Chapter 2
Energy and Energy Types

2.1 Energy

Energy is the capacity to do work. Energy comes in various forms, such as motion, heat, light, electrical, chemical, nuclear energy, and gravitational. *Total energy* is the sum of all forms of the energy a system possesses. In the absence of magnetic, electrical and surface tension effects, the total energy of a system consists of the *kinetic, potential, and internal energies*. The *internal energy* of a system is made up of sensible, latent, chemical, and nuclear energies. The sensible internal energy is due to translational, rotational, and vibrational effects of atoms and molecules. *Thermal energy* is the sensible and latent forms of internal energy. The classification of energy into different "types" often follows the boundaries of the fields of study in the natural sciences. For example, c*hemical energy* is the kind of potential energy stored in chemical bonds, and *nuclear energy* is the energy stored in interactions between the particles in the atomic nucleus. *Microscopic forms of energy* are related to the molecular structure of a system and they are independent of outside reference frames.

Hydrogen represents a store of potential energy that can be released by fusion of hydrogen in the Sun. Some of the fusion energy is then transformed into sunlight, which may again be stored as gravitational potential energy after it strikes the earth. For example, water evaporates from the oceans, may be deposited on elevated parts of the earth, and after being released at a hydroelectric dam, it can drive turbines to produce energy in the form of electricity. Atmospheric phenomena like wind, rain, snow, and hurricanes, are all a result of energy transformations brought about by solar energy on the atmosphere of the earth. Sunlight is also captured by plants as *chemical potential energy* in photosynthesis, when carbon dioxide and water are converted into carbohydrates, lipids, and proteins. This chemical potential energy is responsible for growth and development of a biological cell.

British thermal unit (Btu) is the energy unit in the English system needed to raise the temperature of 1 $\mathrm{lb_m}$ of water at 68°F by 1°F. *Calorie* (cal) is the amount

Y. Demirel, *Energy*, Green Energy and Technology,
DOI: 10.1007/978-1-4471-2372-9_2, © Springer-Verlag London Limited 2012

Table 2.1 Some energy units and definitions

Name of unit	Symbol	Definitions
British thermal unit	Btu	1055 J = 5.4039 psia ft^3
Btu/lb_m	Btu/lb_m	2.326 kJ/kg
Joule	J	$J = m{\cdot}N = 1\ kg{\cdot}m^2/s^2$
Calorie	Cal	4.1868 J
kJ	kJ	kPa m^3 = 1000 J
kJ/kg	kJ/kg	0.43 Btu/lb_m
Erg	erg	$g{\cdot}cm^2/s^2 = 10^{-7}$ J
Foot pound force	ft lb_f	$g \times lb \times ft = 1.355$ J
Horsepower hour	hph	$hp \times h = 2.684 \times 10^6$ J
Kilowatt hour	kWh	$kW \times h = 3.6 \times 10^6$ J
Quad	quad	10^{15} Btu = 1.055×10^{18} J
Atmosphere liter	atml	atm × l = 101.325 J
kW	kW	3412 Btu/h
Horsepower	hp	2545 Btu/h
Therm	therm	29.3 kWh
Electronvolt	eV	$\approx 1.602\ 17 \times 10^{-19} \pm 4.9 \times 10^{-26}$ J

of energy in the metric system needed to raise the temperature of 1 g of water at 15°C by 1°C. Table 2.1 displays some of the important energy units and their definitions.

2.2 Energy Types

Primary and secondary types of energy are the two main types as shown in Fig. 2.1. Primary energy is extracted or captured directly from the environment, while the secondary energy is converted from the primary energy in the form of electricity or fuel. Distinguising the primary and secondary energy sources are important in the energy balances to count and record energy supply, transformations, and losses. These energy types are discussed in the next sections.

2.2.1 Primary Energy

Primary energy is the energy extracted or captured directly from the environment. Three distinctive groups of primary energy are:

- Nonrenewable energy (fossil fuels): coal, crude oil, natural gas, nuclear fuel.
- Renewable energy: hydropower, biomass, solar energy, wind, geothermal, and ocean energy.
- Waste.

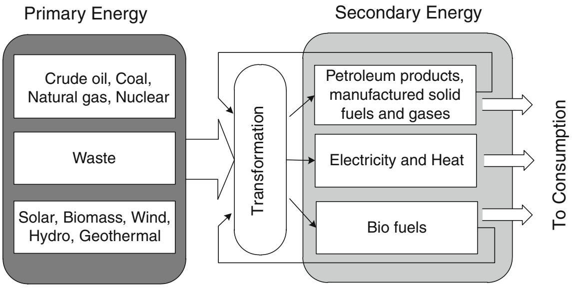


Fig. 2.1 Primary and secondary energy types. To separate primary and secondary energy is important in energy balances for energy supply, transformation, and losses [33]

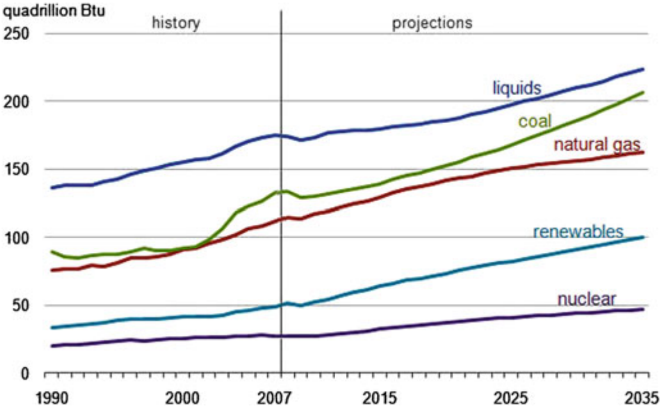


Fig. 2.2 History and projections of energy use by fuel type in the world (Quad = 10^{15} Btu) [13]

Primary sources of energy consisting of petroleum, coal, and natural gas amount to about 85% of the fossil fuels in primary energy consumption in the world [13, 37]. Projected energy use in the world shows that petroleum, coal, and natural gas will still be the dominant energy sources by 2035 (Fig. 2.2). The principle of supply and demand suggests that as fossil fuels diminish, their prices will rise and renewable energy supplies, particularly biomass, solar, and wind resources, will become sufficiently economical to exploit [13, 37]. Figure 2.3 shows the primary energy flow in the US.

The energy content may be converted to ton of oil equivalent (TOE): 1 TOE = 11630 kWh = 41870 MJ.

2.2.2 Secondary Energy

The primary energy is transformed to *secondary energy* in the form of electrical energy or fuel, such as gasoline, fuel oil, methanol, ethanol, and hydrogen [3]. The

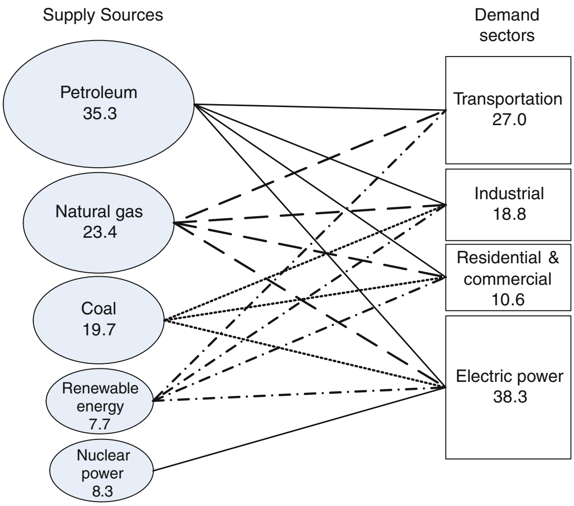


Fig. 2.3 US primary energy flow by source and sector in 2009 in quadrillion Btu- quad = 10^{15} Btu. Sum of components may not be equal to total due to independent rounding [14]

primary energy of *renewable energy* sources, such as sun, wind, biomass, geothermal energy, and flowing water is usually equated with either electrical or thermal energy produced from them. Final energy is often electrical energy and fuel, which is referred to as *useful energy*. The selected four types of final energy are electrical, thermal, mechanical, and chemical energy. These types of final energy set a boundary between the energy production and the consumption sectors [7, 14, 33].

2.3 Non Renewable Energy Sources

It is generally accepted that nonrenewable energy sources or *fossil fuels* are formed from the remains of dead plants and animals by exposure to heat and pressure in the earth's crust over the millions of years. Major nonrenewable energy sources are:

- Coal
- Petroleum
- Natural gas
- Nuclear

Fossil fuels contain high percentages of carbon and include mainly coal, petroleum, and natural gas. Natural gas, for example, contains only very low boiling point and gaseous components, while gasoline contains much higher boiling point components. The specific mixture of hydrocarbons gives a fuel its characteristic properties, such as boiling point, melting point, density, and viscosity. These types

Table 2.2 Typical properties of various coals

	Anthracite coal	Bituminous coal	Lignite coal
Fixed carbon, weight%	80.5–85.7	44.9–78.2	31.4
Moisture, weight%	2.8–16.3	2.2–15.9	39
Bulk density, lb/ft^3	50–58	42–57	40–54
Ash, weight%	9.7–20.2	3.3–11.7	3.3–11.7
Sulfur, weight%	0.6–0.77	0.7–4.0	0.4

ETB [18], Gaur and Reed [15]

of fuels are known as nonrenewable energy sources. The following sections discuss some important nonrenewable energy sources.

2.3.1 Coal

Coals are sedimentary rocks containing combustible and incombustible matters as well as water. Coal comes in various composition and energy content depending on the source and type. Table 2.2 shows some typical properties of various coals. The poorest lignite has less than 50% carbon and an energy density lower than wood. Anthracites have more than 90% carbon, while bituminous coals mostly between 70 and 75%. Bituminous coal ignites easily and burns with a relatively long flame [35]. If improperly fired, bituminous coal is characterized with excess smoke and soot. Anthracite coal is very hard and shiny and the ultimate maturation. Anthracite coal creates a steady and clean flame and is preferred for domestic heating. Furthermore it burns longer with more heat than the other types. For countries with rising oil prices coal may become a cheaper source of energy. It was in the 1880s when coal was first used to generate electricity for homes and factories. Since then coal played a major role as source of energy in the industrial revolution.

Coal has impurities like sulfur and nitrogen and when it burns the released impurities can combine with water vapor in the air to form droplets that fall to earth as weak forms of sulfuric and nitric acid as acid rain. Coal also contains minerals, which do not burn and make up the ash left behind in a coal combustor. Carbon dioxide is one of several gases that can help trap the earth's heat and, as many scientists believe, cause the earth's temperature to rise and alter the earth's climate. Because of high carbon content, coals generate more CO_2 per unit of released energy than any other fossil fuel such as crude oil. Sulfur content of coal is also a drawback. Sulfur makes up, typically, about 2% of bitumen coals. However, advanced coal technology can filter out 99% of the tiny particles, remove more than 95% of the acid rain pollutants, and reduce the release of carbon dioxide by burning coal more efficiently. Many new plants are required to have flue gas desulfurization units called *scrubbers* [7, 27].

Table 2.3 Typical elemental composition by weight of crude oil [17]

Element	Percent range (%)
Carbon	83–87
Hydrogen	10–14
Nitrogen	0.1–2
Oxygen	0.1–1.5
Sulfur	0.5–6
Metals	<0.1

Table 2.4 Composition by weight of hydrocarbons in petroleum

Hydrocarbon	Average (%)	Range (%)
Paraffins (alkanes)	30	15–60
Naphtanes (cycloalkanes)	49	30–60
Aromatics	15	3–30
Asphaltics	6	Remainder

2.3.2 Petroleum (Crude Oil)

Oil is a naturally occurring flammable liquid consisting of a complex mixture of hydrocarbons of various molecular weights, which define its physical and chemical properties, like heating value, color, and viscosity. The composition of hydrocarbons ranges from as much as 97% by weight in the lighter oils to as little as 50% in the heavier oils. The proportion of chemical elements varies over fairly narrow limits as seen in Table 2.3. The hydrocarbons in crude oil are mostly alkanes, cycloalkanes and various aromatic hydrocarbons while the other organic compounds contain nitrogen, oxygen, sulfur, and trace amounts of metals. The relative percentage of each varies and determines the properties of oil (see Table 2.4).

- *Alkanes*, also known as *paraffin*, are saturated hydrocarbons with straight or branched chains containing only carbon and hydrogen and have the general formula C_nH_{2n+2}. They generally have from 5 to 40 carbon atoms per molecule. For example, CH_4 represents the methane, which is a major component of natural gas. The propane (C_3H_8) and butane (C_4H_{10}) are known as petroleum gases. At the heavier end of the range, *paraffin wax* is an alkane with approximately 25 carbon atoms, while *asphalt* has 35 and up. These long chain alkanes are usually cracked by modern refineries into lighter and more valuable products.
- *Cycloalkanes*, also known as *naphthenes*, are saturated hydrocarbons which have one or more carbon rings to which hydrogen atoms are attached according to the formula C_nH_{2n}. Cycloalkanes have similar properties to alkanes but have higher boiling points.
- *Aromatic hydrocarbons* are unsaturated hydrocarbons which have one or more six-carbon rings called benzene rings with double and single bonds and hydrogen atoms attached according to the formula C_nH_n.

Oil currently supplies more than 40% of our total energy demands and more than 99% of the fuel are used in transportation. Known oil reserves are typically estimated at around 1.2 trillion barrels without oil sands, or 3.74 trillion barrels with oil sands [3, 26].

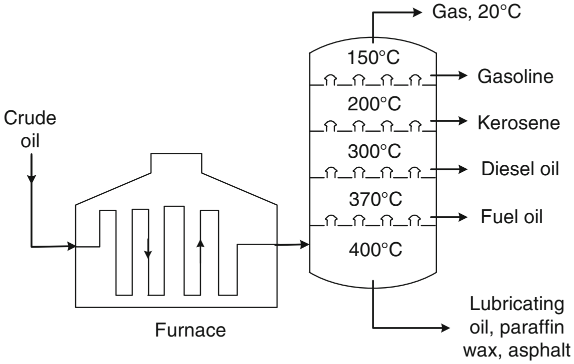
2.3.3 Petroleum Fractions

Oil is refined and separated into a large number of commodity products, from gasoline and kerosene to asphalt and chemical reagents used to make plastics and pharmaceuticals. Figure 2.4 shows a part of a typical refinery processing crude oil to produce various fuels. 84% by volume of the hydrocarbons present in petroleum is converted into energy-rich fuels, including gasoline, diesel, jet fuel, heating, and other fuel oil and liquefied petroleum gases. The remaining oil is converted to pharmaceuticals, solvents, fertilizers, pesticides, and plastics [22]. Therefore, petroleum is vital to many industries, and thus is a critical concern to many nations.

Some common fractions from petroleum refining are:

- *Liquefied petroleum gas* (LPG) is a flammable mixture of propane (C_3H_8) (about 38% by volume and more in winter) and butane (C_4H_{10}) (about 60% by volume and more in summer) used as a fuel in heating appliances and vehicles. Energy content of liquefied petroleum gas per kilogram is higher than for gasoline because of higher hydrogen to carbon ratio. Liquefied petroleum gas emits 81% of the CO_2 per kWh produced by oil and 70% of that of coal. Liquefied petroleum gas has a typical specific heat of 46.1 MJ/kg compared with 43.5 MJ/kg for gasoline. However, its energy density of 26 MJ/l is lower than either that of gasoline. Pure *n*-butane is liquefied at around 220 kPa (2.2 bar), while pure propane (C_3H_8) at 2200 kPa (22 bar). At liquid state, the vapor pressure of liquefied petroleum gas is about 550 kPa (5.5 bar).
- *Gasoline* is primarily used as a fuel in internal combustion engines. A typical gasoline consists of hydrocarbons with between 4 and 12 carbon atoms per molecule. It consists mostly of aliphatic hydrocarbons obtained by the fractional distillation of petroleum, enhanced with iso-octane or the aromatic hydrocarbons toluene and benzene to increase its octane rating. The specific density of gasoline ranges from 0.71 to 0.77 (6.175 lb/US gal) higher densities having a greater volume of aromatics. Gasoline contains about 132 MJ/US gal (higher heating value), while its blends differ by up to 4% more or less than the average. The emission of CO_2 from gasoline is around 73.38 g/MJ.
- *Petroleum diesel* contains 8–21 carbon atoms per molecule with a boiling point in the range of 180–360°C (360–680°F). The density of petroleum diesel is about 6.943 lb/gal. About 86.1% of the fuel mass is carbon and it offers a net heating value of around 43.1 MJ/kg. However, due to the higher density, diesel

Fig. 2.4 A distillation tower showing the differing weights of various products produced from petroleum



offers a higher volumetric energy density at 128,700 Btu/gal versus 115,500 Btu/gal for gasoline, some 11% higher (see Table 2.7). The CO_2 emissions from diesel are 73.25 g/MJ, (similar to gasoline). Because of quality regulations, additional refining is required to remove sulfur which may contribute to a higher cost.

- *Kerosene* is a thin, clear liquid formed containing between 6 and 16 carbon atoms per molecule, with density of 0.78–0.81 g/cm^3. The flash point of kerosene is between 37 and 65°C (100 and 150°F) and its autoignition temperature is 220°C (428 F). The heat of combustion of kerosene is similar to that of diesel: its lower heating value is around 18,500 Btu/lb, (43.1 MJ/kg), and its higher heating value is 46.2 MJ/kg (19,861 Btu/lb).
- *Jet fuel* is a type of aviation fuel designed for use in aircraft powered by gas-turbine engines. The commonly used fuels are Jet A and Jet A-1 which are produced to a standardised international specification. Jet B is used for its enhanced cold-weather performance. Jet fuel is a mixture of a large number of different hydrocarbons with density of 0.775−0.840 kg/l at 15°C (59°F). The range is restricted by the requirements for the product, for example, the freezing point or smoke point. Kerosene-type jet fuel (including Jet A and Jet A-1) has a carbon number between about 8 and 16; wide-cut or naphtha-type jet fuel (including Jet B), between about 5 and 15.
- *Fuel oil* is made of long hydrocarbon chains, particularly alkanes, cycloalkanes, and aromatics and heavier than gasoline and naphtha. Fuel oil is classified into six classes, numbered 1 through 6, according to its boiling point, composition, and purpose. The boiling point, ranging from 175 to 600°C, and carbon chain length, 9–70 atoms. Viscosity also increases with number, and the heaviest oil has to be heated to get it to flow. Price usually decreases as the fuel number increases. Number 1 is similar to kerosene, number 2 is the diesel fuel that trucks and some cars run on, leading to the name "road diesel". Number 4 fuel oil is usually a blend of heavy distillate and residual fuel oils. Number 5 and 6 fuel oils are called residual fuel oils or heavy fuel oils. Table 2.5 shows the heating values of various fuel oils per gallon.

Table 2.5 Typical heating values of various fuel oils

Type	Unit	Btu
No. 1 Oil	Gallon	137400
No. 2 Oil	Gallon	139600
No. 3 Oil	Gallon	141800
No. 4 Oil	Gallon	145100
No. 5 Oil	Gallon	148800
No. 6 Oil	Gallon	152400

ETB [15] with permission

Carbon fuels contain sulfur and impurities. Combustion of such fuels eventually leads to producing sulfur monoxides (SO) and sulfur dioxide (SO_2) in the exhaust which promotes acid rain. One final element in exhaust pollution is ozone (O_3). This is not emitted directly but made in the air by the action of sunlight on other pollutants to form *ground level ozone*, which is harmful on the respiratory systems if the levels are too high. However, the *ozone layer* in the high atmosphere is useful in blocking the harmful rays from the sun. Ozone is broken down by nitrogen oxides. For the nitrogen oxides, carbon monoxide, sulfur dioxide, and ozone, there are accepted levels that are set by legislation to which no harmful effects are observed.

2.3.4 Natural Gas

Natural gas is a naturally occurring mixture, consisting mainly of methane. Table 2.6 shows the typical components of natural gas. Natural gas provides 23% of all energy consumed in the world. The International Energy Agency predicts that the demand for natural gas will grow by more than 67% through 2030. Natural gas is becoming increasingly popular as an alternative transportation fuel. Typical theoretical flame temperature of natural gas is 1960°C (3562°F), ignition point is 593°C.

Natural gas is a major source of electricity production through the use of gas turbines and steam turbines. It burns more cleanly and produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal for an equivalent amount of heat produced. Combined cycle power generation using natural gas is thus the cleanest source of power available using fossil fuels, and this technology is widely used wherever gas can be obtained at a reasonable cost. The gross heat of combustion of one cubic meter of natural gas is around 39 MJ and the typical caloric value is roughly 1,000 Btu per cubic foot, depending on gas composition.

Liquefied natural gas exists at −161°C (−258°F). Impurities and heavy hydrocarbons from the gaseous fossil fuel are removed before the cooling process. The density of liquefied natural gas is in the range 410–500 kg/m^3. The volume of the liquid is approximately 1/600 of the gaseous volume at atmospheric conditions.

Table 2.6 Typical composition in mole % and heating value of a natural gas

Component	Composition	Range
Methane	95.2	87.0–96.0
Ethane	2.5	1.5−5.1
Propane	0.2	0.1−1.5
Butane, *n*-butane	0.03	0.01−0.3
Iso-pentane, *n*-pentane, hexane plus	0.01	Trace−0.14
Nitrogen	1.3	0.7−5.6
Carbon dioxide	0.7	0.1−1.0
Oxygen	0.02	0.01−0.1
Hydrogen	Trace	Trace−0.02
Specific gravity	0.58	0.57−0.62
Gross heating value (MJ/m^3), dry basis	37.8	36.0−40.2

2.3.5 Nuclear Energy

Nuclear energy plants produce electricity through the fission of nuclear fuel, such as uranium, so they do not pollute the air with harmful gases. *Nuclear fission* is a nuclear reaction in which the nucleus of an atom splits into smaller parts, often producing free neutrons and photons in the form of gamma rays and releasing large amounts of energy. Nuclear fuels undergo fission when struck by free neutrons and generate neutrons leading to a self-sustaining chain reaction that releases energy at a controlled rate in a nuclear reactor [5, 7]. This heat is used to produce steam to be used in a turbine to produce electricity. This is similar to most coal, oil, and gas-fired power plants.

Typical fission release about two hundred million eV (200 MeV) of energy, which is much higher than most chemical oxidation reactions. For example, complete fission energy of uranium-235 isotope is 6.73×10^{10} kJ/kg [8]. The energy of nuclear fission is released as kinetic energy of the fission products and fragments, and as electromagnetic radiation in the form of gamma rays in a nuclear reactor. The energy is converted to heat as the particles and gamma rays collide with the atoms that make up the reactor and its working fluid, usually water or occasionally heavy water. The products of nuclear fission, however, are far more radioactive than the heavy elements which are normally fissioned as fuel, and remain so for a significant amount of time, giving rise to a nuclear waste problem. More than 400 nuclear power plants operating in 25 countries supply almost 17% of the world's electricity.

Nuclear power is essentially carbon-free. However, the electricity from new nuclear power plants would be relatively expensive, and nuclear energy faces a number of significant obstacles. The biggest challenges are the disposal of radioactive waste and the threat of nuclear proliferation. New plants would also require long licensing times, and it would likely be at least a decade before nuclear energy could be brought to bear on the climate change problem.

2.4 Heating Value of Fuels

The heating value of a fuel is the quantity of heat produced by its combustion at constant pressure and under "normal" conditions (i.e. to 25°C and under a pressure of 1 atm). The combustion process generates water. Various heating values are:

- The *higher heating value* (HHV) consists of the combustion product of water condensed and that the heat of vaporization contained in the water vapor is recovered. So the all the water produced in the combustion is in liquid state.
- The *lower heating value* (LHV) assumes that the water product of combustion is at vapor state and the heat of vaporization is not recovered.
- *Net heating value* is the same with lower heating value and is obtained by subtracting the latent heat of vaporization of the water vapor formed by the combustion from the gross or higher heating value.
- *The gross heating value* is the total heat obtained by complete combustion at constant pressure including the heat released by condensing the water vapor in the combustion products. Gross heating value accounts liquid water in the fuel prior to combustion, and valuable for fuels containing water, such as wood and coal. If a fuel has no water prior to combustion then the gross heating value is equal to higher heating value. A common method of relating HHV to LHV per unit mass of a fuel is

$$\mathrm{HHV} = \mathrm{LHV} + \Delta H_{\mathrm{vap}}\left[\left(MW_{\mathrm{H_2O}} n_{\mathrm{H_2O,out}}\right) / \left(MW_{\mathrm{Fuel}} n_{\mathrm{Fuel,in}}\right)\right] \tag{2.1}$$

  where ΔH_{vap} is the heat of vaporization per mole of water (kJ/kg or Btu/lb), $n_{\mathrm{H_2O,out}}$ is the moles of water vaporized, $n_{\mathrm{fuel,in}}$ is the number of moles of fuel combusted, and MW is the molecular weight.

Tables 2.7 and 2.8 show the properties and heating values of some common fuels. The heating value of fossil fuels may vary depending on the source and composition.

2.4.1 Energy Density

Energy density is the amount of energy per unit volume. *Specific energy* is the amount of energy per unit amount. Comparing, for example, the effectiveness of hydrogen fuel to gasoline, hydrogen has a higher specific energy than gasoline but a much lower energy density even in liquid form. Energy per unit volume has the same physical units as pressure. Table 2.9 lists energy densities of some fuel and fuel mixtures.

Table 2.7 Properties heating values of some common fuels and hydrocarbons at 1 atm and 20°C; at 25°C for liquid fuels, and 1 atm and normal boiling temperature for gaseous fuels

Fuel (phase)	Formula	MW (kg/kmol)	ρ (kg/l)	ΔH_v (kJ/kg)	T_b (°F)	C_p (kJ/kg °C)	HHV[a] (kJ/kg)	LHV[a] (kJ/kg)
Carbon (s)	C	12.01	2.000	–		0.71	32,800	32,800
Hydrogen (g)	H_2	2.01	–	–		14.40	141,800	120,000
Methane (g)	CH_4	16.04	–	509	−258.7	2.20	55,530	50,050
Methanol (l)	CH_3OH	32.04	0.790	1168	149.0	2.53	22,660	19,920
Ethane (g)	C_2H_6	30.07	–	172	−127.5	1.75	51,900	47,520
Ethanol (l)	C_2H_5OH	46.07	0.790	919	172.0	2.44	29,670	26,810
Propane(g)	C_3H_8	44.09	0.500	420	−43.8	2.77	50,330	46,340
Butane (l)	C_4H_{10}	58.12	0.579	362	31.1	2.42	49,150	45,370
Isopentane (l)	C_5H_{12}	72.15	0.626	–	82.2	2.32	48,570	44,910
Benzene (l)	C_6H_6	78.11	0.877	433	176.2	1.72	41,800	40,100
Hexane (l)	C_6H_{14}	86.18	0.660	366	155.7	2.27	48,310	44,740
Toluene (l)	C_7H_8	92.14	0.867	412	231.1	1.71	42,400	40,500
Heptane (l)	C_7H_{16}	100.204	0.684	365	209.1	2.24	48,100	44,600
Octane (l)	C_8H_{18}	114.23	0.703	363	258.3	2.23	47,890	44,430
Decane (l)	$C_{10}H_{22}$	142.28	0.730	361		2.21	47,640	44,240
Gasoline (l)	$C_nH_{1.87n}$	100–110	0.72−0.78	350		2.40	47,300	44,000
Light diesel (l)	$C_nH_{1.8n}$	170.00	0.78−0.84	270		2.20	46,100	43,200
Heavy diesel (l)	$C_nH_{1.7n}$	200.00	0.82-0.88	230		1.90	45,500	42,800
Natural gas (g)		~18.00	–	–		2.00	50,000	45,000

ETB [15] with permission

[a] HHV, LHV; higher heating value and lower heating value, respectively; (s): solid; (l): liquid; (g): gas

---

Example 2.1 Energy consumption by a car

An average car consumes 50 gallons gasoline per month. Estimate the energy consumed by the car per year.

Solution:

Assume that gasoline has an average density of 0.72 g/cm^3 and the heating value of 47.3 MJ/kg (Table 2.7).

Data: $V = 50$ gallons/month $=$ 189.25 l/month, 2271.01/year (3.785 l $=$ 1 gallon)

$\rho_{gas} = 0.72$ g/cm^3 $= 0.72$ kg/l

Mass of gasoline: $m_{gas} = \rho V = 1635.1$ kg/year

Energy consumed per year:

$E_{gas} = 1635.1$ kg/year (47,300 kJ/kg) $=$ **77,340,230 kJ/year**
$=$ **77,340.2 MJ/year**

Example 2.2 Fuel consumption by a low and a high-mileage car

An average daily traveling distance is about 40 miles/day. A car has a city-mileage of 20 miles/gal. If the car is replaced with a new car with a city-mileage of 30 miles/gal and the average cost of gasoline is $3.50/gal, estimate the amount of fuel, energy, and money conserved with the new car per year.

Assume: The gasoline is incompressible with $\rho_{av} = 0.75$ kg/l.

Table 2.8 Higher heating values (gross calorific value) of some common fuels

Fuel	Higher heating value	
	kJ/kg	Btu/lb
Anthracite	32,500−34,000	14,000−14,500
Bituminous coal	17,000−23,250	7,300−10,000
Butane	49,510	20,900
Charcoal	29,600	12,800
Coal(anthracite)	30,200	13,000
Coal(bituminous)	27,900	12,000
Coke	28,000−31,000	12,000−13,500
Diesel	44,800	19,300
Ether	43,000	
Gasoline	47,300	20,400
Glycerin	19,000	
Hydrogen	141,790	61,000
Lignite	16,300	7,000
Methane	55,530	
Oils, vegetable	39,000−48,000	
Peat	13,800−20,500	5,500−8,800
Petroleum	43,000	
Propane	50,350	
Semi anthracite	26,700−32,500	11,500−14,000
Wood (dry)	14,400−17,400	6,200−7,500
	kJ/m^3	Btu/ft^3
Acetylene	56,000	
Butane C_4H_{10}	133,000	3200
Hydrogen	13,000	
Natural gas	43,000	950−1,150
Methane CH_4	39,820	
Propane C_3H_8	101,000	2550
Butane C_4H_{10}		3200
	kJ/l	Btu/gal
Gasoline	32,000	115,000
Heavy fuel oil #6	42,600	153,000
Kerosene	37,600	135,000
Diesel	36,300	130,500
Biodiesel	33,500	120,000
Butane C_4H_{10}	36,200	130,000
Methanol	15,900	57,000
Ethanol	21,100	76,000

Gaur and Reed [18]; ETB [15] with permission
1 kJ/kg = 1 J/g = 0.43 Btu/lb$_m$ = 0.239 kcal/kg
1 Btu/lb$_m$ = 2.326 kJ/kg = 0.55 kcal/kg
1 kcal/kg = 4.187 kJ/kg = 1.8 Btu/lb$_m$

Table 2.9 Energy densities of some fuels

Fuel type	Gross (HHV)			Net (LHV)
	MJ/l	MJ/kg	Btu/gal	Btu/gal
Conventional gasoline	34.8	44.4	125,000	115,400
High octane gasoline	33.5	46.8	120,200	112,000
LPG (60%Pr. + 40%Bu.)	26.8	46.0		
Ethanol	24.0	30.0	84,600	75,700
Methanol	17.9	19.9	64,600	56,600
Butanol	29.2	36.6		
Gasohol E10 (ethanol 10% vol.)	33.2	43.5	120,900	112,400
Gasohol E85 (ethanol 85% vol.)	25.6	33.1		
Gasoline (petrol)	34.2	46.4		115,500
Diesel	38.6	45.4	138,700	128,700
Biodiesel	33.5	42.2	126,200	117,100
Jet fuel (kerosene based)	35.1	43.8	125,935	
Jet fuel (naphtha)	42.8	33.0	127,500	118,700
Liquefied natural gas (160°C)	22.2	53.6	90,800	
Liquefied petroleum gas	26.8	46.0	91,300	83,500
Hydrogen (liquid at 20 K)	10.1	142.0		130
Hydrogen gas	0.0108	143.0		
Methane (1 atm, 15°C)	0.0378	55.6		
Natural gas	0.0364	53.6		
LPG propane	25.3	49.6		
LPG butane	27.7	49.1		
Crude oil	37.0	46.3		
Coal, anthracite	72.4	32.5		
Coal, lignite		14.0		
Coal, bituminous	20.0	24.0		
Wood		18.0		

Gaur and Reed [18], ETB [15]

Lower heating value (LHV) = 44000 kJ/kg; 44,000 kJ of heat is released when 1 kg of gasoline is completely burned and the produced water is in vapor state (Table 2.7).

Fuel needed for the old car: (40 miles/day)/(20 miles/gal) = 2 gal/day
Fuel needed for the new car: (40 miles/day)/(30 miles/gal) = 1.34 gal/day

Old car:
Mass of gasoline:
$m_{gas} = \rho_{av}$ (Volume) = (0.75 kg/l)(2.0gal/day)(3.785 l/gal) = **5.7 kg/day**

Energy of gasoline:
E_{gas} (LHV) = (5.7 kg/day) (44000 kJ/kg) = 250800 kJ/day (365 day/year)
= 91542,000 kJ/year = **91,542 MJ/year**
Cost: ($3.50/gal)(2 gal/day)(365 day/year) = $2555/year

New car:
Mass of gasoline:
$m_{gas} = \rho_{av}$ (Volume) = (0.75 kg/l)(1.34gal/day)(3.785 l/gal) = **3.8 kg/day**
Energy of gasoline:
E_{gas} (LHV) = (3.8 kg/day) (44000 kJ/kg) = 167,200 kJ/day (365 day/year)
= 61,028,000 kJ/year = **61,028 MJ/year**
Cost: ($3.50/gal)(1.34 gal/day)(365 day/year) = $1712/year

The new car reduces the fuel consumption by around 33%, which is significiant.

Example 2.3 Daily consumption of natural gas by a city
The new car reduces the fuel consumption by around 33%, which is significant. A city consumes natural gas at a rate of 500 × 10^6 ft^3/day. The volumetric flow is at standard conditions of 60°F and 1 atm = 14.7 psia. If the natural gas is costing $6/GJ of higher heating value what is the daily cost of the gas for the city.

Solution:
Q = 500 × 10^6 ft^3/day at 60°F and 1 atm = 14.7 psia.

The higher heating value is the heat of combustion of the natural gas when the water product is at liquid state. From Table 2.7, the value of HHV is: 1,030 Btu/ft^3 (Table 2.8)

Heating value: 1030 Btu/ft^3 (500 × 10^6 ft^3/day) = 515.0 × 10^9 Btu/day
(515.0 ×10^9 Btu/day) (1055 J/Btu) = 543,325 GJ/day

Daily cost: (543,325 GJ/day) ($6/GJ) = **$32.6 × 10^5/day**

Example 2.4 Energy consumed by a car
An average car consumes about 2 gallons (US gallon = 3.785 l) a day, and the capacity of the fule tank is about 15 gallon. Therefore, a car needs to be refueled once every week. The density of gasoline ranges from 0.72 to 0.78 kg/l (Table 2.7). The lower heating value of gasoline is about 44,000 kJ/kg. Assume that the average density of gasoline is 0.75 kg/l. If the car was able to use 0.2 kg of nuclear fuel of uranium-235, estimate the time in years for refueling.

Solution:
Assume: The gasoline is incompressible with $\rho_{av} = 0.75$ kg/l.
Lower heating value (LHV) = 44,000 kJ/kg; 44,000 kJ of heat is released when 1 kg of gasoline is completely burned and the produced water is in vapor state.

Complete fission energy of U-235 = 6.73 × 10^{10} kJ/kg
Mass of gasoline per day:
$m_{gas} = \rho_{av} V$ = (0.75 kg/l)(2gal/day)(3.785 l/gal) = 5.67 kg/day

Energy of gasoline per day :
$E_{gas} = m_{gas}\,(LHV)$ = (5.67 kg/day)(44,000 kJ/kg) = 249,480 kJ/day

Energy released by the complete fission of 0.2 kg U-235:
$E_{\text{U-235}} = (6.73\ 10^{10}\ \text{kJ/kg})(0.2\ \text{kg}) = 1.346\ 10^{10}\ \text{kJ}$

Time for refueling: $(1.346\ 10^{10}\ \text{kJ})/(249{,}480\ \text{kJ/day})$ = **53952 days = 148 years**
Therefore, the car will not need refueling for about 148 years.

2.5 Renewable Energy Resources

Renewable energy comes from natural resources and are naturally replenished. Major renewable energy sources are:

- Hydroelectric
- Solar energy
- Biomass
- Wind
- Geothermal heat
- Ocean

In its various forms, renewable energy comes directly from the sun, or from heat generated deep within the earth. In 2008, about 19% of global final energy consumption came from renewables, with 13% coming from traditional biomass, which is mainly used for heating, and 3.2% from hydroelectricity. Other renewables, such as small hydro, biomass, wind, solar, geothermal, and biofuels contributed around 2.7% and are growing rapidly. The share of renewables in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3% from new renewables. Climate change concerns, high oil prices, and government support are leading to increase in renewable energy usage and commercialization [14]. Consequently, between 2004 and 2009, worldwide renewable energy capacity grew at rates of 10–60% annually creating businesses and employment. Renewable energy replaces conventional fuels in four distinct areas: power generation, hot water/space heating, transport fuels, and rural (off-grid) energy services [6, 7]:

- *Renewable power generation* provides 18% of total electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas.
- *Solar hot water* contributes a portion of the water heating needs of over 70 million households in many countries.
- *Renewable biofuels* have contributed to a decline in oil consumption in Brazil, the United States and many other countries. The 93 billion liters of biofuels produced worldwide in 2009 displaced the equivalent of an estimated 68 billion liters of gasoline, equal to about 5% of world gasoline production.

New and emerging renewable energy technologies are still under development and include cellulosic ethanol, hot-dry-rock geothermal power, and ocean energy. Renewable energy generally gets cheaper in the long term, while fossil fuels generally get more expensive. Fossil fuel technologies are more mature, while renewable energy technologies are being rapidly improved to increase the efficiency of renewable energy and reduce its cost. In rural and remote areas, transmission and distribution of energy generated from fossil fuels can be difficult and expensive; therefore producing renewable energy locally can offer a viable alternative.

The International Renewable Energy Agency (IRENA) promotes the adoption of renewable energy worldwide. As of March 2010, IRENA has 143 member states. Renewable energy policy targets exist in some 73 countries around the world, and public policies to promote renewable energy use have become more common in recent years. Mandates for blending biofuels into vehicle fuels have been enacted in 17 countries. The shift from food crop feedstock to waste residues and native grasses offers significant opportunities for farmers and investors [30].

2.5.1 Hydroenergy

Hydroenergy is derived from the force or energy of moving water. Most hydroelectric energy comes from the potential energy of dammed water driving a water turbine and generator. The power extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the head. The amount of potential energy in water is proportional to the head. To deliver water to a turbine while maintaining pressure arising from the head, a large pipe called a penstock may be used. In 1878, the world's first house to be powered with hydroelectricity was in Northumberland, England. The old Schoelkopf Power Station near Niagara Falls in the US began to produce electricity in 1881.

One of the major advantages of hydroelectricity is the elimination of fuel. Because there is no fuel combustion, there is little air pollution in comparison with fossil fuel plants and limited thermal pollution compared with nuclear plants. Hydroelectric plants also tend to have longer economic lives than fuel-fired power generation, with some plants now in service which were built 50–100 years ago. Operating labor cost is also usually low, as plants are automated and need few personnel on site during normal operation. The sale of electricity from the station may cover the construction costs after 5–8 years of full operation.

Hydroelectric usually refers to large-scale hydroelectric dams. Micro hydro systems typically produce up to 100 kW of power. Hydro systems without dam derive kinetic energy from rivers and oceans. Ocean energy includes marine current power, ocean thermal energy conversion, and tidal power. Figure 2.5 shows the Ice Harbor dam in the US.

2.5.2 Solar Energy

Solar energy is derived from the sun through the form of solar radiation. Solar powered electrical generation relies on photovoltaics and heat engines. Other solar applications

Fig. 2.5 Ice Harbor Dam. Hydroelectric plants operate where suitable waterways are available. Water may be a source of cheap and relatively clean power. In addition, because there is no fuel combustion, there is little air pollution in comparison with fossil fuel plants and limited thermal pollution compared with nuclear plants. The use of water for power generation has environmental impacts caused by damming rivers and streams, which affects the habitats of the local plant, fish, and animal life [14]

includes space heating and cooling through solar architecture, daylighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy:

- *Active solar techniques* include the use of solar thermal collectors to harness the energy. Some active solar techniques include s*olar process heat* by commercial and industrial buildings, *space heating/cooling*, and water heating. A typical water heating system includes solar collectors that work along with a pump, heat exchanger, and one or more large heat storage tanks. The most common collector is called a *flat-plate collector*. Mounted on a roof, it consists of a thin, flat, rectangular box with a transparent cover that faces the sun (see Fig. 2.6a). Small tubes run through the box and carry the heat transfer fluid mainly water or air to be heated. The tubes are attached to an absorber plate, which is painted black to absorb the heat. As heat builds up in the collector, it heats the fluid passing through the tubes. The storage tank then holds the hot liquid. It can be just a modified water heater, but it is usually larger and very well-insulated. Systems that use fluids other than water usually heat the water by passing it through a coil of tubing in the storage tank, which is full of hot fluid.
- *Passive solar systems* rely on gravity and the tendency for water to naturally circulate as it is heated. *Passive solar techniques* orient buildings to the Sun, select materials with favorable thermal mass or light dispersing properties, and design spaces that naturally circulate air. Figure 2.6a shows solar hot water systems and Fig. 2.6b a house with passive solar design.

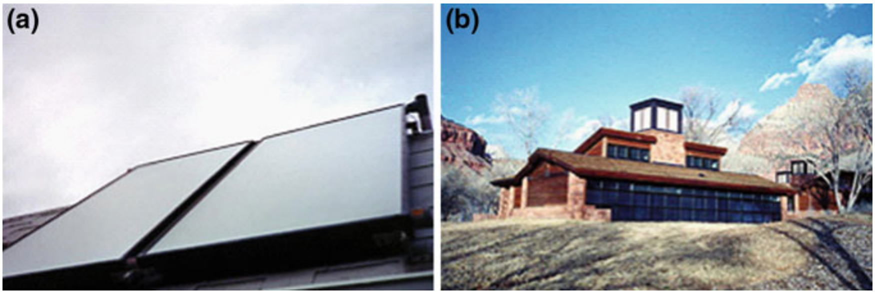


Fig. 2.6 **a** For solar hot water systems, flat-plate solar collectors are typically installed facing south on a rooftop; **b** the Zion National Park Visitor Center incorporates passive solar design features, including clerestory windows for daylighting and Trombe walls that absorb heat during the day and give off heat at night [32]

2.5.2.1 Nonresidential Solar Collectors

The two main types of solar collectors used for nonresidential buildings are an *evacuated-tube collector* and a *linear concentrator*. They can operate at high temperatures with high efficiency. An evacuated-tube collector is a set of many double-walled, glass tubes and reflectors to heat the fluid inside the tubes. A vacuum between the two walls insulates the inner tube, retaining the heat. Linear concentrators use long, rectangular, U-shaped mirrors tilted to focus sunlight on tubes that run along the length of the mirrors. The concentrated sunlight heats the fluid within the tubes. Solar absorption systems use thermal energy to evaporate a refrigerant fluid to cool the air. In contrast, solar desiccant systems use thermal energy to regenerate desiccants that dry the air, thereby cooling the air [4, 14].

2.5.2.2 Solar Electric Generating Systems

Solar electric generating system use parabolic trough collectors to collect the sun's energy to generate steam to drive a conventional steam turbine [4]. The parabolic mirrors automatically track the sun throughout the day. The sun light is directed to central tube carrying synthetic oil, which heats around 400°C. The heat is used to convert water to steam to drive a steam turbine and produce electricity. The largest solar thermal power station is in the Mojave Desert in the US with a power output of 354 MW (see Fig. 2.7).

2.5.2.3 Photovoltaic

Solar photovoltaic (PV) convert light into electricity using semiconductor materials. Photovoltaic cell is a *solar cell*, which is a solid state electrical device that converts the energy of light directly into electricity. Assemblies of cells are known

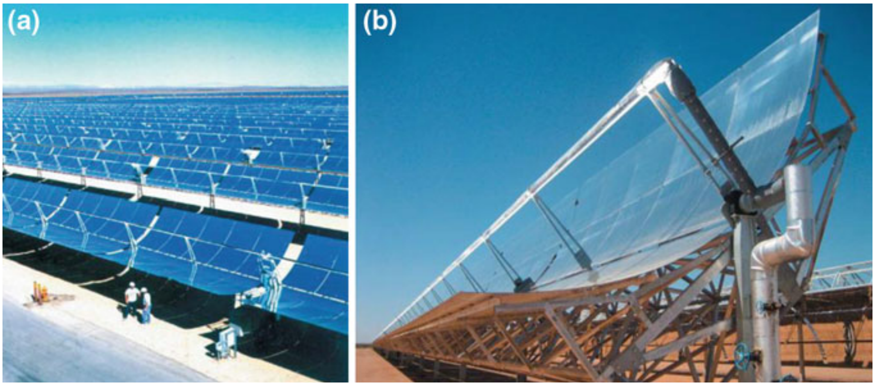


Fig. 2.7 **a** The 150-MW Kramer Junction plants shown here are part of a 354 MW series of SEGS (solar electric generating system) facilities, each using parabolic trough collectors to collect the sun's energy to generate steam to drive a conventional steam turbine. The plants have been operating in the California Mojave Desert for two decades [32]; **b** parabolic trough solar collectors at the recently dedicated 1-MW Saguaro power plant outside Tucson concentrate sunlight onto a receiver tube located along the trough's focal line. The solar energy heats the working fluid in the receiver tube, which vaporizes a secondary fluid to power a turbine. A next-generation version of this collector is being installed at a new 64-MW plant in Nevada [25]

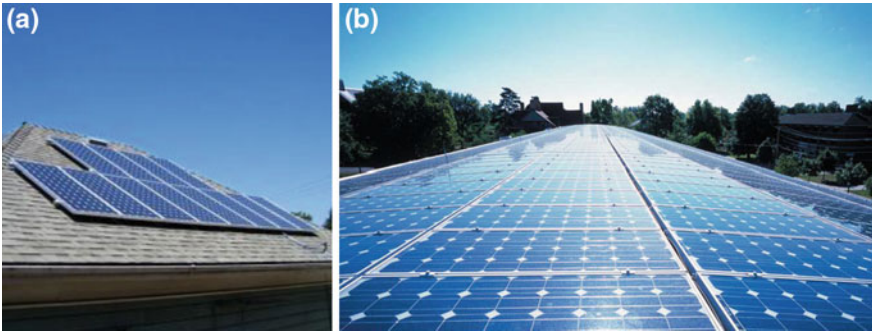
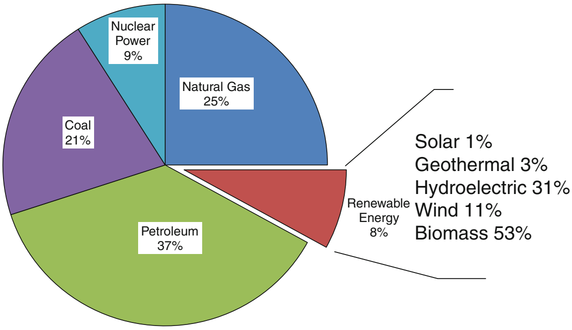


Fig. 2.8 **a** Photovoltaic systems are typically sited on roofs and may be connected to the electrical grid. Photovoltaic modules can compete against the retail price of electricity, offsetting the technology's high cost; **b** rooftop photovoltaic module (Oberlin College's Adam Joseph Lewis Center for Environmental Studies features a south-facing curved roof covered in Williamson) [25]

as *solar modules* or *solar panels*. Solar modules are typically deployed as an array of individual modules on rooftops, building facades, or in large-scale ground-based arrays (see Fig. 2.8). A module consists of many jointly connected solar cells. Most crystalline modules usually consist of 60–72 cells. Photovoltaic cell and modules use various semiconductors; they have three types (1) crystalline silicon, (2) thin-film, and (3) concentrator. Photovoltaic systems produce direct

Fig. 2.9 Renewable energy consumption in the U.S.'s energy supply in 2009. (quad = 10^{15} Btu): Total; 97892 quadrillion Btu, Total renewables: 8049 quadrillion Btu [14]



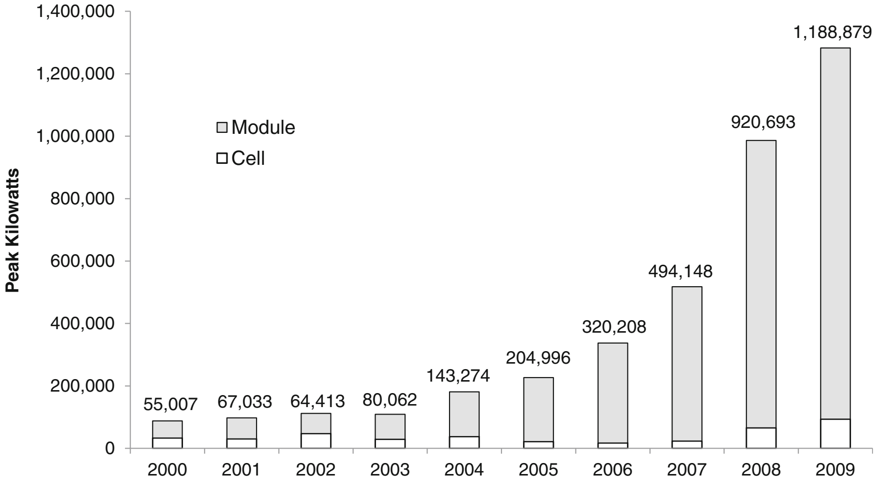


Fig. 2.10 Growth of US photovoltaic industry between 2000 and 2009. Assemblies of cells are known as solar modules or solar panels. Photovoltaic cell and modules use various semiconductors; they have three types (1) crystalline silicon, (2) thin-film, and (3) concentrator [14]

current, which must be converted to alternating current via an inverter if the output from the system is to be used in the grid. Annual production of photovoltaic modules in 2005 was about 150 MW in the US and about 1.7 gigawatts (GW) worldwide [11].

A major goal is to increase solar photovoltaic efficiency and decrease costs. Current efficiencies for crystalline silicon cells equal to about 15–20%. The total costs of photovoltaic systems are currently in the \$6 to \$9 per peak watt range. Component costs include the photovoltaic modules at about \$3–\$4/W (direct current), with another \$3–\$5/W for the inverter, installation, and balance of system. The cost of residential electricity from solar photovoltaic should be around 10–12 cents/kWh by 2015 and 6–8 cents/kWh by 2030. Figure 2.9 shows the renewable energy consumption in the U.S. energy supply in 2009. Figure 2.10 shows the use of photovoltaic in kW in the U.S. between 2000 and 2009.

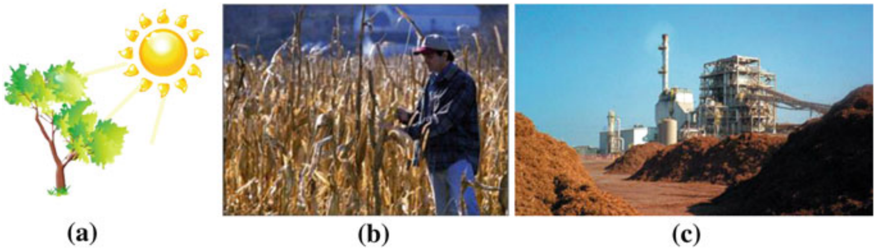


Fig. 2.11 **a** Photosynthesis; in the photosynthesis plants convert solar energy into chemical energy in the form of glucose: Water + Carbon dioxide + Sunlight → Glucose + Oxygen and $H_2O + CO_2 + \text{Sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$; **b** biomass growth; **c** the 21 MW Tracy Biomass Plant uses wood residues discarded from agricultural and industrial operations to provide the San Francisco Bay Area with base load capacity [32]

2.5.3 Biomass and Bioenergy

Biomass is organic material made from plants including microorganisms and animals. Plants absorb the sun's energy in photosynthesis and store the energy as biomass (see Fig. 2.11). Therefore, biomass is a renewable energy source based on the carbon cycle. Some examples of biomass fuels include wood, crops, and algae. When burned, the chemical energy in biomass is released as heat. Biomass can be converted to other biofuels, such as ethanol and biodiesel. Biomass grown for biofuel includes corn, soybeans, willow switch grass, rapeseed, sugar beet, palm oil, and sorghum [30]. Cellulosic biomass, such as corn stover, straw, timber, rice husks can also be used for biofuel production (see Fig. 2.11). Anaerobic digestion of biomass produces biogas, while gasification produces syngas, which is the mixture of hydrogen and carbon dioxide to be converted to liquid fuels. Cellulosic ethanol can also be created by a thermo-chemical process, which uses various combinations of temperature, pressure, water, oxygen or air, and catalysts to convert biomass to cellulosic ethanol. Table 2.10 shows lower heating values, moisture, and ash content of some biomass.

As Fig. 2.12 indicates that between years 2006 and 2010 the use of wind power and biomass increased, while the hydropower share decreased; the use of solar and geothermal sources remained the same [14].

2.5.3.1 Carbon Cycle

In the carbon cycle, carbon in various forms is transported between the various components of the Earth's biosphere, between the atmosphere, hydrosphere (seas and oceans), lithosphere (rocks, soils and mineral deposits, including fossil fuels) and biological material including plants and animals. Carbon cycle maintains a state of dynamic equilibrium. Other forms, most notably fossil fuels, can potentially store carbon indefinitely, however if they are burned the carbon is released and makes a net addition to the carbon cycle and raising the total free carbon. If

Table 2.10 Lower heating values (LHV) for selected biomass

Product	Moisture (%)	Ash content[a] (%)	LHV (MJ/kg)
Bagasse sugarcane	18	4	17–18
Coconut husks	5–10	6	16,7
Coffee husks	13	8–10	16,7
Corn stover	5–6	8	17–19
Corncobs	15	1–2	19,3
Cotton husks	5–10	3	16,7
Oil-palm fibers	55	10	7–8
Oil-palm husks	55	5	7–8
Poplar wood	5–15	1.2	17–19
Rice hulls	9–11	15–20	13–15
Rice straw and husk	15–30	15–20	17–18
Switchgrass	8–15	6	18–20
Wheat straw and husk	7–15	8–9	17–19
Willow wood	12	1–5	17–19

[a] Approximate [15]

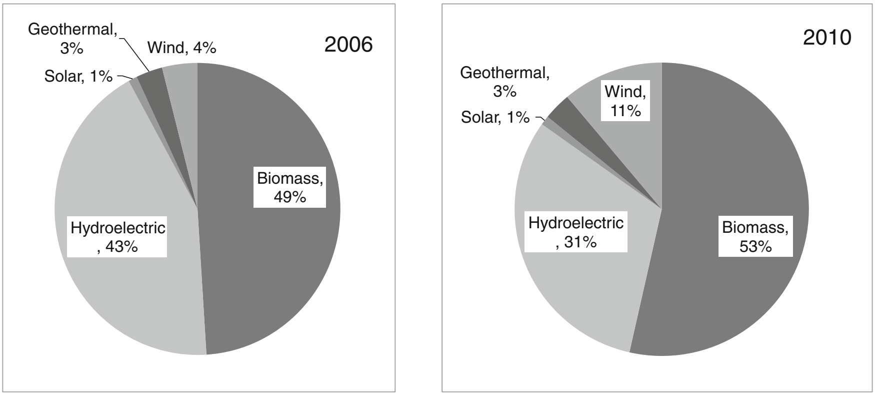


Fig. 2.12 Use of renewable energy in the US; the use of wind power and biomass increased, while the hydropower share decreased; the use of solar and geothermal sources remained the same [14]

biomass is used without replacement, for example in the case of forest clearance, this too can make a net addition to the carbon cycle. As growing plant absorbs the carbon released by the harvested biomass, sustainable use of biomass makes no direct net contribution [19, 20].

2.5.3.2 Gross Heating Values of Biomass Fuels

Biomass fuels are usually characterized by the *proximate* and *ultimate analyses*.

Table 2.11 Proximate and ultimate analyses of biomass fuels in weight percentage

Name	Fixed Carbon	Volatiles %	Ash %	C %	H %	O %	N %	S %	HHV$_m$ kJ/g	HHV$_{est}$ kJ/g
Douglas Fir	17.70	81.50	0.80	52.30	6.30	40.50	0.10	0.00	21.05	21.48
Hickory	–	–	0.73	47.67	6.49	43.11	0.00	0.00	20.17	19.82
Maple	–	–	1.35	50.64	6.02	41.74	0.25	0.00	19.96	20.42
Ponderosa Pine	17.17	82.54	0.29	49.25	5.99	44.36	0.06	0.03	20.02	19.66
Poplar	–	–	0.65	51.64	6.26	41.45	0.00	0.00	20.75	21.10
Redwood	16.10	83.50	0.40	53.50	5.90	40.30	0.10	0.00	21.03	21.45
Western Hemlock	15.20	84.80	2.20	50.40	5.80	41.10	0.10	0.10	20.05	20.14
Yellow Pine	–	–	1.31	52.60	7.00	40.10	0.00	0.00	22.30	22.44
White Fir	16.58	83.17	0.25	49.00	5.98	44.75	0.05	0.01	19.95	19.52
White Oak	17.20	81.28	1.52	49.48	5.38	43.13	0.35	0.01	19.42	19.12
Douglas Fir bark	25.80	73.00	1.20	56.20	5.90	36.70	0.00	0.00	22.10	22.75
Loblolly Pine bark	33.90	54.70	0.40	56.30	5.60	37.70	0.00	0.00	21.78	22.35
Peach Pits	19.85	79.12	1.03	53.00	5.90	39.14	0.32	0.05	20.82	21.39
Walnut Shells	21.16	78.28	0.56	49.98	5.71	43.35	0.21	0.01	20.18	19.68
Almond Prunings	21.54	76.83	1.63	51.30	5.29	40.90	0.66	0.01	20.01	19.87
Black Walnut Prunings	18.56	80.69	0.78	49.80	5.82	43.25	0.22	0.01	19.83	19.75
Corncobs	18.54	80.10	1.36	46.58	5.87	45.46	0.47	0.01	18.77	18.44
Wheat Straw	19.80	71.30	8.90	43.20	5.00	39.40	0.61	0.11	17.51	16.71
Cotton Stalk	22.43	70.89	6.68	43.64	5.81	43.87	0.00	0.00	18.26	17.40
Corn Stover	19.25	75.17	5.58	43.65	5.56	43.31	0.61	0.01	17.65	17.19
Sugarcane Bagasse	14.95	73.78	11.27	44.80	5.35	39.55	0.38	0.01	17.33	17.61
Rice Hulls	15.80	63.60	20.60	38.30	4.36	35.45	0.83	0.06	14.89	14.40
Pine needles	26.12	72.38	1.50	48.21	6.57	43.72			20.12	20.02
Cotton gin trash	15.10	67.30	17.60	39.59	5.26	36.38	2.09	0.00	16.42	15.85
Cellulose	–	–	162	44.44	6.17	49.38	–	–	–	17.68
Lignin (Softwood)	–	–	–	63.8	6.30	29.90	–	–	–	26.60
Lignin (Hardwood)	–	–	–	59.8	6.40	33.70	–	–	–	24.93

Gaur and Reed [18]

- The *proximate analysis* gives moisture content, volatile content (when heated to 950°C), the free carbon remaining at that point, the ash (mineral) in the sample, and the higher heating value based on the complete combustion of the sample to carbon dioxide and liquid water.
- The *ultimate analysis* is the elemental analysis and provides the composition of the biomass in wt% of carbon, hydrogen, oxygen, sulfur, and nitrogen.

Table 2.11 shows measured and estimated gross heating values as well as the proximate and ultimate analyses of some selected fuels, including biomass components, natural biomass (woods, agricultural products), processed biomass, and other solid and liquid fuels.

A relationship between the high heating value, HHV and the elemental composition is given by

$$\text{HHV(in kJ/g)} = 0.3491\text{C} + 1.1783\text{H} - 0.1034\text{O} - 0.0211\text{A} + 0.1005\text{S} \\ - 0.0151\,\text{N} \tag{2.2}$$

where C is the weight fraction of carbon, H of hydrogen, O of oxygen, A of ash, S of sulfur, and N of nitrogen appearing in the ultimate analysis. This equation represents the experimental data with an average error of 1.45% and can be used in estimating heat values and modeling of biomass processes [18].

Based on chemical functional groups of the fuels, the heating values may vary. When the oxygen percentage is higher in a fuel, the percentages of carbon and hydrogen available for combustion are reduced. This leads to the lower heating values. By using the values of fixed carbon (FC, wt%), the higher heating value of the biomass samples can be estimated by

$$\text{HHV(MJ/kg)} = 0.196(\text{FC}) + 14.119 \tag{2.3}$$

The heating values calculated from Eq. (2.3) shows a mean difference of 2.2% between estimated and measured values [10]. Another correlation between the HHV and dry ash content from proximate analysis of biomass (in weight percent) is expressed by

$$\text{HHV(MJ/kg)} = 19.914 - 0.2324\text{Ash} \tag{2.4}$$

Based on the composition of main elements (in wt%) C, H, and O, the heating value is estimated by

$$\text{HHV(MJ/kg)} = 0.3137\text{C} + 0.7009\text{H} + 0.0318\text{O} - 1.3675 \tag{2.5}$$

with more than 90% predictions in the range of ±5% error [34].

Example 2.5 Gross heating value estimations

Using data in Table 2.11, estimate the gross heating values in kJ/kg for the biomass redwood from: (a) ultimate analysis, (b) fixed carbon, (c) dry ash content, and (d) carbon (C), hydrogen (H), and oxygen (O) compositions.

Name	Fixed Carbon	Volatiles (%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV_m (kJ/g)	HHV_{est} (kJ/g)
Redwood	16.10	83.50	0.40	53.50	5.90	40.30	0.10	0.00	21.03	21.45

Solution:

(a) From ultimate analysis

HHV (in MJ/kg)

$= 0.3491\text{C} + 1.1783\ \text{H} - 0.1034\ \text{O} - 0.0211\ \text{A} + 0.1005\ \text{S} - 0.0151\ \text{N}$

HHV (in MJ/kg) = 0.3491(53.50) + 1.1783 (5.90) − 0.1034 (40.3) − 0.0211 (0.0040) + 0.1005 (0.0) −0.0151 (0.0010) = 21.44 MJ/kg = **21,440 kJ/kg**

(b) From fixed carbon percentage
HHV (MJ/kg) = 0.196(FC) + 14.119
HHV (MJ/kg) = 0.196(16.10) + 14.119 = 17.3 MJ/kg = **17,300 kJ/kg**

(c) From dry ash content
HHV (MJ/kg) = 19.914 – 0.2324 Ash
HHV (MJ/kg) = 19.914 – 0.2324 (0.0040) = 19.914 MJ/kg = **19,914 kJ/kg**

(d) From the main elements (in wt%) C, H, and O
HHV (MJ/kg) = 0.3137 C + 0.7009 H + 0.0318 O−1.3675
HHV (MJ/kg) = 0.3137 (53.50) + 0.7009 (5.9) + 0.0318 (40.3)−1.3675 = 20.83 MJ/kg = **20,830 kJ/kg**

Estimation from Eq. (2.5), used in part (d), is the closest to the measured value of 21.03 MJ/kg (21,030 kJ/kg)

2.5.3.3 Bioenergy

Biological fuels produced from photosynthesis can be categorized in three groups:

- *Carbohydrates*, representing a mixture of mono-di-and poly-saccharides (4 kcal/g or 17 kJ/g).
- *Fats*, unsaturated and saturated fatty acids (triacylglycerol or triglyceride) (9 kcal/g or 39 kJ/g).
- *Proteins*, used partly as fuel source (4 kcal/g or 17 kJ/g).

Carbohydrates are straight-chain aldehydes or ketones with many hydroxyl groups that can exist as straight chains or rings. Carbohydrates such as starch are the most abundant biological molecules, and play numerous roles, such as the storage and transport of energy, and structural components such as cellulose in plants. Triglycerides and fatty free acids both contain long, linear aliphatic hydrocarbon chains, which are partially unsaturated and have a carbon number range. The fuel value is equal to the heat of combustion (oxidation) of fuel. Carbohydrates and fats can be completely oxidized while proteins can only be partially oxidized and hence has lower fuel values [28].

Synthetic biofuels are:

- Bioethanol—In the United States, corn-based ethanol is currently the largest source of biofuel as a gasoline substitute or additive. The gasoline sold in the United States today is mixed with 10% ethanol, a mix known as E10 (or gasohol). Only specific types of vehicles named as flexible fuel vehicles can use mixtures with greater than 10% ethanol. E85 is an alternative fuel that contains up to 85% ethanol (see Fig. 2.13; [16]).

Fig. 2.13 Biofuels can displace imported oil for transportation. This triple biofuels dispenser at the Baca Street Biofuels Station in Santa Fe, New Mexico, offers consumers a choice of renewable transportation fuels [32]

- Biodiesel—Biodiesel is most often blended with petroleum diesel in ratios of 2% (B2), 5% (B5), or 20% (B20). It can also be used as pure biodiesel (B100). Biodiesel can be produced from various feedstock [2] and used in regular diesel vehicles without making any changes to the engines [24].
- Green diesel—Green diesel is produced by removing the oxygen by catalytic reaction with hydrogen from renewable feedstock containing triglycerides and fatty acids, producing a paraffin-rich product, water, and carbon oxides. Therefore, green diesel has a heating value equal to conventional diesel and is fully compatible for blending with the standard mix of petroleum-derived diesel fuels [9, 23]. Biodiesel has around 11% oxygen, whereas petroleum-based diesel and green diesel have no oxygen.

Bioethanol and biodiesel provided 1.8% of the world's transport fuel in 2008 and provided about 4% of the energy used in the United States [14]. Using biomass as a feedstock for liquid fuels production may cut back on waste and greenhouse gas emissions, and can offset the use of fossil fuels in heat and power generation. The total worldwide biomass electrical capacity is on the order of 40 GW. The current global growth rate for biomass-based transportation fuels is more than 10% per year.

2.5.4 Wind Energy

The Earth is unevenly heated by the sun and the differential heating drives a global atmospheric convection system reaching from the earth's surface to the

Fig. 2.14 **a** Each 1.65 MW wind turbine at the Maple Ridge Wind Farm near Lowville, New York, generates enough electricity to power about 500 homes. Jennifer Harvey, NYSERDA, NREL PIX 14399; **b** offshore wind resources. Currently, the US has more than 35,000 MW of land-based installed wind power capacity. That is enough to serve more than 9 million homes and avoid the annual emissions of 62 million tons of carbon dioxide [13]

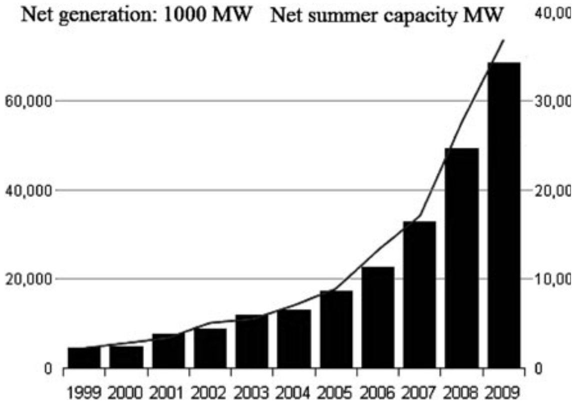
stratosphere. Most of the energy stored in these wind movements can be found at high altitudes where continuous wind speeds of over 160 km/h (99 mph) occur (see Fig. 2.14). To assess the frequency of wind speeds at a particular location, a probability distribution function is often fitted to the observed data. Wind power is a totally renewable energy source with no greenhouse gas emissions, but due to its unpredictability, has problems integrating with national grids. At the end of 2009, worldwide wind farm capacity was 157,900 MW, representing an increase of 31% during the year, and *wind power* supplied some 1.3% of global electricity consumption. Installed US wind power capacity reached 25,170 MW at the end of 2008 and still growing (15% in cumulative wind power capacity in 2010) [1, 39].

The potential for wind to supply a significant quantity of energy is considerable (see Fig. 2.15). Availability of transmission capacity helps large-scale deployment by reducing the cost of delivered wind energy.

2.5.5 Geothermal Energy

Geothermal energy is the heat originating from the original formation of the planet, from radioactive decay of minerals, from volcanic activity, and from solar energy absorbed at the surface (see Fig. 2.16). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. Geothermal power is cost effective, reliable, sustainable, and environmentally friendly. The world's largest geothermal power installation is The Geysers in California, with a rated capacity of 750 MW. Worldwide, about 10,715 MW of geothermal power is produced. An additional 28 GW of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination, and agricultural applications.

Fig. 2.15 Wind generation versus capacity; growth of wind power [14]




(a) (b)

Fig. 2.16 **a** The Earth's heat—called geothermal energy—escapes as steam at a hot springs in Nevada; **b** the Mammoth Lakes power plant is located in a picturesque area of northern California. Binary-cycle geothermal power plants release no carbon dioxide or water vapor plumes and blend into the environment [32]

Hot water or steam reservoirs deep in the earth are accessed by drilling. Geothermal reservoirs located near the earth's surface maintain a relatively constant temperature of 50°–60°F. The hot water and steam from reservoirs can be used to drive generators and produce electricity. In other applications, the heat produced from geothermal is used directly in heating buildings and industrial plants. As in the case of biomass electricity, a geothermal plant runs 24 hours per day, 7 days per week and can provide base load power, thus competing against coal plants.

2.5.6 Ocean Energy

Systems to harvest electrical power from ocean waves have recently been gaining momentum as a viable technology. The potential for this technology is considered promising. The world's first commercial tidal power station was installed in 2007

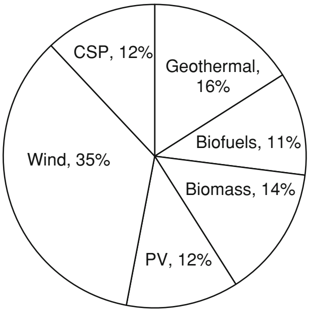


Fig. 2.17 Pie chart showing future projections of relative contributions of the various renewables in 2030 [14]. *PV* Photovoltaic; *CSP* Concentrated solar power

in the narrows of Strangford Lough in Ireland. Although the generator is powerful enough to power a thousand homes, the turbine has minimal environmental impact, as it is almost entirely submerged, and the rotors pose no danger to wildlife as they turn quite slowly. Ocean thermal energy conversion uses the temperature difference that exists between deep and shallow waters to run a heat engine (see Sect 7.16).

2.5.7 Projection on Renewable Energy Contributions

The pie chart in Fig. 2.17 shows the relative contributions of different renewable energy technologies. *Hybrid renewable energy systems* usually consist of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. For example, consider a load of 100% power supply and there is no renewable system to fulfill this need, so two or more renewable energy systems can be combined. For example, 60% from a biomass system, 20% from a wind energy system and the remainder from fuel cells. Thus combining all these renewable energy systems may provide 100% of the power and energy requirements for the load, such as a home or business. Another example is the combination of a photovoltaic array coupled with a wind turbine. This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output.

2.6 Hydrogen

Hydrogen is the simplest element. Each atom of hydrogen has only one proton. The sun is basically a giant ball of hydrogen and helium gases. In the sun's core, hydrogen atoms combine to form helium atoms (called fusion process) and gives off *radiant energy*. This radiant energy sustains life on earth as it drives the photosynthesis in plants and other living systems, and is stored as chemical energy in fossil fuels.

Hydrogen does not exist on earth as a gas and is found only in compound form with other elements, such as water H_2O and methane CH_4. Hydrogen is produced from other resources including natural gas, coal, biomass, and even water. The two most common production methods are steam reforming and electrolysis in which the water is split into oxygen and hydrogen. Steam reforming is currently the least expensive and most common method of producing hydrogen. Electrolysis is currently an expensive process. Currently, global hydrogen production is 48% from natural gas, 30% from oil, 18% from coal, and 4% from water electrolysis.

Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline), but the lowest energy content by volume (see Table 2.9). Hydrogen transports energy in a useable form from one place to another. Like electricity, hydrogen is an energy carrier. Hydrogen burns cleanly, producing water H_2O. When burned in an engine or; used a fuel cell, it is converted to water only. To make hydrogen a renewable fuel it should use renewable energy, such as wind power or solar power, for production.

There are two primary uses for hydrogen today. About half of hydrogen is used to produce ammonia (NH_3) via the Haber process. Ammonia, in turn, is used directly or indirectly as fertilizer. The other half of current hydrogen production is used in hydrocracking process to convert heavy petroleum sources into lighter fractions suitable for use as fuels. Hydrogen fuel cells produce electricity. They are very efficient, but expensive to build. Small fuel cells can power electric cars, while large fuel cells can provide electricity in remote places with no power lines.

2.7 Electric Energy

The protons and electrons of an atom carry an *electrical charge*. Protons have a positive charge (+) and electrons have a negative charge (−). Opposite charges attract each other. The electrons in an atom's outermost shells do not attract strongly to the protons and can move from one atom to another and create electricity. The amount of electricity a power plant generates or a customer uses over a period of time is measured in kilowatt hours (kWh), which is equal to the energy of 1,000 watts working for 1 h. For example, if you use a 100-W light bulb for 7 h, you have used 700 Wh or 0.7 kWh of electrical energy. Figure 2.18 shows the resources for electricity, while Fig. 2.19 shows how the electricity is used in US.

Most of the electricity used in the residential sector is for air conditioning, refrigerators, space and water heating, lighting, and powering appliances and equipment. Electricity is the fastest growing form of end-use energy worldwide through 2030, as it has been over the past several decades. Electricity is the most well-known energy carrier to transfer the energy in coal, natural gas, uranium, wind power, and other energy sources to homes, businesses, and industry. We also use electricity to transfer the energy in flowing water from hydropower dams to consumers. For many energy needs, it is much easier to use electricity than the energy sources themselves.

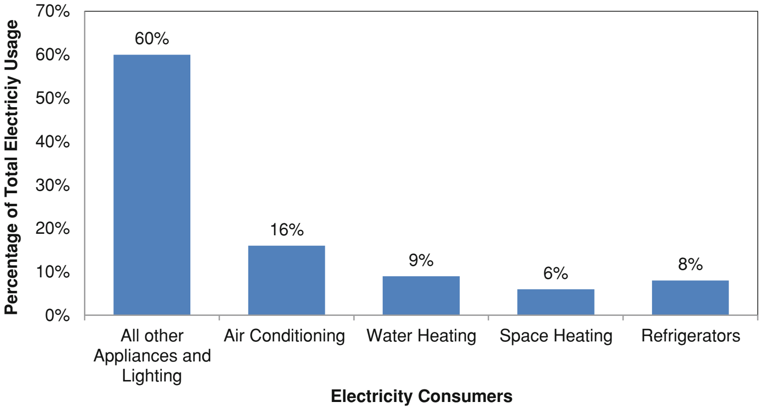


Fig. 2.18 Usage of electricity in homes in 2008 in the US [14]

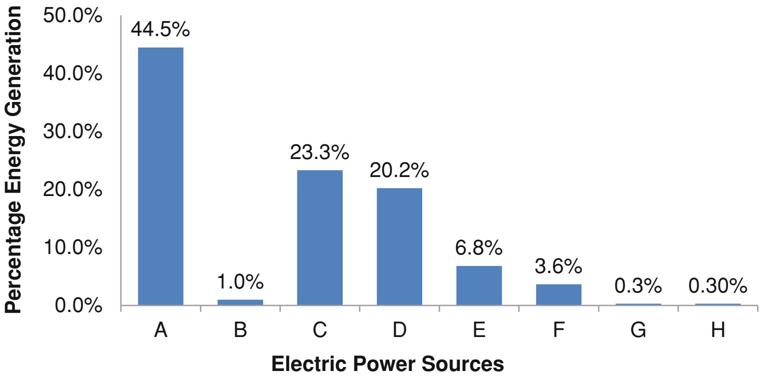


Fig. 2.19 US electric power industry net production by fuel [13]. *A* Coal, *B* Petroleum, *C* Natural gas, *D* Nuclear, *E* Hydroelectric, *F* Other renewables, *G* Other gases, *H* Other [14]

If the current passes through an electric appliance, some of the electric energy will be converted into other forms of energy (although some will always be lost as heat). The amount of electric energy, E_e, due to an electric current can be expressed in a number of different ways:

$$E_e = VIt = I^2Rt \tag{2.6}$$

where V is the electric potential difference (in volts), I is the current (in amperes), t is the time for which the current flows (in seconds), and R is the electric resistance (in ohms).

In *alternating current* (AC) the direction of the flow of electrons switches back and forth at regular intervals or cycles. Current flowing in power lines and normal household electricity that comes from a wall outlet is alternating current. The standard current used in the US is 60 cycles per second (i.e. a frequency of 60 Hz); in Europe and most other parts of the world it is 50 cycles per second (i.e. a frequency of 50 Hz.). In *Direct current* (DC)**,** on the other hand, electrical current flows consistently in one direction. The current that flows in a flashlight is direct current. One advantage of alternating current is that it is relatively cheap to change the voltage of the current. Furthermore, the inevitable loss of energy that occurs when current is carried over long distances is far smaller with alternating current than with direct current.

Example 2.6 Electricity consumption of a laptop computer

A laptop consuming 90 Watt is used on average 10 h per day. The laptop costs $500 and will be used for 4 years. Electricity cost is $0.15/kWh. Estimate the total electricity cost in four years for the laptop.

Solution:

$$\text{Cost}_{\text{laptop}} = \frac{\$500}{4\,\text{year}} = \$125/\text{year}$$

$$\text{Cost}_{\text{electricity}} = \frac{\$0.15}{\text{kWh}}\frac{10\,\text{h}}{\text{day}}\frac{365\,\text{days}}{\text{year}}90\,\text{W}\frac{\text{kW}}{1000\,\text{W}} = \$49.3/\text{year}$$

$$\text{Cost}_{\text{total}} = \text{Cost}_{\text{laptop}} + \text{Cost}_{\text{electricity}} = (\$125/\text{year} + \$49.3/\text{year})4\,\text{years} = \$\mathbf{697.2}$$

2.8 Magnetic Energy

There is no fundamental difference between magnetic energy and electric energy: the two phenomena are related by Maxwell's equations. The potential energy of a magnet of magnetic moment m in a magnetic field B is defined as the work of magnetic force (magnetic torque), and is estimated by

$$E_m = -mB \tag{2.7}$$

Calculating work needed to create an electric or magnetic field in unit volume results in the electric and magnetic fields energy densities. Electromagnetic radiation, such as microwaves, visible light, or gamma rays, represents a flow of electromagnetic energy. The energy of electromagnetic radiation has discrete energy levels. The spacing between these levels is equal to $E = h\nu$ where h is the

Planck constant, 6.626×10^{-34} Js [31], and v is the frequency of the radiation. This quantity of electromagnetic energy is usually called a photon. The photons which make up visible light have energies of $160 - 310$ kJ/mol.

2.9 Chemical Energy

Chemical energy results from the associations of atoms in molecules and various other kinds of aggregates of matter. It may be defined as a work done by electric forces that is electrostatic potential energy of electric charges. If the chemical energy of a system decreases during a chemical reaction, the difference is transferred to the surroundings in the form of heat or light. On the other hand, if the chemical energy of a system increases as a result of a chemical reaction, the difference then is supplied by the surroundings in form of heat or light. Typical values for the change in molar chemical energy during a chemical reaction range from tens to hundreds of kilojoules per mole. For example, 2,2,4-trimethylpentane (isooctane), widely used in petrol, has a chemical formula of C_8H_{18} and it reacts with oxygen exothermically and produces 10.86 MJ per mole of isooctane

$$C_8H_{18}(l) + 25/2\ O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g) + 10.86\,\mathrm{MJ/mole} \tag{2.8}$$

When two hydrogen atoms react to form a hydrogen molecule, the chemical energy decreases by the bond energy of the H–H. When the electron is completely removed from a hydrogen atom, forming a hydrogen ion, the chemical energy called the ionization energy increases.

2.10 Energy and Global Warming

The burning of fossil fuels produces around 21.3 Gigatons of carbon dioxide per year, and natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tons of atmospheric carbon dioxide per year [21].

One tonne of carbon is equivalent to: $MW_{CO_2}/MW_C = 44/12 = 3.7$ tons of carbon dioxide

Carbon dioxide emission can be calculated as

$$e_{CO_2} = \left(C_f/E_f\right)\left(MW_{CO_2}/MW_C\right) \tag{2.9}$$

where e_{CO_2} is the CO_2 emission in $kgCO_2/kWh$, C_f is the carbon content in the fuel (kg_C/kg_{fuel}) and E_f is the energy content of the fuel (kWh/kg_{fuel}).

Table 2.12 shows typical emission of carbon dioxide from the combustion of various fuels. An average car traveling 10,000 miles per year and consuming an average 25 miles per gallon emits about 1.2 tons of carbon dioxide per year. Since the early 1800s, it is known that various atmospheric gases, acting like the glass in

Table 2.12 Emission of carbon dioxide from the combustion of various fuels

Fuel	Specific carbon (kg_c/kg_{fuel})	Specific energy (kWh/kg_{fuel})	Specific CO_2 emission (kg_{CO_2}/kg_{fuel})	Specific CO_2 emission (kg_{CO_2}/kWh)
Coal (bituminous/anthracite)	0.75	7.5	2.3	0.37
Gasoline	0.9	12.5	3.3	0.27
Light oil	0.7	11.7	2.6	0.26
Diesel	0.86	11.8	3.2	0.24
LPG—liquid petroleum gas	0.82	12.3	3.0	0.24
Natural gas, methane	0.75	12	2.8	0.23
Crude oil				0.26
Kerosene				0.26
Wood[a]				0.39
Peat[a]				0.38
Lignite				0.36

(ETB [15] with permission)

[a] Commonly viewed as a biofuel

a greenhouse, transmit incoming sunlight but absorb outgoing infrared radiation, thus raising the average air temperature at the earth's surface. Carbon dioxide is clearly the most influential greenhouse gas. The most compelling evidence we have for climate change lies in the so-called paleoclimatic data obtained from ancient ice core samples in Greenland and Antarctica. By analyzing air bubbles that were trapped in the ice when it formed, scientists are able to determine the content of greenhouse gases and even the average temperature at each point in time. Figure 2.20 shows that over the past 420,000 years, the CO_2 content in the atmosphere has varied cyclically between about 180 and 290 ppm by volume with a period of about 100,000 years in conjunction with variations in the Earth's orbit. The earth's temperature has closely followed the greenhouse gas concentration.

Around 1850, when the CO_2 level was about 280 ppm, the level began to increase and now reached the value of 380 ppm, which indicates a 36% increase over the pre-industrial value (see Fig. 2.20). Increase in temperature can release CO_2 from the ground and seawater so the two effects reinforce each other. The possible consequences of these increases include ice melts, sea level rises, and severe storms because of the additional energy in the atmosphere. As the ice melts, the resulting darker water and ground absorb more sunlight, thus exacerbating the warming. The melt water flows like a river, causing rapid heat transfer and erosion.

The *global warming potential* is a measure of how much a given mass of a chemical substance contributes to global warming over a given period of time. The global warming potential is the ratio of the warming potential caused by a substance to the warming potential caused by a similar mass of carbon dioxide. Various hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) have

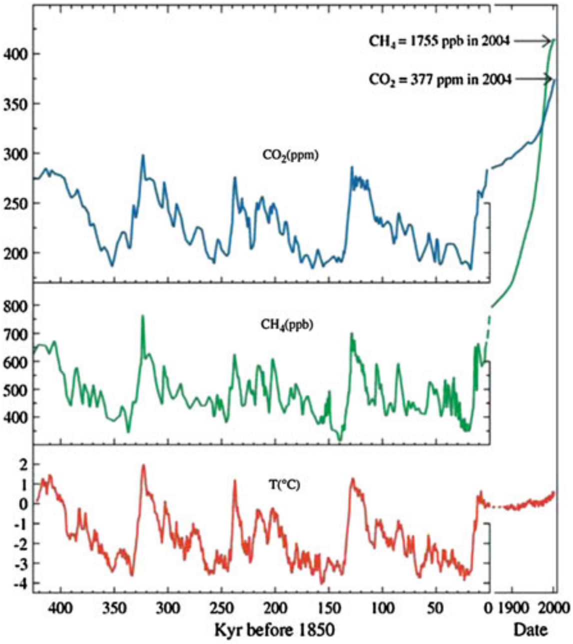


Fig. 2.20 Paleoclimatic data from ice cores shows recent increases in carbon dioxide and methane. The temperature, though increasing, has not yet reached record levels but will likely do so by midcentury [38]

global warming potentials ranging from 93 to 12100. These values are calculated over a 100-year period of time [12, 36].

Example 2.7 Carbon dioxide emission from natural gas combustion

When a hydrocarbon fuel is burned, almost all of the carbon in the fuel burns completely to form carbon dioxide CO_2, which is causes the greenhouse effect. On average, 0.59 kg of CO_2 is produced for each kWh of electricity generated from a power plant that burns natural gas. A typical new household uses about 7,000 kWh of electricity per year. Determine the amount of CO_2 production that is due to the refrigerators in a city with 200,000 households.

Solution:

Carbon dioxide emission from natural gas combustion A kWh is kW times hours. It is the amount of energy consumed in an hour by a device that uses 1 kW of power (1 kJ/s for 3,600 s), so you are left with units of energy.

Data: $m_{CO2} = 0.59$ kg CO_2/kWh, 200,000 houses, power 7,000 kWh/house per year

The total mass of CO_2 produced per year is the product of the rate of CO_2 production per kWh and the number of houses:

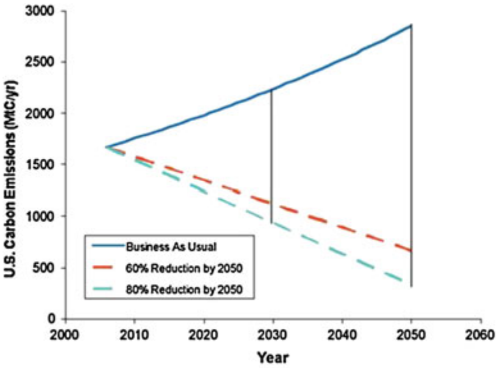


Fig. 2.21 Triangle of US fossil fuel carbon reductions needed by 2030 for a 60–80% reduction from today's levels by 2050 [25]

$$m_{\text{total}\,\mathrm{CO_2}} = \text{Power}(m\mathrm{CO_2})(\text{Number of houses}) = \left(\frac{\text{kWh}}{\text{house year}}\right)\left(\frac{\text{kg}\,\mathrm{CO_2}}{\text{kWh}}\right)(\text{Houses})$$

$$m_{\text{total }\mathrm{CO_2}} = \mathbf{8.26 \times 10^8\ kg\ CO_2/year = 826.0\ Mton\ CO_2/year}$$

2.11 Tackling the Global Warming

Electricity production (~40%) and transportation fuels (~30%) accounts a large part of total carbon dioxide emissions (see Fig. 2.21). Therefore, targeting electricity generation and transportation fuels will address about 70% of the carbon dioxide emissions. For example, the use of renewable energy for electricity generation does not cause additional carbon dioxide emissions, and is sustainable into the future. The major challenges with greatly expanded use of renewables are the cost, intermittency of supply, and distance between the resources and the end use. Some possible renewable energy sources are concentrating solar power, geothermal electric plants, wind power, distributed rooftop photovoltaic, and solar hot water heaters. Hybrid electric vehicles represent an important advance. A hybrid electric vehicle can cover a distance of about 10 to 20 miles, and if it can be plugged into the grid to be recharged, it is possible to greatly reduce the amount of gasoline the vehicle uses. Using E85 (85% and 15% blend of ethanol and gasoline, respectively) may help reducing carbon dioxide emission [29].

Example 2.8 Consumption of coal and emission of carbon dioxide from coal
A large public computer lab runs six days per week from Monday through Saturday. Each computer uses a power of around 240 W. If the computer lab contains 45 computers and each is on for 12 hours a day, during the course of the year how much CO_2 will the local coal power plant have to release to the atmosphere in kg and kmol to keep these computers running?

Solution:
Data: Coal(bituminous/anthracite): 0.37 kg of CO_2/kWh. Data from Table 2.12.

$$\left(\frac{240\,\text{W}}{\text{computer}}\right)\left(\frac{\text{kW}}{1,000\,\text{W}}\right)\left(\frac{52\,\text{weeks}}{\text{year}}\right)\left(\frac{6\,\text{days}}{\text{week}}\right)\left(\frac{12\,\text{h}}{\text{day}}\right)\left(\frac{45\,\text{computers}}{\text{lab}}\right)$$
$$= 40,435.2\,\text{kWh}$$

We know that 40,435.2 kWh is needed from the lab per year and since the power plant is coal we can use its emission value of 0.37 kg of CO_2/kWh.
(40435.2 kWh) (0.37 kg CO_2/kWh) = **14,961 kg CO_2 released**
or
14,962 kg/(44.01 kg/mole) = **339.9 kmols CO_2 released**

Example 2.9 Reducing air pollution by geothermal heating
A district uses natural gas for heating. Assume that average NO_x and CO_2 emissions from a gas furnace are 0.0045 kg/therm and 6.4 kg/therm, respectively. It is considered to replace the gas heating system with a geothermal heating system. The projected saving by the geothermal heating system would be 20×10^6 therms of natural gas per year. Determine the amount of NO_x and CO_2 emissions the geothermal heating system would save every year.

Solution:
therm = 29.3 kWh (Table 2.1)
Reduction in NO_x emission = (0.0045 kg/therm) (20×10^6 therm/year)
= **9.0×10^4 kg/year**
Reduction in CO_2 emission = (6.4 kg/therm) (20×10^6 therm/year)
= **$12.8.0 \times 10^7$ kg/year**

Atypical car produces about 8.5 kg NO_x and 6000 kg of CO_2 per year. Replacing the gas heating system by the geothermal heating system is equivalent to taking 10600 cars off the road for NO_x emission and taking 21000 cars of the road for CO_2 emission. Therefore, the proposed geothermal heating would have a positive impact on the air pollution [8].

Student Concern of Global Warming

Each generation has its own crisis, in which people are gravely affected. Some generations have wars or famine, however my generation will certainly have both if our energy crisis is not addressed. Our reliance on fossil fuels has become an addiction. We enjoy many luxuries such as air conditioning, television, and the ability to surf the web or make a call across the country. All of these luxuries are telling of the modernized society we live in, but sadly in times where energy is scarce, we are hardest hit. It would be hard to believe that the generation following the greatest rise in human ingenuity could be blind to such an issue. Our fossil fuel energy resources are limited and many scientists say the expiration date is within our lifetime. We need to better understand the basic principles of energy and its usage so that we can make better choices and change the direction we are currently heading.—Brad Healey-Senior UNL-2012

Problems

2.1. What are the advantages and disadvantages of using coal?
2.2. Does an electric car reduce the use of fossil fuels?
2.3. Is a fuel oil heater or an electric resistance heater the best for the environment?
2.4. Is a natural gas heater or a geothermal heating system the best for the house?
2.5. Why is electrical energy so useful?
2.6. How can the energy in the wind be used?
2.7. 2.7. How can wind power help conserve our oil supplies?
2.8. How might using wind energy help reduce the air pollution?
2.9. What is the best energy source to convert to electricity?
2.10. Do the white-colored roof tiles keep houses cool?
2.11. How can energy from the sun be used to heat water?
2.12. With the clear advantages of nuclear power, why is it not more commonly used?
2.13. How can using solar energy help reduce pollution in the atmosphere and help conserve our oil supplies?
2.14. Why is the process of photosynthesis so valuable?
2.15. Name some foods that are known to be high energy foods.
2.16. Why are battery-powered vehicles considered to be the transport of the future?
2.17. Why is chemical energy useful to us?
2.18. What other forms of energy can be produced from chemical energy?
2.19. Name three examples of other fuels that contain chemical energy.
2.20. An over used car may consume around 250 gallons of gasoline per month. Estimate the energy consumed by the car per year.
2.21. An over used car may consume around 150 gallons gasoline per month. Estimate the energy consumed by the car per year.
2.22. A car's daily travelling distance is about 80 miles/day. A car has a city-mileage of 20 miles/gal. If the car is replaced with a new car with a city-mileage of 30 miles/gal and the average cost of gasoline is \$4.50/gal, estimate (a) the amount of fuel, energy, and money conserved with the new car per year, (b) reduction in CO_2 emission.
2.23. A car's daily travelling distance is about 80 miles/day. A car has a city-mileage of 10 miles/gal. If the car is replaced with a new car with a city-mileage of 32 miles/gal and the average cost of gasoline is \$4.50/gal, estimate (a) the amount of fuel, energy, and money conserved with the new car per year, (b) reduction in CO_2 emission.
2.24. A city consumes natural gas at a rate of 500 10^6 ft^3/day. The volumetric flow is at standard conditions of 60°F and 1 atm = 14.7 psia. If the natural is costing \$12/GJ of higher heating value what is the daily cost of the gas for the city.
2.25. A city consumes natural gas at a rate of 800×10^6 ft^3/day. The volumetric flow is at standard conditions of 60°F and 1 atm = 14.7 psia. If the natural

is costing \$10/GJ of higher heating value what is the daily cost of the gas for the city.

2.26. A car consumes about 6 gallons a day, and the capacity of a full tank is about 15 gallons. The density of gasoline ranges from 0.72 to 0.78 kg/l (Table 2.2). The lower heating value of gasoline is about 44,000 kJ/kg. Assume that the average density of gasoline is 0.75 kg/l. If the car was able to use 0.2 kg of nuclear fuel of uranium-235, estimate the time in years for refueling.

2.27. A car consumes about 3 gallons a day, and the capacity of the full tank is about 11 gallon. The density of gasoline ranges from 0.72 to 0.78 kg/l (Table 2.2). The lower heating value of gasoline is about 44,000 kJ/kg. Assume that the average density of gasoline is 0.75 kg/l. If the car was able to use 0.1 kg of nuclear fuel of uranium-235, estimate the time in years for refueling.

2.28. Using data in Table 2.11 and ultimate analysis, fixed carbon, dry ash content, C, H, and O compositions estimate the gross heating values in kJ/kg for the biomass white oak.

2.29. Using data in Table 2.11 and ultimate analysis, fixed carbon, dry ash content, and C, H, and O compositions only estimate the gross heating values in kJ/kg for the biomass corn stover and wheat straw.

2.30. When a hydrocarbon fuel is burned, almost all of the carbon in the fuel burns completely to form CO_2 (carbon dioxide), which is the principle gas causing the greenhouse effect and thus global climate change. On average, 0.59 kg of CO_2 is produced for each kWh of electricity generated from a power plant that burns natural gas. A typical new household uses about 7,000 kWh of electricity per year. Determine the amount of CO_2 production that is due to the refrigerators in a city with 100,000 households

2.31. When a hydrocarbon fuel is burned, almost all of the carbon in the fuel burns completely to form CO_2 (carbon dioxide), which is the principle gas causing the greenhouse effect and thus global climate change. On average, 0.59 kg of CO_2 is produced for each kWh of electricity generated from a power plant that burns natural gas. A typical new household uses about 10,000 kWh of electricity per year. Determine the amount of CO_2 production that is due to the refrigerators in a city with 250,000 households

2.32. A large public computer lab operates Monday through Saturday. There the computers are either being used constantly or remain on until the next user comes. Each computer needs around 240 W. If the computer lab contains 53 computers and each is on for 12 h a day, during the course of the year how much CO_2 will the local coal power plant have to release to the atmosphere in gram moles to keep these computers running?

2.33. The average university will have a large public computer lab open Monday through Saturday. There the computers are either being used constantly or remain on until the next user comes. Each computer needs around 240 W. If the computer lab contains 53 computers and each is on for 12 h a day, during the course of the year how much coal will the local coal power plant have to consume to keep these computers running?

2.34. A large public computer lab runs six days per week from Monday through Saturday. Each computer uses a power of around 120 W. If the computer lab contains 45 computers and each is on for 12 h a day, during the course of the year how much CO_2 will the local coal power plant have to release to the atmosphere in gram moles to keep these computers running?

2.35. If a car consumes 60 gallons gasoline per month. Estimate the energy consumed by the car per year.

2.36. A car having an average 22 miles/gal is used 32 miles every day. If the cost of a gallon fuel is $3.8 estimate the yearly cost of fuel.

2.37. A car having an average 22 miles/gal is used 32 miles every day. Estimate the yearly energy usage.

2.38. How can you control your carbon footprint?

2.39. A 150-W electric light bulb is used on average 10 h per day. A new bulb costs $2.0 and lasts about 5,000 h. If electricity cost is $0.15/kWh, estimate the yearly cost of the bulb.

2.40. A laptop consuming 90 Watt is used on average 5 h per day. If a laptop costs $500 and will be used for four years estimate the total electricity cost in four years for the laptop. Electricity cost is $0.15/kWh.

2.41. A laptop consuming 90 Watt is used on average 7 h per day. If a laptop costs $500 and will be used for four years estimate the total electricity cost in four years for the laptop. Electricity cost is $0.10/kWh.

2.42. A 20-hp electric motor is used to pump ground water into a storage tank 4 h every day. Estimate the work done by the pump in kW every year and the cost of electricity every year. Assume that the electricity unit cost is $0.1/kWh.

2.43. A city consumes natural gas at a rate of 250×10^6 ft^3/day. The volumetric flow is at standard conditions of 60°F and 1 atm = 14.7 psia. If the natural gas is costing $6/GJ of higher heating value what is the daily cost of the gas for the city.

2.44. A home consumes natural gas at a rate of 4.3ft^3/day to heat the home. The volumetric flow is at standard conditions of 60°F and 1 atm = 14.7 psia. If the natural gas is costing $0.67/MJ of higher heating value what is the daily cost of the gas for the home?

2.45. A district uses natural gas for heating. Assume that average NO_x and CO_2 emissions from a gas furnace are 0.0045 kg/therm and 6.4 kg/therm, respectively. The district wants to replace the gas heating system with a geothermal heating system. The projected saving by the geothermal heating system would be 40×10^6 therms of natural gas per year. Determine the amount of NO_x and CO_2 emissions the geothermal heating system would save every year.

2.46. A water heater consumes propane, which is providing 80% of the standard heat of combustion when the water produced after combustion is vapor. If the price of propane is \$2.2/gal measured at 25°C. What is the heating cost in \$ per million Btu and in \$ per MJ?

2.47. An average video games system consumes 170 W of power during gameplay. If a person were to play an hour a day for 80% of the year how many liters of gasoline would the person have burned? (Evaluated at HHV)

2.48. A competitive road cyclist can hold an average of 300W of power during a 4 h race. During long races he must do this each day for three weeks. How many protein bars will the cyclist have to eat at 184 calories per bar to just make up the calories lost during the race?

2.49. Describe the process of how natural gas goes from its natural state to the market?

2.50. Some people like to have background noise when they are falling asleep. Many choose to listen to their television. The television will usually run on about 340 W and will run during the 8 h that you are asleep. With electricity costing \$0.20/kWh, calculate how much this will cost you if you do this for five days a week for an entire year.

2.51. What are the advantages and disadvantages of electrical energy in an alternating current?

2.52. What are the advantages and disadvantages of electrical energy flowing in direct current?

2.53. In the search for new sources of energy that are renewable and emit less greenhouse gases, carbon-based biofuels are of major interest. These fuels are still carbon-based and must undergo combustion to release the chemical energy. Why is this process being looked at as a reasonable energy source?

2.54. While fixing wiring in a house, an electrician aims to deliver the same amount of electric energy to a devise at the same rate it is currently coming in. The wiring he is replacing runs at has 2 ohms of resistance and has a 20 A current. To deliver the same amount of electric energy how many amps will be needed if the resistance is changed to 4 ohms?

2.55. Calculate the yearly dollar savings if you cut down from a daily 9 min shower to a 6 min shower. The shower volumetric flow rate is 3.2 gpm and the amount of energy used per gallon is 440 Btu and energy costs \$0.13/kWh.

2.56. Rank the following carbon-based fuels in order of lowest to highest gross energy density; diesel, ethanol, conventional gasoline, and kerosene-based jet fuel.

References

1. AWEA (2006) U.S. Wind industry ends most productive year, sustained growth expected for at least next two years. American Wind Energy Association in http://www.awea.org
2. Behzadi S, Farid MM (2007) Review: examining the use of different feedstock for the production of biodiesel. Asia-Pac J Chem Eng 2:480–486

3. Belyaev LS, Marchenko OV, Filippov SP, Solomin SV, Stepanova TB, Kokorin AL (2002) World energy and transition to sustainable development. Kluwer, Boston
4. Blair N, Short W, Mehos M, Heimiller D (2006) Concentrating solar deployment systems (CSDS)—A new model for estimating U.S. concentrating solar power market potentialpotential. ASES Solar conference, 8–13 July 2006
5. Bodansky D (2004) Nuclear energy: principles practices and prospects. Springer, Oxford
6. Bolinger M, Wiser R (2005) Balancing cost and risk: the treatment of renewable energy in western utility resource plans, Lawrence Berkeley National Laboratory, Berkeley, California. http://eetd.lbl.gov/EA/EMP/reports/58450.pdf
7. Capehart BL (2007) Encyclopedia of energy engineering and technology. CRC Press, Boca Raton
8. Çengel YA, Boles MA (2002) Thermodynamics an engineering approach. McGraw-Hill, New York
9. Demirbas A (2008) Biodiesel: a realistic fuel alternative for diesel engines. Springer, Berlin
10. Demirbas A (1997) Calculation of higher heating values of biomass fuels. Fuel 76:431–434
11. Denholm P, Margolis R (2006) Very large-scale deployment of grid-connected solar photovoltaicphotovoltaic in the United States: challenges and opportunities. ASES Solar conference, 8–13 July 2006
12. Davidson E, Janssens I (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440:165
13. DOE/EIA (2010) International energy outlook. Report #:DOE/EIA-0484. http://www.eia.gov/oiaf/ieo/highlights.html. Accessed May 2011
14. EIA (2011) Renewable energy consumption and electricity preliminary statistics 2010, Release date: June 28, 2011. http://www.eia.gov/renewable/. Accessed July 2011
15. ETB (2011) Engineering Tool Box. http://www.engineeringtoolbox.com. Accessed May 2011
16. Farrell A, Plevin R et al (2006) Ethanol can contribute to energy and environmental goals. Science 311:506–508
17. Gary JH, Handwerk GH (1994) Petroleum refining technology, 3rd edn. Marcel Dekker, New York
18. Gaur S, Reed T (1998) Thermal data for natural and synthetic fuels. Marcel Dekker, New York
19. Houghton RA (2005) The contemporary carbon cycle. In: Schlesinger WH (ed) Biogeochemistry. Elsevier, Amsterdam
20. Janzen HH (2004) Carbon cycling in earth systems -a soil science perspective. Agric Ecosys Environ 104:399–417
21. Jacobson MZ (2009) Review of solutions to global warming, air pollution, and energy security. Energy Environ Sci 2:148–173
22. Kaes GL (2000) Refinery process modeling. Kaes Enterprises, Colbert
23. Kalnes T, Marker T, Shonnard DR (2007) Green diesel: a second generation biofuel. Int J Chem Reactor Eng 5:1–9
24. Knothe G (2006) Dependence of biodiesel fuel properties on the structure of fatty acids alkyl esters. Fuel Process Technol 86:1059–1070
25. Kutscher CF (2007) (ed) Tackling climate change in the U.S., American Solar Energy Society. www.ases.org/climatechange. Accessed May 2011
26. Kydes AS, Kanudiab A, Loulouc R (2004) National energy modeling systems. In: Cleveland CJ (ed) The encyclopedia of energy. Elsevier, Oxford
27. Laursen JKr, Karavanov AN (2006) Processes for sulfur recovery, regeneration of spent acid, and reduction of nox emissions. Chem Petrol Eng 42:229–234
28. Marks DB (1999) Biochemistry, 3rd edn. Kluwer, Ney York
29. Metz B, Davidson O et al (2005) IPCC special report on carbon dioxide capture and storage. Working Group III. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

30. Milbrandt A (2005) A geographic perspective on the current biomass resource availability in the United States, NREL, Golden, Colorado. http://www.nrel.gov/learning
31. Mohr PJ, Taylor BN, Newell DB (2011) The 2010 CODATA Recommended values of the fundamental physical constants. This database was developed by Baker J, Douma M, Kotochigova S. http://physics.nist.gov/constants
32. NREL (2011) National Renewable Energy Laboratory Golden Colorado. http://www.nrel.gov/learning. Accessed May 2011
33. Øvergaard S (2008) Issue paper: definition of primary and secondary energy. www.og.ssb.no. Accessed April 2011
34. Sheng C, Azevedo JLT (2005) Estimating the higher heating value of biomass fuels from basic analysis data. Biomass Bioenergy 28:499–507
35. Smoot LD, Smith PJ (1985) Coal combustion and gasification. Plenum Press, New York
36. Swisher J (2006) Tackling climate change in the U.S.: the potential contribution from energy efficiency, the ASES Solar National Conference, 8–13 July 2006
37. EP UN (2009) Towards sustainable production and use of resources: assessing biofuels. United Nations Environment Programme, Renewable Energy World
38. Vimeux F, Cuffey KM, Jouzel J (2002) New insights into southern hemisphere temperature changes from Vostok ice cores using deuterium excess correction. Earth Planet Sci Lett 203:829–843
39. Wiser R, Bolinger M (2010) DOE EERE, 2010 Wind technologies market report. http://www.osti.gov/bridge. Accessed July 2011