CHAPTER 1

ENERGY AND POWER IN TODAY'S WORLD

An enormous amount of energy is used by humanity on a daily basis around the world, with unfortunate environmental consequences such as smog, acid rain, and global warming. This first chapter explores the energy sources that are employed at present, discusses the ultimate fate of all the energy that is used on Earth, and provides quantitative measures of how much energy is used from a variety of sources.

1.1 SOURCES OF ENERGY

Various sources of energy are available to the human race for day-to-day functions such as cooking, transportation, and heating. It might seem at first glance that there are many energy sources. For instance, buildings are often heated with oil, gas, wood, solar energy, or electricity generated from coal, gas, falling water, nuclear energy, or wind. Nonetheless, we will see that at the most fundamental level, there are only three energy sources available on Earth. In the next few pages, we give a brief introductory discussion of energy sources, all of which will be described in more detail in later chapters.

Fossil Fuels

About 90% of the energy used in the world today is provided by fossil fuels: oil, natural gas, and coal. The energy stored in these fuels — often referred to as chemical energy — is a combination of electric potential energy of the electrons and nuclei that constitute atoms and molecules, and the kinetic energy (energy of motion) of these electrons.

Where did this fossil-fuel energy come from? As you probably know, fossil fuels were created by the action of pressure and heat on the remains of plants and animals that lived hundreds of millions of years ago. The fundamental source of energy for these plants and animals was the Sun; plants use the energy of sunlight to convert carbon dioxide and water to carbohydrates (sugars and starches), some animals eat plants, other animals eat these animals, etc. So when we use gasoline to power our automobiles, natural gas to heat our buildings, and coal to generate electricity, we are actually using solar energy that has been stored for a long time.

But what provides the Sun's energy? In the Sun, hydrogen nuclei are fused together in a multi-step process, creating larger nuclei of helium and releasing energy. This process of combining small nuclei into larger ones — *nuclear fusion* — is the subject of much research in the hope of developing commercial fusion-energy sources here on Earth, but this prospect appears to be decades in the future.

Wind and Wave Energy

Although people are now starting to use the wind to generate electricity, it has been used for hundreds of years for sailing-ships and windmills (Fig. 1-1). Like fossil fuels, the wind is a form of stored solar energy: the Sun heats Earth's surface unevenly, thus developing regions of high and low air pressure, and the resulting air movements often cause high winds at ground level. Of course, solar energy is stored in the wind for a much shorter time than in fossil fuels.

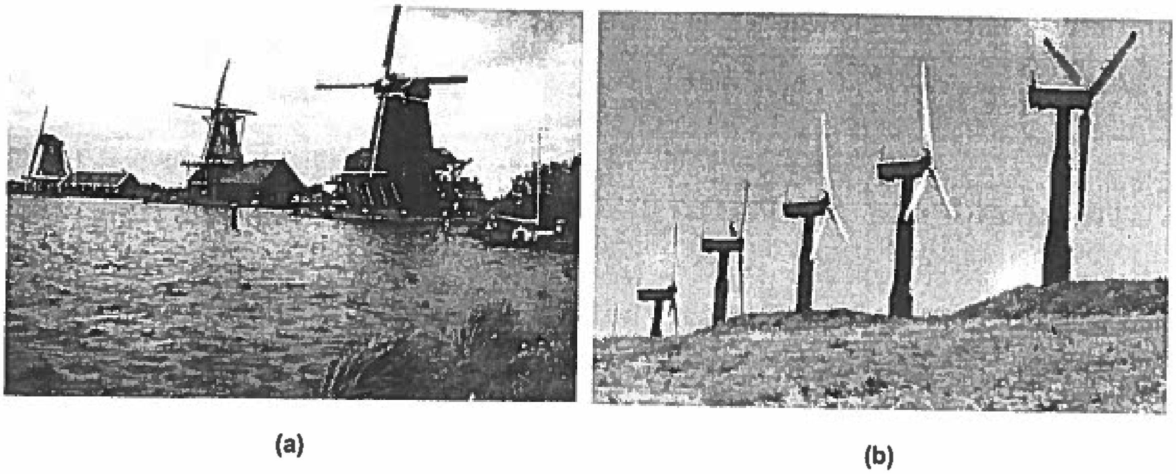
(a) (b)

Figure 1-1 (a) In the Netherlands wind has been used for centuries as a source of energy for small industries such as mills. (b) Modern electric-generating windmills.

Another source of energy, derived primarily from the wind, is wave energy. Except for wave-powered navigation buoys, wave energy is not yet economically competitive with other energy sources (especially inexpensive fossil fuels), and small pilot projects are progressing slowly.

Wind and wave energy are both examples of *kinetic energy*, or energy of motion. Mathematically, the kinetic energy (KE) of a moving object is defined as:

$$KE = \frac{1}{2}mv^2 \qquad [1\text{-}1]$$

where m and v represent the mass and speed, respectively, of the object.

Biomass Energy

There are many different energy sources that are categorized as biomass. Biomass refers to carbon-based material produced by plants and animals in recent years (up to decades). The largest contributor at present is wood, which is primarily burned for heating or cooking. Also included in this category are:

- crops such as sugarcane whose sugars can be fermented to produce ethanol, which can be used as a fuel;

- manure or garbage which produce methane gas through anaerobic digestion by bacteria;
- woody biomass which can produce either combustible gases (methane, hydrogen, and carbon monoxide) through a gasification process, or methanol, which is a liquid fuel.

Since all biomass results directly or indirectly from photosynthesis, biomass energy is yet another form of stored solar energy. Biomass provides medium-term storage of solar energy, whereas wind gives short-term storage, and fossil fuels represent long-term storage.

Hydro Energy

Another example of short-term stored solar energy is falling water, often called hydro energy. The Sun evaporates water from bodies of water and soil, the water forms clouds and eventually falls as rain, snow, etc. Where local geography happens to provide a large drop in elevation, then there is the possibility of using falling water to provide energy, usually for the generation of electricity.

The energy of the water (before it falls) is an example of *gravitational potential energy* (PE_{grav}). As the water falls, this gravitational PE is converted to KE of the water, and in the case of a hydroelectric station, this KE is used to turn a turbine generator, which produces electricity.

The gravitational PE of an object of mass m at an elevation h is defined as:

$$PE_{\text{grav}} = mgh \qquad \textbf{[1-2]}$$

where g is the magnitude of the gravitational acceleration (or gravitational field). Near the surface of Earth, the value of g is: $g = 9.80\ \text{m/s}^2$.

(Notice that when we say that an object has an elevation h, we mean that the *centre of mass* of the object has this elevation; for a symmetrical object such as a sphere or a rectangular box, the centre of mass is at the geometric centre.)

Direct Solar Energy

So far we have been discussing various types of stored solar energy, but of course solar energy itself can be used directly to provide heat or electricity. Solar energy is in the form of electromagnetic radiation, emitted from the Sun in many regions of the electromagnetic spectrum: ultraviolet, visible, infrared, microwave, and radio. The energy of this radiation is quantized in packets called photons.

Nuclear Energy

In common parlance, nuclear energy refers to the energy released in the fission, or breaking apart, of a large nucleus (typically uranium) to produce two mid-sized nuclei. This *nuclear fission*, which occurs in a controlled way in a nuclear reactor, generates large amounts of heat that can be used to make steam and turn a turbine for the generation of electricity or for motive power, as in a nuclear-powered submarine.

Uranium is a naturally-occurring element in Earth, and its formation was not due to the Sun; thus, nuclear energy is the first energy source discussed here that is not derived from solar energy.

Geothermal Energy

Most people are aware that Earth's temperature increases with depth below the surface, and that there are regions where Earth's surface is extremely hot, producing hot springs and geysers. This surface heat can be exploited as an energy source. But what generates this heat? Some elements in Earth — uranium, thorium, and radium, for example — are naturally radioactive and decay by emitting high-energy particles that heat the surrounding material. And so geothermal energy is actually a derivative of natural nuclear energy.

Tidal Energy

The final energy source in this discussion is the tides. In a few locations around the world, the tides are high enough on a regular basis that it is feasible to consider trapping the water with a dam at high tide, and allowing the water to run out through turbines at low tide to generate electricity.

Tidal energy is neither solar nor nuclear in origin, but comes from the gravitational *PE* and the *KE* of the Earth-Moon-Sun system. The gravitational *PE* is associated with the separation of the three bodies, and the *KE* is associated with Earth's rotation and the orbital motion of the bodies about each other.

Electricity

You might be wondering where electricity fits into the energy picture. Electricity itself is not a source of energy — it must be generated by a source such as a nuclear reactor, falling water, or fossil-fuel burning. Electricity is sometimes referred to as an *energy currency*, which (like monetary currency) serves as a medium of exchange between a raw source of energy such as coal and a convenient end-use such as lighting. Another term used to describe electricity is *energy carrier,* that is, something that carries energy from a producer to a user. Another potential energy currency or carrier is hydrogen, which is discussed in a later chapter.

Fundamental Sources of Energy

You can now understand why it was stated at the beginning of this Section that there are only three fundamental sources of energy that are available to us. All the sources that we have mentioned — fossil fuels, geothermal energy, tides, etc. — are derived either from solar energy, or nuclear energy, or (in the case of the tides) the gravitational *PE* and the *KE* of the Moon, Earth, and Sun. Table 1-1 summarizes the connection between the various derived sources and their fundamental sources. Of course, since solar energy results from nuclear fusion, we could classify solar energy as nuclear energy, and list only two fundamental sources. However, because of the importance of solar energy to life on Earth, it has been considered separately as a fundamental source.

Table 1-1
Fundamental Energy Sources Corresponding to Various Derived Energy Sources

DERIVED ENERGY SOURCE	FUNDAMENTAL ENERGY SOURCE
Fossil fuels	Solar energy (nuclear fusion)
Wind	"
Waves	"
Biomass	"
Hydro	"
Direct solar energy	"
Nuclear energy (reactors)	Nuclear energy (fission)
Geothermal energy	Nuclear energy (radioactive decay)
Tides	*KE* and grav. *PE* of Earth-Moon-Sun

1.2 ULTIMATE FATE OF EARTH'S ENERGY

Section 1.1 briefly listed several energy sources. It is important to consider what eventually happens to all the energy that people consume, whether for transportation, heating, communications, lighting, or whatever. The electricity generated in a coal-fired power plant is a representative example.

In the electric power plant, coal is burned in a furnace, thereby producing heat to convert water to steam; some of the *heat is lost* up the chimney. The hot high-pressure steam is used to turn turbine generators to produce electricity, and is then condensed back to liquid water (to begin the cycle again) by being cooled by water from, say, a lake or river. This cooling water is then returned to the lake or river, which *becomes hotter* as a result.

The electricity that is generated is transmitted by power lines to the customer; some of the energy is lost as *heat* in the transmission lines themselves. This lost energy is typically about 10% of the total energy transmitted.

The consumer now uses the electricity in a light bulb, for example. For an incandescent light bulb, only about 5% of the electrical energy goes into light; the rest appears as *heat*. (Put your hand near a light bulb if you don't believe this.) The light is radiated outward from the bulb, and is absorbed by surrounding objects: walls, furniture, people, etc. As a result of this absorption, the surrounding objects *become slightly hotter*.

By considering together all the statements that appear in italics in the preceding paragraphs, you can see that *all* the energy in the coal is eventually converted to heat. This complete conversion to heat is true for all energy processes here on Earth. (As another example, consider the kinetic energy of an automobile travelling down a highway: when the brakes are applied, all the kinetic energy is converted to heat in the brakes.)

And what happens to this heat? It gets radiated away into space as electromagnetic radiation. Any object at a temperature above absolute zero emits such radiation; for objects at typical temperatures on Earth (about 20°C), this radiation is primarily in the infrared region of the spectrum, although there is also some in the microwave and radio regions. This invisible radiation is sent out into space and lost to us forever. In other words, there is only one chance to use the energy available to us, and it is then irretrievably gone.

1.3 UNITS OF ENERGY

One of the unfortunate facts of life in the energy field is the plethora of units in common use. Energy values can be quoted in calories, barrels of oil, electron-volts, British thermal units, etc., and in order to make sense of all these units, you will need to be adept in converting one unit to another. See Appendix I for a link to a Web-based tutorial on this subject if you need help.

In this book as throughout the scientific and technological community, the units used are generally those of the SI (Système International d'Unités). The SI unit of energy may be determined by using the definition of, say, kinetic energy given by Eq. [1-1]:

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

On the right-hand side of this definition, the SI unit for mass m is kg, and the unit for speed v is m/s. (The "½" is unitless.) Thus, the unit for $\frac{1}{2}mv^2$ is $\mathrm{kg{\cdot}m^2/s^2}$. By convention, this unit is called the *joule* (J), named after James Prescott Joule (1818-1889), an outstanding British experimental physicist who was one of the leaders in the development of the principle of conservation of energy.

$$\mathrm{kg{\cdot}m^2/s^2} = \text{joule (J)}$$

Although this unit was developed using kinetic energy, the same unit arises regardless of the type of energy considered. You might wish to use the definition of gravitational potential energy given in Section 1.1 to show that its SI unit also works out to be $\mathrm{kg{\cdot}m^2/s^2}$.

Another energy unit is the calorie (cal), originally defined as the heat required to raise the temperature of one gram of water from 14.5°C to 15.5°C. The calorie was introduced as a unit of heat about two centuries ago, when it was thought that heat and energy were different quantities. Today the US National Bureau of Standards defines the calorie in terms of joules, with no reference to the heating of water:

$$1 \text{ cal} = 4.184 \text{ J (exact)}$$

You have undoubtedly encountered another type of calorie in connection with food consumption: the food calorie, or Calorie (Cal). (Notice the upper case "C.") This Calorie is 1000 cal, or 1 kcal (kilocalorie), which is equivalent to 4184 J, or 4.184 kJ.[1]

$$1 \text{ Cal} = 1 \text{ food calorie} = 1 \text{ kcal} = 4184 \text{ J} = 4.184 \text{ kJ}$$

In North America, food energy is still commonly measured in the archaic Calories, but civilization is proceeding at a more rapid pace in some other countries, where joules are being used (Fig. 1-2).

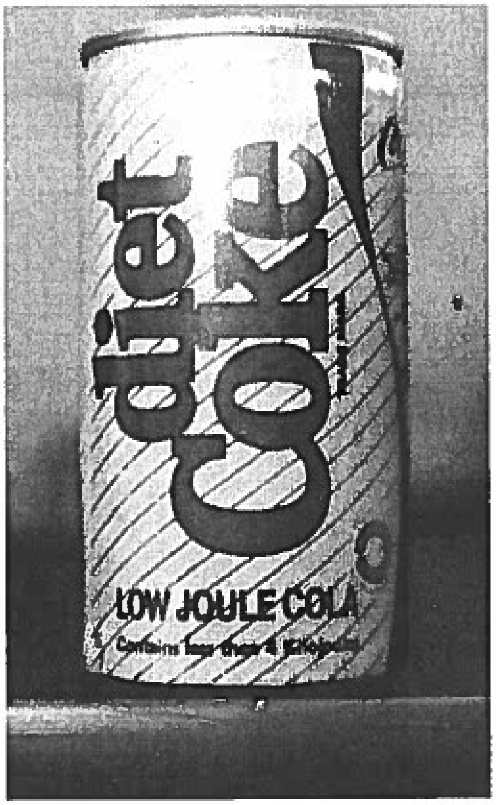

Figure 1-2 SI units are taken seriously in Australia.

Another unit of energy frequently used in North America is the British thermal unit (Btu); furnaces and air conditioners are often rated in terms of how many Btu of heat energy they can supply or remove per hour. The definition of the Btu is similar to the original definition of the calorie: 1 Btu is the amount of heat energy required to raise the temperature of one pound of water from 63°F to 64°F. In joules, this is [2]:

$$1 \text{ Btu} = 1055 \text{ J}$$

A huge quantity of energy is consumed in the world each year, and to express this amount of energy handily, we need correspondingly large units. One such unit is the quad:

$$1 \text{ quad} = 1 \text{ quadrillion Btu} = 10^{15} \text{ Btu}$$

Although calories, Btu's, and quads are still in use, they are gradually being replaced by SI units. For example, a quad and an exajoule ($1 \text{ EJ} = 10^{18} \text{ J}$) are roughly equal (as shown below), and exajoules are now being used more and more frequently instead of quads.

$$1 \text{ quad} = 10^{15} \text{ Btu} = 1.055 \times 10^{18} \text{ J (using 1 Btu = 1055 J)} = 1.055 \text{ EJ}$$

World energy consumption in 2005 was 445 EJ, of which 99 EJ was consumed in the USA. The US, which has about 5% of the world's population, is responsible for approximately 22% of the world's energy consumption. Canada consumed 13 EJ of

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[1] A table of SI prefixes, such as "k" for kilo or 10^3, appears in Appendix IV.

[2] There are also other definitions of the Btu, which result in values from 1054 J to 1060 J.

energy in 2005, which although obviously less than the US total, is actually somewhat higher than US consumption on a per-capita basis. The per-capita energy consumption in the USA and Canada (as well as the United Arab Emirates and Kuwait) is considerably higher than that of other countries.

Oil is a dominant energy source today, whether measured in calories of energy, in dollars of value, or in importance to international development. The price of crude oil in $US per barrel is an important general indicator of world energy prices, and is widely published in daily newspapers. As a result, consumption of energy resources other than oil is often quoted in terms of the amount of oil that would be required to provide the same amount of energy. The quantity of oil is usually given in barrels or in tonnes. (1 tonne = 1 metric tonne = 1000 kg ≈ 7.3 barrels.) For example, North American coal consumption in 2005 is tabulated in a variety of publications as "614 million tonnes of oil equivalent." Conversion to more conventional energy units is straightforward using the following (approximate) conversion factor:

$$\text{1 barrel of crude oil is approx. equal to } 5.8 \times 10^{9}\ \text{J}$$
$$\text{1 tonne of crude oil is approx. equal to } 4.2 \times 10^{10}\ \text{J}$$

A final energy unit, which is important in the study of subatomic particles, and which will be useful in our later discussion of nuclear reactors, is the electron-volt (eV). This unit is defined as the energy gained by an electron in passing through a potential difference of one volt. In joules:

$$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$$

Energies in the keV to MeV range are common for single subatomic particles.

1.4 ENERGY CONSUMPTION AND SOURCES

In Section 1.3 world energy consumption in 2005 was stated as 445 EJ. Figure 1-3 shows a breakdown of this energy according to source.[3] You can see that fossil fuels (oil, gas, and coal) account for 92% of world energy. This heavy dependence on fossil fuels is rather disturbing — the reserves of these fuels are finite, and there are serious environmental problems (climate change, air pollution, etc.) associated with using them.

How is all this energy used? About 38% is used by industry, another 38% by the residential and commercial sectors (including public buildings such as schools and government offices), and 24% in transportation. Oil is the dominant source for transportation, of course, and road vehicles account for half of the annual consumption of oil.

The hydroelectric and nuclear energy components in Fig. 1-3 together provide 5% of world energy as electricity. However, do not be misled into thinking that electricity

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[3] Sources: BP Amoco Statistical Review of World Energy 2006; U.S. Energy Information Administration

constitutes only 5% of world energy — fossil fuels are also used to produce electricity. Approximately 50% of annual coal consumption generates electricity, along with smaller percentages of gas and oil. Combining this fossil-fuel use with hydro and nuclear energy, a total of about 30% of world energy goes into the production of electricity.

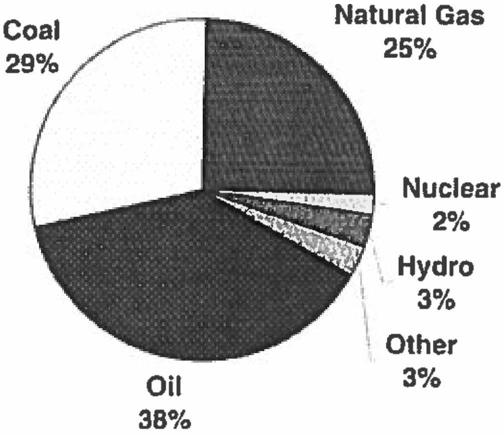

Figure 1-3 World Energy Consumption by Source in 2005

In some publications (including the previous edition of this book), the nuclear and hydro components of world energy consumption are stated as about 2.5 times larger than the quantities shown in Fig. 1-3. This is because nuclear and hydro electricity production is sometimes quoted in terms of the quantity of oil that would be needed to produce the electricity. When oil is used to generate electricity, about 60% of the energy goes into waste heat and only 40% into electrical energy. Hence, to produce a given amount of hydroelectric energy, for example, about 2.5 times that amount of energy would be needed if oil were used.

US and Canadian energy consumption by source are illustrated in Figures 1-4 and 1-5, respectively. Although the US source percentages are very close to the world values in Fig. 1-3, this is not the case for Canada. Fossil fuels account for 82% of Canadian energy, compared with 92% for the world, largely because of a smaller dependence on coal (13% for Canada versus 29% for the world). Hydroelectricity plays a larger role in Canada, supplying 12% of the energy, in contrast to only 3% in the world.

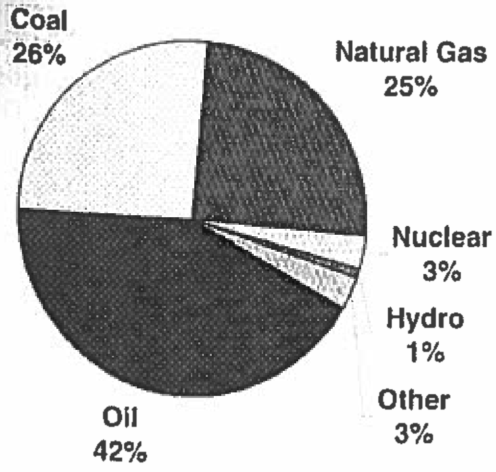

Figure 1-4 US Energy Consumption by Source in 2005

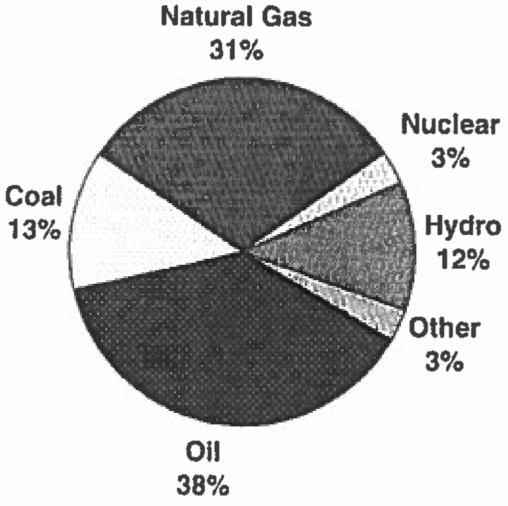

Figure 1-5 Canadian Energy Consumption by Source in 2005

1.5 POWER

In everyday speech, the words "energy" and "power" are often used interchangeably, but the scientific meanings of these words are different. Energy has already been discussed above, and now our focus turns to power. The SI unit of power, the watt, is one that you have undoubtedly heard of; for example, hair dryers and light bulbs are labelled according to their "wattage."

Power is the rate at which energy is used or provided, that is, power P is simply energy E divided by the time t during which the energy was used. For example, if a car's KE increases, the power input to the car is the increase in the KE divided by the time taken. Mathematically, power can be written as:

$$\text{Power} \quad P = \frac{E}{t} \qquad [1\text{-}3]$$

With energy in joules and time in seconds, the unit of power is joule per second (J/s), which is conventionally referred to as a *watt* (W):

$$\text{W (watt)} = \frac{\text{J}}{\text{s}}$$

Watts and kilowatts (kW) are often used to indicate the power consumption of home appliances such as light bulbs and hair dryers, and megawatts (MW) are used in describing power output of electrical plants. A 60-W lightbulb uses 60 J of electrical energy per second (but as stated in Section 1.2, only 5% of this energy is converted to light). As you sit reading this book, you use about 100 W of power, that is, each second you convert 100 J of food energy into other forms of energy (mainly thermal energy, which is then radiated away). A typical Canadian nuclear power reactor produces about 600 to 800 MW of electrical power, enough for 300 000 to 400 000 homes. At Niagara Falls, Ontario Power Generation produces a total of 2300 MW of power at five hydroelectric stations. The electrical power demand in the province of Ontario has a peak of about 26 000 MW or 26 GW, which occurs in midsummer. The solar power striking Earth's surface is 178 000 TW, or 178 PW.

Did You Know? The watt is named after James Watt (1736-1819) who did not, contrary to common opinion, invent the steam engine. Using scientific principles he improved the efficiency of the engine, invented by Thomas Newcomen (1663-1729), making it a commercial success.

Another unit of power, often used in the automotive industry, is the horsepower:

$$1 \text{ horsepower} = 1 \text{ hp} = 746 \text{ W}$$

EXAMPLE 1-1

A small hydroelectric plant produces 250 kW of electrical power from water falling through a vertical height of 18 m. What volume of water passes through the turbine each second?

(Assume complete conversion of the water's gravitational potential energy to electrical energy.)

SOLUTION

In a hydro plant, the gravitational potential energy of the water is converted to kinetic energy as it falls, and then to electrical energy. Hence, the electrical power can be expressed as the gravitational potential energy lost by the water divided by the time:

$$P = \frac{mgh}{t}$$

where m is the mass of water falling through a vertical height h in time t, and g is the magnitude of the gravitational acceleration. Since we are asked for volume of water, the mass m is replaced with the product of density ρ and volume V:

$$P = \frac{\rho V g h}{t}$$

Re-arranging to solve for volume, and substituting numerical values:

$$V = \frac{Pt}{\rho g h} = \frac{(250 \times 10^3 \text{ W})(1.0 \text{ s})}{(1.00 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(18 \text{ m})} = 1.4 \text{ m}^3$$

Hence, a volume of 1.4 m^3 of water passes through the generator each second.

Kilowatt·hour — An Energy Unit

One of the most confusing units for the general public (and even for physics students) is the kilowatt·hour (kW·h). Because part of the unit is kilowatt, which is a unit of power, many people believe that the kilowatt·hour is a power unit. However, since the kilowatt is multiplied by a time unit (hour), the kilowatt·hour is actually a unit of energy, as shown below.

Since power is energy divided by time ($P = E/t$), then energy can be written as $E = Pt$. This relationship states that the product of power and time is energy (regardless of the particular units used). If SI units are used, power in watts multiplied by time in seconds gives energy in joules, that is, joule = watt·second. But power and time can be expressed in other units; if power has units of kilowatts and time has units of hours, then the product — still an energy — has units of kilowatt·hour (kW·h). An energy of 1 kW·h can be expressed in joules through a unit conversion, using 1 kW = 10^3 W, 1 W = 1 J/s, and 1 h = 3600 s:

$$1 \text{ kW}\cdot\text{h} \times \frac{10^3 \text{ W}}{1 \text{ kW}} \times \frac{1 \text{ J/s}}{1 \text{ W}} \times \frac{3600 \text{ s}}{1 \text{ h}} = 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}$$

Hence, 1 kW·h is equivalent to 3.6 MJ.

The kilowatt·hour is a very handy unit of electrical energy consumption, since the total power requirement of a house is often in the kilowatt range, and time can easily be measured in hours. Using joules for electrical energy would result in extremely large numbers. For electrical energy consumption at the national and world levels, gigawatt·hours (GW·h) and terawatt·hours (TW·h) are often used.

Electrical energy used in homes and businesses is normally priced by the kilowatt·hour. For example, in Guelph, Canada as of May 1, 2006, the residential price is 10¢ per kilowatt·hour for the first 600 kW·h used per month, and 11¢ per kilowatt·hour for all remaining kilowatt·hours in the month. In most other countries around the world, the residential price lies between 15¢ and 30¢ per kilowatt·hour.

EXAMPLE 1-2

What is the cost of the electrical energy consumed by a 100-W lightbulb that is turned on for 12 h? Assume a price of 11¢ per kilowatt·hour.

SOLUTION

To determine the energy in kilowatt·hours consumed by the lightbulb, the power in kilowatts is multiplied by the time in hours. Since the power is given in watts, this must first be converted to kilowatts:

$$100\ \mathrm{W} \times \frac{1\ \mathrm{kW}}{10^3\ \mathrm{W}} = 0.10\ \mathrm{kW} \quad \text{(assuming two significant digits)}$$

$$\text{Then, } E = Pt = (0.10\ \mathrm{kW})(12\ \mathrm{h}) = 1.2\ \mathrm{kW{\cdot}h}$$

$$\text{The cost of } 1.2\ \mathrm{kW \cdot h} \text{ is: } 1.2\ \mathrm{kW \cdot h} \times \frac{11¢}{\mathrm{kW \cdot h}} = 13¢ \quad \text{(to the nearest cent)}$$

1.6 ELECTRICAL ENERGY

Now that the kilowatt·hour has been introduced, we turn our attention to electrical energy around the world. A brief summary of important events[4] in the development of commercial electrical energy is presented in Table 1-2.

Table 1-3 provides an international comparison of electricity generation (in terawatt·hours) by fuel type for the world's 10 largest electrical energy-producing countries in 2003. Notice that over 65% of the world's electricity is generated by burning fossil fuels, primarily coal. This is followed by hydroelectric and nuclear generation, both approximately at 16%. The category "other," accounting for only 2% of world electricity, includes wind, solar, geothermal, and biomass. The USA leads all countries in total electricity generation, and Canada is the leader in hydroelectric production. Almost 60% of Canada's electricity is generated from hydro, compared to

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[4] Sources: *Electric Power in Canada 1990*, Energy, Mines and Resources Canada; A. Hellemans and B. Bunch, *The Timetables of Science*, Simon and Schuster, New York, (1988).

Table 1-2
Significant Developments in Electricity Production

Year	Event
1876	Alexander Graham Bell made first long-distance telephone call (218 km, in Ontario, Canada)
1879	Thomas Edison (U.S.A.) and Joseph Swan (England) each produce carbon-thread electric lamps that can be used for practical lengths of time
1880	Thomas Edison's first electric generation station opened in London
1881	First practical electric generator and electric distribution system were built
1881	First electric streetcar introduced in Berlin
1882	First hydroelectric power plant went into operation in Appleton, Wisconsin
1883	Canada's first street lights installed in Hamilton, Ontario
1884	Charles Algernon Parsons designed and installed the first steam turbine generator for electric power
1888	Nikolai Tesla developed an alternating current motor
1897	Canada's first long-distance high-voltage transmission line (11 kV) carried power 29 km to Trois-Rivières, Quebec
1921	Sir Adam Beck No. 1 generating plant, then the largest in the world, opened in Niagara Falls, Ontario
1956	First large-scale nuclear power plant designed for peaceful purposes opened in England
1967	Canada's first commercial-scale (220 MW) CANDU nuclear generating station entered service at Douglas Point, Ontario
2005	The contribution of wind energy to electricity in Denmark increased to 20%

only 16% in the world overall. Notice the large nuclear production in France: 78% of the electricity in this country, which has no oil or gas and only a little coal, comes from nuclear power.

As seen in Table 1-3 the mix of energy sources used for electricity generation varies greatly from country to country. As well, it varies on a local basis within a country, depending on resources available. For example, in the mountainous province of British Columbia, Canada, 90% of the electricity is generated from hydro resources, whereas in the relatively flat prairie province of Saskatchewan, burning fossil fuels provides 78% of the electricity.

Table 1-3
Electricity Generation in Terawatt·hours by Fuel Type, 2003
For the World's 10 Largest Electricity-producing Countries[5]

Country	Conventional Thermal (primarily coal)	Hydro	Nuclear	Other	Total
USA	2891	306	788	97	4082
China	1578	284	43	2	1907
Japan	681	104	240	22	1047
Russian Fdn.	606	158	150	2	916
Germany	377	24	165	33	599
Canada	164	338	75	10	587
France	56	64	441	6	567
India	535	75	18	5	633
U.K.	296	6	89	8	399
Brazil	33	306	13	13	365
World Total	11057 (66.0%)	2726 (16.3%)	2635 (15.7%)	324 (1.9%)	16742 (100.0%)

Installation Cost for Electricity Generation

There are many energy sources that can be used to generate electricity. However, there is wide variation in the cost to install the power-generating facilities. Figure 1-6 shows this cost in US dollars per kilowatt of power generation.[6] The technologies associated with generating electricity from each of these sources are discussed in later chapters.

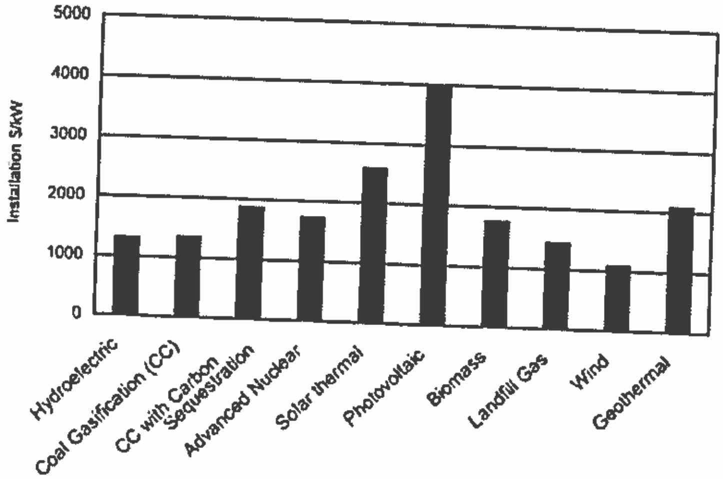

Figure 1-6 Installation Cost for Electricity Generation

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[5] International Energy Agency

[6] *Assumptions to the Annual Energy Outlook 2006*, US Department of Energy Website

EXERCISES

Please refer to the Appendices for useful information concerning unit conversions, significant digits, numerical constants, etc.

1-1. A truck of mass 4500 kg brakes to a halt from a speed of 82 km/h in a distance of 77 m.
(a) How much energy (in megajoules) must be dissipated?
(b) What happens to this energy?

1-2. By using conversion factors provided in Section 1.3 or Appendix IV, perform the following unit conversions.
(a) 5.82 Btu to Calories
(b) 22 tonnes of crude oil to quads
(c) 52 billion barrels of crude oil to quads

1-3. A sprinter, starting from rest, has a power output of 5.1×10^2 W for a time of 7.2 s. Neglecting losses due to production of heat, etc., determine his final speed. The sprinter's mass is 67 kg.

1-4. (a) By using the basic definition of a watt (and the meaning of kilo), determine how many joules there are in one kilowatt·hour.
(b) Convert 581 kW·h to joules.

1-5. The solar energy striking Earth's surface every year is 178000 TW·yr. Convert this to joules.

1-6. (a) Given below are the electrical power requirements for five household appliances. Determine the number of kilowatt·hours of electrical energy consumed if all these appliances are running simultaneously for two hours in a house.

solid state colour TV: 145 W
automatic washing machine: 512 W
furnace fan: 500 W
clock: 2 W
humidifier: 177 W

(b) If the average residential cost for electricity is 12¢ per kW·h, what would be the cost (to the nearest cent) for the energy calculated in (a)?

1-7. The residential rates for electricity in Guelph, Ontario (as of May 2006) are 10¢ per kilowatt·hour for the first 600 kW·h used per month, and 11¢ per kilowatt·hour for all remaining kilowatt·hours in the month. If a family has a consumption of 1475 kW·h in a month, what is its average cost per kW·h?

PROBLEMS

Please refer to the Appendices for useful information concerning unit conversions, significant digits, numerical constants, etc.

1-8. In a 770-kW hydrolectric plant, 300 m^3 of water pass through the turbine each minute. Assuming complete conversion of the water's initial gravitational potential energy to electrical energy, through what distance does the water fall? Assume two significant digits.

1-9. Calculate the power in megawatts available from a tidal power scheme where the incoming tide fills up a catchment area enclosed by concrete walls, and then at low tide this water is allowed to fall through openings at the bottom of one of the walls to spin turbines. The square catchment area has 1.2-km sides, and the tide rises by 3.7 m. Assume that the process of emptying takes 1.0 h, and that all the energy of the water is converted to energy of the turbines. Hint: when using the expression mgh for gravitational potential energy, remember that h represents the height of the centre of mass.

1-10. (a) Suppose that an automobile is travelling at a constant speed on a horizontal road; the engine is running and obviously producing energy. Where does this energy go? (It does not go into kinetic energy of the automobile, because the kinetic energy does not change if the speed is constant.)
(b) An automobile moving at 90 km/h ascends a hill of gradient 1 in 25 (i.e., a vertical rise of 1 unit for a horizontal distance of 25). Its mass is 1300 kg. What power (in kilowatts) is needed for the climb up the hill over and above the normal power used when moving horizontally? Assume two significant digits.

1-11. The intensity of radiation from a distant source like the Sun varies inversely with the square of the distance from the source. At the top of Earth's atmosphere the solar intensity (power per unit area) is 1.35 kW/m^2. If a space ship with a solar panel of area 125 m^2 were halfway between the Sun and Earth, determine the total solar energy that the panel would receive in a day. Express your answer in kilowatt·hours and in joules.

ANSWERS

1-1. (a) 1.2 MJ (b) given in Section 1.2
1-2. (a) 1.47 Cal (b) 8.8×10^{-7} quads (c) 2.9×10^{2} quads
1-3. 1.0×10^{1} m/s
1-4. (a) 3.6×10^{6} J (b) 2.09×10^{9} J
1-5. 5.61×10^{24} J
1-6. (a) 2.67 kW·h (b) 32¢
1-7. 10.59¢ per kW·h
1-8. 16 m
1-9. 27 MW
1-10. (b) 13 kW
1-11. 1.62×10^{4} kW·h, 5.83×10^{10} J