Energy Resources—Alternative Sources

Nuclear Power—Fission

Fission—Basic Principles

The phrase *nuclear power* actually comprises two different types of processes with different advantages and limitations.

Fission is the splitting apart of atomic nuclei into smaller ones, with the release of energy. **Fusion** is the combining of smaller nuclei into larger ones, also releasing energy. Currently, only one of these processes is commercially feasible: fission. Fission basics are outlined in figure 15.3. Very few isotopes—some 20 out of more than 250 naturally occurring isotopes—can undergo fission spontaneously, and do so in nature. Some additional nuclei can be induced to split apart, and some naturally fissionable nuclei can be made to split up more rapidly, thus increasing the rate of energy release. The fissionable nucleus of most interest in modern nuclear power reactors is the isotope of uranium-235 with 92 protons and 143 neutrons.

A uranium-235 nucleus can be induced to undergo fission by firing another neutron into the nucleus. The nucleus splits into two lighter nuclei (not always the same two) and releases additional neutrons as well as energy. Some of the newly released neutrons can induce fission in other nearby uranium-235 nuclei, which, in turn, release more neutrons and more energy in breaking up, and so the process continues in a **chain reaction .** A controlled chain reaction, with a continuous, moderate release of energy, is the basis for fission-powered reactors (figure 15.4). The energy released heats cooling water that circulates through the reactor's core. The heat removed from the core is transferred through a heat exchanger to a second water loop in which steam is produced. The steam, in turn, is used to run turbines to produce electricity.

This scheme is somewhat complicated by the fact that a chain reaction is not sustained by ordinary uranium. Only 0.7% of natural uranium is uranium-235. The material must be processed to increase the concentration of this isotope to several percent of the total to produce reactor-grade uranium. As the reactor operates, the uranium-235 atoms are split and destroyed so that, in time, the fuel is so depleted in this isotope that it must be replaced with fresh fuel enriched in uranium-235.

The Geology of Uranium Deposits

Worldwide, 95% of known uranium reserves are found in sedimentary or metasedimentary rocks. In the United States, the great majority of deposits are found in sandstone. They were formed by weathering of uranium source rocks, followed by

uranium migration in and deposition by ground water. Minor amounts of uranium are present in many crustal rocks. Granitic rocks and carbonates may be particularly rich in uranium (meaning that its concentration in these may be in the range of ppm to tens of ppm; in most rocks, it is even lower). In granites, the uranium is concentrated in the late stages of magma crystallization m. Uranium is concentrated in carbonate rocks during precipitation of the carbonates from water, including seawater. As uranium-bearing rocks weather under near-surface conditions, that uranium goes into solution: uranium
is particularly soluble in an oxygen-rich environment. The uranium-bearing solutions then infiltrate and join the groundwater system. As they percolate through permeable rocks, such as sandstone, they may encounter chemically reducing conditions, created by some factor such as an abundance of carbon-rich organic matter, or sulfide minerals, in shales bounding the sandstone.
Under reducing conditions, the solubility of uranium is much lower. The dissolved uranium is then precipitated and concentrated in these reducing zones. Over time, as great quantities of uranium-bearing ground water percolate slowly through such
a zone, a large deposit of precipitated uranium ore may form.

Concerns Related to Nuclear Reactor Safety
A major concern regarding the use of fission power is reactor safety. In normal operation, nuclear power plants release very minor amounts of radiation, which are believed to be harmless. The small but finite risk of damage to nuclear reactors through accident or sabotage is more worrisome to many.
One of the most serious possibilities is a so-called loss of-coolant event, in which the flow of cooling water to the reactor core would be interrupted. Resultant overheating of the core might lead to **core meltdown ,** in which the fuel and core materials
would deteriorate into a molten mass that might or might not melt its way out of the containment building and thus release high levels of radiation into the environment, depending upon the design of the reactor and containment building. A partial loss of coolant, with 35 to 45% meltdown, occurred at Three Mile Island in 1979 (figure 15.6).
No matter how far awry the operation of a commercial power plant might go, and even if there were a complete loss of coolant, the reactor could *not* explode like an atomic bomb. Bomb-grade fuels must be much more highly enriched in the fissionable isotope uranium-235 for the reaction to be that intensive and rapid. Also, the newest reactors have additional safety features designed to reduce the risk of accident. However, an ordinary explosion originating within the reactor (or by saboteurs' use of

conventional explosives) could, if large enough, rupture both the containment building and reactor core, and thus release large amounts of radioactive
material. The serious accident at Chernobyl reinforced reservations about reactor safety in many people's minds.
Plant siting is another problem. Siting nuclear plants close to urban areas puts more people potentially at risk in case of accident; placing the plants far from population centers where energy is needed means more transmission loss of electricity (which already claims nearly 10% of electricity generated).
Proximity to water is often important for cooling purposes but makes water pollution in case of mishap more likely. There are also concerns about the structural integrity of nuclear plants located close to fault zones—the Diablo Canyon station in California, the Humboldt Bay nuclear plant, and others; several proposed reactor sites have been rejected when investigation revealed nearby faults.

Concerns Related to Fuel and Waste Handling

The mining and processing of uranium ore are operations that affect relatively few places in the United States (fi gure 15.7). Nevertheless, they pose hazards because of uranium's natural radioactivity. Miners exposed to the higher radiation levels in
uranium mines have experienced higher occurrence rates of some types of cancer. Carelessly handled tailings from processing plants have exposed others to radiation hazards; the case of Grand Junction, Colorado, where radioactive tailings were unknowingly mixed into concrete used in construction. The use of reprocessing or breeder reactors to produce and recover plutonium to extend the supply of fissionable fuel poses special problems. Plutonium itself is both radioactive and chemically toxic. Of greater concern to many people is that, as a readily fissionable material, it can also be used to make nuclear weapons. Extensive handling, transport, and use of plutonium would pose a significant security problem and would therefore require very tight control to prevent the material from falling into hostile hands.

The radioactive wastes from the production of fission power are another concern. Here, two aspects of the problem are highlighted. First, radioactive materials cannot be treated by chemical reaction, heating, and so on to make them nonradioactive. In this respect, they differ from many toxic chemical wastes that can be broken down by appropriate treatment.
Second, there has been sufficient indecision about the best method of radioactive-waste disposal and the appropriate site(s) for it that none of

the radioactive wastes generated anywhere in the world have been disposed of permanently to date.
Currently, the wastes are in temporary storage while various disposal methods are being explored, and many of the temporary waste-holding sites are filled almost to capacity. Clearly acceptable waste-disposal methods must be identified and adopted,
if only to dispose of wastes already accumulated.
Nuclear plants have another unique waste problem. The bombardment of the reactor core and structure by neutrons and other atomic debris from the fission process converts some of the structural materials to radioactive ones and changes the physical properties of others, weakening the structure. At some point, then, the plant must be **decommissioned** — taken out of operation, broken down, and the most radioactive parts delivered to radioactive-waste disposal sites.
In late 1982, an electricity-generating plant at Shippingport, Pennsylvania, became the first commercial U.S. fission power plant to face decommissioning, after twenty-five years of operation. Costs of demolition and disposal have exceeded $800 million for a single power plant in the United States, and the process may take a decade or more. Dozens of reactors are being, or have been, decommissioned worldwide. A total of 28 U.S. reactors, including Shippingport, had been retired by the close of 2008. Historically, the nominal lifetime allowed by regulatory agencies was about 30 years; currently, it is about 40 years; with rigorous plant monitoring and replacement of some key components, it may be possible to operate a fission-powered electricity-generating plant for 70 years.

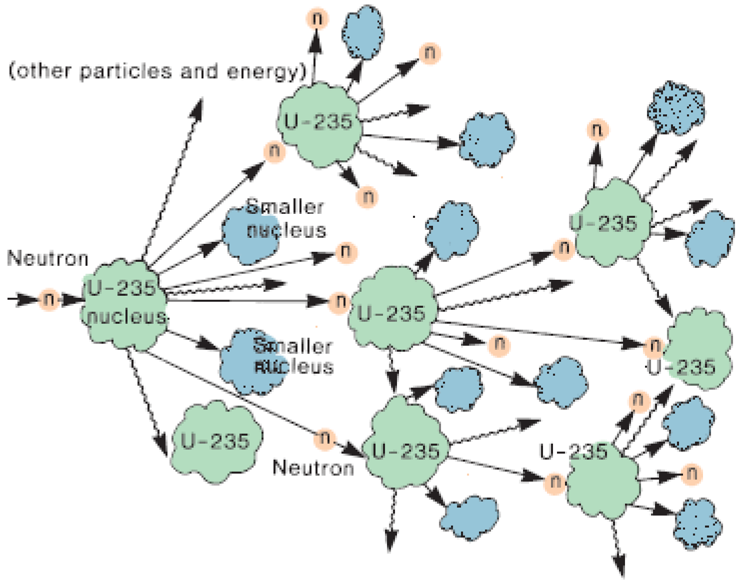


Figure 15.3

Nuclear fission and chain reaction involving uranium-235 (schematic). Neutron capture by uranium-235 causes fission into two smaller nuclei plus additional neutrons, other subatomic particles, and energy. Released neutrons, in turn, cause fission in other uranium-235 nuclei. As U-235 nuclei are used up, reaction rate slows; eventually fresh fuel must replace "spent" fuel.

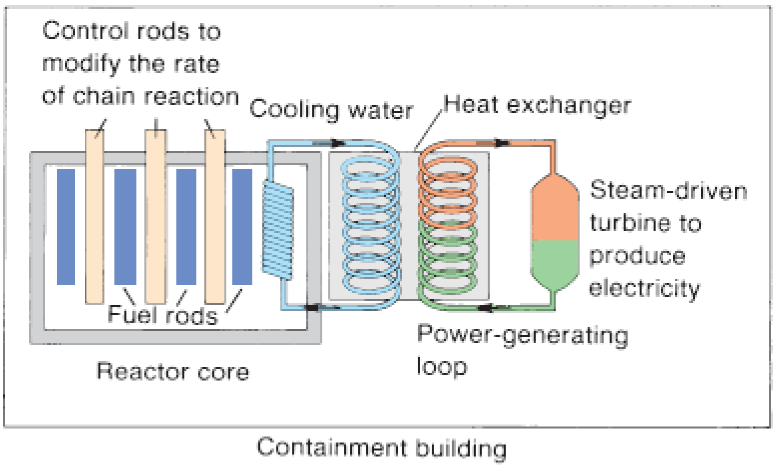


Figure 15.4

Schematic diagram of conventional nuclear fission reactor. Heat is generated by chain reaction; withdrawing or inserting control rods between fuel elements varies rate of reaction, and thus rate of release of heat energy. Cooling water also serves to extract heat for use. Heat is transferred to power loop via heat exchanger, so the cooling water, which may contain radioactive contaminants, is isolated from the power-generating equipment.

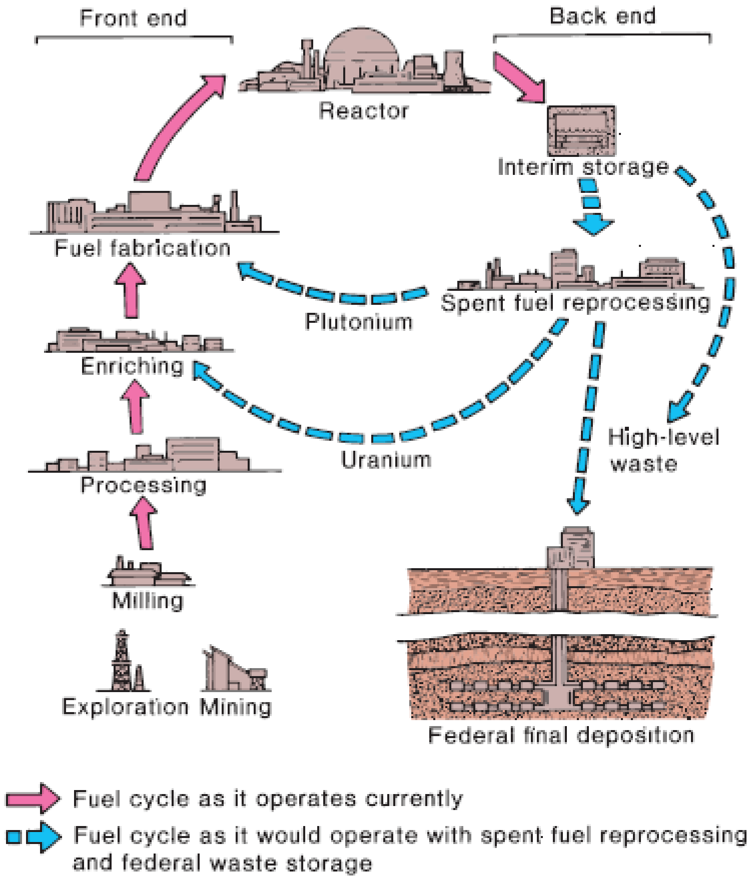


Figure 15.5

The nuclear fuel cycle, as it currently operates and as it would function with fuel reprocessing.

Figure 15.6

Three Mile Island near Harrisburg, Pennsylvania; damaged reactor remains shut down, while others are still operative.

Solar Energy

The earth intercepts only a small fraction of the energy radiated by the sun. Much of that energy is reflected in the atmosphere. Even so, the total solar energy reaching the earth's surface far exceeds the energy needs of the world at present and for the future. The sun can be expected to go on shining for approximately 5 billion years—in other words, the resource is inexhaustible, which contrasts with nonrenewable sources like uranium or fossil fuels. Sunlight falls on the earth without any mining, drilling, pumping, or disruption of the land. Sunshine is free; it is not under the control of any company or cartel, and it is not subject to embargo or other political disruption of supply. The *use* of solar energy is essentially pollution-free, at least in the sense that the absorption of sunlight for heat or the operation of a solar cell for electricity are very "clean" processes. It produces no hazardous solid wastes, air or water pollution, or noise. For most current applications, solar energy is used where it falls, thereby avoiding transmission losses. All these features make solar energy an attractive option for the future. Several practical limitations on its use also exist, however, particularly in the short term.

The solar energy reaching the earth is dissipated in various ways. Some is reflected into space; some heats the atmosphere, land, and oceans, driving ocean currents and winds. The sun supplies the energy needed to cause evaporation and thus to keep the hydrologic cycle going; it allows green plants to generate food by photosynthesis. More than ample energy is still left over to provide for all human energy needs, in principle. However, the energy is distributed over the whole surface of the earth. In other words, it is a very dispersed resource: Where large quantities of solar energy are used, solar energy collectors must cover a wide area. Sunlight is also variable in intensity, both from region to region (figure 15.12) and from day to day as weather conditions change. The two areas in which solar energy can make the greatest immediate contribution are in space heating and in the generation of electricity, uses that together account for about two-thirds of U.S. energy consumption.

Solar Heating

Solar space heating typically combines direct use of sunlight for warmth with some provision for collecting and storing additional heat to draw on when the sun is not shining. It is typically employed on the scale of an individual building.

The simplest approach is *passive-solar heating*, which does not require mechanical assistance. The building design should allow the maximum amount of light to stream in through south and west windows during the cooler months. This heats the materials inside the house, including the structure itself, and the radiating heat warms indoor air. Media used specifically for storing heat include water—in barrels, tanks, even indoor swimming pools—and the rock, brick, concrete, or other dense solids used in the building's construction (figure 15.13 A). Thermal mass that radiates heat back when needed, in times of less (or no) sunshine. Additional common features of passive solar design (figure 15.13B) include broad eaves to block sunshine during hotter months (feasible because the sun is higher in the sky during summer than during winter) and drapes or shutters to help insulate window areas during long winter nights.

Active-solar heating systems usually involve the mechanical circulation of solar-heated water (figure 15.13C). The flat solar collectors are water-filled, shallow boxes with a glass surface to admit sunlight and a dark lining to absorb sunlight and help heat the water. The warmed water is circulated either directly into a storage tank or into a heat exchanger through which a tank of water is heated. The solar-heated water can provide both space heat and a hot-water supply. If a building already uses conventional hot-water heat, incorporating solar collectors is not necessarily extremely expensive (especially considering the free "fuel" to be used). With the solar collectors mounted on the roof, an active-solar system does not require the commitment of any additional land to the heating system—another positive feature. The method can be as practical for urban row houses or office buildings as for widely
spaced country homes. While solar heating may be adequate by itself in mild, sunny climates, in areas subject to prolonged spells of cloudiness or extreme cold, a conventional backup heating system is almost always needed. In the latter areas, then, solar energy can greatly reduce but not wholly eliminate the need for some consumption of conventional fuels. It has been estimated that, in the United States, 40 to 90% of most homes' heating requirements could be supplied by passive-solar heating systems, depending on location. It is usually more economical to design and build passive-solar technology features into a new structure initially than to incorporate them into an existing building later.

Solar Electricity

Direct production of electricity using sunlight is through **photovoltaic cells ,** also called simply "solar cells" (figure 15.14). In simplest form, they consist of two layers of semiconductor material sandwiched together, with a barrier between that allows electrons to flow predominantly in one direction only. Sunlight striking the exposed side can dislodge some electrons, which flow as electric current through a circuit, to return to the cell and continue the cycle. Solar cells have no moving parts and, like solar heating systems, do not emit pollutants during operation. For many years, they have been the principal power source for satellites and for remote areas difficult to reach with power lines (figure 15.15). A major limitation on solar-cell use has historically been cost, which is several times higher per unit of power-generating capacity than for either fossil-fuel or nuclear-powered generating plants. This has restricted the appeal of home-generated solar electricity. The high cost is partly a matter of technology (present solar cells are not very efficient, though they are being improved) and partly one of scale (the industry is not large enough to enjoy the economies of mass production).

Currently, low solar-cell efficiency and the diffuse character of sunlight continue to make photovoltaic conversion an inadequate option for energy-intensive applications, such as many industrial and manufacturing operations. Even in the areas of strongest sunlight in the United States, incident radiation is of the order of 250 watts per square meter. Operating with commercial solar cells of about 20% efficiency means power generation of only 50 watts per square meter. In other words, to keep one 100-watt light bulb burning would require at least 2 square meters of collectors (with the sun always shining). A 100- megawatt power plant would require 2 square kilometers of collectors and many nuclear or coal-fired generating plants have more than ten times that capacity. Using solar cells at that scale represents a large commitment of both land and the mineral resources from which the collectors are made.

Storing solar electricity is also a more complex matter than storing heat. For individual homeowners, batteries may suffice, but no wholly practical scheme for large-scale storage has been devised, despite advances in battery technology. Some
of the proposals are shown in figure 15.17.

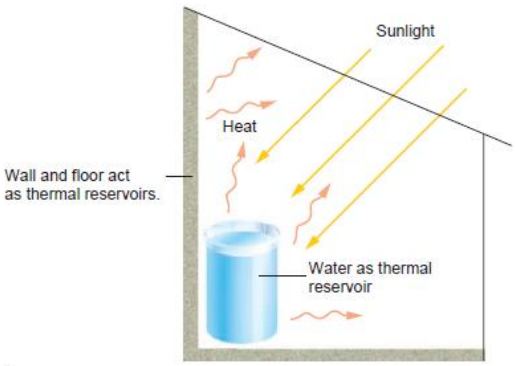
For the time being, it appears that solar-generated electricity could eventually supply perhaps 10 to 15% of U.S. electricity needs, but currently, it accounts for less than half a percent. Major improvements in efficiency of generation and in storage technology are needed before the sun can be the principal source of electricity, resource and land-use issues aside. It may be still longer before solar electricity can contribute to the transportation energy budget.

Potential Environmental impacts to solar electricity:

Using solar cells at that scale represents a large commitment of both land and the mineral resources from which the collectors are made. For the collector array alone, a 100-megawatt solar electric plant operating with basic solar cells would use at least an
estimated 30,000 to 40,000 tons of steel, 5000 tons of glass, and 200,000 tons of concrete. A nuclear plant, by contrast, would require about 5000 tons of steel and 50,000 tons of concrete; a coal-fired plant, still less. The solar cells present additional resource issues as their use is scaled up.

There are various photovoltaic technologies, but some of the most efficient use materials such as gallium, arsenic, selenium, indium, and tellurium. Most of these are potentially toxic, presenting health hazards in both the mining and manufacturing
processes. The United States is essentially 100% dependent on imports for arsenic, gallium, and indium. As demand has increased, prices of some of these elements have risen spectacularly. Siting a sizable array requires a substantial commitment and disturbance of land. Its presence

could alter patterns of evaporation and surface runoff. These considerations could be especially critical in desert areas, which are the most favorable sites for such facilities from the standpoint of intensity and constancy
of incident sunlight. Construction could also disturb desert-pavement surfaces and accelerate erosion.



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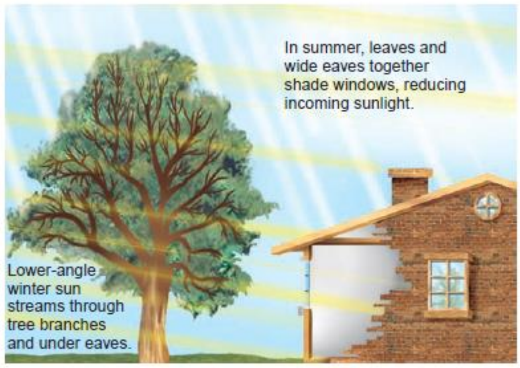

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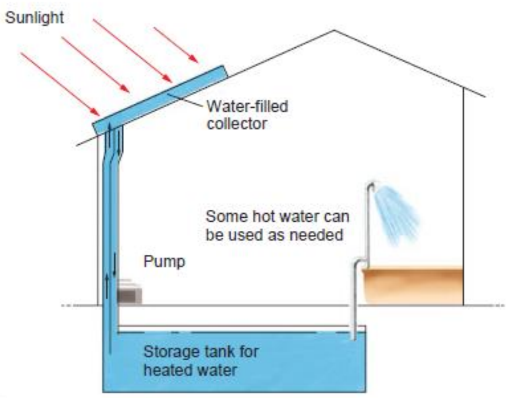

C

Figure 15.13

(A) Basics of passive-solar heating with water or structural materials as thermal reservoir: Sunlight streams into greenhouse with glass roof and walls, heat is stored for nights and cloudy days. (B) Design features of home and landscaping can optimize use of sun in colder weather, provide protection from it in summer. (C) A common type of active-solar heating system with a pump to circulate the water between the collector and the heat exchanger/storage tank.

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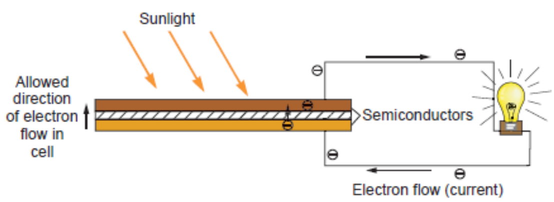

Figure 15.14

In a photovoltaic cell, incident sunlight dislodges electrons in top layer, which flow through wire as electric current, to return to the other side of the cell. Accumulated electrons move back to upper layer of cell and the cycle continues.

Figure 15.15

Solar electricity is very useful in remote areas. High in the mountains of Denali National Park, at the base camp that is the takeoff point for expeditions to climb Denali (Mount McKinley), solar cells (right) power vital communications equipment.

Figure 15.16

To make solar electricity without photovoltaic cells, solar heat can be used to make steam to power turbines, but it must first be concentrated, as here in the California desert, where parabolic mirrors focus sunlight on tubes of water.

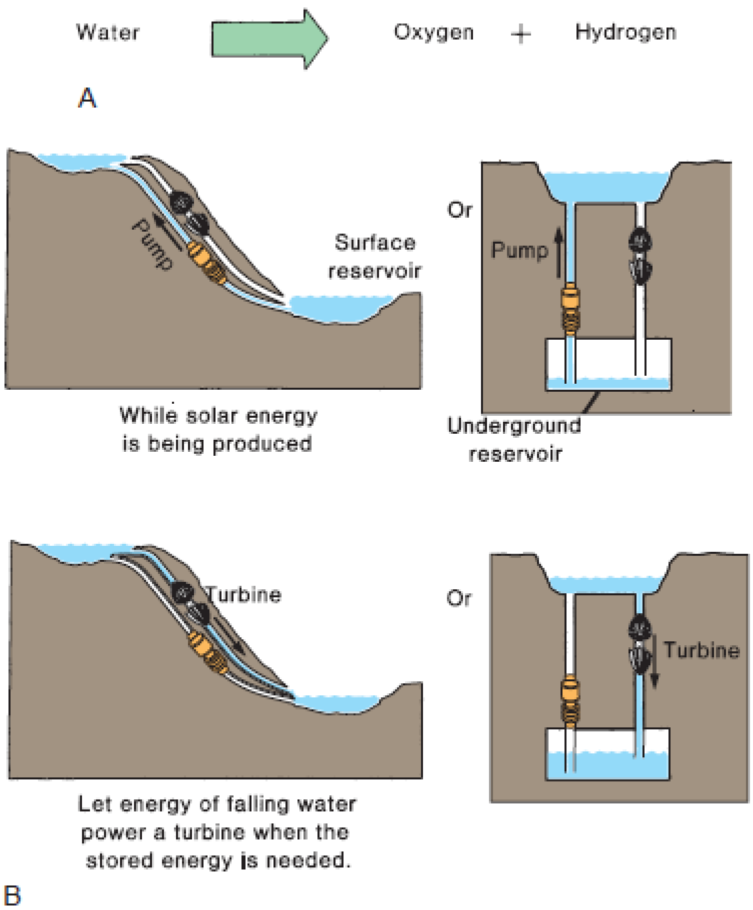

Figure 15.17

Some possible schemes for storing the energy of solar-generated electricity. (A) Use solar electricity to break up water molecules into hydrogen and oxygen; recombine them later (burn the hydrogen) to release energy. (B) Use solar energy to pump water up in elevation; when the energy is needed, let the water fall back and use it to generate hydropower.

Geothermal Energy

The earth contains a great deal of heat, some of it left over from its early history, some continually generated by decay of radioactive elements in the earth. Slowly, this heat is radiating away and the earth is cooling down, but under normal circumstances,
the rate of heat escape at the earth's surface is so slow that we do not even notice it and certainly cannot use it. If the heat escaping at the earth's surface were collected over an average square meter for a year, it would be sufficient only to heat about 2 gallons of water to the boiling point, though local heat flow can be substantially higher, for example in young volcanic areas.

Geothermal resource

Magma rising into the crust from the mantle brings unusually hot material nearer the surface. Heat from the cooling magma heats any ground water circulating nearby (figure 15.18). This is the basis for extracting **geothermal energy** on a commercial scale. The magma-warmed waters may escape at the surface in geysers and hot springs, signalling the existence of the shallow heat source below (figure 15.19). More subtle evidence of the presence of hot rock at depth comes from sensitive measurements of heat flow at the surface, the rate at which heat is being conducted out of the ever-cooling earth: High heat flow signals unusually high temperatures at shallow depths. High heat flow and recent (or even current) magmatic activity go together and, in turn, are most often associated with plate boundaries. Therefore,
most areas in which geothermal energy is being tapped extensively are along or near plate boundaries (figure 15.20).

Traditional Geothermal Energy Uses

Exactly how the geothermal energy is used depends largely on how hot the system is. In some places, the ground water is warmed, but not enough to turn to steam. Still, the water temperatures may be comparable to what a home heating unit produces (50 to 90°C). Such warm waters can be circulated directly through homes to heat them. This is being done in Iceland and in parts of the former Soviet Union. Other geothermal areas may be so hot that the water is turned to steam. The steam can be used, like any boiler- generated steam produced using conventional fuels, to run electric generators. The largest U.S. geothermal-electricity operation is The Geysers, in California (figure 15.21), which has operated since 1960 and now has a generating capacity of close to 2 billion watts. In 1989, The Geysers and six smaller geothermal areas together generated close to 10 billion kilowatt-hours of electricity (0.3%

of total energy consumed) in this country, though its output has since declined, as described below. Other steam systems are being used in Larderello, Italy, and in Japan, Mexico, the Philippines, and elsewhere. Altogether, there are about forty sites worldwide where geothermal electricity is actively being developed.

Environmental considerations of geothermal power

Where most feasible, geothermal power is quite competitive economically with conventional methods of generating electricity. The use of geothermal steam is also largely pollution-free. Some sulfur gases derived from the magmatic heat source may be mixed with the steam, but these certainly pose no more serious a pollution problem than sulfur from coal burning. Moreover, there are no ash, radioactive-waste, or

carbon-dioxide problems as with other fuels. Warm geothermal *waters* may be a somewhat larger problem. They frequently contain large quantities of dissolved chemicals that not only build geyser structures, but that can clog or corrode pipes (a potentially significant problem that will increase operational costs) or may pollute local ground or surface waters if allowed to run off freely. Sometimes, there are surface subsidence problems, as at Wairakei (New Zealand), where subsidence of up to 0.4 meters per year has been measured.

Limitations on geothermal power

While the environmental difficulties associated with geothermal power are relatively small, three other limitations severely restrict its potential. First, each geothermal field can only be used for a period of time—a few decades, on average—before the rate of heat extraction is seriously reduced. This is a negative consequence of the fact that rocks conduct heat very poorly. As hot water or steam is withdrawn from a geothermal field, it is replaced by cooler water that must be heated before use. Initially, the heating can be rapid, but in time, the permeable rocks become chilled to such an extent that water circulating through them heats too slowly or too little to be useful. The heat of the magma has not been exhausted, but its transmittal into the permeable rocks is slow. Some time must then elapse before the permeable rocks are sufficiently reheated to resume normal operations.

A second limitation of geothermal power is that not only are geothermal power plants stationary, but so is the resource itself. Oil, coal, or other fuels can be moved to power-hungry population centers. Geothermal power plants must be put where the hot rocks are, and long-distance transmission of the power they generate is not technically practical, or, at best, is inefficient. Most large cities are far removed from major geothermal resources. Also, of course, geothermal power cannot contribute to such energy uses as transportation.

The total number of sites suitable for geothermal power generation is the third limitation. Clearly, plate boundaries cover only a small part of the earth's surface, and many of them are inaccessible (seafloor spreading ridges, for instance). Not all have abundant circulating subsurface water in the area, either. Even accessible regions that do have adequate subsurface water may not be exploited. Yellowstone National Park has the highest concentration of thermal features of any single geothermal area in the world, but because of its scenic value and uniqueness, the decision was made years ago not to build geothermal power plants there.

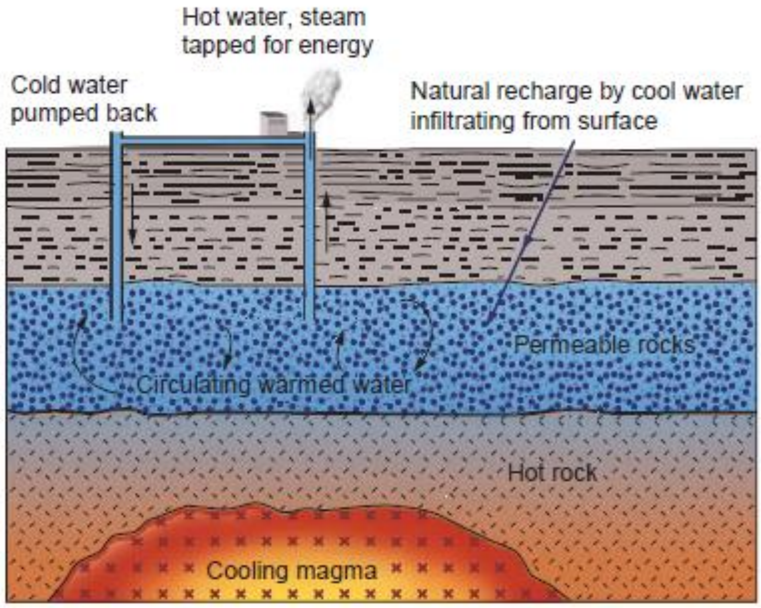

Figure 15.18

Geothermal energy is utilized by tapping circulating warmed ground water.

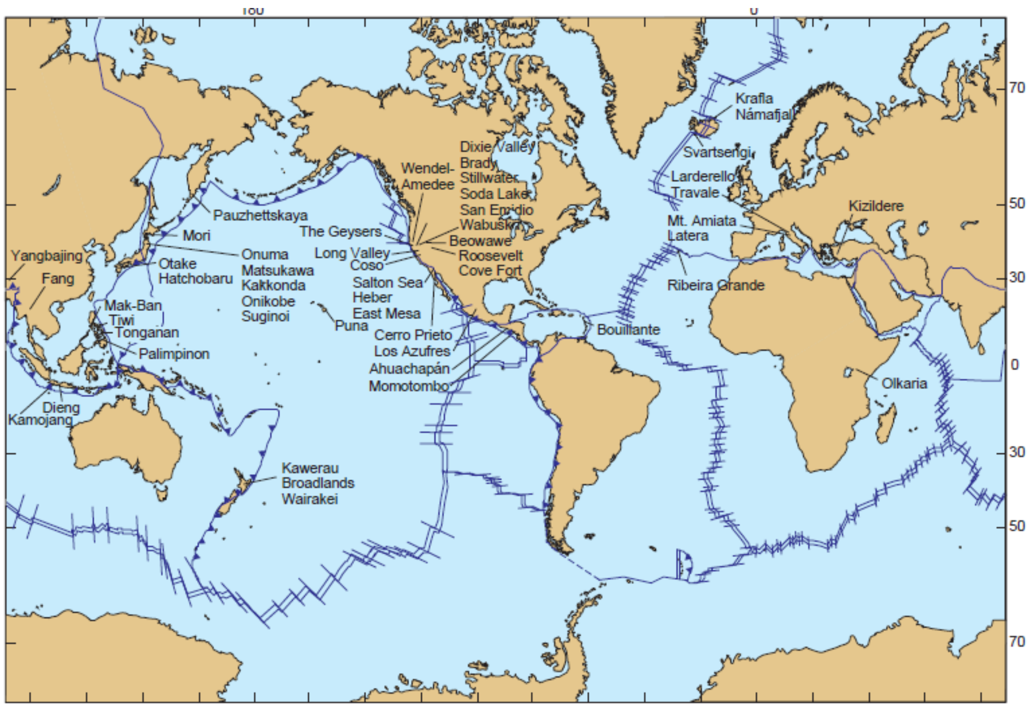

Figure 15.20

Geothermal power plants worldwide

Figure 15.21
The Geysers geothermal power complex, California, is the largest such facility in the world.

Hydropower

The energy of falling or flowing water has been used for centuries. It is now used primarily to generate electricity. Hydroelectric power has consistently supplied a small percentage of U.S. energy needs for several decades; it currently provides close to 3% of U.S. energy (about 6% of U.S. electricity). The principal requirements for the generation of substantial amounts of hydroelectric power are a large volume of water and the rapid movement of that water. Nowadays, commercial generation of
hydropower typically involves damming up a high-discharge stream, impounding a large volume of water, and releasing it as desired, rather than operating subject to great seasonal variations in discharge. The requirement of plentiful surface water is reflected in large regional variations in water use for hydropower generation (figure 15.23).
Hydropower is a very clean energy source in that the water is not polluted as it flows through the generating equipment. No chemicals are added to it, nor are any dissolved or airborne pollutants produced. The water itself is not consumed during power generation; it merely passes through the generating equipment. In fact, water use for hydropower in the United States is estimated to be more than 2½ times the average annual surface-

water runoff of the nation, which is possible because the same water can pass through multiple hydropower dams along a stream. Hydropower is renewable as long as the streams continue to flow. Its economic competitiveness with other sources is demonstrated by the fact that nearly one-third of U.S. electricity-generating plants are hydropower plants; worldwide, about 6% of all energy consumed is hydropower.

Limitations on Hydropower Development

We have already considered, some of the problems posed by dam construction, including silting-up of reservoirs, habitat destruction, water loss by evaporation, and even, sometimes, earthquakes. Evaluation of the risks of various energy sources must also consider the possibility of dam failure. There are over a thousand dams in the United States (not all constructed for hydropower generation). Several dozen have failed within the twentieth century. Aside from age and poor design or construction, the reasons for these failures may include geology itself. Fault zones often occur as topographic lows, and streams thus frequently flow along fault zones. It follows that a dam built across such a stream is built across a fault zone, which may be active or may be reactivated by filling the reservoir. Not all otherwise-suitable sites, then, are safe for hydropower dams.

Construction of dams might destroy a unique wildlife habitat or threaten an endangered species. It might deface a scenic area or alter its natural character; suggestions for additional power dams along the Colorado River that would have involved backup of reservoir water into the Grand Canyon were met by vigorous protests. Many potential sites—in Alaska, for instance—are just too remote from

population centers to be practical unless power transmission efficiency is improved.

An alternative to development of many new hydropower sites would be to add hydroelectric-generating facilities to dams already in place for flood control, recreational purposes, and so on.

Although the release of impounded water for power generation alters stream flow patterns, it is likely to have far less negative impact than either the original dam construction or the creation of new dam/reservoir complexes. Still, it is clear that flood control and power generation are somewhat conflicting aims: the former requires considerable reserve storage capacity, while the latter is enhanced by impounding the maximum volume of water.

Like geothermal power, conventional hydropower is also limited by the stationary nature of the resource. In addition, hydropower is more susceptible to natural disruptions than other sources considered so far. Just as torrential precipitation and 100-year floods are rare, so, too, are prolonged droughts—but they do happen. U.S. hydropower generation declined by about 25% from 1986 to 1988, largely as a consequence of drought. A western drought that began in 1999 dropped water levels in Lake Powell, the reservoir behind Glen Canyon Dam (fi gure 15.24), by more than 100 feet, reducing water storage by more than 50%. Hydropower generation at the dam declined from a 1997 high of 6.7

billion kilowatt-hours (kwh) to just 3.2 billion kwh in 2005, and it has remained depressed along with the lake level.
Heavier reliance on hydropower could thus leave many energy consumers vulnerable to interruption of service in times of extreme weather.
For various reasons, then, it is unlikely that numerous additional hydroelectric power plants will be developed in the United States. This clean, cheap, renewable energy source can continue indefinitely to make a modest contribution to energy use, but it cannot be expected to supply much more energy in the future than it does now. Still, hydropower is an important renewable energy source in the United States (figure 15.25).

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Questions for Review

1. Briefly describe the nature of the fission chain reaction used to generate power in commercial nuclear power plants. How is the energy released utilized?

2. What is “decommissioning” in a nuclear-power context?

3. In what areas might solar energy potentially make the greatest contributions toward our energy needs? Explain.

4.What technological limitations do solar energy

5. Explain the nature of geothermal energy and how it is extracted.

6. What factors restrict the use of geothermal energy in time and in space? How do hot-dry-rock geothermal areas expand its potential?

14. Choose any two energy sources from this chapter and compare/ contrast them in terms of the negative environmental impacts associated with each.