large items such as bedsprings, dangerous materials, and flammable liquids are removed by hand. The trash is then shredded and screened to remove glass, rocks, and other material that cannot be burned. The remaining material is usually sifted a second time with an air separator to yield fluff, which is placed in storage bins. It can also be compressed into pellets or briquettes for long-term storage. This fuel can be used alone or with other fuels, such as coal or wood.

TABLE 6.2

Electricity net generation by renewables, selected years 1949–2007

[Billion kilowatthours]

	Renewable energy						
	Conventional hydroelectric	Biomass		Geo-	Solar/		
Year	power	Wood[a]	Waste[b]	thermal	PV[c]	Wind	Total
1949	94.8	0.4	NA	NA	NA	NA	95.2
1950	100.9	.4	NA	NA	NA	NA	101.3
1955	116.2	.3	NA	NA	NA	NA	116.5
1960	149.4	.1	NA	(s)	NA	NA	149.6
1965	197.0	.3	NA	.2	NA	NA	197.4
1970	251.0	.1	.2	.5	NA	NA	251.8
1971	269.5	.1	.2	.5	NA	NA	270.4
1972	275.9	.1	.2	1.5	NA	NA	277.7
1974	304.2	.1	.2	2.5	NA	NA	306.9
1976	286.9	.1	.2	3.6	NA	NA	290.8
1978	283.5	.2	.1	3.0	NA	NA	286.8
1980	279.2	.3	.2	5.1	NA	NA	284.7
1982	312.4	.2	.1	4.8	NA	NA	317.5
1984	324.3	.5	.4	7.7	(s)	(s)	332.9
1986	294.0	.5	.7	10.3	(s)	(s)	305.5
1988	226.1	.9	.7	10.3	(s)	(s)	238.1
1990	292.9	32.5	13.3	15.4	.4	2.8	357.2
1992	253.1	36.5	17.8	16.1	.4	2.9	326.9
1994	260.1	37.9	19.1	15.5	.5	3.4	336.7
1996	347.2	36.8	20.9	14.3	.5	3.2	423.0
1998	323.3	36.3	22.4	14.8	.5	3.0	400.4
2000	275.6	37.6	23.1	14.1	.5	5.6	356.5
2002	264.3	38.7	15.0	14.5	.6	10.4	343.4
2003	275.8	37.5	15.8	14.4	.5	11.2	355.3
2004	268.4	37.6	15.5	14.8	.6	14.1	351.0
2005	270.3	38.7	15.5	14.7	.6	17.8	357.5
2006	[R]289.2	[R]38.6	[R]16.1	[R]14.6	.5	[R]26.6	[R]385.7
2007[P]	248.3	38.5	16.9	14.8	.6	32.1	351.3

[a]Wood and wood-derived fuels.
[b]Municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural byproducts, and other biomass. Through 2000, also includes non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
[c]Solar thermal and photovoltaic energy.
R = Revised.
P = Preliminary.
NA = Not available.
(s) = Less than 0.05 billion killowatthours.
Note: Totals may not equal sum of components due to independent rounding.

SOURCE: Adapted from "Table 8.2a. Electricity Net Generation: Total (All Sectors), Selected Years, 1949–2007 (Sum of Tables 8.2b and 8.2d; Billion Kilowatthours)," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

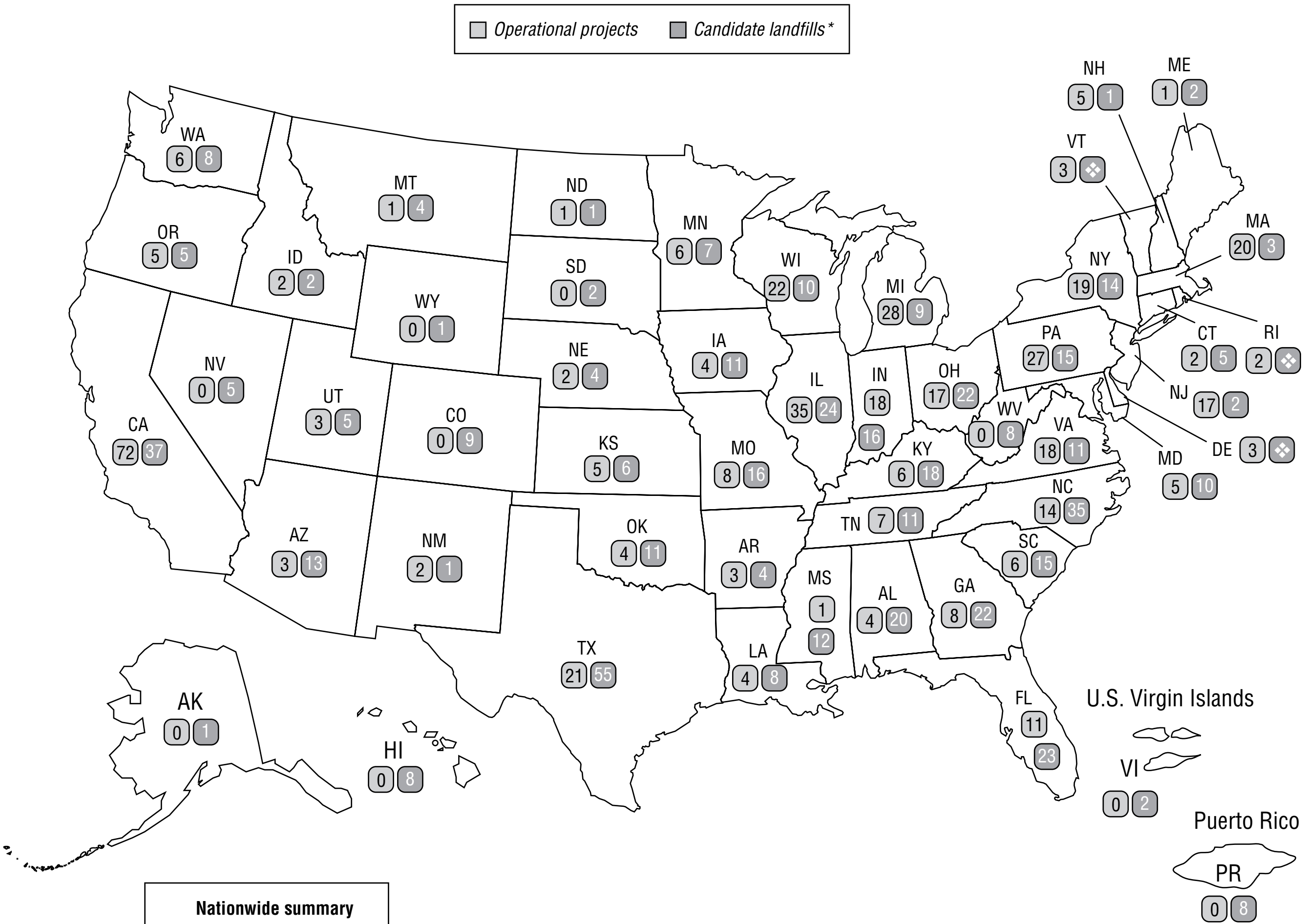
DISADVANTAGES OF WASTE-TO-ENERGY PLANTS. The major problem with increasing the use of municipal waste-to-energy plants is their effect on the environment. The emission of particles into the air is partially controlled by electrostatic precipitators, and many gases can be eliminated by proper combustion techniques. However, large amounts of dioxin (a dangerous air pollutant) and other toxins are often emitted from these plants. Noise from trucks, fans, and processing equipment can also be unpleasant for nearby residents.

Landfill Gas Recovery

Landfills contain a large amount of biodegradable matter that is compacted and covered with soil. Methanogens,

FIGURE 6.2

Landfill gas energy sites and candidate landfills, April 2008



Nationwide summary

450 operational projects (1,372 MW and 235 mmscfd)

~ 540 candidate landfills (1,280 MW or 665 mmscfd, 15 MMTCE Potential)

LMOP = Landfill Methane Outreach Program.
mmscfd = Million Standard Cubic Feet Per Day.
MMTCE = Million Metric Tons of Carbon Equivalent.
MW = Megawatts.
mmtons = Million Metric Tons.
LFGE = Landfill Gas Energy.

*Landfill is accepting waste or has been closed for 5 years or less and has at least 1 mm tons of waste and does not have an operational/under construction LFGE project; or is designated based on actual interest/planning.

SOURCE: "Landfill Gas Energy Projects and Candidate Landfills," U.S. Environmental Protection Agency, Landfill Methane Outreach Program, April 11, 2008, http://www.epa.gov/lmop/docs/map.pdf (accessed July 15, 2008)

which are anaerobic microorganisms, thrive in this oxygen-depleted environment. They metabolize the biodegradable matter in the landfill, producing methane gas and carbon dioxide as by-products. In the past, as landfills aged, these gases built up and leaked out, which prompted some communities to drill holes in landfills and burn off the methane to prevent dangerously large amounts from exploding.

The energy crisis of the 1970s made landfill methane gas an energy resource too valuable to waste. The first landfill gas recovery site was built in 1975 at the Palos Verdes Landfill in Rolling Hills Estates, California. Since then the number of landfill gas recovery sites (landfill gas energy sites) has skyrocketed. Figure 6.2 shows the number and location of the landfill gas energy sites and candidate landfills throughout the United States as of April 2008. The map shows the 450 sites that were operational in 2008 and the approximately 540 landfill sites identified for potential development as gas recovery/energy sites.

In a typical landfill gas energy site, garbage is allowed to decompose for several months. When a sufficient amount of methane gas has developed, it is piped to a generating plant, where it is used to create electricity. In its purest form, methane gas can be used like natural gas. Depending on the extraction rates, most sites can produce gas for about twenty years. Besides the energy provided, tapping the methane reduces landfill odors and the chances of explosions.

HYDROPOWER

In the past, flowing water turned waterwheels of mills to grind grain; in the twenty-first century, hydropower plants convert the energy of flowing water into mechanical energy, turning turbines to create electricity. Hydropower is the most widely used renewable energy source in the world. In the United States it provided 248.3 billion kWh, or 71% of all electricity produced from renewable sources in 2007. (See Table 6.2.)

Advantages and Disadvantages of Hydropower

In the twenty-first century, hydropower is the only means of storing large quantities of energy for almost instant use. Water is held in a large reservoir behind a dam, with a hydroelectric power plant below. The dam creates a height from which water can flow at a fast rate. When it reaches the power plant, it pushes the turbine blades attached to the electrical generator. Whenever power is needed, the valves are opened, the moving water spins the turbines, and the generator quickly produces electricity.

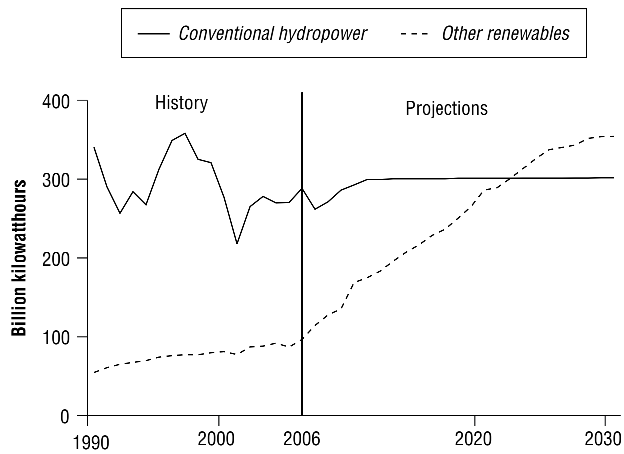
Nearly all the best sites for large hydropower plants are being used in the United States. Small hydropower plants are expensive to build but may eventually become economical because of their low operating costs. One of the disadvantages of small hydropower generators is their reliance on rain and melting snow to fill reservoirs; drought conditions can affect the water supply. Additionally, environmental groups strongly protest the construction of new dams, pointing to ruined streams, dried up waterfalls, and altered aquatic habitats.

The Future of Hydropower

The last federally funded hydropower dam, completed by the U.S. Army Corps of Engineers in 1986, was the Richard B. Russell Dam and Lake on the Savannah River, which forms the border between South Carolina and Georgia. Since then, local governments have been required to contribute half the cost of any new dam proposed in the United States. Even though expansion and efficiency improvements at existing dams offer significant potential for additional energy, hydropower's future contribution to U.S. energy generation should remain relatively constant, with increases in production offset by increases in consumption. (See Figure 6.3.) Additional supplies of hydroelectric power for the United States will likely come from Canada.

FIGURE 6.3

Electricity generation from hydropower and other renewable sources, 1990–2030



SOURCE: "Figure 67. Grid-Connected Electricity Generation from Renewable Energy Sources, 1990–2030 (Billion Kilowatthours)," in *Annual Energy Outlook 2008*, U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, June 2008, http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf (accessed July 2, 2008)

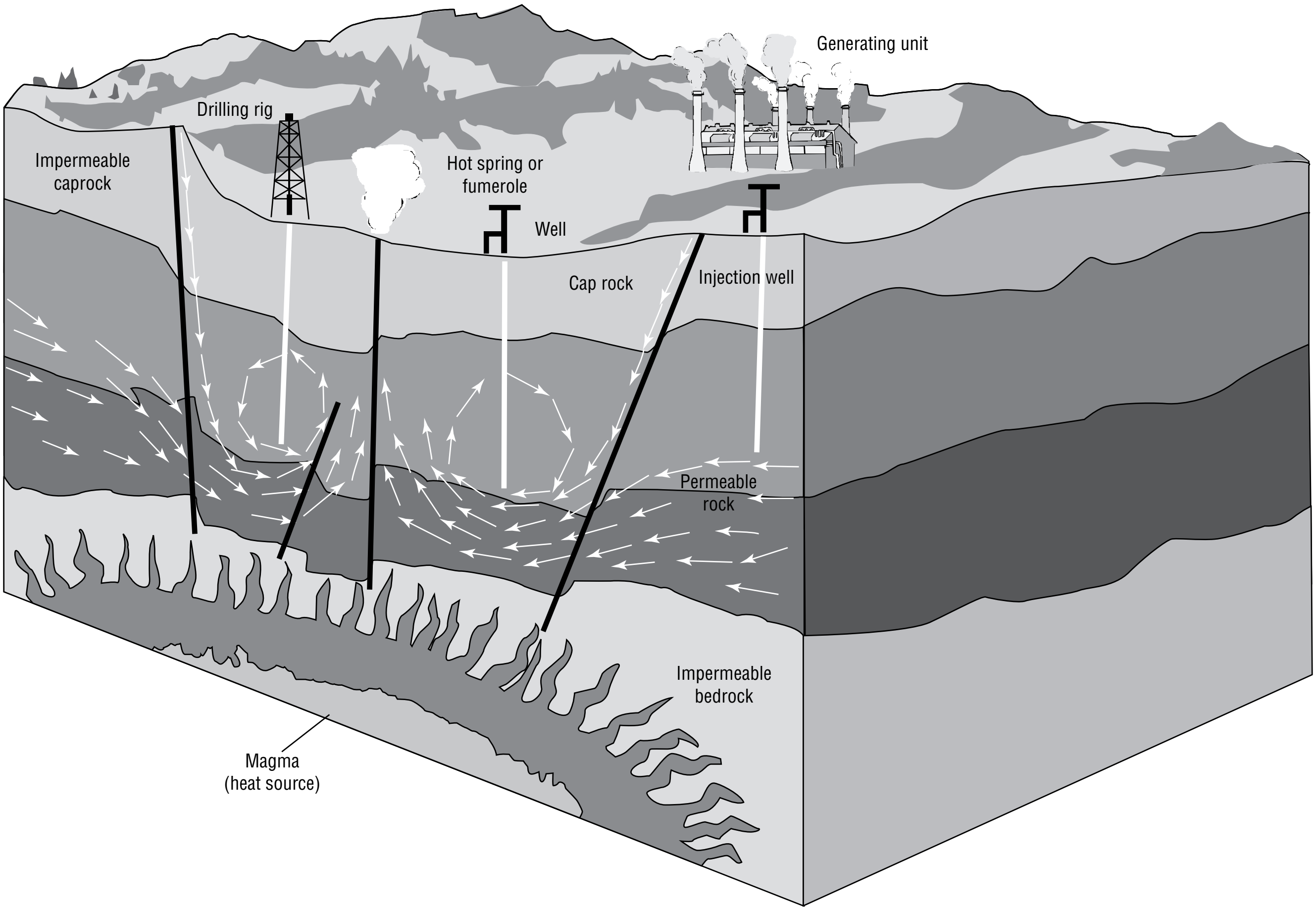
Most of the new development in hydropower is occurring in developing nations, which see it as an effective method of supplying power to growing populations. These massive public-works projects usually require huge amounts of money—most of it borrowed from the developed world. Hydroelectric dams are considered worth the cost and potential environmental threats because they bring cheap electric power to the citizenry.

The Chinese government (January 10, 2008, http://english.gov.cn/special/sanxia_index.htm) has constructed the world's largest dam, the Three Gorges Dam, on the Yangtze River in Hubei province, China. Five times the size of the Hoover Dam in the United States, the dam is 607 feet (185 m) tall and 7,575 feet (2,309 m) in length. One decade after the project was launched in 1993, the Three Gorges Dam began generating power. By 2007 the plant was generating 61.6 billion kWh of electricity. After installation of its twenty-six generators is completed at the end of 2008, the dam is expected to produce 84.7 billion kWh of electricity per year. Under an expansion plan, six more turbines will be added to the dam by 2012.

By November 2007 problems with the dam became evident that had been discussed in years prior as possibilities. Controversy over the dam heightened as water rose behind it and pollution, soil erosion, and landslides occurred. In response, Jim Yardley reports in "China to Address Issues around Dam" (*New York Times*, November 22, 2007) that the director of the Three Gorges Dam

FIGURE 6.4

Cross-section of the Earth showing source of geothermal energy



Note: Drawing not to scale.

SOURCE: "Figure A-4. Cross-Section of the Earth Showing Source of Geothermal Energy," in *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies*, U.S. Department of Energy, Energy Information Administration, September 1991, http://www.osti.gov/energycitations/servlets/purl/5212047-gTiC1e/native/ (accessed July 30, 2008)

project announced measures that would be taken to lessen the environmental impact of the dam. On May 12, 2008, an earthquake measuring 7.9 on the Richter scale occurred near the dam, with the epicenter of the quake a few hundred miles to the east. No immediate problems were reported.

GEOTHERMAL ENERGY

Even though bubbling hot springs became public baths as early as ancient Rome, using hot water and underground steam to produce power is a relatively recent development. Electricity was first generated from natural steam in Italy in 1904. The world's first natural steam power plant was built in 1958 in a volcanic region of New Zealand. A field of twenty-eight geothermal power plants covering 30 square miles (78 sq km) in northern California was completed in 1960.

What Is Geothermal Energy?

Geothermal energy is the natural, internal heat of the earth trapped in rock formations deep underground. Only a fraction of it can be extracted, usually through large fractures in the earth's crust. Hot springs, geysers, and fumaroles (holes in or near volcanoes from which vapor escapes) are the most easily exploitable sources. (See Figure 6.4.) Geothermal reservoirs provide hot water or steam that can be used for heating buildings and processing food. Pressurized hot water or steam can also be directed toward turbines, which spin, generating electricity for residential and commercial customers.

Types of Geothermal Energy

Like most natural energy sources, geothermal energy is usable only when it is concentrated in one spot—in this case, in what is known as a thermal reservoir. There are four types of reservoirs: hydrothermal reservoirs, dry rock reservoirs, geopressurized reservoirs, and magma. Most of the known reservoirs for geothermal power in the United States are located west of the Mississippi River, and the highest-temperature geothermal resources occur for the most part west of the Rocky Mountains.

HYDROTHERMAL RESERVOIRS. Hydrothermal reservoirs are underground pools of hot water covered by a permeable formation through which steam escapes under pressure. Once at the surface, the steam is purified and piped directly to the electrical generating station. These systems are the cheapest and simplest form of geothermal energy. The Geysers thermal field, 90 miles (145 km) north of San Francisco, California, is the world's largest source of geothermal power. According to the Calpine Corporation (March 5, 2008, http://www.geysers.com/), which operates nineteen of the twenty-two power generating plants at the site, the Geysers generate enough electricity to satisfy the power needs of a city the size of San Francisco and provide nearly 60% of the electricity used in the region extending northward from the Golden Gate Bridge to the Oregon border. The remaining three facilities are operated by the Northern California Power Agency and the Western GeoPower Corporation.

DRY ROCK. These formations are the most common geothermal sources, especially in the West. However, reservoirs of this type are typically more than 6,000 feet (1,829 m) below the surface, which poses many difficulties. To tap them, water is injected into hot rock formations that have been fractured, and the resulting steam or water is collected. Hot dry rock technologies were developed and tested at the Fenton Hill plant, which operated between 1970 and 1996.

GEOPRESSURIZED RESERVOIRS. These sedimentary formations contain hot water and methane gas. Supplies of geopressurized energy remain uncertain, and drilling is expensive. Scientists are developing new technology to exploit the methane content in these reservoirs.

MAGMA. This molten or partially liquefied rock is found from 10,000 to 33,000 feet (3,048 to 10,058 m) below the earth's surface. Because magma is so hot, ranging from 1,650 to 2,200° Fahrenheit (899° to 1,204° C), it is a good geothermal resource. Extracting energy from magma is still in the experimental stages.

Domestic Production of Geothermal Energy

In 2007 geothermal energy produced 14.8 billion kWh of electricity, or 4% of the 351.3 billion kWh of electricity produced by renewable energy sources in the United States. (See Table 6.2.) According to the International Geothermal Association (IGA), in "Installed Generating Capacity" (July 29, 2008, http://iga.igg.cnr.it/geoworld/geoworld.php?sub=elgen), in 2005 the United States had 28% of the installed geothermal generating capacity of the world and the largest installed generating capacity of any single country. However, most of the easily exploited geothermal reserves in the United States have already been developed. Continued growth in the U.S. market depends on the regulatory environment, oil price trends, who pays for the new plants, and the success of new technologies to exploit previously inaccessible reserves.

International Production of Geothermal Energy

The IGA indicates in "Installed Generating Capacity" that 7974.1 megawatts (MW) of geothermal electrical generating capacity was present in twenty-one countries in 2000. By 2005 the worldwide geothermal electrical generating capacity was 9,064.1 MW distributed among twenty-four countries.

This output is considered only a small fraction of the overall potential: many countries are believed to have more than 100,000 MW of geothermal energy available. As with other fuel sources, however, world geothermal reserves are unevenly distributed. They occur mostly in seismically active areas at the margins or borders of the planet's nine tectonic plates. Areas rich in geothermal reserves include the west coasts of North and South America, Japan, the Philippines, and Indonesia.

Disadvantages of Geothermal Energy

Geothermal plants, which are not very efficient, must be built near a geothermal source, so they are not accessible to many consumers. They also produce unpleasant odors when sulfur is released during processing and generate considerable noise. Environmental concerns have been raised about potentially harmful pollutants, such as ammonia, arsenic, boron, hydrogen sulfide, and radon, which are often found in geothermal waters. Other concerns are the collapse of the land from which the water is being drained and water shortages from massive withdrawals.

Geothermal Heating/Cooling Systems

The term *geothermal* is also used with a particular type of home heating/cooling system but has a much different meaning than is used in this section on geothermal energy. Geothermal heating/cooling systems for individual residences or other types of buildings use the constant temperature of the earth (approximately 55° Fahrenheit [13° C]) to help heat interiors in the winter and cool them in the summer. Such systems circulate water or a water/antifreeze solution in pipes located at least a few feet beneath the surface of the ground. As the liquid circulates within the underground pipes it becomes warmed in the winter and cooled in the summer. This water is used in conjunction with a special type of heat pump called a ground source heat pump. Heat pumps are machines used in heating and cooling applications.

WIND ENERGY

Winds are created by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the planet. They are strongly influenced by bodies of water, weather patterns, vegetation, and other factors. When "harvested" by turbines, wind can be used to generate electricity.

Early windmills produced mechanical energy to pump water and grind grain in mills. By the late 1890s, Americans had begun experimenting with wind power to generate electricity. Their early efforts produced enough electricity to light one or two modern lightbulbs.

Beginning in the late twentieth century, industrial and developing countries alike started using wind power on a significant scale to complement existing power sources and to bring electricity to remote regions. Wind turbines cost less to install per unit of kilowatt capacity than either coal or nuclear facilities. After installing a windmill, there are few additional costs.

Compared to the pinwheel-shaped farm windmills that still dot the rural parts of the United States, the twenty-first century's state-of-the-art wind turbines look more like airplane propellers. Their sleek fiberglass design allows them to generate an abundance of mechanical energy, which can be converted to electricity.

The most favorable locations for wind turbines are in mountain passes and along coastlines, where wind speeds are generally highest and most consistent. Of all the places in the world, Europe has the greatest coastal wind resources. In *International Energy Outlook 2007* (May 2007, http://www.eia.doe.gov/oiaf/archive/ieo07/pdf/0484(2007).pdf), the EIA indicates that at the end of 2006, European Union countries accounted for 65% of the world's total installed wind capacity.

Domestic Energy Production by Wind Turbines

The U.S. wind energy industry began in California in 1981 with the installation of 144 relatively small turbines with a combined capacity of 7 MW. During 1998 and 1999 wind farm activity expanded into other states, motivated by financial incentives (such as tax credits for wind-energy production), regulatory incentives, and state mandates (in Iowa and Minnesota). In 1999 Iowa, Minnesota, and Texas added capacity exceeding 100 MW each. At the end of 2007, the total installed generating capacity of the United States was 16,596 MW, and wind power plants operated in thirty-four states. (See Figure 6.5.) Twelve states—Texas (4,296 MW), California (2,439 MW), Minnesota (1,258 MW), Washington (1,163 MW), Iowa (1,115 MW), Colorado (1,067 MW), Oregon (885 MW), Illinois (733 MW), Oklahoma (689 MW), New Mexico (496 MW), New York (425 MW), and Kansas (364 MW)—contained 90% of the U.S. wind energy capacity.

In *Annual Energy Outlook 2008* (June 2008, http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf), the EIA projects that wind power capacity in the United States will nearly quintuple from 0.6% of total generation in 2006 to 2.4% in 2030. The EIA qualifies its forecast, however, suggesting that this projection is uncertain due to a variety of factors, which include fossil fuel costs, programs for renewable energy sources, improvements in technology, access to transmission grids, environmental concerns, and the future of the federal Production Tax Credit (PTC) program for renewable energy sources. The PTC has lapsed in the past and often gets renewed for only short periods of time.

International Development of Wind Energy

According to the Global Wind Energy Council (GWEC), in *Global Wind: 2007 Report* (May 2008, http://www.gwec.net/fileadmin/documents/test2/gwec-08-update_FINAL.pdf), global wind-power installed capacity was 94,123 MW in 2007, up 31% from 2006. Wind power was being used in more than seventy countries in 2007. The five countries with the highest installed wind capacity at the end of 2007 were Germany (22,247 MW), the United States (16,818 MW), Spain (15,145 MW), India (7,845), and China (5,906 MW). The GWEC predicted that by 2009 the United States would hold the top spot for installed wind capacity worldwide.

Interest in wind energy has been driven, in part, by the declining cost of capturing wind energy. In "Wind Power Set to Become World's Leading Energy Source" (June 25, 2003, http://www.earth-policy.org/Updates/Update24_printable.htm), Lester R. Brown of the Earth Policy Institute explains that for new turbines at sites with strong winds, prices declined from more than $0.38 per kWh in the early 1980s to about $0.04 per kWh in 2003. Decreasing costs could make wind power competitive with gas and coal power plants, even before considering wind's environmental advantages.

Advantages and Disadvantages of Wind Energy

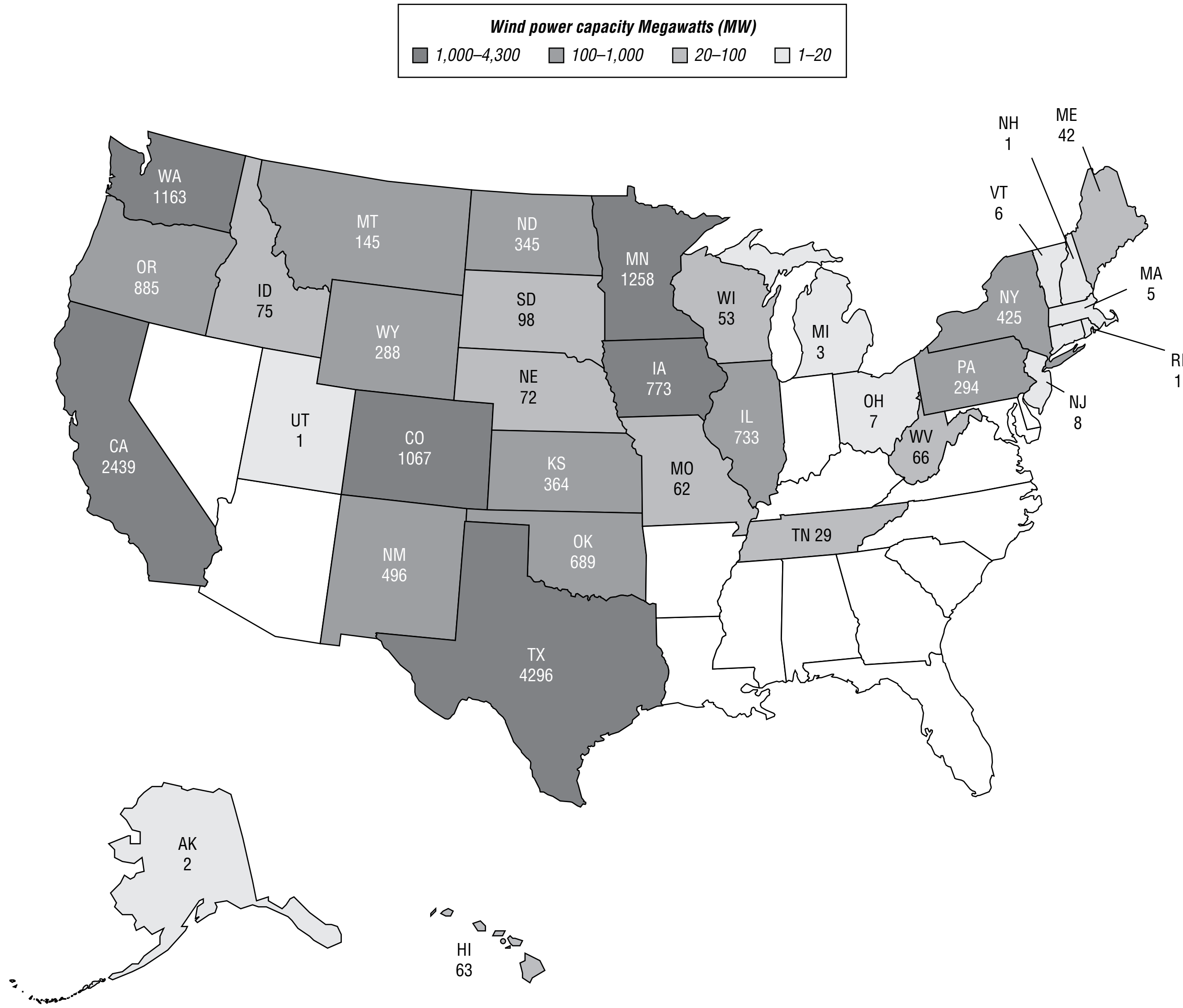
The main problem with wind energy is that the wind does not always blow. In addition, some people find the whirring noise of wind turbines annoying and object to clusters of wind turbines in mountain passes and along shorelines, where they interfere with scenic views. Environmentalists also point out that wind turbines are responsible for the loss of thousands of birds and bats that inadvertently fly into the blades. Birds frequently use windy passages in their travel patterns. However, wind farms do not emit climate-altering carbon dioxide and other pollutants, respiratory irritants, or radioactive waste. Furthermore, because wind farms do not require water to operate, they are especially well suited to semiarid and arid regions.

SOLAR ENERGY

Solar energy, which comes from the sun, is a renewable, widely available energy source that does not generate

FIGURE 6.5

Wind capacity map, 2007



Total: 16,596 megawatts (As of 12/31/07)

SOURCE: "2007 Year End Wind Power Capacity (MW)," in *Wind Powering America*, U.S. Department of Energy, Wind and Hydropower Technologies Program, January 28, 2008, http://www.eere.energy.gov/windandhydro/windpoweringamerica/images/windmaps/installed_capacity_2007.jpg (accessed July 3, 2008). Data from the American Wind Energy Association (AWEA) and Global Energy Concepts (GEC) database.

huge amounts of pollution or radioactive waste. Solar-powered cars have competed in long-distance races, and solar energy has been used for many years to power spacecraft. Even though many people consider solar energy a product of the space age, architectural researchers at the Massachusetts Institute of Technology built the first solar-heated house in 1939.

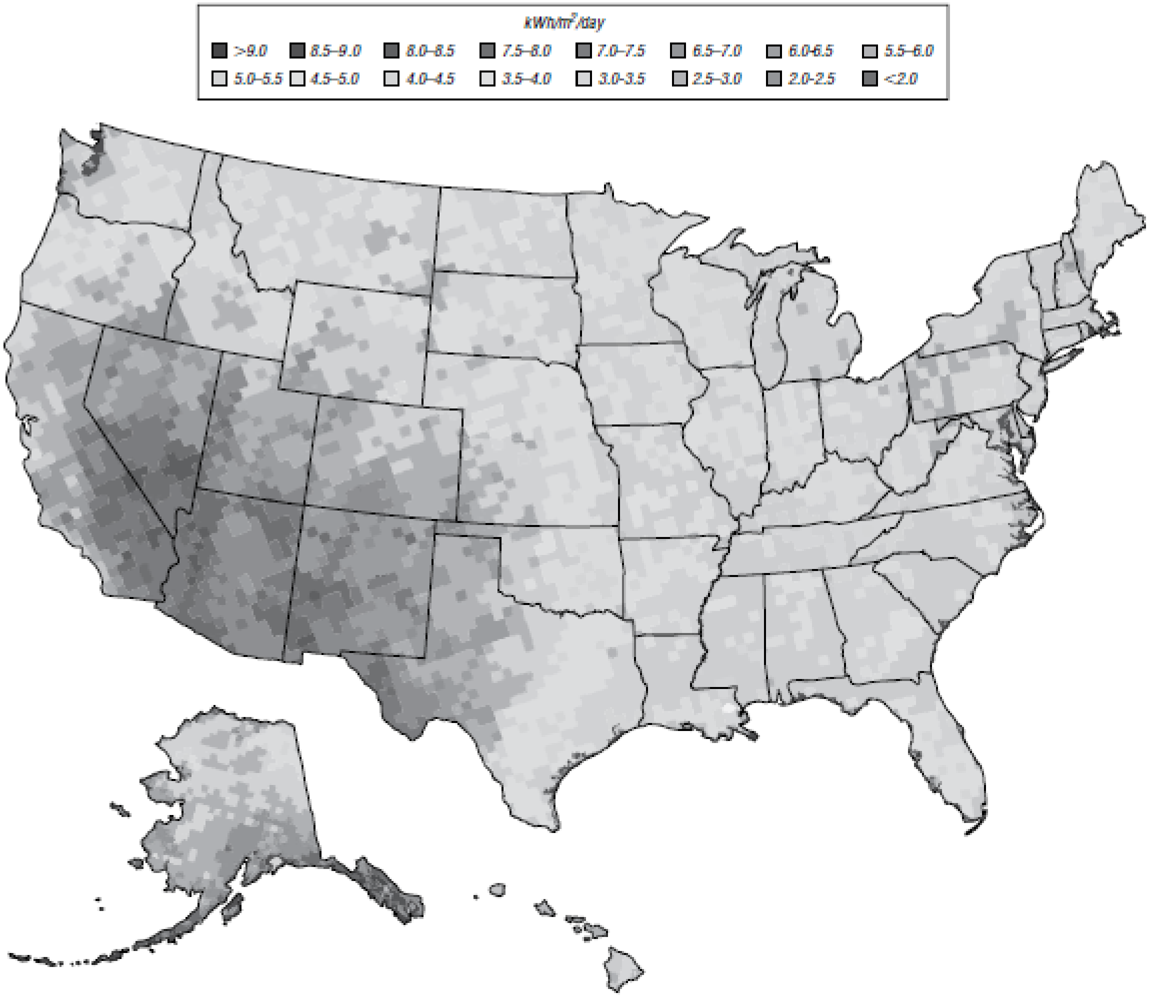
Solar radiation is nearly constant outside the Earth's atmosphere, but the amount of solar energy reaching any point on Earth varies with changing atmospheric conditions, such as clouds and dust, and the changing position of the earth relative to the sun. In the United States, exposure to the sun's rays is greatest in the Southwest, although almost all regions have some solar resources. Displaying nearly thirty years of averaged data, Figure 6.6 shows general trends in the amount of solar energy received in the United States.

Passive and Active Solar Systems

Passive solar energy systems, such as greenhouses or windows with a southern exposure, use heat flow, evaporation, or other natural processes to collect and transfer heat. (See Figure 6.7.) They are considered the least costly and least difficult solar systems to implement.

FIGURE 6.6

Solar resources



Note: Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to 40km resolution.

SOURCE: "Direct Normal Solar Radiation (Two-Axis Tracking Concentrator)," in *Dynamic Maps, GIS Data, & Analysis Tools: Solar Maps*, National Renewable Energy Laboratory, May 2004, http://www.nrel.gov/gis/images/us_csp_annual_may2004.jpg (accessed July 15, 2008)

Active solar systems require collectors and storage devices as well as motors, pumps, and valves to operate the systems that transfer heat. (See Figure 6.7.) Collectors consist of an absorbing plate that transfers the sun's heat to a working fluid (liquid or gas), a translucent cover plate that prevents the heat from radiating back into the atmosphere, and insulation on the back of the collector panel to further reduce heat loss. Excess solar energy is transferred to a storage facility so it may provide power on cloudy days.

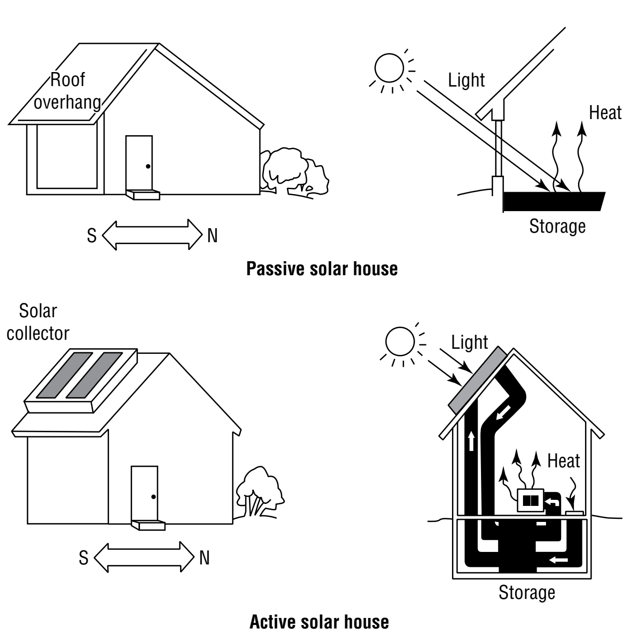
In both passive and active systems, the conversion of solar energy into a form of power is made at the site where it is used. The most common and least expensive active solar systems are used for heating water.

Solar Thermal Energy Systems

In a solar thermal energy system, mirrors or lenses constantly track the sun's position and focus its rays onto solar receivers that contain water or other fluids. The fluid is heated to more than 750° Fahrenheit (399° C);

FIGURE 6.7

Active vs. passive solar houses



SOURCE: U.S. Department of Energy

that heat is used to power an electric generator. In a distributed solar thermal system, the collected energy powers irrigation pumps, provides electricity for small communities, or captures normally wasted heat from the sun in industrial areas. In a central solar thermal system, the energy is collected at a central location and used by utility networks for many customers.

Other systems include solar ponds and trough systems. Solar ponds are pools filled with water and salt. Because saltwater is denser than freshwater, the saltwater on the bottom absorbs the heat, which is trapped by the freshwater on top. Trough systems use U-shaped mirrors to concentrate the sunshine on water or on oil-filled tubes.

Photovoltaic Conversion Systems

The photovoltaic cell system converts sunlight directly into electricity without the use of mechanical generators. Photovoltaic cells have no moving parts, are easy to install, require little maintenance, and can last up to twenty years. The cells are commonly used to power small devices, such as watches or calculators. On a larger scale they provide electricity for rural households, recreational vehicles, and businesses. Solar panels using photovoltaic cells have generated electricity for space stations and satellites for many years.

The cells produce the most power around noon, when sunlight is the most intense. They are usually connected to storage batteries that provide electricity during cloudy days and at night. A backup energy supply is usually required.

The use of photovoltaic cells is expanding around the world. Because they contain no turbines or other moving parts, operating costs are low and maintenance is minimal. Above all, the fuel source (sunshine) is free and plentiful. The main disadvantage of photovoltaic cell systems is the high initial cost, although prices have fallen considerably. Even though toxic materials are often used in the construction of the cells, researchers are investigating new materials, recycling, and disposal.

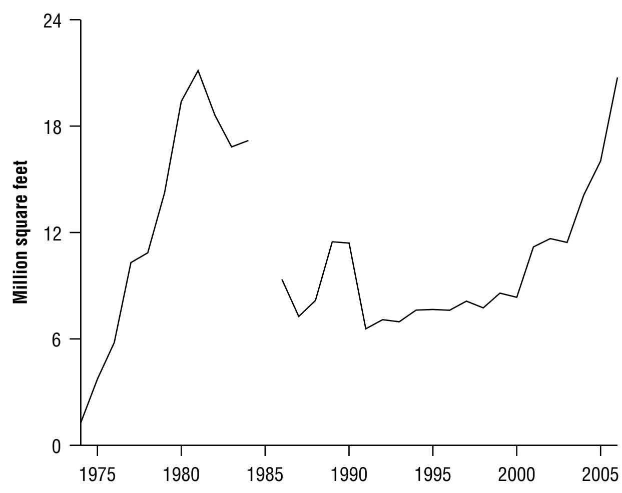
Solar Energy Usage

The use of solar energy is difficult to measure because it is rarely connected to any kind of metered grid. However, shipments of solar equipment can be used as an indicator of use. The EIA notes in *Annual Energy Review 2007* that the total shipments of solar thermal collectors peaked in 1981 at 21.1 million square feet (2 million sq m), fell to 6.6 million square feet (613,000 sq m) in 1991, and rose again to 11.6 million square feet (1.1 million sq m) in 2002. By 2006 the total shipments of solar thermal collectors had almost doubled to 20.7 million square feet (1.9 sq m). (See Figure 6.8.)

In 2006 most solar thermal collectors were sold for residential purposes in Sunbelt states, usually to heat water

FIGURE 6.8

Solar thermal collector shipments, 1974–84 and 1986–2006

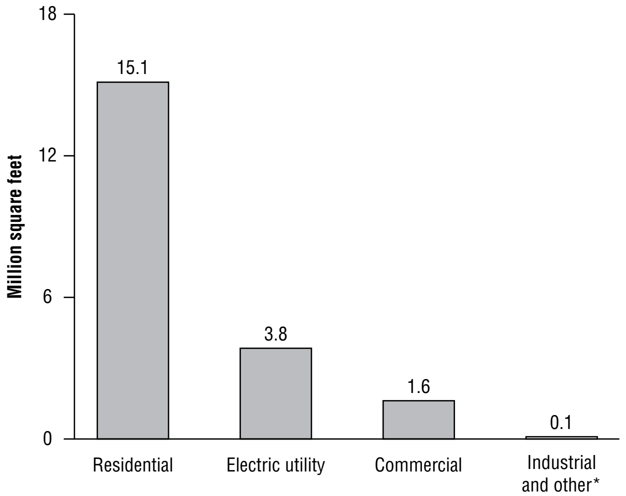


Notes: Shipments are for domestic and export shipments, and may include imports that subsequently were shipped to domestic or foreign customers. Data were not collected for 1985.

SOURCE: Adapted from "Figure 10.5. Solar Thermal Collector Shipments by Type, Price, and Trade: Total Shipments, 1974–1984 and 1986–2006," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

FIGURE 6.9

Solar thermal collector shipments, by market sector, 2006

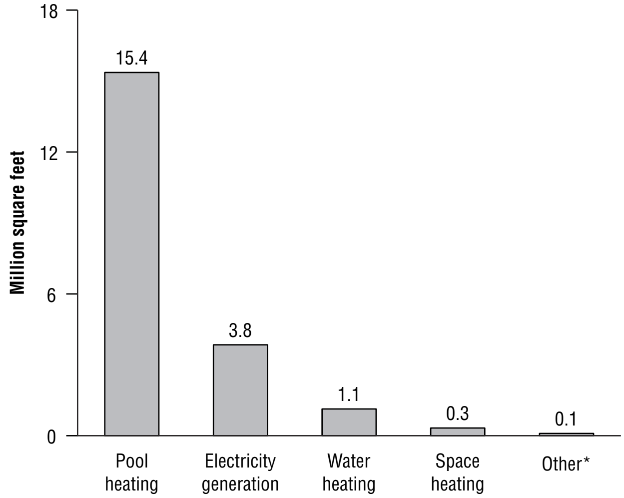


*Other sectors, such as government, including the military but excluding space applications.
Notes: Data are for domestic and export shipments, and may include imports that subsequently were shipped to domestic or foreign customers.

SOURCE: Adapted from "Figure 10.6. Solar Thermal Collector Shipments by End Use, Market Sector, and Type, 2006: Market Sector," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

FIGURE 6.10

Solar thermal collector shipments, by end use, 2006



*Combined space and water heating, and space cooling.
Note: Data are for domestic and export shipments, and may include imports that subsequently were shipped to domestic or foreign customers.

SOURCE: Adapted from "Figure 10.6. Solar Thermal Collector Shipments by End Use, Market Sector, and Type, 2006: End Use," in *Annual Energy Review 2007*, U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use, June 2008, http://www.eia.doe.gov/aer/pdf/aer.pdf (accessed June 28, 2008)

for swimming pools. (See Figure 6.9 and Figure 6.10.) The market for solar energy space heating has virtually disappeared. Only a small proportion of solar thermal collectors are used for commercial purposes, although some state and municipal power companies have solar energy systems they can use for additional power during peak hours.

Solar Power as an International Rural Solution

Getting electricity to rural areas has always been more expensive than serving cities. In the United States most farmers did not receive electrical power until 1935, when the Rural Electrification Administration provided low-cost financing to rural electric cooperatives. In places such as western China, the Himalayan foothills, and the Amazon basin today, the cost of connecting new rural customers to electricity grids remains high.

Even though rural families may not have access to electrical grid systems, they do have sunlight: in most tropical countries, considerable sunlight falls on rooftops. Photovoltaic cells can be installed on them to run water pumps, lights, refrigerators, and communications equipment. Electricity produced by photovoltaic cells was initially extremely expensive, but prices have continually fallen, making solar energy a competitive choice in some areas.

Advantages and Disadvantages of Solar Energy

The primary advantage of solar energy is its inexhaustible supply. It is especially useful in rural or remote areas that cannot be easily connected to an electrical power grid. Michael Kanellos notes in "Shrinking the Cost for Solar Power" (CNET News, May 11, 2007) that even though solar power still costs two to three times as much as fossil fuel energy, utilities often turn to solar energy to provide peaking power on extremely hot or cold days. Building solar energy systems to provide peak power capacity is often cheaper than building the backup diesel generators that are often used.

Solar power's primary disadvantage is its reliance on a consistently sunny climate, which is possible in limited geographical areas. It also requires a large amount of land for the most efficient collection of solar energy by electricity plants.

POWER FROM THE OCEAN

Oceans are not as easily controlled as rivers or water directed through canals into turbines, so unlocking their potential power is far more challenging. Three ideas undergoing experimentation are tidal power, wave energy, and ocean thermal energy conversion.

Tidal Power

Tidal power plants use the movement of water as it ebbs and flows to generate power. A minimum tidal range of 9 to 15 feet (2.7 to 4.6 m) is generally considered necessary for an economically feasible plant. (The tidal range is the difference in height between consecutive high and low tides.)

The largest tidal facility in the world is the 240-MW plant at the La Rance estuary in northern France. Canada built a smaller 40-MW unit at the Bay of Fundy, which has a 45-foot (13.7-m) tidal range, the largest in the world. The Bay of Fundy is located northeast of Maine and is bordered by the Canadian provinces of New Brunswick and Nova Scotia. The Annapolis Tidal Generating Station is on the Nova Scotia side of the bay. The article "Tidal Power to be Studied in Canadian Waters off Maine" (Associated Press, May 27, 2008) notes that in May 2008 New Brunswick granted permission for a two-year feasibility study of eleven potential sites for another tidal power generating station on the bay.

Just months before this announcement, the British government announced the results of a two-year feasibility study on developing a tidal power facility in the Bristol Channel, which divides southwestern England from South Wales. This channel has a 42-foot (12.8-m) tidal range, second only to the Bay of Fundy. However, Erica Gies reports in "U.K. Debates a Barrier on the Severn" (*International Herald Tribune*, February 18, 2008) that the channel is home to an ecologically important estuary, making a tidal power facility at that location highly controversial. The world's first offshore tidal turbine, which is located in the ocean about 1 mile (1.6 km) from Devon, England, began producing energy in 2003.

Wave Energy

One type of wave power plant is the oscillating water column; the first significant examples were built at Toftestallen, on Norway's Atlantic coast, in 1985. In this system, the arrival of a wave forces water up a hollow 65-foot (19.8-m) tower, displacing the air in the tower. The air rushes out the top through a turbine, whose rotors spin, generating electricity. When the wave falls back and the water level falls, air is sucked back in through the turbine, again generating electricity. The Toftestallen plant was destroyed during a winter storm in 1988. Similar systems have been tested in China, India, Japan, Portugal, and Scotland.

A second type of wave power plant uses the overflow of high ocean waves. As the waves splash against the top of a dam, some of the water goes over and is trapped in a reservoir on the other side. The water is then directed through a turbine as it flows back to the sea.

A third and most recent type of significant wave power technology is the Pelamis wave energy converter, developed by a Scottish company. According to the article "Orkney to Get 'Biggest' Wave Farm" (BBC News, February 20, 2007), after successful testing at the European Marine Energy Centre in the Orkney Islands north of the Scottish mainland beginning in 2004, the Scottish government announced financial support for adding wave energy converters to the site as well as testing of other wave power technologies there. Each wave energy converter consists of three cylindrical sections that are hinged together and float semi-submerged. As the waves bounce the sections up and down, the movement of the hinges drives generators that produce electricity. Pelamis Wave Power (2008, http://www.pelamiswave.com/content.php?id=149) notes, however, that Portugal developed the first wave farm using Pelamis wave energy converters in 2006.

Ocean Thermal Energy Conversion

Ocean thermal energy conversion uses the temperature difference between warm surface water and the cooler water in the ocean's depths to power a heat engine to produce electricity. The heat engine is placed between the higher temperature water and the lower temperature water. The water flows naturally from an area of higher temperature to an area of lower temperature. As this occurs, the engine captures some of the heat and uses this energy to produce electricity. Ocean thermal energy conversion systems can be installed on ships, barges, or offshore platforms with underwater cables that transmit electricity to shore.

HYDROGEN: A FUEL OF THE FUTURE?

Hydrogen, the lightest and most abundant chemical element, is the ideal fuel from an environmental point of view. Its combustion produces only water vapor, and it is entirely carbon free. Three-quarters of the mass of the universe is hydrogen, so in theory the supply is ample. However, the combustible form of hydrogen is a gas and is not found in nature. It must be made from other energy sources, such as fossil fuels. Hydrogen can be split from water, but the processes are either quite costly, require a great deal of energy, or both. Matthew W. Kanan and Daniel G. Nocera of the Massachusetts Institute of Technology report in "In Situ Formation of an Oxygen-Evolving Catalyst in Neutral Water Containing Phosphate and Co^{2+}" (*Science*, vol. 321, no. 5892, August 22, 2008) a new process for splitting water. This technique appears to be a breakthrough in water-splitting technologies, but the process is not yet ready to be used in commercial applications.

In hydrogen fuel cells, oxygen and hydrogen react to produce water and electricity. Alternatively, hydrogen can be burned in an engine, much like gasoline. BMW introduced its hydrogen-powered luxury vehicle the Hydrogen 7 in 2006. It burns either gasoline or hydrogen as fuel. The Hydrogen 7 was produced in limited quantities and will be used only by selected individuals worldwide.

Research into the use of hydrogen as a fuel got a boost when President Bush announced a hydrogen fuel initiative in his 2003 State of the Union Address. The

Department of Energy's Hydrogen Program (2008, http://www.hydrogen.energy.gov/budget.html) states that Congress appropriated $156.5 million for hydrogen and fuel cell research and development in fiscal year (FY) 2004; $221.7 million in FY 2005; $232.5 million in FY 2006; $269.2 million in FY 2007, and $283.5 in FY 2008. The budgetary request for FY 2009 was $267.5 million. Goals of the initiative include reducing the cost of hydrogen fuel to make it comparable to gasoline, resolving issues for safe in-vehicle storage of reserve fuel, and lowering the cost of hydrogen power systems to compete with internal combustion engines. In "President's Hydrogen Fuel Initiative: A Clean and Secure Energy Future" (2008, http://www.hydrogen.energy.gov/presidents_initiative.html), the Hydrogen Projects estimates that hydrogen fuel cell vehicles could reduce the U.S. demand for oil by about 11 million barrels per day—the amount the United States now imports—by 2040.

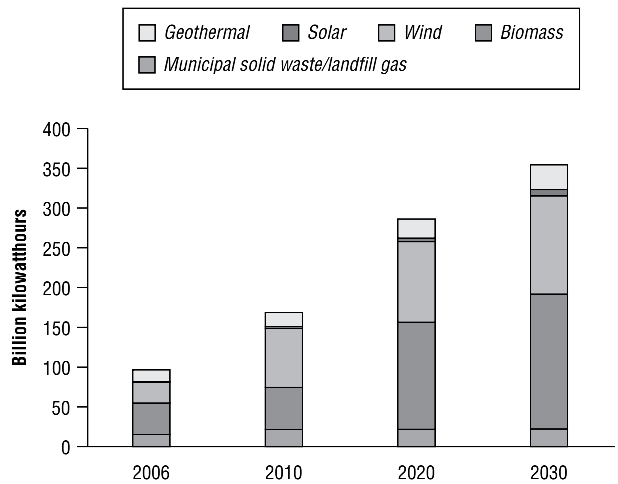
FUTURE TRENDS IN U.S. RENEWABLE ENERGY USE

In *Annual Energy Outlook 2008*, the EIA forecasts that total renewable fuel consumption, including ethanol for transportation, biodiesel, and diesel from biomass, will increase from 6.8 quadrillion Btu in 2006 to 13.7 quadrillion Btu in 2030. About 45% of the projected demand would be for electricity generation. Renewable fuel is expected to remain a small contributor to overall electricity generation through 2030.

The EIA notes that hydropower is expected to remain the largest single source of renewable electricity generation through 2030, but its share of total generation will fall from 7.1% in 2006 to 5.8% in 2030. The production of other renewables should increase steadily. (See Figure 6.3.) The largest source of renewable generation after hydropower was biomass in 2006, but wind is expected to overtake the second spot by 2010, and then biomass will retake its second position in 2020 and 2030. (See Figure 6.11.) The EIA projects that wind power will increase from 0.6% of total generation in 2006 to 2.4% in 2030 and that biomass will increase from 1% of total generation in 2006 to 3.2% in 2030.

FIGURE 6.11

Nonhydroelectric renewable electricity generation by energy source, selected years 2006–30



SOURCE: "Figure 66. Nonhydroelectric Renewable Electricity Generation by Energy Source, 2006–2030 (Billion Kilowatthours)," in *Annual Energy Outlook 2008*, U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, June 2008, http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf (accessed July 2, 2008)

Energy production from municipal solid waste and landfill gas is expected to stay static from 2004 to 2030, remaining at 0.5% of total generation. Geothermal energy production will grow slightly from 0.4% of the total generation in 2006 to 0.6% of the total in 2030. Solar energy is not expected to contribute much to the total of centrally generated electricity.