CHAPTER 1

Energy Fundamentals, Energy Use in an Industrial Society

1.1 Introduction

Energy enters our everyday lives in many different ways. The energy in the food we eat maintains our body temperature and lets us walk, talk, lift things, and toss frisbees. The use of energy in food has been essential for the existence of all humankind and animals throughout our evolution on this planet. In some developing countries the supplying of food for energy and nutrition is a difficult task that requires most of the waking hours of the population. Food acquisition is just as essential in the more developed countries, but because of the greater mechanization of agricultural production, the effort of only a relatively small number of persons is devoted to obtaining food. This leaves most of the rest of us free to pursue other activities throughout our lives.

Energy in forms other than food is also essential for the functioning of a technical society. For example, in the United States, many times more energy in the form of engine fuel goes into the agricultural enterprise than is obtained in the useful food Calorie content of the food produced. Prodigious amounts of energy are also used to power automobiles, heat homes, manufacture products, generate electricity, and perform various other tasks. In order for our society to function in its present patterns, vast amounts of coal, natural gas, and oil are extracted from the earth and burned to provide this energy. To a lesser extent we also derive energy from hydroelectric plants, nuclear reactors, electric wind generators, and geothermal plants, and, of course, we all benefit enormously from the energy obtained directly from the sun.

The fossil fuels: coal, natural gas, and oil, supply about 85% of the energy used in the United States. These resources evolved hundreds of millions of years ago as plant and animal matter decomposed and was converted under conditions of high temperature and pressure under the earth's surface into the hydrocarbon compounds that we now call fossil fuels. Since the beginning of the machine age, industrial societies have become increasingly dependent on fossil fuels. A hundred and fifty years ago, the muscular effort of humans and animals played an important role in the American economy, and firewood supplied most of the heat energy. Now less than one percent of our energy comes from firewood and we rely much less on the physical effort of people and animals. The process by which we have moved to our present dependence on coal, oil, and natural gas is illustrated F1 → in Figure 1.1, where the energy consumed in the United States each year from various sources is shown in terms of quadrillion British thermal units (QBtu) for the years 1850 to 2003. The definition of QBtu will be given in Section 1.6.

Should we be concerned that so much of our energy is now coming from fossil fuels? Here are two of many factors that should cause concern.

First, the fossil fuel resource is limited in amount. The fossil fuels were produced by solar energy hundreds of millions of years ago, and when they are gone, there will be no more. It is true that the fuels are still being formed, but at an entirely negligible rate compared to the rate at which we are consuming them. We first began consuming the fossil fuels at an appreciable rate only about 150 years ago. How long will they last? On a global scale we will still have some coal for a few centuries, but natural gas and oil will be in short supply in only a few decades. In the United States, the situation is worse than the global average because we are depleting our resources at a faster rate than in other fossil fuel-rich F2 → areas around the globe. Figure 1.2 shows the narrow blip of our fossil fuel use set against a time scale of thousands of years. As you consider the brief duration of this blip, remember that we have living trees thousands of years old, a much longer time than what will be spanned by the entire era of fossil fuel consumption. It is clear from this figure that we live in an extraordinary time in the many billion year history of the earth. The entire stock of fossil fuels available for our use has been held in storage under the earth's surface for more than a hundred million years, and now it is being completely exploited in only a few centuries.

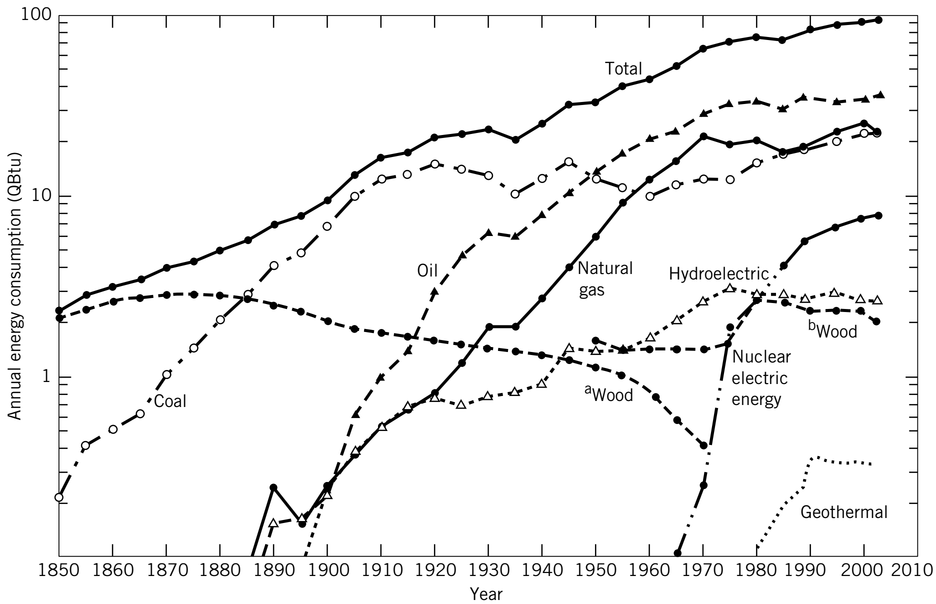

Figure 1.1 Various forms of energy consumed in the United States since 1850. This type of graph is called a semilogarithmic plot, and an explanation of the scales is given in the Appendix. *Sources: Historical Statistics of the United States, Colonial Times to 1970*, U.S. Department of Commerce. Bureau of the Census, 1975; U.S. Energy Information Administration, *Annual Energy Review*, 2003. (a) The wood data set from 1850 to 1970 is from the first source. (b) The wood data set from 1950 to 2003 is from the second source; it includes wood, black liquor (a byproduct of the wood-based paper production process), and wood waste.

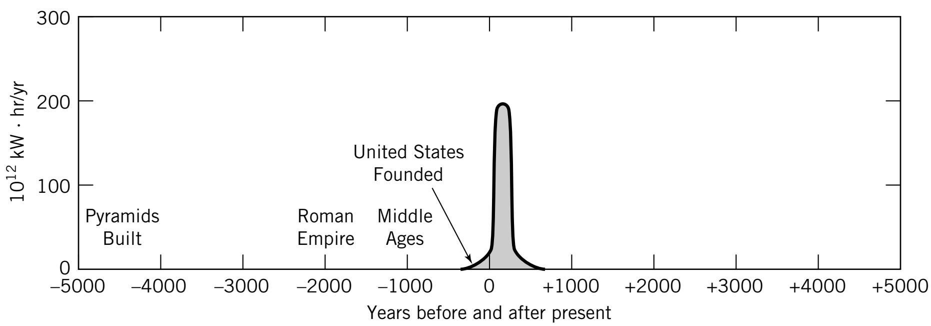

Figure 1.2 The complete exploitation of the world's fossil fuels will span only a relatively brief time in the 10,000 year period shown centered around the present. (*Source*: Reprinted with permission from M. K. Hubbert, *Resources and Man*, Washington, D.C., National Academy of Sciences, 1969.)

Second, unintended environmental consequences result from the extensive scale of our use of the fossil fuels for everything from heating our homes to powering our automobiles. When we burn coal, natural gas, or oil to obtain energy, gaseous compounds are formed and dumped into the atmosphere. This is causing problems we are just beginning to face. For many years it was felt that the emitted gases were not significant, given the vastness of the earth's atmosphere. But now with increasing world population, and industrialization, this is no longer true. The atmospheric pollution is producing health problems and even death, and it is now becoming recognized that carbon dioxide emissions are threatening to produce climate changes over the entire globe.

Can we find solutions to these problems of resource depletion and environmental pollution? Clearly the answers are not simple or the solutions would have been put into effect by now. The subject is complex and involves some understanding of topics such as patterns of resource depletion, the workings of heat engines, solar cells, wind generators, nuclear reactors, and a myriad of other specialized subjects. We do not have to become experts on each of these individual topics to be sufficiently well informed as voting citizens to influence a rational decision-making process. Our goal is to gain understanding concerning the essential points.

1.2 Why Do We Use So Much Energy?

A partial answer to this is simple—we don't use our energy resources as efficiently as we could. The standard of living we enjoy in the United States could be maintained with an expenditure of far less energy per person than at present. This side of solving the energy problem will be explored later under the heading of Energy Conservation. There is a large discrepancy between the rate of energy use by a typical citizen of an industrialized society and the typical citizen of a developing country, and it is accompanied by a notable difference in what
F3 → we perceive as the standard of living. This is illustrated in Figure 1.3, where we see the per capita gross domestic product (GDP) and the per capita energy use for several countries of the world. Although not indicated on this figure, several developing countries have very low rankings by either measure, and they would be located within the small quarter-circle shown at the extreme lower left corner of the figure.

There is no essential relationship between GDP per capita and the standard of living, but both are often related to the use of energy. A citizen of a developing country might use the energy equivalent of less than one barrel of oil per year, compared to an annual energy equivalent of 20 to 60 barrels per capita for the most industrialized countries. The nonindustrialized countries derive a large fraction of their necessary energy from the muscular effort of people and

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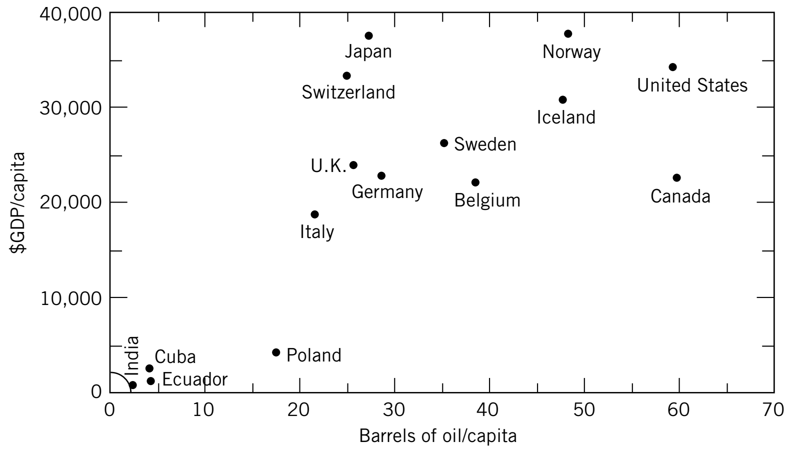

Figure 1.3 The Gross Domestic Product (GDP) per capita in U.S. dollars is compared to the total energy consumed per capita in equivalent barrels of oil for several countries. The small quarter-circle at the lower left corner is discussed in the text. (*Source*: *United Nations Statistical Yearbook*; data January 2003.)

animals. There is an interesting quotation from an early physics textbook written by J. Dorman Steele in 1878:

> *The combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 pounds of coal is equivalent to the work of an able-bodied man for a lifetime.*

This observation, while a bit off the mark in exact technical detail, is essentially correct, and it sets the stage and justifies the enormous effort that has gone into our learning to exploit the fossil fuels—energy reserves held in waiting for hundreds of millions of years—until we have learned to use them with high efficiency to ease human labor. Whether we refer to tons of coal or barrels of oil, it is indeed the fossil fuels that have had the major effect. Without fossil fuels we surely would have made progress toward labor-saving technology based on waterpower, firewood, windpower, and perhaps even nuclear power, but we would not have gone nearly so far in developing the energy-intensive society in which we now live.

We may take the average power available to a person to be a measure of the productive output of a society. As seen in Figure 1.4, in the United States in 1850, about 0.38 horsepower per person was available, of which 0.26 horsepower was provided by work animals. We now have a few hundred times that from other sources. Most of the difference is due to our use of fossil fuels to make the wheels go around. ← F4

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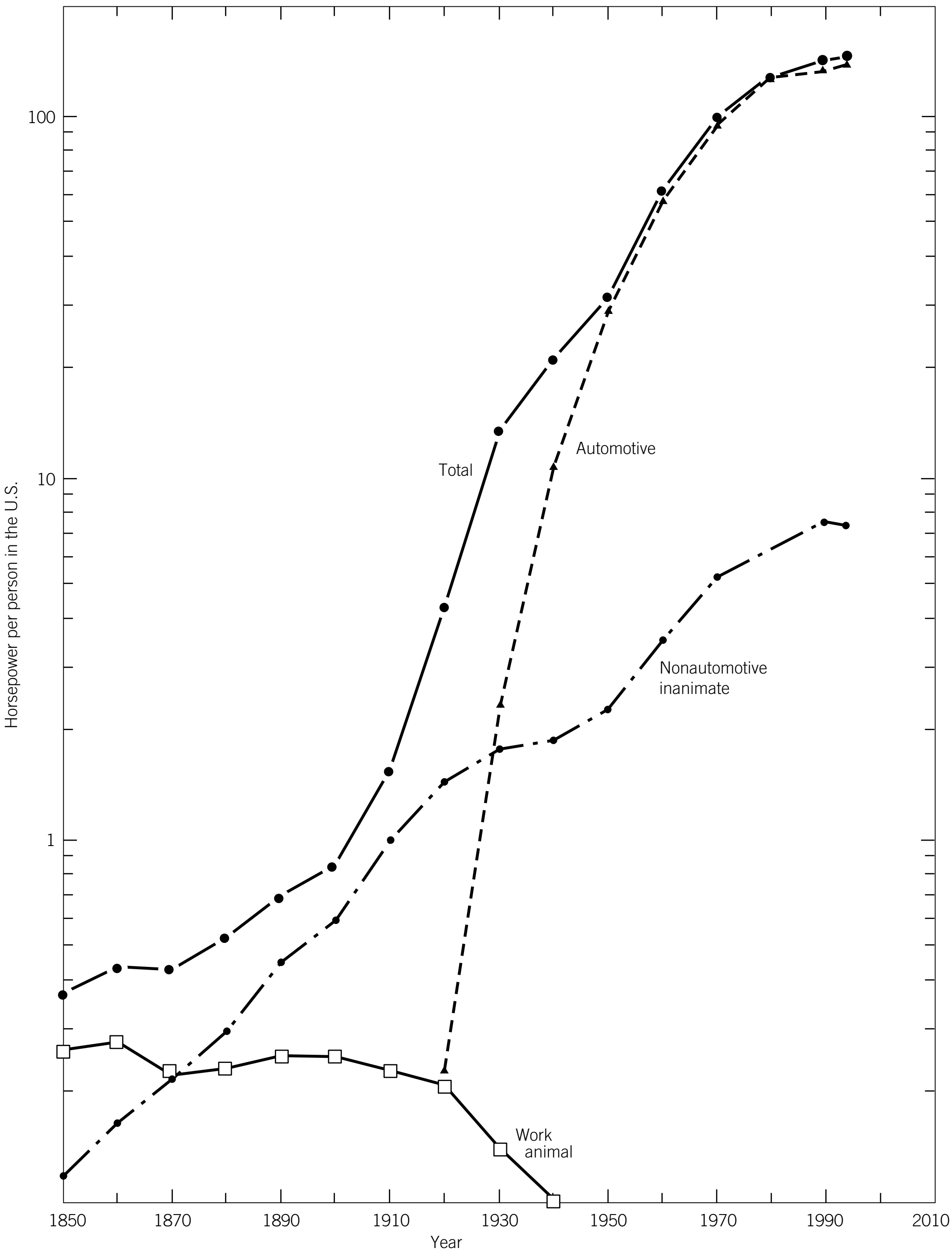

Figure 1.4 Horsepower per capita of all prime movers in the United States since 1850. (*Source*: *Historical Statistics of the United States, Colonial Times to 1970; Statistical Abstracts of the United States 2003*. Washington D.C.: U.S. Department of Commerce, Bureau of the Census.)

Example 1.1

Using generally available information, estimate the dollar value of the equivalent amount of oil which we each use annually.

Solution

Given:

58 barrel/(yr · person); see Figure 1.6.

42 gallons/barrel; see Energy Equivalents chart inside front cover

Oil is approximately \$1.25/gallon; estimated from reported crude oil prices.

$$\frac{\text{bbl}}{(\text{yr} \cdot \text{person})} \times 42 \frac{\text{gal}}{\text{bbl}} \times 1.25 \frac{\$}{\text{gal}} = \mathbf{3045} \frac{\mathbf{\$}}{\mathbf{(yr \cdot person)}}$$

Note that the units of bbl and gal cancel in this calculation. We can extend the answer to obtain the cost per day of this oil.

$$3045 \frac{\$}{(\text{yr} \cdot \text{person}} \times \frac{1 \text{ yr}}{365 \text{ day}} = \mathbf{8.34} \frac{\mathbf{\$}}{\mathbf{(day \cdot person)}}$$

Here the units of yr have canceled. ■

1.3 Energy Basics

1.3.1 General

Our discussions of energy use and resources can proceed effectively only if we have a common understanding of exactly what energy is, and what forms it can take.

Physicists and engineers define energy as *the capacity to do work*, leaving us then with the need to define *work*. Work is a general term to most of us; it signifies everything from shoveling snow off the driveway to making out an income tax form, studying for an examination, or writing an essay. But we may not think of taking a bicycle ride on a nice Saturday afternoon as being work; it's too pleasant an experience. In order to make work a useful concept for scientific purposes, we must forget about the pleasant and unpleasant aspects and come up with a definition suitable for quantitative analysis. We can achieve this by defining work to be the product of force times the distance through which the force acts. A common example of this definition of work is given by a force pushing an object along a rough surface. The force could be exerted by any agent: human, steam engine, sled dog, or electric motor. In the British system of units, the force is given in pounds (lb) and the distance in feet (ft), so work will then be in units of pound-feet, or more commonly foot-pounds (ft·lb). In the metric system, work has the units of newton-meter (N·m), where the newton is the metric unit of force and the meter is the metric unit of distance. The metric unit of energy, the joule, is defined as 1 J = 1 N·m. The two systems of units (British and metric) are both in common use in the United States, and conversions between them are not difficult. The numerical conversion factors are given inside the covers of this book. It is important to note that the same units are used for energy and work. We will often find that energy and work are equivalent; the units are identical and, in many cases, the work done on an object is equal to the energy gained by the object. A more complete discussion of energy units is given in Section 1.4 of this chapter.

In the example given above, the work, equal to the product of force times distance, comes out to be zero if the pushed object doesn't move through some distance. A person can push against a solid wall all day long, but if the wall doesn't move, no work is done, even though the experience will be tiring to the person doing the pushing. In another case, the work being done also comes out to be zero if an object moves through a distance but with no force being exerted on it in the direction of the motion. A hockey puck sliding freely along a perfectly slippery ice surface represents a situation where no work is being done on either the puck or the ice, and no energy is being expended. Both the force and the distance must have nonzero values if work is to be done.

Here's an example that will help us gain a feeling for magnitudes and units of work and energy: Imagine that you slowly lift a 10 pound sack of sugar upward 1 foot. The force is 10 pounds and the distance is 1 foot, so the work (force times distance) you do on the sack of sugar is 10 ft·lb. The energy to do this work would have come from the food you ate. The work done can also be expressed in metric units. From the chart of conversion factors, we see that 1 ft·lb is the same as 1.36 joules, so the 10 ft·lb is 13.6 joules. Or we could deal in terms of British thermal units (Btu), another unit of energy. From the chart of conversion factors, 1 ft·lb is seen to equal 0.00129 Btu. Thus the 10 ft·lb of energy expended would be the same as 0.0129 Btu.

Example 1.2

A force of 50 pounds pushes a box along a floor a distance of 100 feet. How much work (in ft·lb) has been done? How much energy (in joules) has been expended?

Solution

$$\text{Work} = \text{force} \times \text{distance}$$
$$= 50 \text{ lb} \times 100 \text{ ft} = \mathbf{5000\ ft{\cdot}lb}$$

$$\text{Energy expended} = \text{work done}$$
$$= 5000 \text{ ft}{\cdot}\text{lb} \times 1.36 \frac{\text{joule}}{\text{ft}{\cdot}\text{lb}} = \mathbf{6800\ joules}$$

The conversion factor between ft·lb and joule has been taken from the table of conversion factors. ■

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1.3.2 Forms of Energy

Energy comes in many forms and can in principle be transformed from one form to another without loss. This is consistent with the Principle of Energy Conservation, which we will address later in Section 1.7. Some of the common forms of energy are discussed here.

(a) Chemical Energy Chemical energy is the energy stored in certain chemicals or materials that can be released by chemical reactions, often combustion. The burning of wood, paper, coal, natural gas, or oil releases chemically stored energy in the form of heat energy and, as discussed earlier, most of the energy used in the United States is of this form. We heat our homes, power our automobiles, and turn the generators that provide electricity primarily with chemical energy.

Other examples of chemical energy sources are hydrogen, charged electric batteries, and food in the stomach. Chemical reactions release this energy for our use.

(b) Heat Energy Heat energy is the energy associated with random molecular motions within any medium. The term thermal energy is interchangeable with heat energy. Heat energy is related to the concept of temperature. Increases of heat energy contained in any substance result in a temperature increase and, conversely, a decrease of heat energy produces a decrease of temperature.

(c) Mass Energy Albert Einstein taught us that there is an equivalence between mass and energy. Energy can be converted to mass, and mass can be converted to energy. The famous formula

$$E = mc^2$$

gives the amount of energy, E, represented by a mass, m. This energy is often referred to as the *mass energy.* The symbol c stands for the speed of light.

The most dramatic recent examples of this equivalence are in nuclear weapons and nuclear reactors, but our entire existence is now known to depend on nuclear reactions in the sun. There we have atomic nuclei coming together in a reaction with the resulting products having less mass than what went into the reaction. The mass that is lost in the reaction appears as energy according to the Einstein equation

$$\Delta E = \Delta mc^2,$$

where Δm (read it as *delta m*) is the missing mass, and c is the speed of light. The energy that appears, ΔE, is in joules if Δm is in kilograms and c is in meters per second. Because c is such a very large number, 3×10^8 m/sec, a small loss of mass results in a huge release of energy. At a detailed level, any reaction, of any type, chemical or nuclear, which releases energy does so in association with a loss of mass between the inputs and outputs, according to the Einstein equation.

The idea of mass energy is relatively new in human experience. Einstein put forth the $E = mc^2$ equation in the early 1900s. It was not until the 1920s and 1930s that the nuclear fusion processes in stars were first understood, and in the 1940s that energy release from man-made nuclear fission reactions was first demonstrated.

(d) Kinetic Energy Kinetic energy is a form of mechanical energy. It has to do with mass in motion. An object of mass m, moving in a straight line with velocity v, has kinetic energy given by

$$KE = \frac{1}{2} mv^2.$$

If the object in question is an automobile, work must be done to bring the auto up to speed, and, conversely, a speeding car can do work in being brought to rest. The work done on the accelerating car is derived from the fuel, the work done by the stopping car will appear mainly as heat energy in the brakes, if the brakes are used to stop the car.

In a similar manner, an object rotating around an axis has kinetic energy associated with the rotation. It is just a matter of all the mass elements which make up the object each having velocity and kinetic energy according to the description given above. These combined kinetic energies make up the kinetic energy of the rotating object. We commonly see rotational kinetic energy in a potter's wheel, a child's top, an automobile flywheel, and so forth. Some day rapidly rotating flywheels may provide the stored energy needed to power a car.

(e) Potential Energy Potential energy is associated with position in a force field. An obvious example is an object positioned in the gravitational field of the earth. If we hold an object having weight w at a height h above the earth's surface, it will have potential energy

$$PE = w \times h$$

relative to the earth's surface. If we then release the object and let it fall to the earth, it will lose its potential energy but gain kinetic energy in the same amount. Another example would be at a hydroelectric dam where water is effectively, but usually not literally, dropped onto a turbine below. In this example, the water hitting the blades of the turbine has kinetic energy equal to the potential energy it would have had at the top of the reservoir surface. This potential energy is measured relative to the turbine's location. The kinetic energy of the water becomes electric energy as the turbine spins a generator.

(f) Electric Energy The idea of electric energy is less obvious than the examples of other types given previously. Not surprisingly, electric energy is one of the last types of energy to have been brought into practical use. With electric energy, nothing can be seen, either stationary or in motion, but the effects can be readily apparent. In spite of this difficulty, an understanding of electric energy is necessary for the functioning of a complex industrial society. It is electric energy that allows us to have telephones, television, lighting, air-conditioning, electric motors, and so forth.

If an electric charge q is taken to a higher electric potential (higher voltage) V, then it is capable of releasing its potential energy, given by $PE = q \times V$, in some other form such as heat or mechanical energy. A battery, such as we have in a flashlight or automobile, is a common device for storing electric energy. The chemicals in a battery have an inherent difference of electric potential. When the battery is charged, electric charges are brought to the higher-potential so that energy is stored as chemical energy for later use as electric energy. Thus a battery works both ways; it can convert electric energy to chemical energy, or chemical energy to electric energy.

Mechanical energy is converted to electric energy in a generator, where conductors are forced to move through a magnetic field to induce a voltage between the ends of the conductor. And, if a voltage is applied to the terminals of a common type of generator, it can function as a motor, thereby converting electrical energy to mechanical energy.

(g) Electromagnetic Radiation The energy radiated by the sun travels to the earth and elsewhere by electromagnetic radiation. That part of the spectrum of electromagnetic energy to which our eyes are sensitive is known as visible light, and a large fraction of the solar energy we receive is in the form of visible light.

The electromagnetic spectrum covers a very wide range of frequency, and visible light is only a small part of the entire spectrum. Electromagnetic radiation is characterized by a wavelength, λ (the Greek letter lambda), and a frequency, f. In a free space, the velocity of light, c, is related to these quantities by the equation $c = f \times \lambda$. The numerical value of c is 3×10^8 meters/second. The electromagnetic spectrum ranges from radio waves ($\lambda = 200$ m) to microwaves ($\lambda = 0.1$ m), to light ($\lambda = 5 \times 10^{-7}$ m), to x-rays ($\lambda = 1 \times 10^{-8}$ m) and beyond.

Various portions of the electromagnetic spectrum are important to the transformation and use of energy on earth. The portion that includes radio waves and microwaves is generated by electronic devices. Light and x-rays have their origin in atomic excitations and radiating electrons. Gamma rays are produced by the decay of excited states of atomic nuclei.

1.3.3 Power

Energy is often expressed in the units of joules or foot-pounds. We may also find it convenient to work in terms of the *rate* of use of energy, as well as with the energy amounts themselves. We will then speak in terms of joules per second. This is analogous to the way in which we commonly discuss our wages in dollars per hour (a *rate*) as well as in dollars (an *amount*). These two quantities are related, but different.

Power is the time rate of using, or delivering, energy:

$$\text{Power} = \frac{\text{energy}}{\text{time}}$$

and

$$\text{Energy} = \text{power} \times \text{time}.$$

In the metric system, for power we use units of watts, where 1 W = 1 J/sec. In the British system, the unit of power is the horsepower, where one horsepower is 550 foot-pounds per second. The rating of an electric power plant should be in the power unit of *watts*, as it can supply electrical *energy* at a certain *rate*.

The units of *kilowatts* (10^3 W), *megawatts* (10^6 W), and *gigawatts* (10^9 W) are also often used. If a power plant operating at a steady power P has run for a time t, then the energy produced is

$$E = P \times t.$$

The common unit for energy in this case of electricity generation is the kilowatt-hour (kWh). Over a given time, such as a day, the amount of electrical *energy* in kilowatt-hours delivered is given by multiplying the power rating in kilowatts by the number of hours in a day. One kilowatt-hour is 3.6×10^6 joules because one watt is one joule per second and there are 3600 seconds in an hour. When you pay your electric bill, you pay for energy, or the number of kilowatt-hours used.

In the United States, automobile engines and electric motors are often rated in horsepower. Although this may be historically related to the power a horse can deliver, it is more precisely equal to 550 ft·lb per second or, equivalently, to 746 watts. In recent years, it has been common, especially in Europe, to rate engine power in terms of kilowatts rather than in horsepower. In terms of human capabilities, one horsepower is an impressively large unit, as it is equivalent to raising a 55 pound weight a distance of 10 feet every second, and continuing to do this. Even the most powerful human is capable of working at a rate of only a small fraction of a horsepower for any extended time.

1.4 Units of Energy

We have already found that various units are attached to the numbers we use in discussing energy. These units are arranged into consistent systems. The two most common in the treatment of energy are the metric and the British systems. The metric units are also known as the *Système International*, usually abbreviated SI, and this system is becoming standard throughout the world.

Discussing energy without using an orderly system of units would be like trying to discuss American currency without using dollars and cents. It could make a difficult conversation if the units of dollars, pesos, and francs were included all in the same sentence. In dealing with energy, we must frame the discussion in a consistent system of units, using a single system of our choice. The variety of possibilities is often confusing and can lead to errors in even simple computations. Let us start by sorting through some of the common units used to measure energy. Later on we can become concerned with the units for the related concepts of power, work, distance, force, and so forth.

1.4.1 The Joule

The joule is the metric unit of energy. It has its fundamental definition in terms of force and distance. One metric unit of force (the newton) acting through one metric unit of distance (the meter) is equivalent to the expenditure of one joule of energy. The kinetic energy of a tennis ball moving at 14 miles per hour is about one joule. There are constant numerical factors relating the joule to the other energy units: the Btu, the calorie, the foot-pound, and the electron-volt.

1.4.2 The British Thermal Unit

We often encounter the British thermal unit (Btu) in discussions of fuel and insulation. The unit has a simple definition based on the amount of heat energy which must be given to a known amount of water to increase its temperature by a given amount. One Btu is defined to be the amount of heat energy required to raise the temperature of one pound of water by one degree Fahrenheit. Similarly, it is the amount of heat energy given off by one pound of water when it cools by one degree Fahrenheit. As a rough approximation, the burning of a wooden match releases 1 Btu. A Btu is a relatively large amount of energy; it is the same as 1055 joules.

1.4.3 The Calorie

The calorie, like the Btu, is also defined in terms of the heating of water. It is the amount of energy required to raise the temperature of one gram of water by one degree Celsius, or the amount of energy given off when one gram of water cools by one degree Celsius. The calorie is much smaller than the Btu. This should seem reasonable on considering that a gram of water is several hundred times smaller than a pound, and that a Celsius degree is only 1.8 times larger than a Fahrenheit degree. The conversion factor is 252 calories per Btu.

We often speak of food energy in terms of Calories (with a capital C), but here we must be careful. The food Calorie, or Calorie with a capital C, is 1000 times larger than the calorie used in physics or chemistry. This measure of food energy is also known as the kilocalorie. The prefix “kilo” denotes 1000. One Calorie is equal to about 4 Btu.

1.4.4 The Foot-Pound

In the United States it is common to use the ordinary measures of distance (the foot) and force (the pound) along with the equivalence of energy and work to give the foot-pound as a useful unit for energy, as discussed briefly in Section 1.3. A force of one pound acting through a distance of one foot by definition expends one foot-pound of energy, and one foot-pound of work is done. It may be of interest to note that 1 Btu is the same as 778 foot-pounds, or what it would take to lift a one pound weight to a height of 778 feet.

1.4.5 The Electron-Volt

In dealing with problems in electronics, or atomic and nuclear physics, it is convenient to have a very small unit for the extremely small amounts of energy involved. This unit, the electron-volt, abbreviated eV, is related to the idea of moving one electron through an electric potential difference of one volt. This would take an applied external force if the motion is to be against the force exerted on the electron by the electric field. If the motion is in the opposite direction, the electron would gain kinetic energy as the electric field acts on it, giving it a velocity. The electron-volt is so small that it takes 6×10^{18} of them to equal one joule.

1.5 Scientific Notation

Because the numerical quantities of interest to us range from the extremely small to the enormously large, it is hopeless to try to express them by the use of many zeroes before or after the decimal point. For example, in 2003 we consumed about 98×10^{15} Btu of energy in the United States. To write this as 98 followed by 15 zeroes would be awkward and would lead to many mistakes. Similarly, we have about 1.6×10^{-19} joules in an electron-volt. We could write this as a decimal point followed by 18 zeroes and then 16, but there is no reason to do this when we can use the efficient notation 1.6×10^{-19}. This approach is known as powers-of-ten, or scientific, notation.

There are some simple rules to follow when using powers of 10 in multiplication and division. For multiplication, say of 4.30×10^8 by 6.21×10^3, we first multiply in the usual way the 4.30 by the 6.21 and obtain 26.7. In any multiplication, the powers of ten are simply added. For example, $10^8 \times 10^3 = 10^{11}$. We have just added the 8 and the 3 to get the 11. In this case, then,

$$(4.30 \times 10^8) \times (6.21 \times 10^3) = 26.7 \times 10^{11}.$$

If we want to divide 3.50×10^5 by 2.10×10^3, the 2.10 is divided into the 3.50 in the usual way to get 1.67. The power of ten in the denominator is then subtracted from that in the numerator to get $5 - 3 = 2$, or $10^5 \div 10^3 = 10^2$. Putting this together, we get

$$\frac{3.50 \times 10^5}{2.10 \times 10^3} = 1.67 \times 10^2.$$

A special condition is encountered when the power of ten is zero. 10^0 is always equal to 1. In fact, as strange as it may seem at first, *any* number raised to the zero power is equal to 1.

When adding or subtracting numbers with various powers of 10, the numbers must first be converted to the same power of ten and then added or subtracted in the usual way. For example, $(4.8 \times 10^6) + (1.2 \times 10^7)$ should be written $(4.8 \times 10^6) + (12.0 \times 10^6)$, with the result 16.8×10^6. Similarly, $(4.80 \times 10^{-4}) - (3.6 \times 10^{-5})$ should be written

$$(48.0 \times 10^{-5}) - (3.6 \times 10^{25}) = 44.4 \times 10^{-5}.$$

Example 1.3

The temperature of 15 pounds of water in a tank has been raised by 10 degrees Fahrenheit. How many Btu of heat energy was added to the water? What is this energy in joules?

Solution

For water:

$$\begin{aligned} \text{Energy (Btu)} &= \text{weight (lb)} \times \Delta T\ (^\circ\text{F}) \\ &= 15 \text{ lb} \times 10^\circ\text{F} = \mathbf{150\ Btu} \end{aligned}$$

$$\begin{aligned} \text{Energy (joule)} &= 150 \text{ But} \times 1055 \text{ joule/Btu} \\ &= \mathbf{158{,}250\ joules}\ \blacksquare \end{aligned}$$

Example 1.4

The mass of a pencil is 10 grams. What is the equivalent mass energy in joules?

Solution

$$E \text{ (joules)} = m \text{ (kilograms)} \times c^2 \text{ (meters}^2\text{/second}^2\text{)}$$

and

$$m = 10 \text{ g} \times 1 \text{ kg/1000 g} = 0.01 \text{ kg}$$

$$c = 3 \times 10^8 \text{ meter/second}$$

$$c^2 = 9 \times 10^{16} \text{ (m/sec)}^2$$

Therefore,

$$\begin{aligned} E &= 0.01 \times 9 \times 10^{16} \\ &= \mathbf{9 \times 10^{14}\ joules}\ \blacksquare \end{aligned}$$

1.6 Energy Consumption in the United States

We frequently hear various figures put forth for energy consumption rates, and these numbers are sometimes given in terms of so many QBtu/year, where Q is a symbol for quadrillion, or 10^{15}. This number is huge and seems disconnected from our everyday experience. How can we gain a feeling for what the
T1 → numbers actually mean? To make the situation more real, Table 1.1 shows the origin of the energy consumed in the United States in 2003 in terms of tons of coal, barrels of oil, and so forth. We see that coal, natural gas, and petroleum provided most of the energy, but nuclear and renewables also made significant contributions.

In Table 1.1, the values in the third column for coal, natural gas, petroleum, and other sources are for the heat energy released by the burning of the given fuel. The numbers given for nuclear and renewables are different. For these generating technologies, what is shown is the number of QBtu which would be needed to produce the given number of kilowatt-hours of electric energy if fossil fuels were the energy source. This consideration would apply, for instance, if there were a severe drought and hydroelectricity had to be replaced by electricity from a coal-burning plant. Calculation of this number of QBtu uses a prevailing annual heat rate factor for fossil-fueled electric power plants in the United States. This number corresponds to an efficiency for converting thermal energy to electrical energy of approximately 30 to 35%.

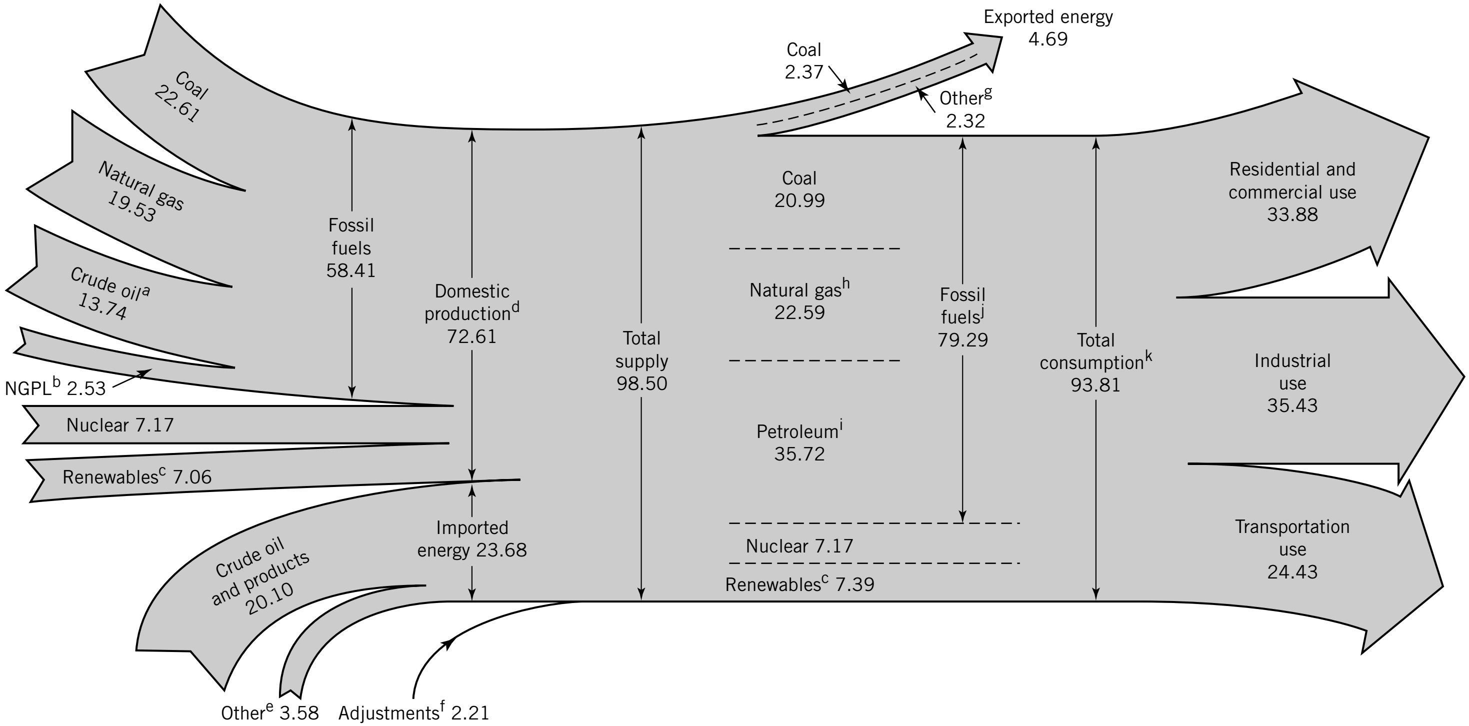
F5 → Figure 1.5 shows in more detail the sources and final uses of energy in the United States as compiled by the U.S. Energy Information Administration for 2003. Here and in Table 1.1 renewables include biofuels, conventional hydroelectric power, geothermal energy, solar energy, and wind energy. The many footnotes shown for Figure 1.5 explain some of the discrepancies in Table 1.1

Table 1.1 U.S. Energy Consumption in 2003

Source	Amount	QBtu	Percent	1 QBtu Equiv.
Coal	1.08×10^9 tons	22.6	23.0	47.8×10^6 tons
Natural gas	21.8×10^{12} ft^3	22.5	22.9	0.97×10^{12} ft^3
Petroleum	6.72×10^9 bbl	39.1	39.8	172×10^6 bbl
Nuclear elec.	757×10^9 kWh	7.97	8.1	95×10^9 kWh
Renewables	578×10^9 kWh	6.15	6.3	94×10^9 kWh
Total		98.3	100	

The data in column 3 are from U.S. Energy Information Administration, *Annual Energy Review*, 2003. The numbers in columns 2 and 3 are given in thermal energy for the first three entries and in terms of equivalent thermal energy for the next two. The numbers in column 5 are from the same source. The last entry includes typical conversion efficiencies from thermal to electrical energy.

Ed1→



[a] Includes lease condensate.
[b] Natural gas plant liquids.
[c] Conventional hydroelectric power, wood, waste, ethanol blended into motor gasoline, geothermal, solar, and wind.
[d] Includes –0.09 QBtu hydroelectric pumped storage.
[e] Natural gas, coal, coal coke, and electricity.
[f] Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.
[g] Crude oil, petroleum products, natural gas, electricity, and coal coke.
[h] Includes supplemental gaseous fuels.
[i] Petroleum products, including natural gas plant liquids.
[j] Includes 0.05 QBtu of coal coke net imports.
[k] Includes, in QBtu, –0.09 hydroelectric pumped storage; –0.24 ethanol blended into motor gasoline, which is accounted for in both fossil fuels and renewable energy but counted only once in total consumption; and 0.02 electricity net imports.
[l] Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales.

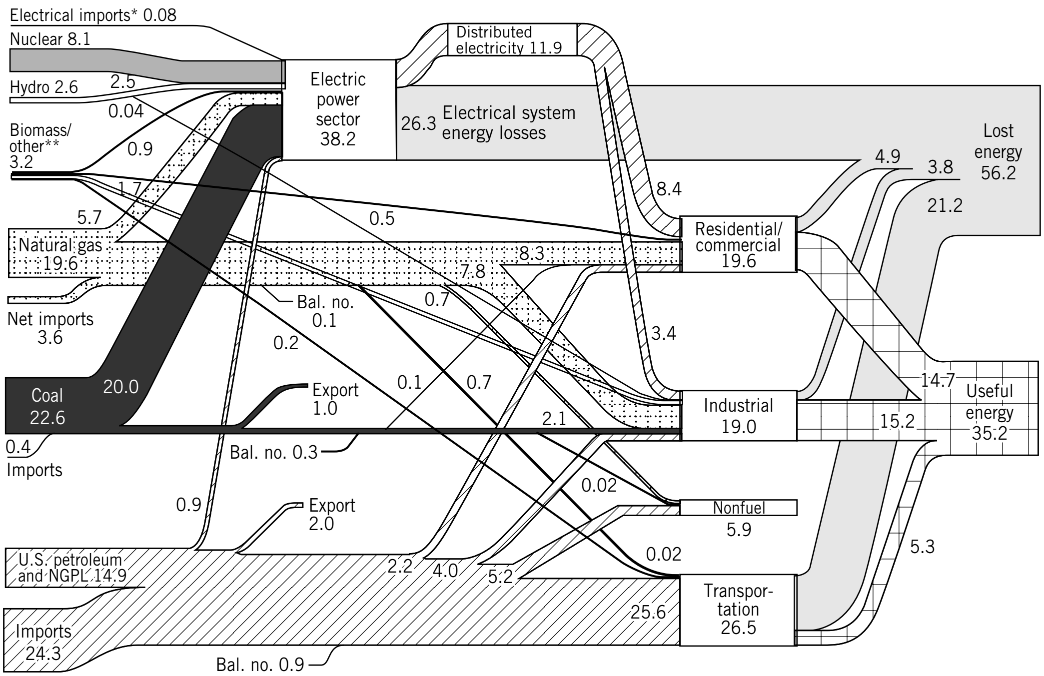
Notes: • Data are preliminary. • Totals may not equal sum of components due to independent rounding. ←Au1

Figure 1.5 Energy flow from source to use in the United States in 2003 in units of QBtu. (*Source*: Washington, D.C.: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, 2003.)

such as the total energy being 98.16 QBtu instead of the exact sum of the third column of Table 1.1.

F6 → Figure 1.6 gives information similar to that of Figure 1.5, but arranged in a different way to provide more detail. For example, this figure shows that in the United States in 2002, 3.4 QBtu of electrical energy was used by industry and 8.4 QBtu of electric energy went to residential and commercial uses, while 26.3 QBtu was lost in generating and distributing electricity. The reasons why most of this loss is unavoidable are discussed later in the text, especially in Chapter 3. Some of the numbers in Figure 1.6 differ slightly from those of Figure 1.5 because they come from different sources and are not for the same year.

If the data of Table 1.1 are divided by the population of the United States (291 million people), we obtain the average amount of energy that we each used T2 → in 2003. These numbers are shown in Table 1.2, which indicates that each of us on average consumed in 2003 about 23 barrels of oil, 3.7 tons of coal, etc. Our average per capita energy consumption is equivalent to the burning of 58 bar-



*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

Figure 1.6 Energy flow in the United States in 2002 in units of QBtu, arranged to separate out useful energy from lost energy. *Source*: Lawrence Livermore National Laboratory (2004) and United States Energy Information Administration, Annual Energy Review 2002.

Table 1.2 U.S. Energy Consumption per Person in 2003

Source	Amount
Coal	3.7 tons
Natural gas	74,900 ft^3
Petroleum	23.2 bbl
Nuclear	2600 kWh
Renewables	1986 kWh

The first three entries are for the thermal energy from the fuel. The last two entries are in terms of equivalent thermal energy, as in Table 1.1. The amounts given here are for a population of 291 million.

rels of oil. This is an impressively large amount of energy by any standard. See Figure 1.7. ← F7

Only in Canada do people use as much energy per person as we do in the United States; most industrialized countries use only about one-half. Figure 1.3 shows the energy use per capita along with the Gross Domestic Product per capita for several representative countries. The energy use is in terms of equivalent barrels of oil; the GDP is in terms of U.S. dollars.

It could be argued from the data shown in Figure 1.3 that in order to have a large per capita GDP, a relatively large per capita energy consumption is also needed. Although there is indeed such a general trend, there is no consistent correlation. For example, Switzerland consumes less than half the per capita en-

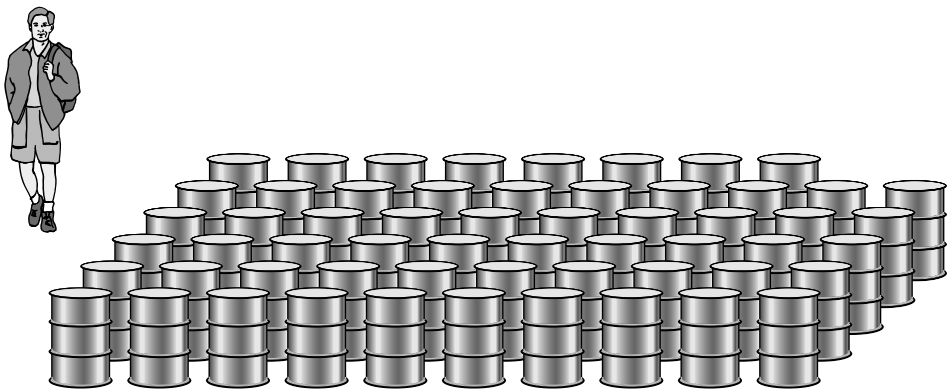


Figure 1.7 Each person in the United States consumes an energy equivalent of 58 barrels of oil burned as fuel each year.

ergy of the United States, but has about the same per capita GDP. The striking element illustrated by Figure 1.3 is the great disparity between the industrialized and the developing nations. A number of developing countries such as Angola, Haiti, and Somalia fall within the little quarter-circle shown at the lower left-hand corner of the figure. The world as a whole used the equivalent of 11.4 barrels of oil per person in 2002. Most of the countries of the world use relatively little energy per capita and have a small per capita GDP compared to the most developed countries.

The world consumption of energy in 2002 was about 410 QBtu. That same year the United States' consumption was about 98 QBtu. With just 4.5%, or one-twentieth, of the world's population, we were using one-quarter of the world's energy. There are several causes for the relatively high rate of energy consumption in the United States. One is related to transportation. The United States is a large and affluent country where a good deal of the personal transportation is by automobile. Although public transportation can be much more energy efficient in regions of high population density such as Europe or Japan, it is not as common in the United States because our population density is far less. It is also true that a large fraction of our population lives in separated houses that are more expensive to heat and cool than are multifamily dwellings. The development of the United States into an industrialized society took place in a time when energy sources appeared to be abundant, even inexhaustible, and it has not been until recently that serious energy conservation steps have been widely undertaken.

T3 → How do we use energy in the United States? Table 1.3 shows the breakdown by major categories. Excluding electricity, residential and commercial use involves mostly natural gas and petroleum; the industrial category mainly involves coal, natural gas, and petroleum. The energy for transportation fuel is supplied almost entirely by petroleum with some inroads made recently by natural gas. The energy resources for electric utilities are quite mixed: 50% coal, 20% nuclear, 18% natural gas, 7% hydroelectric, 3% petroleum, and 3% other.

Table 1.3 Percentage U.S. Energy Use in Various Sectors in 2003

Sector	**Amount**
Electric utilities	39.0%
Transportation	27.3%
Industrial	22.1%
Residential and commercial	11.6%

The last three categories do not include electric energy from the utilities. Data from U.S. Energy Information Administration, *Annual Energy Review*, 2003.

The history of consumption and product of energy in the United States since 1950 is shown in Figure 1.8. In this figure, and elsewhere in this text, energy *production* refers to the mining of coal and the bringing of oil and natural gas to the earth's surface, or to the making of useful energy by nuclear power, hydroelectric power, geothermal power, biomass fuel, solar collectors, and other means. Energy *consumption* occurs when the fossil fuel is burned or when energy is put to use by the consumer. ← F8

It is clear from Figure 1.8 that we now are in a persistent pattern of consuming more energy than we are producing in our nation. The difference must be made up from imports. Over this period, energy consumption has generally gone up with time except for a dip after 1980. The decrease in the 1980s reflected a movement toward greater energy conservation following increases in fuel costs and the "energy crisis" that started in 1973. In this period there was a major turn toward cars with greater fuel efficiency, improved standards for building insulation, and various energy conservation measures in industry. Once the easiest and

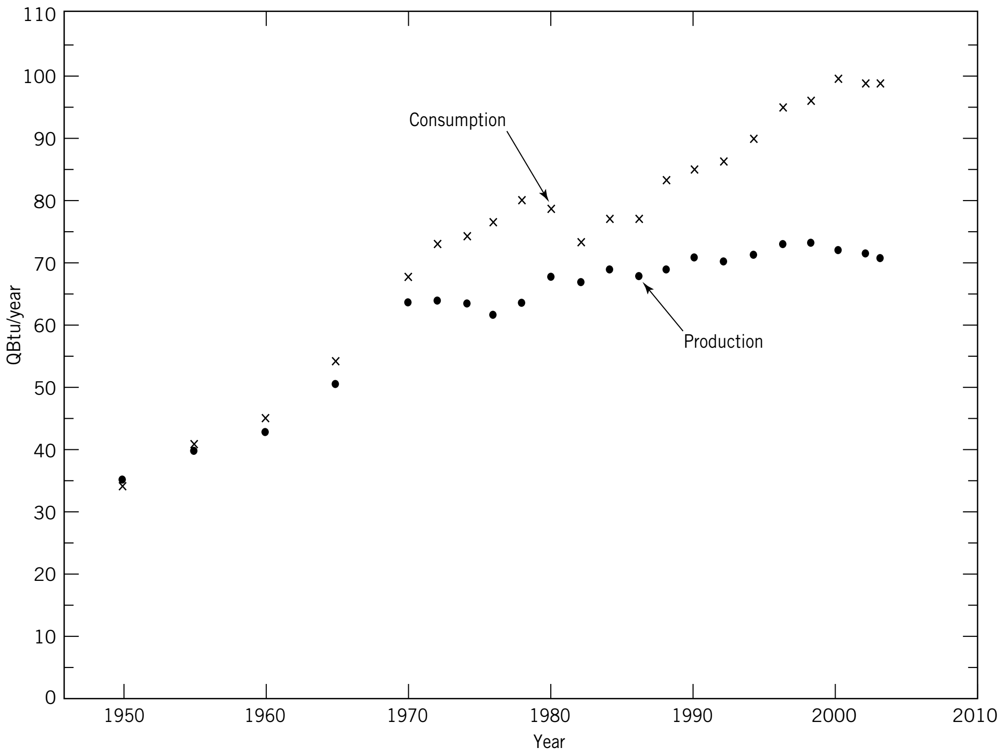


Figure 1.8 The total energy consumption and production in the United States since 1950 in quadrillion British thermal units (QBtu) per year. (*Source*: Washington, D.C.: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 2003*.)

least expensive energy conservation measures had been implemented, the energy consumption curve began to rise again. During this entire period, the national population increased at about 1% per year; this accounts for some of the increases seen.

In Figure 1.8, we see that until about 1957, the energy consumed was about equal to the energy produced in the United States. In fact, because of coal and petroleum exports, for some years in the 1940s and 1950s, production exceeded consumption. Beginning in 1958, however, our energy consumption has been greater than production for every year, indicating a generally increasing trend in this direction. Our energy production has remained relatively constant since about 1980. Production of oil and natural gas has gone down, and coal production has increased. Our country is now experiencing a serious imbalance of international trade due in part to the cost of importing oil to fill the gap between our rising consumption and declining production.

Energy consumption can be related to the general well-being of a country's populace. The advantages of convenient transportation, abundant food and water, comfortably heated and cooled residencies and places of work, ample production of goods, and many other aspects of the good life involve the consumption of energy. So what is the problem with a high level of energy consumption? As we discussed earlier in Section 1.1, the problems arise in two areas. The first has to do with resource depletion. We saw earlier that the majority of our energy supply is derived from fossil fuels. The resources of coal, petroleum, and natural gas are being depleted both in the United States and throughout the rest of the world at alarming rates. For the moment, the United States has sufficient resources of coal and natural gas to meet the needs of the country. We have consumed more natural gas than we have discovered nearly every year for the past 25 years, and we will probably see shortages within a decade or two. Production of petroleum from domestic sources has gone down rather steadily since 1970. In 2003 we produced only 62% of the amount of petroleum produced in 1970, while our consumption went up by 24%. We now import considerably more than half of the petroleum that we use. The balance-of-trade deficit is seriously affected by these purchases, which are likely to increase with time.

The second aspect of the problem is more general in that it relates to the emission into the atmosphere of the by-products of burning any fossil fuel. With petroleum and coal being the worst culprits, effects on the atmosphere both locally and globally are well documented. The rate at which we are burning fossil fuels worldwide has reached a point where restraint must be considered.

1.7 The Principle of Energy Conservation

A well-established law of physics states that the total energy in an isolated region cannot change. By "isolated," it is meant that energy can neither enter nor escape that region. In other words, the total energy in the region is conserved, even though it may be transformed from one form of energy to another. Energy cannot be created or destroyed. This is *The Principle of Energy Conservation*, quite different from the more general ideas about reducing waste of energy.

As an example of The Principle of Energy Conservation, imagine that you have a perfectly insulated box (the isolated region) containing only air and a battery connected to a lightbulb by wires. When the connection is made, a current flows and the chemical energy in the battery becomes electric energy and heats up the filament in the lightbulb. Then electromagnetic energy in the form of light and infrared radiation travels throughout the interior of the box where it becomes heat energy in the air and other materials. After the wires are disconnected, the amount of heat energy that has been added to the lightbulb, the air, the wires, the battery, and the interior of the box will be exactly equal to the chemical energy taken from the battery. The filament in the bulb eventually transfers its heat energy to everything inside of the box and cools from its highest temperature to a new temperature somewhat warmer than its original temperature before the connection was made. The total energy inside the box will be the same before and after the electrical connection is made. It should be noted, however, that the energy originally stored in the battery was in a much more useful form than the heat energy that was created in the lightbulb. Although, according to The Principle of Energy Conservation the total energy remains the same, its usefulness for performing tasks has certainly been diminished.

When the energy was in the form of chemical energy in the battery, it could have been used for powering a motor, lighting a bulb, sounding a horn, and so forth. None of these things can be done with the heat energy finally stored in the box, even though the number of joules is the same. One might say that in this experiment the usefulness of the energy has been degraded, or that it is of a lower form, but nevertheless the energy has been conserved.

Our other common use of the words *energy conservation* is distinct from The Principle of Energy Conservation and applies to the idea of using less energy to perform a given task. An example of energy conservation would be the installing of better insulation in the walls of a house in order to allow one to maintain the interior at a comfortable level on a cold winter day with the use of less fuel in the furnace. Chapter 7 of this book is devoted to discussion of practical ways of achieving energy conservation goals.

At times the two usages of *energy conservation* can be confusing, but usually the nature of the discussion leaves little doubt as to what is meant.

1.8 Transformation of Energy from One Form to Another

We can gain an understanding of energy in our everyday lives by examining some of the ways in which transformation of energy from one form to another takes place. Let's start with the sun. Consider first Figure 1.9. We have known for at ← F9
least the past 70 years that nuclear fusion reactions are taking place on a very large scale deep in the interior of the sun. Before the 1930s it was not understood in detail why the sun is so hot. But now we know that the dominant solar

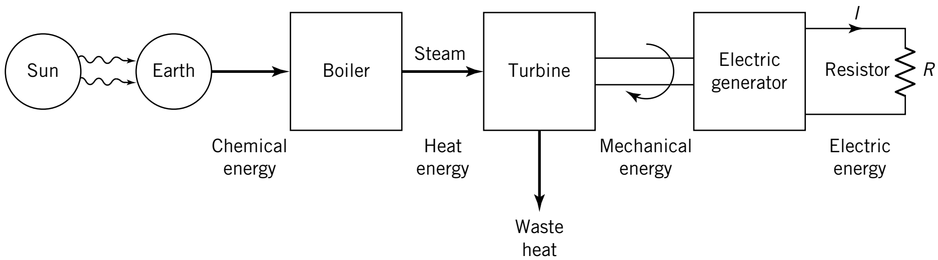


Figure 1.9 Steps in the transformation of the nuclear fusion energy in the sun to the electric energy used in a residence or industry. This example involves a time period of hundreds of millions of years.

fusion reaction is one in which helium is formed following the fusion of hydrogen nuclei. The net effect is to transform nuclear mass into heat energy. This heat energy raises the temperature of the sun's surface to a very high value, high enough to make the surface glow and radiate energy in the form of sunlight. Sunlight is a form of electromagnetic energy; it is radiated outward in all directions and a small part of the total radiated energy is incident on our planet, earth.

The earth has been bathed in this solar radiation since the time of its formation about 5 billion years ago. For the past hundreds of millions of years, plants have captured electromagnetic energy and formed the organic material which makes up the plants through the process of photosynthesis. The ancient plants, and the animals that lived off the plants, were then transformed over the ages into the chemical compounds we call fossil fuels.

We now extract the fossil fuels from beneath the earth's surface to provide fuel for the needs of society. To follow the energy transformation pathway further, let us consider coal that was mined to fuel the boilers of an electric utility plant. The chemical energy in the coal is transformed through the process of burning into heat energy which boils water into high-pressure steam to drive a turbine. The mechanical energy of the rapidly rotating turbine is then transformed into electrical energy by the generator attached to the shaft of the turbine. Then the electrical energy is transmitted over high-voltage transmission lines to the final users.

The electrical energy entering a home is used for light, heat, television, and so forth. For example, suppose that an electric oven is turned on for 45 minutes to cook a frozen pizza. The heat energy in the materials of the oven itself, in the air inside, and in the pizza will soon result in a warming of the air in the kitchen. The warm kitchen air will lose its energy to the rest of the air in the house, and then the heat energy in the house air will eventually find its way to the outside atmosphere. The heat added to the atmosphere will very slightly raise its temperature. The atmospheric heat energy then is radiated off into the coldness of space. The radiated energy does not disappear; it's added to the background energy of the universe.

Thus, in heating up the kitchen oven, we have drawn on nuclear fusion energy from the sun, transforming it from one kind of energy to another many times in the process. Energy is conserved in each transformation.

1.9 Renewable and Nonrenewable Energy Sources

In dealing with energy resources and energy use it is often necessary to distinguish between *renewable* and *nonrenewable* resources. The *nonrenewable resources* are those that could be exhausted within a relatively short time as a result of our exploiting them; *renewable resources* can never be consumed to completion. There is not always complete agreement on the definitions of *renewable* and *nonrenewable*. Some would classify a given category of resource under the heading of renewable, while others, for equally valid reasons, would consider it nonrenewable. We will see this in the case of geothermal energy as an example.

1.9.1 Nonrenewable Energy Sources

Examples of nonrenewable energy sources would be the following: all the fossil fuels (coal, oil, natural gas, shale oil, tar sands, etc.), uranium-235 nuclear fission fuel, deuterium nuclear fusion fuel, and some types of geothermal energy. The time to exhaust a nonrenewable resource depends on the rate of use and size of the resource. We might estimate a time of several centuries to exhaust the entire stock of fossil fuels, several decades for the earth's uranium-235 with a vigorous program of energy from nuclear fission, and a few decades to use up the heat energy at some local geothermal sites. In this sense we could classify geothermal energy as nonrenewable. Although it may be true that fossil fuels are continually being produced far underground from biomass, the time scale for this conversion is hopelessly long for our purposes. It takes perhaps a hundred million years for natural processes to produce useful amounts of petroleum, natural gas, or coal.

It is likely that most forms of nonrenewable energy will get more expensive when they are near exhaustion. It's simply a matter of supply falling short of demand.

1.9.2 Renewable Energy Sources

We have only three sources of renewable energy: solar, geothermal, and tidal.

All energy sources based on the solar energy incident on earth—direct sunlight, wind, hydroelectric power, ocean currents, ocean thermal gradients, and biomass—are renewable. In these cases the time to exhaustion depends on the life of the sun itself, which is certainly far beyond the time period important to any discussion of energy sources for humanity. The rate at which we use solar energy does not affect its lifetime. Whatever solar energy source we put into use will continue to be available, or can be soon renewed. An example would be firewood, which can be grown indefinitely, season after season, as long as water and plant nutrients are available. Another example would be food derived from biomass. This energy can be put to various uses, as shown in Figure 1.10.

F10→

Some local geothermal energy sites might be depleted fairly quickly through use, but they will again become available in several centuries as the earth's inner heat sources (which have effective lifetimes of billions of years, because of the half-lives of radioactive nuclear decays) supply heat energy to the geothermal regions near the earth's surface. This is renewal on a fairly long time scale but is still consistent with geothermal energy being considered renewable.

The energy in the oceans' tides has its origin in the gravitational interaction between the earth and the moon and, to a lesser extent, between the earth and the sun. Our harnessing of this tidal energy will not reduce the magnitude of the total gravitational energy appreciably within the foreseeable future, so we classify tidal energy as renewable.

It is a remarkable fact that, in contrast to the case of nonrenewables, renewable energy will tend to become less expensive as the scale of its use in-

Figure 1.10 The world's first sustained flight powered by renewable energy in the form of food for humans. On August 23, 1977, the *Gossamer Condor* flew a distance of 1.3 miles in under seven minutes in a figure-eight pattern around two markers a half mile apart. It was powered by Bryan Allen, who provided the one-third horsepower required for the flight.

creases. To the extent that the supply is unlimited, mass production of the energy extraction technologies will lead to reduced per unit costs. In some limited cases this argument may fail, as when all the prime hydroelectric sites are being utilized, or when we rely too much on marginal yields of firewood. In general though, *the more renewable energy we use, the cheaper it will be*, and there will always be more for succeeding generations. What could be nicer?

Because of concerns over resource depletion and environmental damage, the use of renewable energy presents an option that is often preferable to the use of nonrenewables. We often are tempted to associate the use of renewables with "good" and the use of nonrenewables with "bad," but let's not rush to dam the Grand Canyon for renewable hydroelectricity when we can still find other options, even including nonrenewables. In the United States, we are seeing increasing interest in obtaining energy from renewable sources, but the progress is painfully slow. In 2003, only about 6.3%, or 6.15 QBtu of a total of 98.2 QBtu, came from renewable sources.

Key Terms

Energy efficiency
The Principle of Energy Conservation
Energy consumption
Energy production
Fossil fuels
Renewable and nonrenewable energy
British Thermal Unit (Btu)
Foot-pound (ft·lb)
Joule (J)
calorie (cal)
Calorie (Cal)
Watt (W)
Horsepower
Geothermal
Hydroelectric
Energy conservation
Nuclear fission
Nuclear fusion
Work
Chemical energy
Newton (N)
Heat energy
Mass energy
Mechanical energy
Potential energy
Electric energy
Electromagnetic radiation
Energy transformation

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Questions and Problems

1. What are the two major problems created by depending on fossil fuels for most of our energy?
2. Give three examples of work that you have done the past week. Use the physics definition of work.
3. If you push a cart along a horizontal surface with a force of ten pounds, and the cart moves ten feet, how much work have you done in ft·lbs? In joules?
4. Since energy is conserved, where has the energy gone in question 3? Where did it come from?
5. If you throw a ball straight up into the air, at some time it will stop rising and return to you. What form of energy did the ball have just after being thrown? What form of energy did it have exactly at the top of its path? What forms of energy did it have just before and just after being caught?
6. What are some possible ways to provide energy for society after all the fossil fuels on earth have been consumed?
7. How many tons of coal would be needed each year to provide for the entire energy needs for the average person in the United States?
8. A bicyclist on a flat road expends energy at the rate of 80 watts. How many calories of energy are expended in five minutes of pedaling?
9. What happens to all the energy radiated by the sun that does not impinge on the earth or other planets?
10. Solar energy is incident on a black parking lot with an intensity of 1000 W/m^2 and 90% of it is absorbed. What is this in Btu/hr per square meter and per square feet?
11. A windmill produces 1400 watts of electric power that is used to heat water. The efficiency is 100%. How long will it take to raise the temperature of 40 gallons of water by 50°F?
12. Assume that the population of the United States increases by 1%/yr. How many Btu of energy will have to be added to the national annual energy budget this year to maintain the same per capita expenditure? What is this in gallons of petroleum if it all comes from petroleum? In tons of coal?

Multiple Choice Questions

1. The product of $(5 \times 10^5) \times (6 \times 10^6) \times (7 \times 10^7)$ = ________
   a. 18×10^{18}
   b. 18×10^{20}
   c. 18×10^{210}
   d. 18×10^{180}
   e. 210×10^{210}
   f. 2.1×10^{20}
   g. 20×10^{21}
   h. 2.1×10^{212}
2. A car has a mass of 2000 kg and is traveling at a speed of 30 m/sec. What is its kinetic energy in joules?
   a. 4.5×10^3
   b. 1.5×10^4
   c. 3×10^4
   d. 1.5×10^5
   e. 3×10^5
   f. 4.5×10^5
   g. 9×10^5
3. A 5 kg mass is attached to the end of a string 2 meters long. The other end of the string is fixed to a hook to make a simple pendulum. Initially, the mass is held so that the string is horizontal. The mass is then released. At the point when the string is vertical, what is the kinetic energy of the mass?
   a. 10 joules
   b. 49 joules
   c. 98 joules
   d. cannot be determined because we do not know the velocity
4. Per person, the energy consumption in the United States is about 3.3×10^8 Btu/yr. This is equivalent to a power of
   a. 11.0 W
   b. 11.0 W
   c. 11.0 MW
   d. 11.0 kW
   e. 110 kW
   f. 1.10 kW
   g. 11.0 QW
   h. 0.11 kW
5. A typical U.S. citizen consumes ___ times as much energy as does a typical citizen of India.
   a. 6
   b. 300
   c. 2
   d. 25
6. What is the potential energy increase of a 1000 kg auto driven up the 1000 meter elevation gain from Boulder to Nederland, CO?
   a. 1×10^6 joules/sec
   b. 9.8 joules
   c. 1×10^5 Btu
   d. 1×10^6 joules
   e. 9.8×10^5 watts
   f. 9.8×10^6 joules
7. In the United States, the average person eats about 3000 food calories per day. What is the average power of this energy intake?
   a. 14.5 watts
   b. 145 watts
   c. 1450 watts
   d. 14,500 watts

8. The principle of energy conservation is

a. a possible means for extending our fossil fuel reserves
b. inconsistent with the motion of a pendulum
c. a law of physics often violated in thermodynamic systems
d. a law of physics with no known exceptions
e. obeyed in chemical reactions but not in nuclear reactions.

9. In the United States, fossil fuels account for about ___% of our energy use. (Do not consider direct use of solar energy in this context).

a. 30
b. 50
c. 85
d. 91
e. 99

10. Kinetic and potential energies are energies of ___ and ___, respectively.

a. springs and gravity
b. solids and liquids
c. position and motion
d. motion and position
e. force and power

11. The total mass energy of one pound of anything is about:

a. 9×10^{16} J
b. 4×10^{16} J
c. 4×10^{19} J
d. 3×10^{8} J
e. 1.36×10^{8} J
f. 1.36×10^{11} J

12. One horsepower for one hour represents how many joules?

a. 44,760
b. 2,685,600
c. 33,390,960
d. 746
e. 3,413
f. none of the above

13. $$\frac{(4.8 \times 10^{9}) \times (3.6 \times 10^{5})}{2.8 \times 10^{10}}$$

a. 2.76×10^{5}
b. 3.00×10^{35}
c. 6.17×10^{4}
d. 9.42×10^{24}
e. 8.40×10^{45}
f. 49.8×10^{5}

14. Classify the following terms according to whether they represent energy (E), power (P), or neither (N).

a. calorie ___
b. horsepower ___
c. joules/sec ___
d. joule·sec ___
e. kilowatt/hour ___
f. watt ___
g. Btu/hr ___
h. kilowatt·hour ___
i. Btu ___
j. horsepower/day ___

Chapter 1

Ed1
Art in file doesn't match msp.

Au1
OK to omit, or clarify cross-reference.