INTERCHAPTER L

The World Supply of Energy

Image of the world at night. The heavily populated and industrial areas are readily identified by the numerous lights, which denote areas of intense energy use. The majority of these light sources are electrical lighting, gas flares, and agricultural burning.

Eighty-five percent of the energy used in the United States and eighty-six percent of that used in the world is generated from the combustion of fossil fuels. The remainder is supplied primarily by hydroelectric and nuclear power. At present alternative energy sources (solar, sustainable biomass, geothermal, wind, and so forth) contribute less than ten percent to global energy use (Table L.1). The world's population is expected to double by 2050, which would lead to great pressure on our finite natural resources. In addition, many developing nations are undergoing rapid economic growth with an associated increase in their demand for energy. In this Interchapter we shall discuss some of the advantages and disadvantages of various energy sources.

L-1. The World Consumes Over 485×10^{15} Kilojoules of Energy Annually

In 2005 the United States with a population of about 300 million people used just over 105×10^{15} kJ of energy, an amount that corresponds to an average per-person annual energy consumption of 3.5×10^{8} kJ·year^{-1}·person^{-1}. This value is equivalent to the consumption of 58 barrels of crude oil per person per year.

The United States produces about 70% of its total annual energy requirements from a variety of domestic sources; the 30% shortfall is made up for the most part by imported oil. Currently, 70% of the oil used in the United States is imported, which represents a 10% increase in dependence on imported oil since 1990. The major uses of energy in the United States are industry (33%), transportation (28%), and space heating (18%).

Estimates of U.S. oil reserves vary greatly by source. According to the U.S. Energy Information Administration, the United States had proven oil reserves of 21 400 million barrels in 2004. At the current rate of domestic oil consumption, these supplies are sufficient to last until around 2020. Were we to continue to consume oil at the current rates without reliance on foreign imports, then based on these estimates, our reserves would be sufficient to last only three years.

Although our oil resources are rapidly being depleted, the United States has over 275 billion tons of recoverable coal reserves. The known U.S. coal reserves are sufficient to supply total U.S. energy needs at present rates of consumption for well over 250 years (Figure L.1). Unfortunately, coal is not a very clean source of energy. In addition, while the

TABLE L.1 Energy utilization by type for the United States and world production*

	Amount of energy utilized/10^{15} kJ		Percentage of total	
Energy source	**United States**	**World**	**United States**	**World**
petroleum liquids	42.7	178.6	40.4	36.8
natural gas	23.9	111.1	22.6	22.9
coal	24.1	129.0	22.8	26.6
nuclear power	8.6	29.0	8.1	6.0
hydroelectric power	2.9	30.6	2.7	6.3
sustainable biomass†	2.9	2.7	2.8	0.5
alternative energies‡	0.6	4.5	0.6	0.9
Totals	105.6	485.4	100	100

*Data from 2005 Statistical Abstracts of the United States and U.S. Energy Information Administration Key World Energy Statistics Report.

†Sustainable biomass includes wood, fuels derived from plants such as ethanol, and waste material burned for heat.

‡Alternative energies include geothermal, wind, solar, tidal, etc.

Figure L.1 The Kemmerer coal mine in Wyoming. This is the largest open-pit surface coal mine in the United States. The large drill, which is dwarfed by the coal seams, bores holes in which explosive charges are placed.

Figure L.2 China currently has the largest fleet of natural gas–powered vehicles in the world. All of the taxis in China now use compressed natural gas while operating within city boundaries. Although capable of running on gasoline as well, Chinese drivers prefer compressed natural gas because it is more cost-efficient. China is also developing a fleet of electric taxis to replace these in the near future.

burning of coal can provide electricity for homes and businesses, it requires reprocessing into a liquid fuel before it can be used practically for transportation.

At present the world consumes just over 485×10^{15} kJ of energy per year (Table L.1), about 36.8% of which comes from oil. It is estimated by the U.S. Energy Information Administration that the production of oil from world reserves will peak between 2025 and 2050, and then decline steadily. Unlike the 20th century, which had an energy economy based primarily on oil, the energy economy of the 21st century will likely be based on a mixture of various technologies.

L-2. Most of Our Energy Today Comes from Fossil Fuels

Fossil fuels are essentially mixtures of hydrocarbons. Thermal energy is obtained from fossil fuels by burning them in air. Some of the major fossil fuels used today are natural gas, propane, petroleum, and coal.

Natural gas is primarily methane, $CH_4(g)$, with traces of other hydrocarbons. It is second only to hydrogen in the amount of energy released per gram of fuel burned. Natural gas is used for heating and in many home appliances such as dryers and water heaters. It is also burned in power plants to generate electricity. In addition, many of the world's cars are now being converted to run on **compressed natural gas** (Figure L.2). Cars that run on compressed natural gas currently have a limited range of about 170 km (100 miles) per tank, thus restricting their use to mostly urban areas. Today many of the world's car manufacturers produce "multifuel vehicles" that can run on gasoline, compressed natural gas, ethanol, or a variety of other fuels (Figure L.3).

Propane, $C_3H_8(g)$, is used as a fuel in areas not serviced by natural gas delivery and is stored onsite as a liquid in metal tanks. When a valve is opened to the atmosphere, the vapor over the liquid propane has a sufficiently high pressure to flow out of the tank into the combustion region. In many countries a mixture of pressurized propane and butane, $C_4H_{10}(g)$, is sold as **liquefied petroleum gas** for use in cars and other vehicles. Liquefied petroleum gas is cheaper

Figure L.3 A multifuel vehicle produced by Volvo is capable of running on hythane (a mixture of natural gas and hydrogen), biomethane, compressed natural gas, ethanol, and gasoline. Other car manufacturers now produce similar multifuel and flex-fuel vehicles.

and cleaner-burning than gasoline and, unlike compressed natural gas, gives automobiles a range of about 500 km (300 miles) per tank.

Liquid petroleum fuels such as gasoline, jet fuel, diesel fuel, and heating oils are complex mixtures of hydrocarbons. For example, gasoline consists of mixtures of over 100 different hydrocarbon compounds in variable proportions. The hydrocarbons have from 4 to 14 carbon atoms per formula unit. Various blends are produced, depending on the environmental conditions of use and the quality of the gasoline. Diesel fuel and heating oils contain various hydrocarbons that have from 10 to 20 carbon atoms per formula unit.

Coal is a complex substance that contains highly variable amounts of many different elements. Sulfur is a major impurity in many coals, and the sulfur dioxide, $SO_2(g)$, produced when the coal is burned is a major contributor to acid rain. Consequentially, most countries' environmental laws require the removal of $SO_2(g)$ and other pollutants, greatly increasing the cost of building coal-fired power plants. For the same reason, many developing countries that have traditionally relied on coal as a fuel for cooking or heating are now limiting the use of coal to environmentally regulated power plants. Coal is not as convenient or versatile an energy source as petroleum liquids because it is a solid. Coal is much more expensive to mine and to transport than oil, which is moved through pipelines, so coal is most economically used on a large scale close to where it is mined. However, because petroleum liquids are in short supply relative to coal and because petroleum liquids are much more valuable as transportation fuels, many oil-fired power plants have been converted to coal-fired plants in the last few decades.

L-3. The Burning of Fossil Fuels Contributes to Global Climate Change

One of the major downsides of all fossil fuels is that the combustion of fossil fuels releases carbon dioxide, $CO_2(g)$, a major contributor to global climate change. Of the fossil fuels, coal produces the most $CO_2(g)$ per unit of energy released in combustion, while natural gas produces the least (see Table 14.4). This is because coal is essentially pure carbon and so all the energy derived from coal is obtained by the production of $CO_2(g)$, according to

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H^\circ_{rxn} = -393.5\ \text{kJ·mol}^{-1}$$

In contrast, natural gas or methane, $CH_4(g)$, which contains the highest ratio of hydrogen to carbon of any fossil fuel, derives a significant fraction of its energy of combustion from the formation of water, according to

$$CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(g)$$
$$\Delta H^\circ_{rxn} = -890.5\ \text{kJ·mol}^{-1}$$

As a general rule, the greater the hydrogen-to-carbon ratio of a particular fossil fuel, the less $CO_2(g)$ formed per unit of energy produced.

According to data collected from ice core samples, for most of the past 10 000 years, atmospheric $CO_2(g)$ comprised about 280 parts per million (ppm) of our atmosphere. Naturally occurring $CO_2(g)$ is produced by volcanic eruptions, by respiration in plants, and by the decay of organic matter. Carbon dioxide is removed from the atmosphere by photosynthesis, by dissolution in the oceans, and by the formation of shales and carbonate rocks, such as $CaCO_3(s)$ and $MgCO_3(s)$. In the years following the Industrial Revolution, the amount of $CO_2(g)$ and other greenhouse gases in the atmosphere has increased dramatically, primarily as a result of the combustion of fossil fuels, deforestation, and agricultural burning. In 2009 $CO_2(g)$ comprised 385 ppm of our atmosphere (Figure L.4). The increasing amount of atmospheric $CO_2(g)$ and other greenhouse gases is cited as a major cause of **global climate change**. These gases absorb heat radiation from the earth's surface and thereby act to hold the radiated energy in the atmosphere, leading to an increase in average global temperature, a phenomenon known as the **greenhouse effect** because of the way a greenhouse holds in heat.

In 2007 scientists in the United Nations Intergovernmental Panel on Climate Change, which shared the 2007 Nobel Peace Prize with former U.S. Vice President Al Gore, concluded that the average global surface temperature of the earth had risen approximately 0.74°C during the last hundred years due to the increase in greenhouse gas concentrations

In the late 1980s, in response to the depletion of the ozone layer, major nations signed the historic Montreal Protocol agreement, leading to the phase-out of many ozone-depleting compounds. Complete recovery of the ozone layer is expected by sometime in mid-century. Such international efforts demonstrate mankind's ability to address world problems, a hopeful precedent for the current work needed on global climate change.

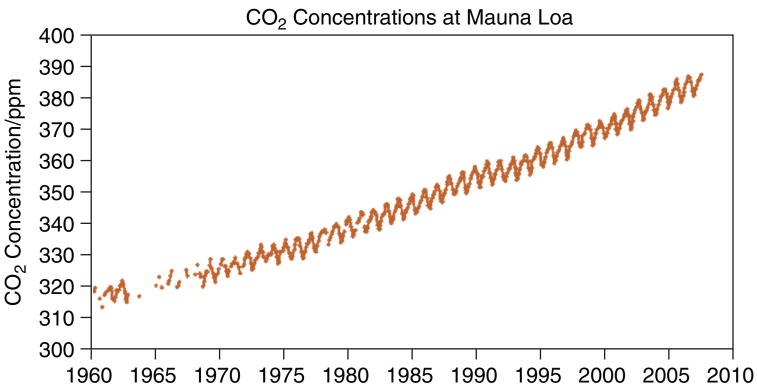


Figure L.4 Increase in atmospheric concentration of $CO_2(g)$ monitored at Mauna Loa observatory in Hawaii over the past half-century. Note the seasonal variation in the concentration of $CO_2(g)$.

resulting from human activities. Climate model projections summarized in their 2007 report suggest that the average global surface temperature will likely rise a further 1.1 to 6.4°C during the coming century. According to the report, even a small rise in global temperature is predicted to change patterns of global precipitation. This could affect water supplies and agricultural yields, increase the number of disease vectors, disrupt economies, and cause other disturbances. Most scientists agree with these conclusions, but a small minority do not. Currently, there is ongoing political debate about how to respond to such changes. Most world governments have now signed and ratified the Kyoto Protocol, a piece of global legislation aimed at reducing the emission of carbon dioxide, methane, and other greenhouse gases.

L-4. Biomass Fuels Include Wood, Plants, Alcohols, and the Burning of Waste Materials

Biomass is the category of fuels derived from plant materials such as wood, alcohol, and waste materials burned for heating. Alcohols, such as methanol, $CH_3OH(l)$, and ethanol, $CH_3CH_2OH(l)$, are biomass products produced by the fermentation of sugars from plants. Like fossil fuels, alcohols are burned to generate energy. A major advantage of sustainably grown biomass fuels is that the plants from which they are derived absorb $CO_2(g)$ from the atmosphere. While the combustion of such fuels produces $CO_2(g)$, the $CO_2(g)$ is recycled in the growth of new plants. This recycling of $CO_2(g)$ does not result in a total elimination of new $CO_2(g)$ produced because of energy expenditures required for transportation, harvesting, fermentation, and fertilization associated with the production of such fuels. However, the net amount of $CO_2(g)$ generated per unit of energy obtained is significantly less than that from fossil fuels.

One disadvantage is that many biomass-derived fuels require the use of farmland for their production, in direct competition with the growing of food. Another concern is that the production of such fuels may result in deforestation, resulting in a net increase in the amount of global $CO_2(g)$ because forested land removes a significant quantity of $CO_2(g)$ from our atmosphere, as seen by the seasonal variation in atmospheric $CO_2(g)$ in Figure L.4. The use of switchgrass (which can grow in arid nonarable regions), plant waste, and algae for the production of ethanol may help to alleviate these problems.

L-5. There Is Sufficient Solar Radiation Striking the Earth to Meet Our Energy Needs

The earth's atmosphere receives about 174×10^{12} kJ of energy from sunlight per second, with about 30% of this being reflected back into space by the atmosphere. The amount of solar energy entering the earth's atmosphere in an hour is greater than the quantity of energy used by the world's population in a year. It is estimated that the energy needs of the world could be provided for by covering a portion of the earth's deserts with current solar paneling. However, the cost and maintenance of doing so would far exceed those of other sources of energy. Moreover, even if we were to embark on such a project, at present there is no effective means of efficiently distributing this energy to the places in the world where it is needed. Nevertheless, as a local supplement to other forms of available energy, solar power has many advantages.

The sunlight that reaches the surface of the United States has an average power level of about 0.5 $kW \cdot m^{-2}$. The electrical energy requirements of a typical U.S. home are about 30 kilowatt-hours per day. A **kilowatt-hour** (kWh) is the energy produced by a one-kilowatt power source operating for one hour, where 1 Watt =

$1\ J\cdot s^{-1}$. If 25% of the incident solar energy could be collected over an eight-hour day, then all the energy requirements of a typical U.S. household could be satisfied by a solar energy collector surface of about 30 m^2, which is less than the surface area of the roof of a single-family home.

One of the major drawbacks of solar energy is the fact that sunshine is inherently intermittent in nature. An energy storage device is needed to supply energy for use at night or when the day is overcast. The energy collected can be stored in basically three ways: by using it to heat up a large mass of substance, such as water or rocks; to charge a battery (some power companies now act as a battery by providing a credit for excess energy generated and fed back into their power grid); or to drive an endothermic reaction, where the reverse reaction can then be used to provide energy.

A substance that is sometimes used to store solar energy is **Glauber's salt,** $Na_2SO_4\cdot 10\,H_2O(s)$, which at 32.3°C dissolves in its own waters of hydration to form a solution, according to:

$$Na_2SO_4\cdot 10\,H_2O(s) \rightarrow Na_2SO_4(aq) + 10\,H_2O(l)$$

When the temperature of the salt solution drops below 32.3°C, the reverse reaction occurs, and the $Na_2SO_4\cdot 10\,H_2O(s)$ crystallizes out of the solution, simultaneously evolving about −354 kJ per liter of salt solution. As the salt crystallizes, the heat can be drawn off and used for heating.

Another approach to solar energy conversion is to use mirrors to concentrate sunlight onto a reactor vessel and use the high temperatures produced to drive an endothermic chemical reaction. An example is the reaction described by

$$CO_2(g) + CH_4(g) \xrightarrow{750^\circ C} 2\,CO(g) + 2\,H_2(g)$$

$$\Delta H^\circ_{rxn} = 247\ kJ\cdot mol^{-1}$$

The 247 $kJ\cdot mol^{-1}$ of stored energy can be released by running the reaction in reverse. The energy evolved can be used to heat water and steam for power generation. Focused sunlight can also be used to convert liquid water to steam, which is then used to drive a turbine that produces electricity (Figure L.5).

Adoption of solar energy systems is slow at present because petroleum, coal, and natural gas are less expensive energy sources that are readily used with existing large-scale technologies, but as these sources dwindle in the future it is expected that solar power will play a much greater role in the global energy economy.

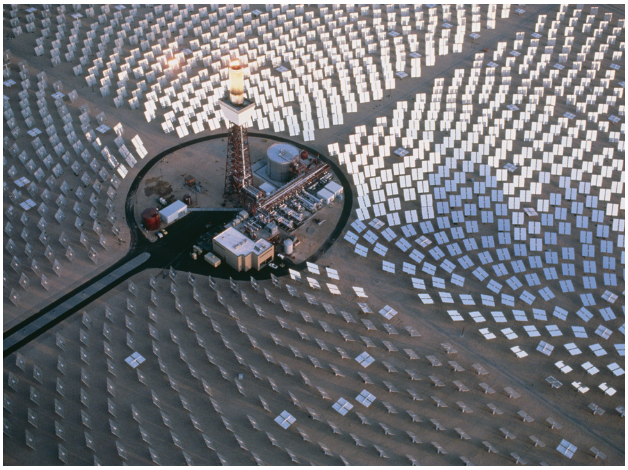


Figure L.5 A solar power tower. A large receiver structure is located on top of a high tower at the focal point of a large array of sun-tracking mirrors called heliostats. "Solar One," shown here, is located near Barstow, California, in the Mojave Desert. The power tower is capable of generating 10 megawatts peak power from 1818 heliostats, each of which is 430 square feet in area.

Other sources of alternative energy include: **geothermal energy** that derives its power from natural heat emanating from magma deposits close to the earth's surface; **wind energy** that uses windmill-like turbines to turn electric generators (Figure L.6); and **hydroelectric power** that generates electricity by channeling water through turbines (Figure L.7). Like solar energy, these sources of alternative energy are limited to regions where the source of such power is readily available. Table L.2 compares the benefits and detriments of various sources of energy.

Figure L.6 A wind farm located in Palm Springs, CA. Similar wind farms can be found throughout the world. Wind is the fastest-growing source of alternative energy in the world today.

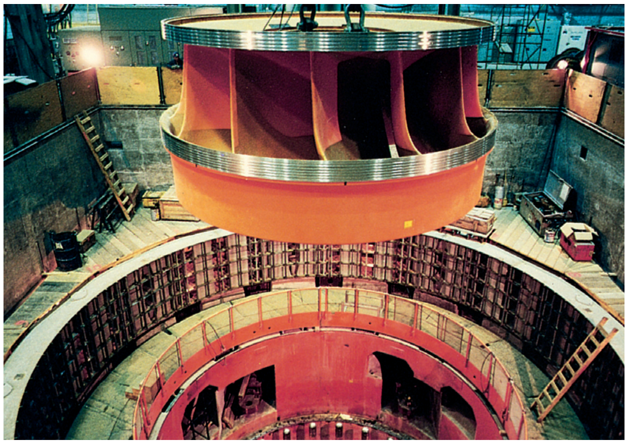


Figure L.7 A large water-driven turbine blade unit from a Canadian power plant (Hydro-Québec).

L-6. Sixteen Percent of the World's Electrical Energy Comes from Nuclear Fission

Nuclear reactions can release great amounts of energy per mole (Interchapter O). A particularly important nuclear reaction is the reaction of a uranium-235 nucleus with a neutron, ${}^{1}_{0}\text{n}$, an example of which is described by the equation

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3\,{}^{1}_{0}\text{n}$$

A nuclear reaction in which a nucleus is split into two roughly equal pieces is called **fission**. The key thing to notice about the above fission reaction equation is the release of three neutrons. Each of these neutrons can cause another uranium-235 nucleus to undergo fission, thereby producing nine neutrons. These in turn can react with other uranium-235 nuclei, and this rapidly increasing release of neutrons generates what is called a **chain reaction** (Figure L.8).

A nuclear reactor is designed to run a chain reaction in a controlled manner and thereby regulate the rate of energy release. The reactor core consists of a bank of **fuel rods** charged with uranium-235-enriched $U_2O_3(s)$ (Figure L.9). One way to control the chain reaction is through the use of moveable **control rods** made of materials such as cadmium or boron that absorb neutrons strongly and act as

TABLE L.2 Comparison of various sources of energy

Fuel	Estimated cost in \$/MWh*	Benefits and detriments
oil and gas	37–60	+: proven technology, low construction cost –: produces $CO_2(g)$, cost may increase, limited resources
coal	25–50	+: large world coal reserves, low cost –: produces $CO_2(g)$ and $SO_2(g)$
nuclear	60–150	+: clean energy –: waste disposal, safety, possible weaponization, limited uranium reserves
hydroelectric	40–80	+: clean energy –: impact on fish and rivers, limited by region
biomass‡	—	+: produces no new $CO_2(g)$ if managed sustainably, renewable –: costs vary, utilizes farmland, can result in deforestation
wind	35–60+	+: clean energy, low cost –: limited by region, intermittent
geothermal	—	+: clean energy –: costs vary, limited availability by region
solar thermal solar photovoltaic	150 250–400	+: clean energy, independence from power grid –: expensive, large area required, intermittent, requires energy storage media

*Insufficient data available to make accurate estimates of the costs of biomass and geothermal power plants.

‡Biomass includes wood, fuels derived from plants such as ethanol, and waste material burned for heat.

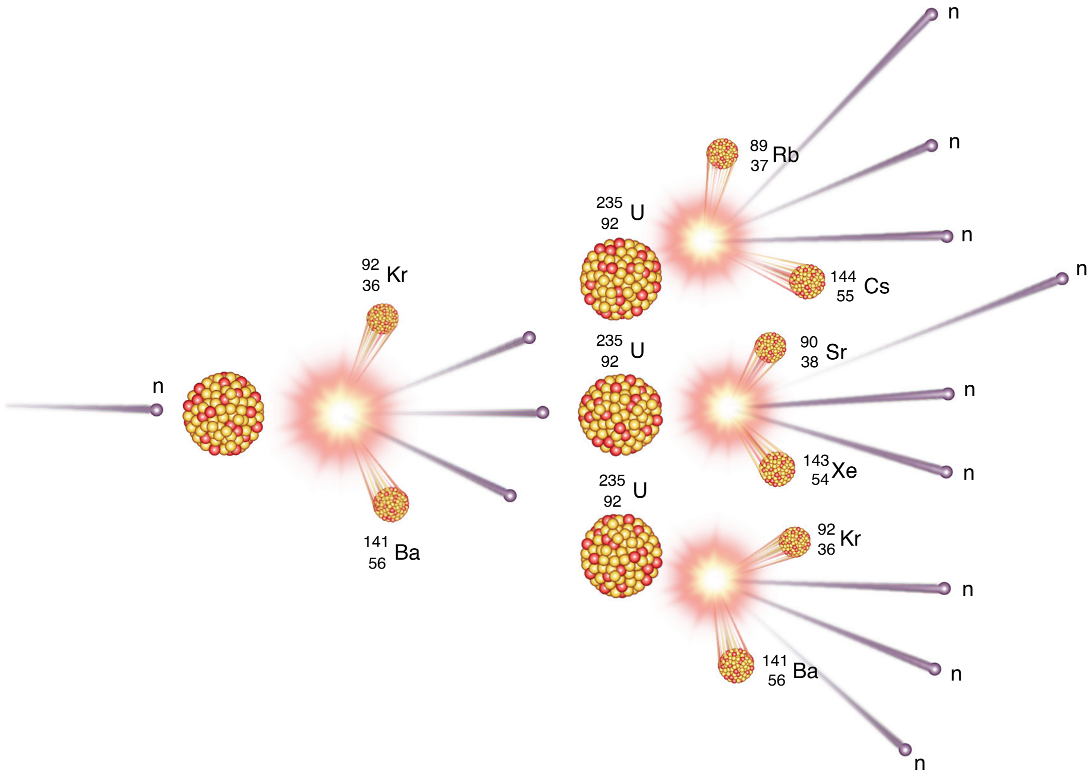
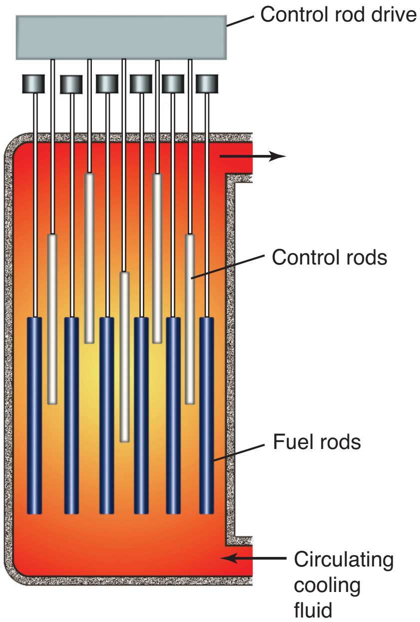


Figure L.8 The chain reaction produced when uranium-235 undergoes fission after absorbing a neutron. The key point is that several neutrons are produced in each reaction. Consequently, after the first step, three other uranium nuclei absorb a neutron and undergo fission. These three nuclei produce 9 neutrons, which lead to the production of 27 neutrons in the third step, and so on. The number of fission reactions increases very rapidly with the number of steps, and the result can be an explosive release of energy. In a nuclear reactor, control rods are used to keep the reaction running at a steady state.



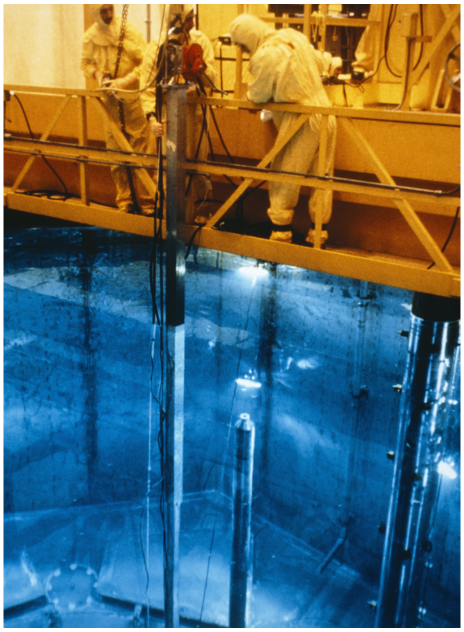


Figure L.9 Diagram of the core of a nuclear reactor. (*left*) The fuel rods contain the fissionable material. The control rods consist of a material that is a good absorber of neutrons. By raising and lowering the control rods, the density of neutrons in the core, and thus the rate of production of energy, can be controlled. (*right*) Loading of fuel rods into a nuclear reactor core. The fuel rods are the long, thin, shiny metal tubes, which are filled with fissionable material.

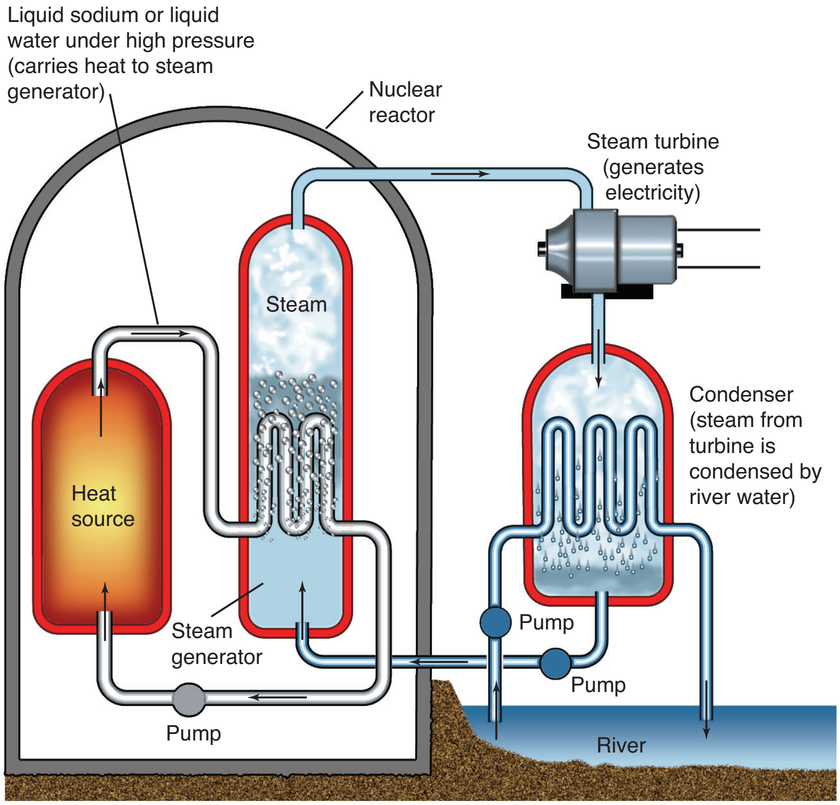


Figure L.10 Diagram of a nuclear reactor. The heat source is the core of the reactor (Figure L.9). The heat produced by the core is transferred by a closed loop of liquid sodium or liquid water to a steam generator. The steam produced runs a steam turbine, which produces electricity. The steam from the turbine is cooled by water from a nearby source, such as a river, or through a forced-flow cooling tower; and the cooled water is pumped back into the steam generator.

neutron moderators to maintain the chain reaction at a steady rate. The energy produced in the form of heat is used to generate steam, which drives a turbine to produce electricity. A diagram of a conventional light-water nuclear reactor, such as those used in the United States, is shown in Figure L.10.

Nuclear reactors provide about 16% of the world's total electrical energy, or about 6% of the total of all forms of energy used (Table L.1). Nuclear fission is a clean source of energy in that it creates no atmospheric pollutants (Table L.2). However, due to the issues surrounding the disposal of nuclear waste, the potential for major accidents, and the possible weaponization of nuclear materials, it is also the most politically controversial. Moreover, there are only sufficient terrestrial uranium reserves to provide electrical energy from uranium for about 40 more years at our current rate of consumption, and less if we rely increasingly on the fission of uranium for power. Despite these challenges, nuclear energy continues to be an important component of future energy plans. The International Atomic Energy Agency anticipates the construction of at least 60 new plants worldwide in the next 15 years, the bulk of these in developing regions of Asia.

L-7. Hydrogen Is a Carrier of Energy

Hydrogen gas may one day replace fossil fuels in automobiles and homes. Hydrogen can be used to power **fuel cells** (see Chapter 25) that work by converting the energy stored in hydrogen and oxygen gases into electrical energy according to the equation

$$2\,H_2(g) + O_2(g) \xrightarrow[\text{fuel cell}]{} 2\,H_2O(l) + \text{electrical energy}$$

Because water is the only product of this reaction, hydrogen is considered one of the cleanest fuels available. Some cars, buses, and scooters now run on hydrogen (Figure L.11). However, the economical production, transportation, and storage of hydrogen still pose many difficulties.

Major savings in energy consumption can be gained by increasing energy efficiency. A large portion of the energy we use today is lost as heat. This can be recaptured and used to perform useful work or to provide space heating. Other losses come from poor insulation in buildings; outdated equipment such as older pumps, motors, and incandescent bulbs; and inefficient vehicles. Finally, recycling and reuse of resources is another way to lower energy

Figure L.11 An experimental hydrogen fuel-cell-powered car. The vehicle and filling station are part of research being conducted at the University of Birmingham, UK.

consumption. In short, increased efficiency can be regarded as another source of energy for the future.

Although a wide variety of energy sources exist, it seems no one source will replace fossil fuels. In the next century we shall likely use a variety of different energy sources until a new inexpensive and practical source of sustainable energy becomes viable.

TERMS YOU SHOULD KNOW

fossil fuels *L2*
natural gas *L2*
compressed natural gas *L2*
propane *L2*
liquefied petroleum gas *L2*
liquid petroleum fuels *L3*
coal *L3*
global climate change *L3*
greenhouse effect *L3*
biomass *L4*
kilowatt-hour *L4*
Glauber's salt *L5*
geothermal energy *L5*
wind energy *L5*
hydroelectric power *L5*
fission *L6*
chain reaction *L6*
fuel rods *L6*
control rods *L6*
fuel cells *L8*

QUESTIONS

L-1. Using the enthalpy of formation data given in Appendix D, calculate the number of moles of $CO_2(g)$ produced per megajoule of energy in the form of heat released from the combustion of one mole of coal, $C(s)$; natural gas, $CH_4(g)$; propane, $C_3H_8(g)$; and octane, $C_8H_{18}(l)$ at 25°C under standard conditions. The value of ΔH_f° for octane is $-250.1\ \text{kJ·mol}^{-1}$.

L-2. Describe two ways in which solar energy can be collected and stored by means of chemical reactions.

L-3. What is the function of the control rods in a nuclear reactor?

L-4. In 2005 the per-person annual energy consumption of the United States was about 3.5×10^8 kJ per person per year. Given that 1 watt = $1\ \text{J·s}^{-1}$, calculate the average power in kilowatts continuously consumed by each person in the United States. How many continuously burning 100-watt lightbulbs does this correspond to per U.S. citizen?

L-5. Using the data in Section L-1, estimate the number of barrels of crude oil imported per day by the United States.

L-6. Calculate the mass of $CO_2(g)$ produced by the burning of a 12-gallon tank of gasoline. Assume that gasoline consists entirely of octane, $C_8H_{18}(l)$, and that the density of octane is $0.80\ \text{g·mL}^{-1}$.

L-7. Explain why coal is considered the dirtiest fossil fuel in terms of carbon dioxide emissions, while natural gas is considered the cleanest.

L-8. Natural gas use in the United States is billed in therms. A therm is defined as 100 000 BTU. Given that 1 BTU = 1.05 kJ, estimate the cost per mole of $CH_4(g)$, where natural gas costs $1.20 per therm.

L-9. Convert 30 kWh (kilowatt-hours) to kJ.

L-10. Using the data given in Section L-5, show that the energy requirements of a typical U.S. home could be satisfied if 25% of the average incident solar energy in an eight-hour period per day were collected by 30 m^2 of collector surface.

L-11. Calculate the number of kilojoules that can be stored at 32.3°C by dissolving 100 kilograms of $Na_2SO_4 \cdot 10\,H_2O(s)$ in its own waters of hydration. Take the density of the resulting solution to be $1.5\ \text{g·mL}^{-1}$.