

Energy Usage in the USA and the World

1.1 Energy and Power

A review of the customary units used for energy and power is appropriate to initiate a study of alternative energy sources and applications. Although much of the world uses the SI system (Le Système International d'Unités), the USA, in addition to the SI system, also uses the English Engineering and the British Gravitational systems of units. The unit of energy in the SI system is the newton meter (Nm) which is defined as the joule (J). Energy in the English Engineering system is defined as the British thermal unit (Btu), or alternately, the foot-pound force (ft lbf); the conversion factor is $1 \text{ Btu} = 778.16 \text{ ft lbf}$. Power is the rate of energy usage or transfer, in joules per second, British thermal units per second, or foot-pound force per second. Power expressed in joules per second is defined as the watt (W). The most frequently used power unit is 1000 W or 1 kW. In the USA, power is sometimes expressed in terms of horsepower (hp), where 1 hp is 550 ft lbf/s or 0.7457 kW. The kilowatt-hour (kW h) is a frequently used unit of energy and represents an energy rate (kilowatts) times a time (hour). The conversion is $3412.14 \text{ Btu} = 1 \text{ kW h}$. Anyone engaged in an energy engineering activity needs to remember the conversion between British thermal units and kilowatt-hours; in most instances $3412 \text{ Btu} = 1 \text{ kW h}$ is used.

Tester *et al.* (2012) provide a sampling of power expended for various activities. Some of their results are reproduced as Table 1.1.

The range of power expended is astonishing, about nine orders of magnitude. The entries of Table 1.1 indicate various levels of power expended referenced to everyday experiences and can be used to establish a sense of numeracy for power magnitudes.

1.2 Energy Usage and Standard of Living

An irrefutable fact is that developed countries (e.g., USA, Japan, UK) use more energy per capita than less-developed countries (e.g., Mexico, Indonesia). Figure 1.1 graphically presents the HDI (Human Development Index) as a function of the kilograms of oil equivalent (kgoe) per capita per year. The HDI is a measure of the standard of living, and the kilograms of oil equivalent per capita per year is indicative of the energy consumption. The industrialized nations have HDI values in excess of 0.9, while many of the developing countries' HDI values are dramatically less. The correlation between HDI and kilowatt-hour usage is functionally very strong. However, once a threshold of about 3000 kgoe per capita is reached, further increases in electricity usage do not produce a higher HDI. Iceland has the highest HDI, followed by the USA. Some countries with the higher kilowatt-hour usage have large infrastructure length scales and traditions of abundant energy. One of the main themes from Golemberg and Johansson (2004) is that the only way to increase the HDI in developing nations is to increase their energy usage.

Table 1.1 Power expended for various activities.

Activity	Power expended
Pumping human heart	1.5 W = 1.5×10^{-3} kW
Household light bulb	100 W = 0.1 kW
Human, hard work	0.1 kW
Draft horse	1 kW
Portable floor heater	1.5 kW
Compact automobile	100 kW
SUV	160 kW
Combustion turbine	5000 kW = 5 MW
Large ocean liner	200 000 kW = 200 MW = 0.2 GW
Boeing 747 at cruise	250 000 kW = 250 MW = 0.25 GW
Coal-fired power plant	1×10^6 kW = 1000 MW = 1 GW
Niagara Falls hydroelectric plant	2×10^6 kW = 2000 MW = 2 GW

An alternative approach is to examine the gross national product (GNP) per capita as a function of the energy consumption per capita. Figure 1.2a was developed using World Bank information from 1992. Figure 1.2b was developed from more recent World Bank data. The more recent data were mostly from 2012–2013, although data from some developing countries were less recent.

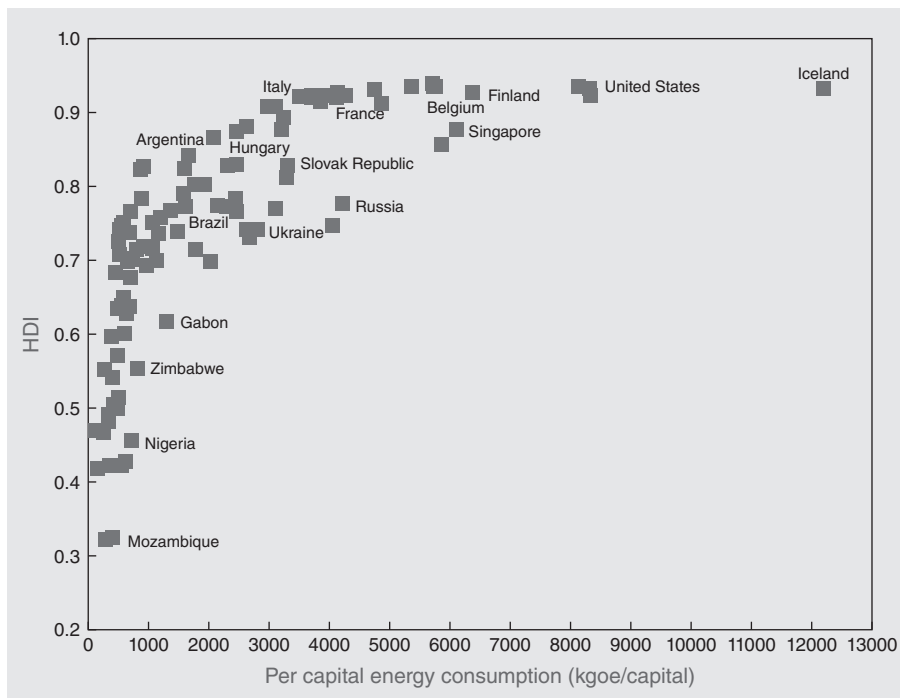


Figure 1.1 Human Development Index (HDI) as a function of per capita kilowatt-hour consumption. Source: Golemberg and Johansson (2004). Reproduced with permission of UNDP.

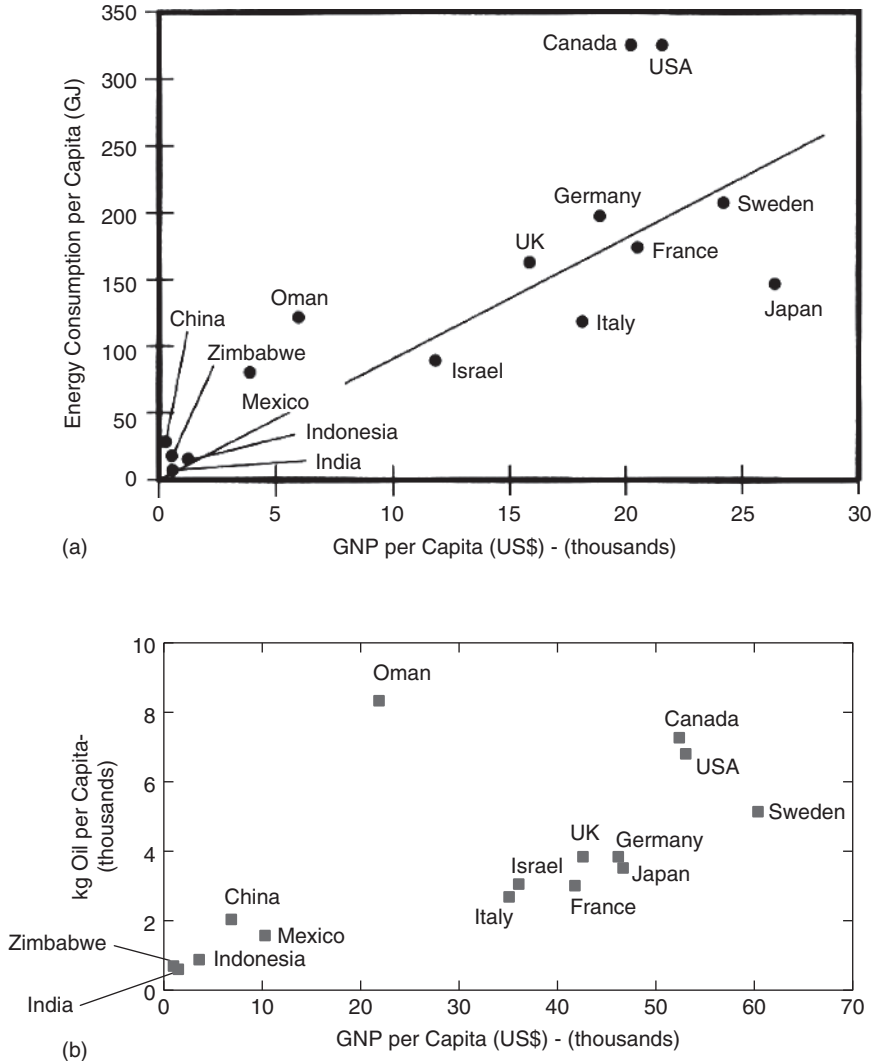


Figure 1.2 Per capita energy consumption versus GNP per capita for a number of countries. (a) 1992 World Bank data. *Source:* Tester *et al.* (2005). (b) Recent World Bank data (www.worldbank.org, 2012–2013).

The energy usage per capita information from the World Bank is presented in kilograms of oil equivalent per capita; hence, the ordinates for Figure 1.2a and b are in different energy units and the abscissas, in dollars, are not adjusted for inflation. A comparison of Figure 1.2a and b reveals no significant differences in relative positions for the developed countries, but China has made real gains in GNP per capita since the 1992 data, and, as expected, the energy use per capita has increased relative to other developing countries since 1992. In Figures 1.1 and 1.2, the USA exhibits per capita kilowatt-hours and energy usages that are large even for developed countries. A number of reasons exist for the high energy consumption per capita in the USA; among them are (1) historically cheap energy, (2) low population density, (3) large area (large infrastructure length scale), and (4) historically an abundance of domestic energy.

Starting with the first “energy crisis” of the late 1970s, low energy costs and domestic energy abundance seemingly vanished from the USA. From the 1970s through to about 2005, the USA required increasing energy imports (chiefly in the form of petroleum) and nearly

monotonic energy cost price escalations. The dependence on energy imports dramatically affected both the economy and the foreign policy posture of the USA. Indeed, the basis of the first edition of this textbook was the need to consider both alternative energy sources and alternative (read more efficient utilization) energy applications to address the energy problems faced in the USA. Since about 2005, increased domestic production of fossil fuels (by enhanced oil recovery via “hydraulic fracturing”) and identification of heretofore undiscovered natural gas reserves have altered the expected increases in both energy imports and energy prices. In effect, the US energy economy is being given another chance to reduce energy cost economic impacts via enhanced energy efficiency of existing resources. Chapter 17 examines this topic.

The energy problems in the USA are exacerbated by the demand and expectation of countries (e.g., India and China) to increase the standard of living for their citizens. World energy consumption is rising faster than energy consumption in the USA. Section 1.5 examines world energy consumption patterns.

1.3 A Historical Perspective of Energy Usage in the USA

The Energy Information Administration (EIA) of the US Department of Energy provides a readily accessible and up-to-date source of energy statistics. The EIA web site is www.eia.doe.gov. The EIA provides on a timely basis monthly and yearly energy statistics for the USA. These monthly energy statistics are available in the *Monthly Energy Review* (MER), and a yearly energy summary appears in the *Annual Energy Review* (AER) about 8 months after the end of the calendar year and can be accessed from www.eia.doe.gov/aer. As of 2012, the AER has been suspended because of budget concerns. The suspension of the AER is quite unfortunate as it was arguably the most useful of the EIA periodic documents. The basis for the information contained herein is from the MERs available online at www.eia.gov/totalenergy/data/monthly/.

Figure 1.3, a mosaic of satellite photographs at night of the USA, is a rather dramatic illustration of the population density and dispersion of the population of the USA as well as the energy intensity distribution of night lighting (primarily electricity usage).



Figure 1.3 Mosaic of night satellite photographs of the USA. *Source:* EIA.

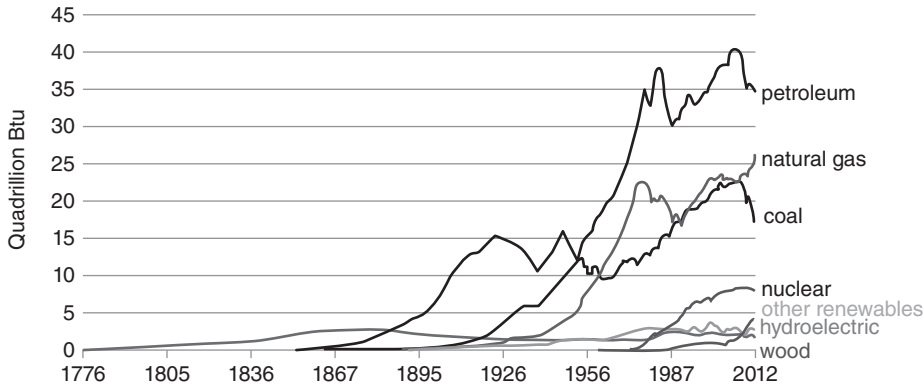


Figure 1.4 Historical energy utilization in the USA (1775–2012). *Source:* EIA.

Consider how the USA arrived at its current energy economy. Figure 1.4, taken from the EIA data, presents a graphical representation of the historical energy utilization. The energy usage unit used is the quad (quadrillion Btu is 10^{15} Btu). Until the mid-1800s, energy utilization was mostly wood, with coal becoming increasingly important after 1850. By 1900, coal usage was much greater than wood, and petroleum was becoming more important as an energy source. And in 1950, petroleum usage exceeded coal usage, and natural gas usage was dramatically rising. At the millennium, petroleum provided the most energy, with natural gas and coal vying for second and third place. Nuclear power was in fourth place, with hydroelectric and renewable energy (including wood) sources making the smallest contributions. Details of the energy utilization in 2014 will be explored in Section 1.4.

The genesis of the energy problem is illustrated in Figure 1.5. Until about 1950, the USA had little dependence on energy imports. However, with the post-World War II prosperity, energy exports began to increase since consumption increased faster than domestic production. From the 1980s to the early 2000s, domestic production increased, but at a rate slower than consumption increased. The result has been a steady increase in energy imports. However, starting about 2005, as demonstrated in Figure 1.6, the result of enhanced domestic production has resulted in a significant decrease in energy-related imports. Much of the increased

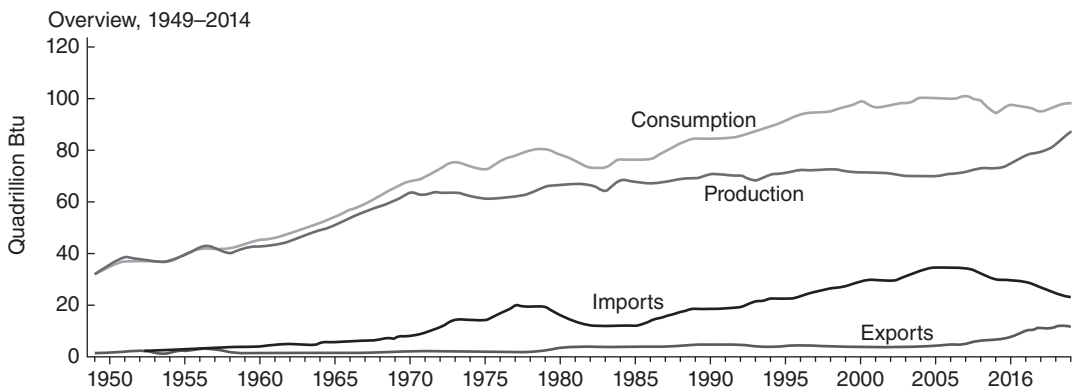


Figure 1.5 Energy consumption, imports, and exports for the USA. *Source:* EIA.

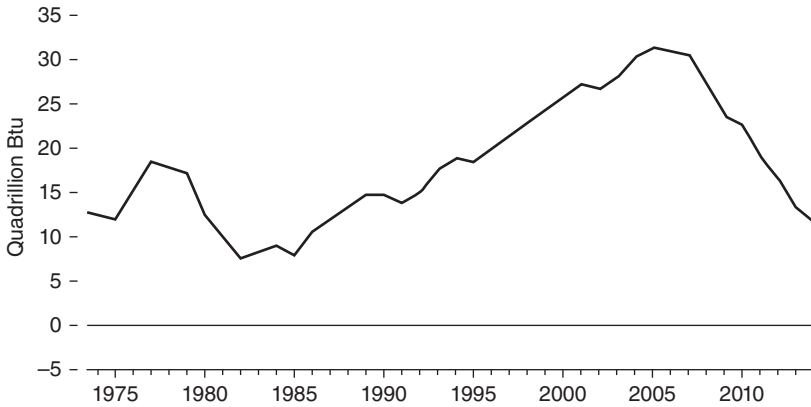


Figure 1.6 Energy imports since 1975. *Source:* EIA.

production has resulted from enhanced oil production from existing oil fields using hydraulic fracturing techniques (see Chapter 17).

Further understanding of how the USA arrived at the current energy consumption is provided in Figures 1.7 and 1.8. Figure 1.7 tracks the per capita energy consumption. Per capita energy consumption reached 344×10^6 Btu/person in 1980, decreased until 1985, and reached a peak at 346×10^6 Btu/person in 1995. Much of the behavior during the 1970s and 1980s was the response to the first “energy crisis.” Since 2005, the energy usage per capita has decreased, with the result that in 2014 the per capita energy consumption was 309×10^6 Btu/person. The 1970s energy crisis resulted in no dramatic decrease in per capita energy consumption in the USA; these results explain, in part, the current energy dilemma of the USA. In short, the USA failed to understand and heed the warnings of the first energy crisis. The energy usage per dollar of gross domestic product (GDP) is presented in Figure 1.8. Since the 1980s, the energy consumed per dollar of GDP has meaningfully declined from near 12 000 Btu/\$GDP to the current value of 6120 Btu/\$GDP (per chained 2009 dollar). Chained dollars are dollars that are adjusted to reflect inflation, “chained” to a base year (2009 in this case). This decline is attributed to increased energy efficiency, especially in manufacturing, and to structural changes (the migration of much energy-intensive industry to other countries) in the economy.

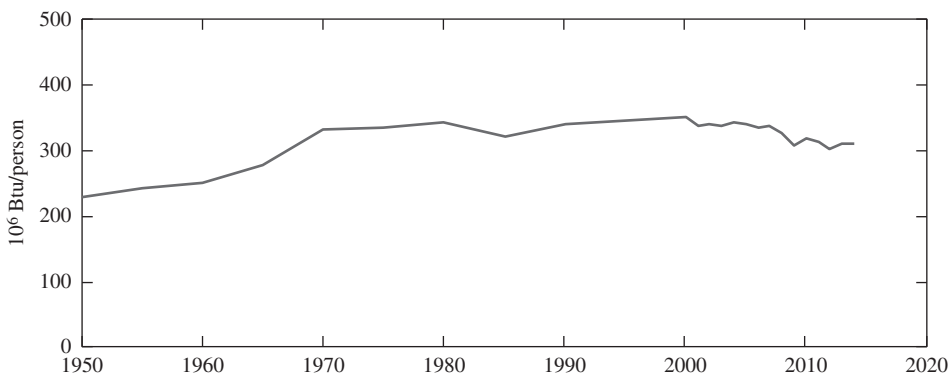


Figure 1.7 Historical per capita energy consumption in the USA. *Source:* EIA.

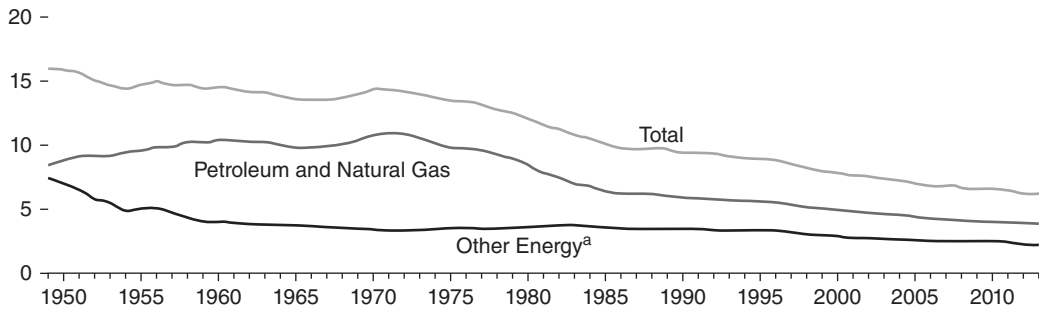


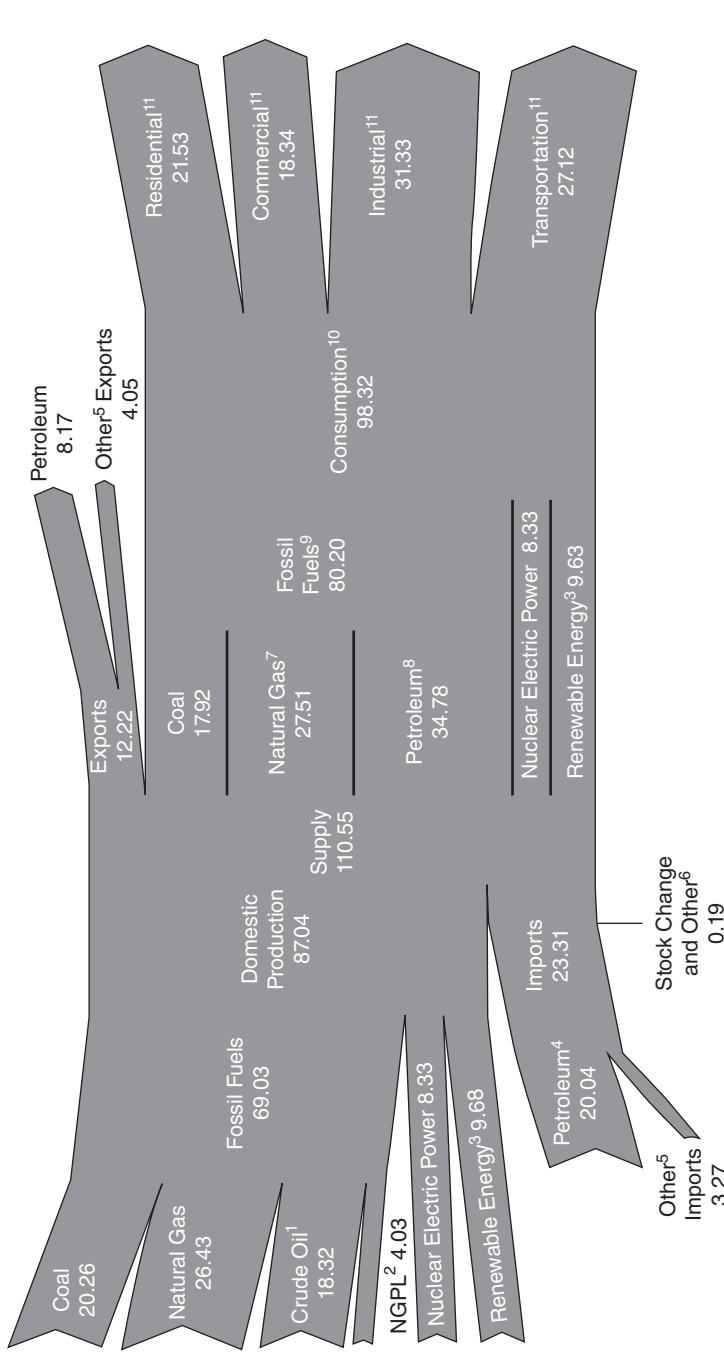
Figure 1.8 Energy consumption per real dollar of GDP. Source: EIA.

1.4 US Energy Usage in 2014

The EIA energy flow diagram for 2014, from the EIA Total Energy (EIA, 2015), is arguably the most informative graphical representation provided by the EIA and is reproduced as Figure 1.9. In this figure, all energy usages are in quads (10^{15} Btu). Energy sources are delineated on the left-hand side of the diagram (e.g., coal at 20.26 quad). The sources are then summed and expressed as domestic production (87.04 quad) and imports (23.31 quad). The total supply is 110.55 quad with exports of 12.22 quad, which yields 98.32 quad for consumption. The end-point energy usages (categorized as residential, commercial, industrial, and transportation) are shown on the right-hand side of the figure. Thus, in 2014, the US energy economy was 98.32 quad of which 23.31 quad was imported. A different perspective of the energy flow diagram is presented in Figure 1.10, which delineates the connection between energy sources and end-point energy usages expressed in two different ways: in Figure 1.10a as “transportation,” “industrial,” “residential and commercial,” and “electric power,” and in Figure 1.10b as the more conventional four, “transportation,” “industrial,” “residential,” and “commercial.” The conventional four end-point energy usages are displayed on a pie chart in Figure 1.11b. Industrial usage accounts for 32% of the total energy used, followed by 28% for transportation. The remainder is almost evenly split between residential and commercial. Since the energy used by no end-use sector is dominant, alternative sources and applications are needed for all end-use sectors if significant reductions in energy uses are to be forthcoming. Figure 1.10a is especially interesting since it directly connects, with percentages indicated, energy sources and end-point energy usages. Mastery of the information in Figures 1.9 and 1.10 is necessary if energy usage in the USA is to be completely understood.

In 2014, renewable energy from all sources contributed about 10% of the total energy utilized in the USA. Figure 1.11 itemizes the percentage contribution of renewable energy sources in the USA for 2014. Perhaps the most amazing statistic is that wood and conventional hydroelectric power accounted for 49% of the total renewable energy that year! Solar and wind contributed 22% of the total renewable energy (or about 2% of the total energy consumption) in 2014. Hence, in spite of much interest and media hype, the penetration of solar and wind energy into the energy mix has not made much progress.

Renewable energy sources have increased in recent years. Figure 1.12 illustrates the contributions of various renewable energy sources since 2000. Hydropower has fluctuated, while biomass and geothermal have exhibited slight increases. But since 2000 wind power has dramatically increased and is now the second largest renewable source after hydropower. Solar has also grown, but not nearly at the rate of wind power. Wind power and hydropower combined to contribute about 87% of the total renewable energy production (excluding



¹ Includes lease condensate.
² Natural gas plant liquids.
³ Conventional hydroelectric power, biomass, geothermal, solar/photovoltaic, and wind.
⁴ Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.
⁵ Natural gas, coal, coal coke, biofuels, and electricity.
⁶ Adjustments, losses, and unaccounted for.
⁷ Natural gas only; excludes supplemental gaseous fuels.
⁸ Petroleum products, including natural gas plant liquids, and crude oil burned as fuel.
⁹ Includes -0.02 quadrillion Btu of coal coke net imports.
¹⁰ Includes 0.16 quadrillion Btu of electricity net imports.
¹¹ Total energy consumption, which is the sum of primary energy consumption, electricity retail sales, and electrical system energy/losses. Losses are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note 1. "Electrical Systems Energy Losses," at the end of U.S. Energy Information Administration, *Monthly Energy Review* (March 2015), Section 2.
 Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.
 Sources: U.S. Energy Information Administration, *Monthly Energy Review* (March 2015), Tables 1.1, 1.2, 1.3, 1.4a, 1.4b, and 2.1.

Figure 1.9 US energy flow diagram (quadrillion Btu) for 2014. *Source:* EIA.

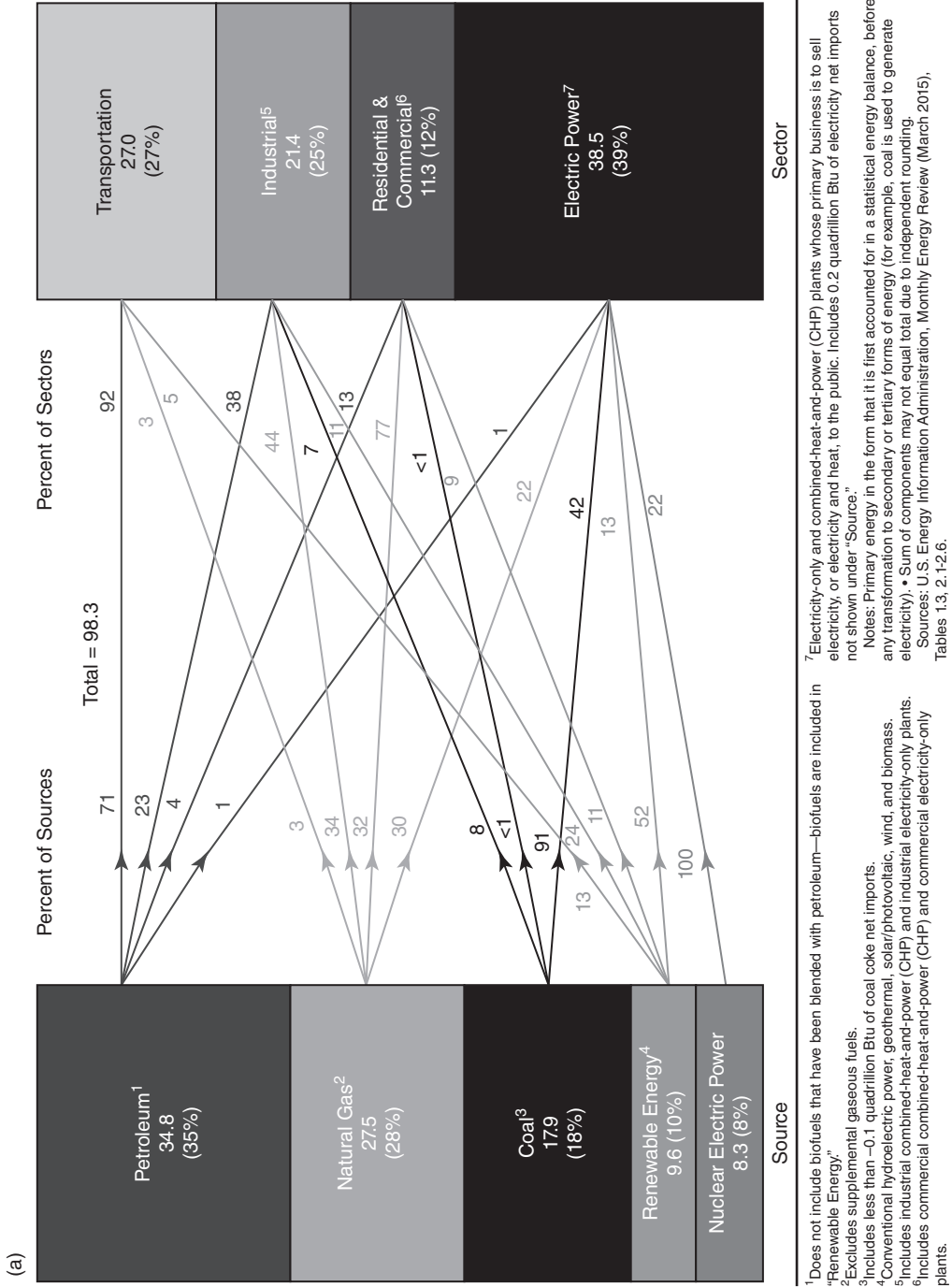


Figure 1.10 End-use energy utilizations in 2014. Source: EIA. (a) End-point energy usages (quadrillion Btu) with electric power separate. (b) End-point energy usages with electric power included in the primary four.

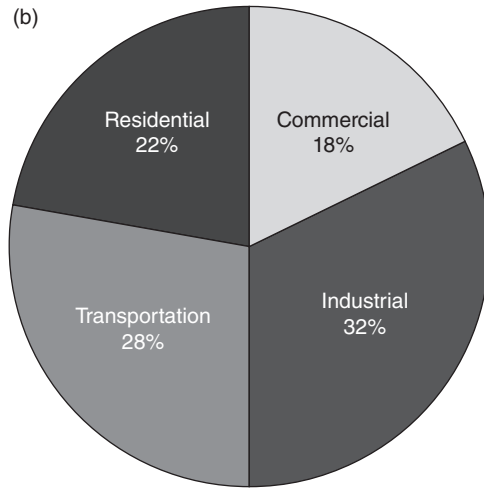


Figure 1.10 (Continued)

biomass) in 2014. Subsequent chapters of this book will examine in more detail hydropower, wind power, solar/photovoltaic, biomass, geothermal, and municipal solid waste as well as ocean energy, combined heat and power, and nuclear (not an alternative or renewable energy, but one that must be considered because of its potential). A very comprehensive study of electricity generated from renewable resources was developed by the National Academy of Sciences *et al.* (2010). The title of the study is *Electricity from Renewable Resources: Status, Prospects, and*

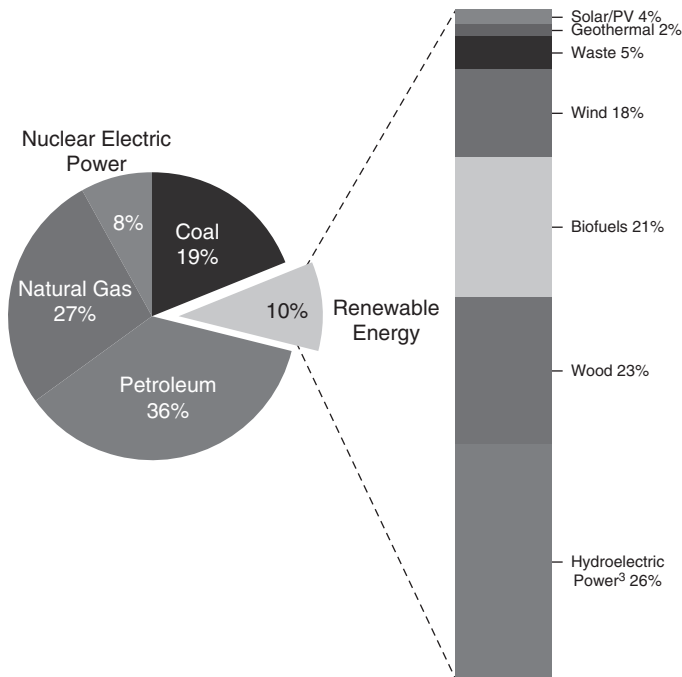


Figure 1.11 Percentage contributions of renewable energy sources in 2014. Source: EIA.

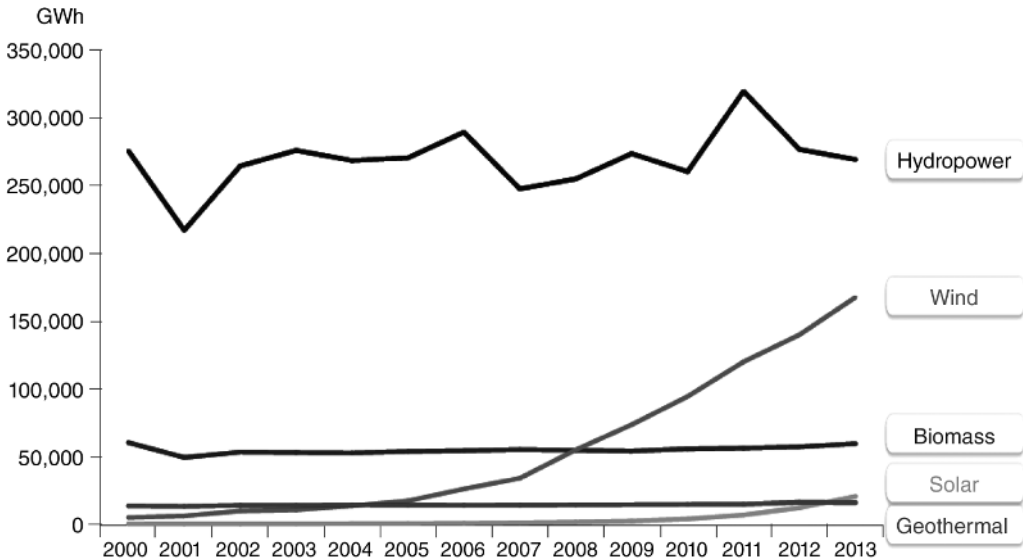


Figure 1.12 Contributions of various renewable energy resources since 2000. *Source:* Esterly and Gelman (2014).

Impediments. The report provides assessments and findings (technical, economic, environmental) for various technologies.

Every year, the Business Center for Sustainable Energy releases the Bloomberg New Energy Finance Study that contains some materials presented from federal sources, typically the EIA, but it also assesses the effects of current events and technologies on the energy scenario. This document is a complimentary, congruent source beyond the EIA. The 2016 edition is *2016 Factbook Sustainable Energy in America* and is available at <http://www.bcse.org/sustainableenergyfactbook.html>.

Prentiss (2015) argues that, through infrastructure changes and energy usage alternatives, the USA could develop a sustainable energy economy not based on petroleum. She recommends the use of hybrid and electric vehicles (see Chapter 16) for personal transportation and suggests that biomass (see Chapter 12) be used as source of jet fuel for aviation. Such an energy economy would be vastly different from the energy economy of 2015.

Figure 1.13 is a diagram of petroleum flow in the USA for 2014. The format of the figure is similar that of Figure 1.9 except that the numbers in the petroleum flow diagram are in millions of barrels per day (MMBD). Starting at the left-hand side, domestic crude oil production is a little less than that of the crude oil imported. The refinery output is cast in terms of motor gasoline, distillate fuel oil, liquefied petroleum, jet fuel, residual fuel oil, and “other.” Motor gasoline, at 8.92 MMBD, accounted for nearly one-half of the total utilization of petroleum products in USA in 2014. The right-hand side of the petroleum flow diagram expresses the end-point petroleum energy usages. Transportation accounts for 71% of the total petroleum. Industrial usage is about 24%, with residential, commercial, and electric power generation responsible for the remaining 5%.

Transportation, the dominant end-point petroleum energy usage, warrants more examination. Much insight can be gained by tracking the cost of a gallon of motor gasoline in terms of “real” and “nominal” dollars. Real dollars are the chained dollars based on the dollar in 2000, while nominal dollars are the actual cost during a given year. Real dollars thus account for

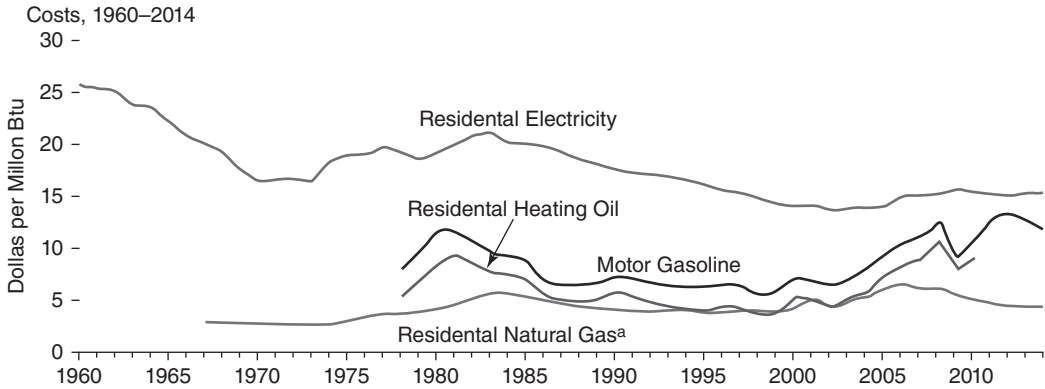


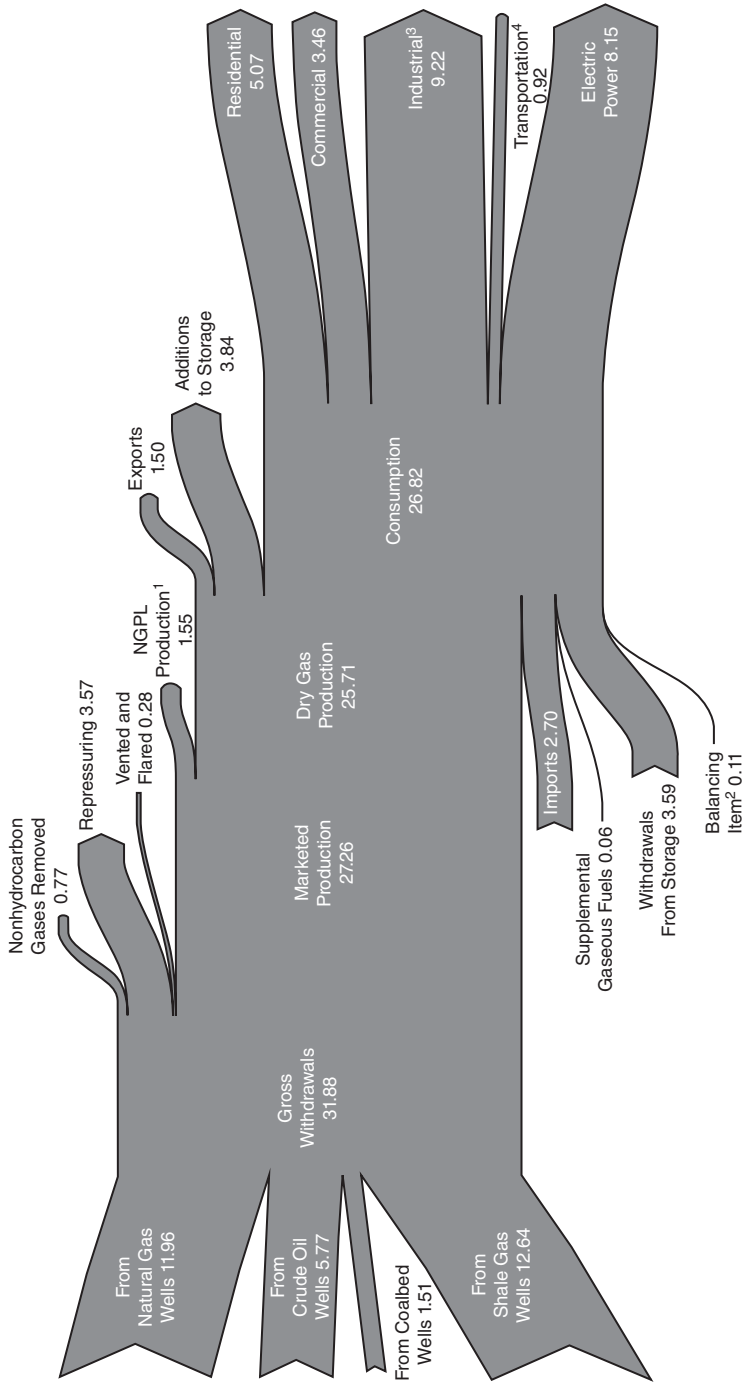
Figure 1.14 Cost of fuels in real (1982–1984) dollars. *Source:* EIA.

inflation. Figure 1.14 shows the real cost in dollars per million British thermal units of motor gasoline from 1978 to 2014. In real dollars gasoline was about $\$12/10^6$ Btu in 1980, a price not reached again until 2008. The rapid increase in gasoline prices, exceeding the inflation rate, after the year 2000 resulted in severe economic strain on the US economy in general. In recent years, the increase in domestic petroleum has reduced the price of gasoline in real dollars. During the prosperous years of the 1980s and 1990s, relative to inflation, gasoline prices declined! No wonder that conservation, higher gas mileage vehicles, and alternative sources possessed little appeal or aroused much interest in the public.

The natural gas flow for 2014 is presented in Figure 1.15. Natural gas usage in this figure is expressed in trillions of cubic feet. As with the other energy flow diagrams (Figures 1.9 and 1.13), information proceeds from the left-hand side (sources) to the right-hand side (end-point usages). Imports account for about 10% of the total consumption. Industrial usage and electric power generation account for 65% of the total natural gas utilization, with the remainder split between residential, commercial, and transportation.

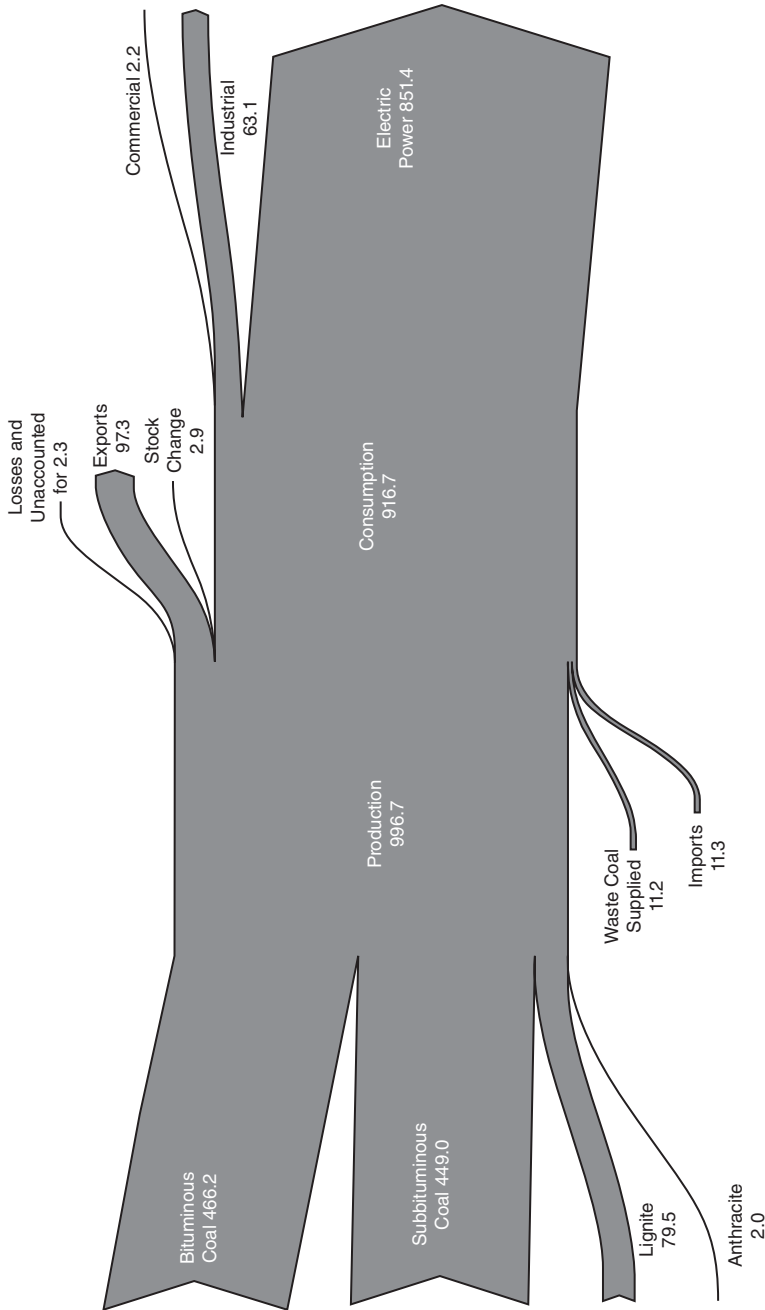
The coal flow for 2014 is illustrated in Figure 1.16 and is expressed in millions of short tons. In a fashion similar to the other energy flow diagrams (Figures 1.9, 1.13, and 1.15), information proceeds from the left-hand side (sources) to the right-hand side (end-point usages). All coal is produced domestically, with a small amount exported. Virtually all of the coal usage (93%) in the USA is for the generation of electricity, with about 7% industrial end-point usage. Coal is the one energy source that does not have to be imported. However, the extensive use of coal for electric generation poses significant environmental issues. The last few years' environmental regulations pertaining to coal usage have become an important political issue in the USA. As a result, coal production and usage have declined.

Although an end-point energy use rather than an energy source, an examination of the electricity flow in the USA is appropriate. Figure 1.17 presents the electricity flow diagram for 2014; the numbers in the figure are in quads. The left-hand side delineates the input energy, including nuclear electric power. Coal is the dominant fossil fuel (64%) source of energy for electricity generation in the USA. The right-hand side of the diagram breaks down the end-point energy usages including transmission and distributions losses (about 9%). With 39.44 quad consumed to generate 14.78 quad of electricity, the overall thermal efficiency of electricity generation is 37%. Hence, of the 39.44 quad of energy used to generate electricity in the USA in 2014, 24.66 quad represents conversion losses. Hence, saving 1 kWh of electricity through conservation and energy efficiency efforts saves nearly 3 kWh equivalents of fuel! Conservation



¹Natural gas plant liquids production (NGPL), gaseous equivalent.
²Quantities lost and imbalances in data due to differences among data sources.
 Excludes transit shipments that cross the U.S.-Canada border (i.e., natural gas delivered to its destination via the other country).
³Lease and plant fuel, and other industrial.
⁴Natural gas consumed in the operation of pipelines (primarily in compressors) and as fuel in the delivery of natural gas to consumers, plus a small quantity used as vehicle fuel.
 Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.
 Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (March 2015), Tables 4.1, 4.3, and 4.4; and EIA estimates based on previous year's data.

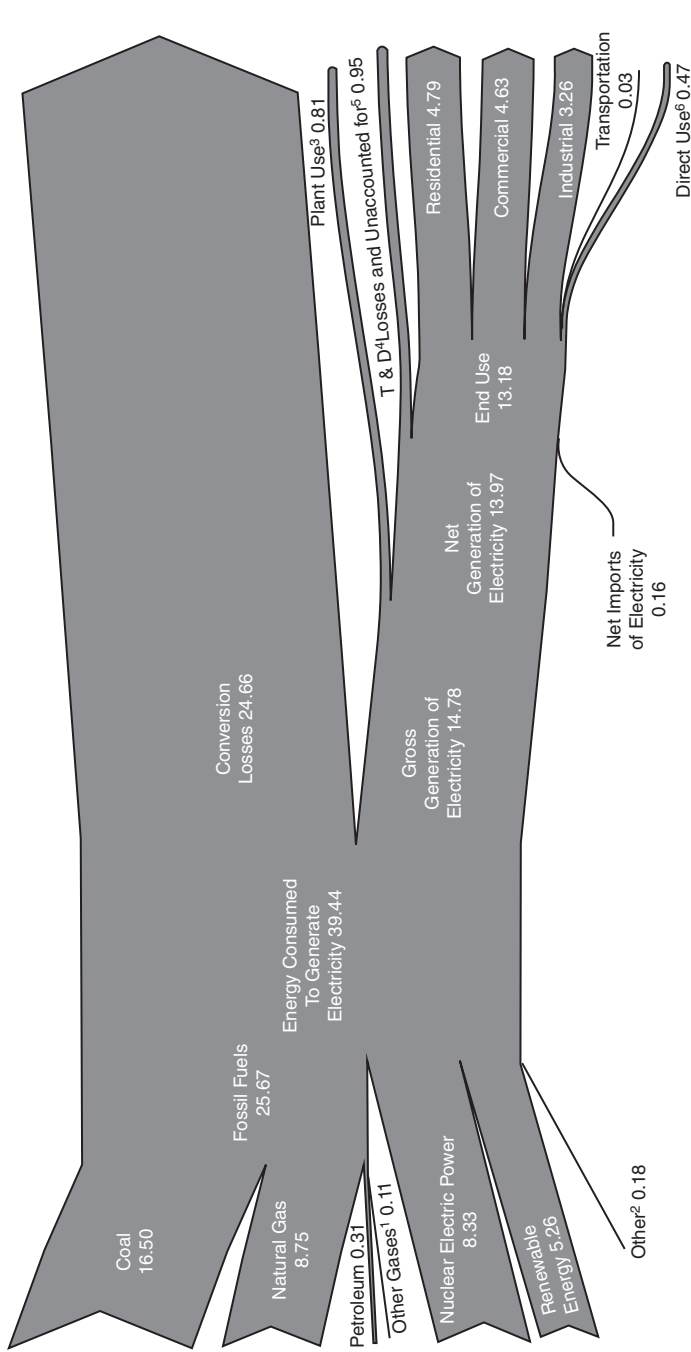
Figure 1.15 US natural gas flow diagram (trillion cubic feet) for 2014. Source: EIA.



Notes: • Production categories are estimated; all data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (March 2015), Tables 6.1 and 6.2; and EIA estimates based on U.S. Department of Labor, Mine Safety and Health Administration, Form 7000-2, "Quarterly Mine Employment and Coal Production Report."

Figure 1.16 US coal flow diagram (million short tons) for 2014. *Source:* EIA.



process located within the same facility or group of facilities that house the generating equipment. Direct use is exclusive of station use.

Notes: • Data are preliminary. • See Note 1. "Electrical System Energy Losses" at the end of EIA, *Monthly Energy Review* (March 2015), Section 2. • Net generation of electricity includes pumped storage facility production minus energy used for pumping. • Values are derived from source that prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: U.S. Energy Information Administration, *Monthly Energy Review* (March 2015), Tables 7.1, 7.2a, 7.3a, 7.6, and A6; and EIA Form EIA-923, "Power Plant Operations Report."

¹Blast furnace gas and other manufactured and waste gases derived from fossil fuels.
²Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, miscellaneous technologies, and non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
³Electric energy used in the operation of power plants.
⁴Transmission and distribution losses (electricity) losses that occur between the point of generation and delivery to the customer).
⁵Data collection frame differences and nonsampling error.
⁶Use of electricity that is 1) self-generated, 2) produced by either the same entity that consumes the power or an affiliate, and 3) used in direct support of a service of industrial

Figure 1.17 US electricity flow diagram (quadrillion Btu) for 2014. Source: EIA.

Table 1.2 Percentage of electricity generation by energy source.

Source	Percentage
Coal	39
Natural gas	27
Nuclear	19
Hydropower	6
Other renewables	7
Biomass	1.7
Geothermal	0.4
Solar	0.4
Wind	4.4
Petroleum	1
Other gases	<1

and energy efficiency are the most cost-effective and energy-effective actions, and should always be considered first in any efforts to reduce energy costs and energy usages.

In 2015 the EIA (<https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3>) reported the 2014 percentage generation of electricity by energy source. As shown in Table 1.2, coal, natural gas, and nuclear were responsible for 85% of the generation.

In addition to motor gasoline prices, Figure 1.14 also tracks the real cost of electricity in dollars per million British thermal units from 1960 until 2014. Real dollars are the chained cents based on the dollar in 1982–1984. Indeed, except for a few years in the 1980s, the real cost of electricity has been less than in 1960. From 1984 until 2003, the real cost of electricity monotonically declined. As with motor gasoline, the declining real cost of electricity during the prosperous years of the 1990s, relative to inflation, provided no economic impetus for conservation or alternative sources. Now with increasing domestic production of petroleum and identification of massive natural gas reserves, the question is whether the USA can take advantage of these opportunities to increase energy efficiency and enhance use of renewable energy options and applications or whether the lessons of the 1990s will be forgotten.

1.5 Worldwide energy use

Although this chapter has concentrated on the energy scenario in the USA, an examination of energy usage on a worldwide basis will enhance understanding of the global nature of the energy problem. Figure 1.18 shows the energy utilization of the world and the countries with the most energy consumption from 1994 to 2007. Until the *Annual Energy Review 2007*, the AER contained a section on international energy usages. However, starting with the year 2008, that section was omitted. Since the AER is currently suspended, updates from this source are moot. But the 2007 information is still useful since the relative growth of the major energy-using economies is illustrated. All data are presented in quads. The increases in energy use worldwide and by China are evident in the figure. The energy usage in Russia declined slightly, and the energy used by the USA increased, but not as rapidly as the energy use by China. The energy

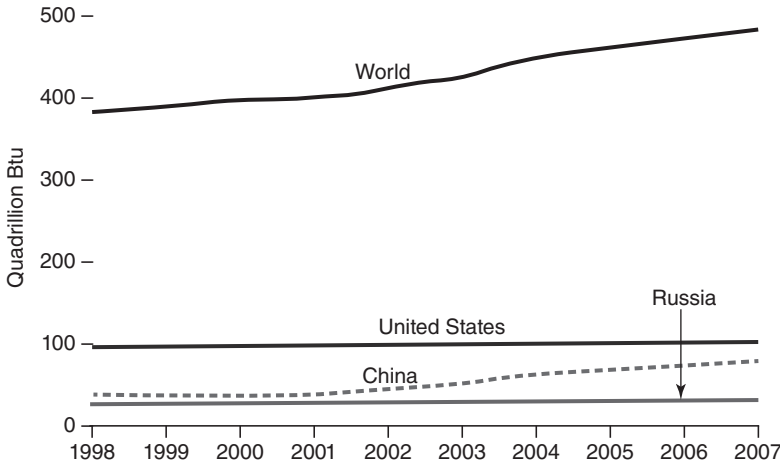


Figure 1.18 World energy utilization from 1994 to 2007. Source: EIA.

problems of the USA are exacerbated by the increasing demand for energy worldwide, especially in countries with rapidly expanding economies.

A good annual source of many world energy use statistics is provided by British Petroleum (BP) in the form of its *Statistical Review of World Energy* that is released in June of most years. The data presented in this chapter are from the June 2014 release. Figure 1.19 provides a convenient summary of world consumption from 1988 to 2013 broken into sources (oil, natural gas, nuclear, hydroelectric, renewable, and coal). The unit is tonnes equivalent, with each tonne representing 7.33 barrels or 307.86 gallons. Overall, the figure demonstrates the same world trend of increasing energy usage as Figure 1.18. The only decrease occurs in 2008 as a result of the economic recession; however, by 2009 the trend of increasing usage is reestablished with growth in all sources. Figure 1.20 delineates world energy consumption by region from 1988 through 2013. This figure is far more revealing than Figure 1.19 in understanding the energy usage pattern changes in the world. While North America and Europe and Eurasia demonstrate

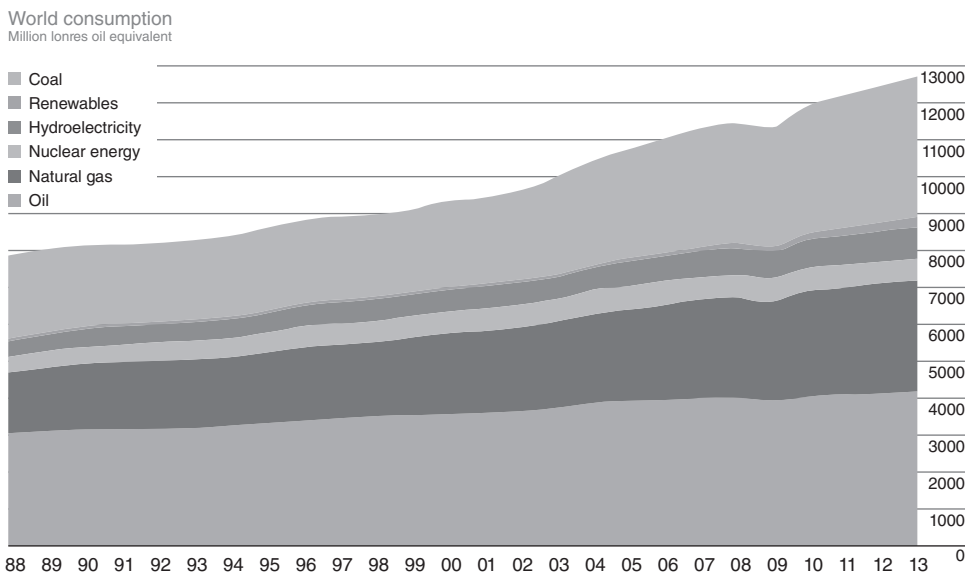


Figure 1.19 World energy consumption from 1988 to 2013. Source: British Petroleum (2014) *British Petroleum Statistical Review of World Energy June 2014*.

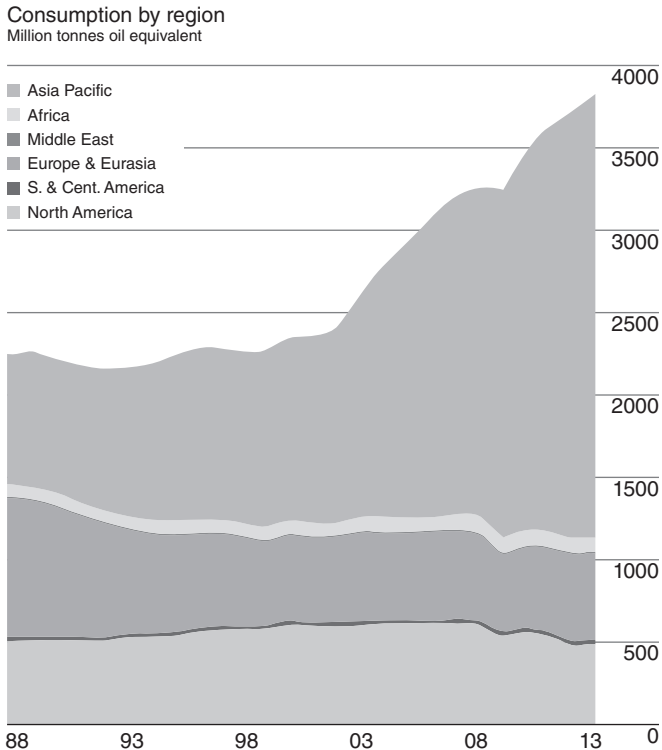


Figure 1.20 World energy consumption by region from 1988 to 2013. *Source: British Petroleum (2014) British Petroleum Statistical Review of World Energy June 2014.*

slight declines during the years approaching 2013, Asia Pacific usage effectively doubled from 2005 to 2013! Continued increases in energy consumption of this magnitude will place severe strain on the world oil supply. Indeed, if not for enhanced oil recovery and the discovery of significant additional natural gas reserves in the USA, fossil fuel prices would greatly exceed the current pricing structure. The implication for carbon dioxide production is even more troubling. North America uses about 25% of the world's energy, but because of environmental concerns produces much less than 25% of the world's CO₂. The Asia Pacific region, as evidenced by Figure 1.20, will in the near future consume significantly more energy than North America, but the CO₂ will dwarf the CO₂ output of North America because of more lax environmental regulations in the Asia Pacific region. Muller (2012) presents an interesting discussion of this issue.

1.6 Efficiencies

The usual definition of the thermal efficiency of a heat engine is

$$\eta = \frac{\text{Power}_{\text{out}}}{\text{Power}_{\text{in}}} \quad (1.1)$$

The following three consequences of the second law of thermodynamics are useful for providing limits to the efficiency of a heat engine:

- 1) No heat engine can be more efficient than an externally reversible engine operating between the same temperature limits.

- 2) All externally reversible heat engines operating between the same temperature limits have the same efficiency.
- 3) The efficiency of any externally reversible heat engine operating between temperatures of T_H (high temperature) and T_L (low temperature) is given by the Carnot efficiency

$$\eta_{\text{Carnot}} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H} \quad (1.2)$$

The Carnot efficiency η_{Carnot} thus provides a bound on the maximum efficiency that could be obtained by any heat engine.

Tester *et al.* (2012) provide a useful summary of typical efficiencies for a number of components and devices associated with energy use. Table 1.3, adapted from Tester *et al.* (2012), presents the efficiency ranges for a number of energy system components, lighting

Table 1.3 Efficiencies of selected components and biological systems.

Component	Energy conversion path ^{a)}	Efficiency (%)
Large electric generators	m → e	98–99
Large power plant boilers	c → t	90–98
Large electric motors	e → m	90–97
Home natural gas furnaces	c → t	90–96
Dry-cell batteries	c → e	85–95
Waterwheels (overshot)	m → m	60–85
Small electric motors	e → m	60–75
Large steam turbines	t → m	40–45
Wood stoves	c → t	25–45
Large gas turbines	c → m	35–40
Diesel engines	c → m	30–35
Photovoltaic cells	r → e	20–30
Large steam engines	c → m	20–25
Internal combustion engines	c → m	15–25
Steam locomotives	c → m	3–6
Light sources		
High-pressure sodium lamps	e → r	15–20
Fluorescent lights	e → r	10–12
Incandescent light bulbs	e → r	2–5
Paraffin candles	c → r	1–2
Biological systems		
Milk production	c → c	15–20
Broiler production	c → c	10–15
Beef production	c → c	5–10
Local photosynthesis	r → c	4–5
Global photosynthesis	r → c	0.3

a) c: chemical; e: electrical; m: mechanical; r: radiant; t: thermal.

sources, and biological systems. Additionally, Table 1.3 also indicates the energy conversion path for each entry. For example, for large gas turbines the energy conversion path is chemical to mechanical ($c \rightarrow m$) and the nominal efficiency range is 35–40%. Some large components possess efficiencies above 90%, but many widely used components (e.g., internal combustion engines) have efficiencies less than 30%. From a historical perspective, the reason for the demise of the steam locomotive is also evident.

Much of the electricity generated is used for lighting. As the data in Table 1.3 demonstrate, even the most efficient lighting source, high-pressure sodium, is only 15–20% efficient. Incandescent lighting is a woeful 2–5% efficient. Biological systems used for food production, milk or beef, for example, also exhibit low efficiencies. Locally, photosynthesis does not exceed 5% efficiency of the incident sunlight, but the global mean is much smaller.

What Table 1.3 ultimately indicates is that much engineering effort is needed to reduce energy utilization by improving efficiencies of various components.

1.7 Closure

The information contained in this chapter brings us to the purpose of this book. If we are to meet the increasing US and world energy demands, then the use of alternative energy sources and the alternative use of existing energy sources must be considered, even in light of recent changes in the US domestic energy outlook. The remaining chapters of this book examine fundamental principles and facts about a wide variety of alternative energy sources and alternative energy utilization. The level of material covered about each topic is, in most instances, fundamental. To do detailed engineering work on most topics represented in this book, additional technical information will be needed. However, the material presented herein provides an introduction and overview for the many alternative energy scenarios possible.

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