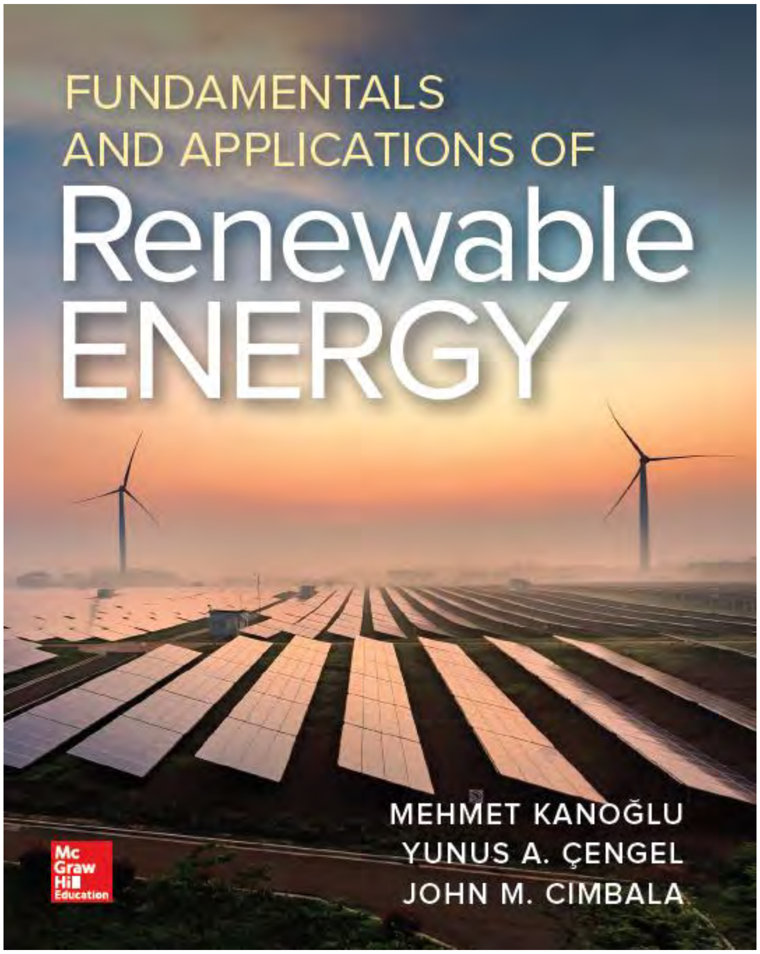
Solutions Manual



Fundamentals and Applications of Renewable Energy
1st Edition
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Chapter 1
INTRODUCTION TO RENEWABLE ENERGY

Why Renewable Energy?

1-1 The combustion of fossil fuels produce the following undesirable emissions and adverse effects:

- Carbon dioxide (CO_2), causes global warming
- Nitrogen oxides (NO_x) and hydrocarbons (HC), cause smog
- Carbon monoxide (CO), toxic
- Sulfur dioxide (SO_2), causes acid rain
- Particulate matter (PM): causes adverse health effects

1-2 Carbon dioxide is not an air pollutant. CO_2 is a greenhouse gas causing global warming. It is a natural product of a fossil fuel combustion. Other emissions, on the other hand, are harmful air pollutants.

1-3 The concern over the depletion of fossil fuels and pollutant and greenhouse emissions associated by their combustion can be tackled by essentially two methods:

(*i*) Using renewable energy sources to replace fossil fuels.

(*ii*) Implementing energy efficiency practices in all aspects of energy production, distribution, and consumption so that less fuel is used while obtaining the same useful output.

1-4 *Energy efficiency* is to reduce energy use to the minimum level, but to do so without reducing the standard of living, the production quality, and the profitability. Energy efficiency is an expression for the most effective use of the energy resources, and it result in energy conservation. Energy efficiency can only reduce the fossil fuel use while renewable energy can directly replace fossil fuels.

1-5 Main renewable energy sources include *solar*, *wind*, *hydropower*, *geothermal*, and *biomass*. Ocean, wave, and tidal energies are also renewable sources but they are currently not economical and the technologies are still in the experimental and developmental stage.

1-6 An energy source is called renewable if it can be renewed and sustained without any depletion and any significant effect on the environment. Coal, oil, and natural gas are not renewable since they are depleted by use and they emit harmful pollutants and greenhouse gases.

1-7 Although solar energy is sufficient to meet the entire energy needs of the world, currently it is not economical to do so because of the *low concentration* of solar energy on earth and *relatively high capital cost* of harnessing it.

1-8 *Wind* and *solar* are the fastest growing renewables. *Hydropower* represents the greatest amount of electricity production among renewable.

1-9 *Wind* and *hydro* (water) energies are converted to electricity only while *solar*, *biomass*, and *geothermal* can be converted to both electricity and thermal energy.

1-10 We do not agree. The electricity used by the electric cars is generated somewhere else mostly by burning fuel and thus emitting pollution. Therefore, each time an electric car consumes 1 kWh of electricity, it bears the responsibility for the pollutions emitted as 1 kWh of electricity (plus the conversion and transmission losses) is generated elsewhere.

1-11 The electric cars can be claimed to be zero emission vehicles only when the electricity they consume is generated by emission-free renewable resources such as hydroelectric, solar, wind, and geothermal energy.

1-12 Noting that 1 Quad = 1×10^{15} Btu, 1 Btu = 1.055 kJ, and 1 kWh = 3412 Btu, we express oil and renewable consumptions in Btu, GJ, and kWh, as follows:

$$\text{Oil Consumption} = (188.8 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right) = \mathbf{1.89\times10^{17}\ Btu}$$

$$\text{Oil Consumption} = (188.8 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1.055\text{ kJ}}{1\text{ Btu}}\right)\left(\frac{1\text{ GJ}}{1\times10^{6}\text{ kJ}}\right) = \mathbf{1.99\times10^{11}\ GJ}$$

$$\text{Oil Consumption} = (188.8 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1\text{ kWh}}{3412\text{ Btu}}\right) = \mathbf{5.53\times10^{13}\ kWh}$$

$$\text{Renewable Consumption} = (19.4 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right) = \mathbf{1.94\times10^{16}\ Btu}$$

$$\text{Renewable Consumption} = (19.4 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1.055\text{ kJ}}{1\text{ Btu}}\right)\left(\frac{1\text{ GJ}}{1\times10^{6}\text{ kJ}}\right) = \mathbf{2.05\times10^{10}\ GJ}$$

$$\text{Renewable Consumption} = (19.4 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1\text{ kWh}}{3412\text{ Btu}}\right) = \mathbf{5.69\times10^{12}\ kWh}$$

1-13 Noting that 1 Quad = 1×10^{15} Btu, 1 Btu = 1.055 kJ, and 1 toe = 41.868 GJ, we express total world delivered energy consumptions by fuel and by end-use sector, in toe, as follows:

$$\text{Energy Consumption by fuel} = (523.9 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1.055\text{ kJ}}{1\text{ Btu}}\right)\left(\frac{1\text{ GJ}}{1\times10^{6}\text{ kJ}}\right)\left(\frac{1\text{ toe}}{41.868\text{ GJ}}\right)$$
$$= \mathbf{1.32\times10^{10}\ toe}$$

$$\text{Energy Consumption by sector} = (382.0 \text{ Quad})\left(\frac{1\times10^{15}\text{ Btu}}{1\text{ Quad}}\right)\left(\frac{1.055\text{ kJ}}{1\text{ Btu}}\right)\left(\frac{1\text{ GJ}}{1\times10^{6}\text{ kJ}}\right)\left(\frac{1\text{ toe}}{41.868\text{ GJ}}\right)$$
$$= \mathbf{9.63\times10^{9}\ toe}$$

1-14 According to the data in Table 1-1, a total of 159.8 Quad coal is consumed in the world and 90.5 Quad of this coal is used to produce electricity. Using an overall thermal efficiency of 30 percent, the amount of electricity produced from coal-burning power plants is

$$\text{Overall thermal efficiency} = \frac{\text{Electricity produced}}{\text{Fuel energy consumed}}$$
$$0.30 = \frac{\text{Electricity produced}}{90.5 \times 10^{15}\ \text{Btu}}$$
$$\text{Electricity produced} = 2.715 \times 10^{16}\ \text{Btu}$$

which is equivalent to

$$\text{Electricity produced} = 2.715 \times 10^{16}\ \text{Btu}\left(\frac{1\ \text{kJ}}{0.94782\ \text{Btu}}\right)\left(\frac{1\ \text{kWh}}{3600\ \text{kJ}}\right)\left(\frac{1\ \text{GWh}}{10^6\ \text{kWh}}\right)$$
$$= \mathbf{7.96 \times 10^6\ GWh}$$

1-15 Since 21.7 percent of total electricity is produced from natural gas-burning power plants,

$$\text{Electricity produced} = (0.217)(23{,}332\ \text{TWh})\left(\frac{10^9\ \text{kWh}}{1\ \text{TWh}}\right) = 5.063 \times 10^{12}\ \text{kWh}$$

The heat input by the natural gas consumption is

$$\text{Fuel energy consumed} = (45\ \text{Quad})\left(\frac{1 \times 10^{15}\ \text{Btu}}{1\ \text{Quad}}\right)\left(\frac{1\ \text{kWh}}{3412\ \text{Btu}}\right) = 1.319 \times 10^{13}\ \text{kWh}$$

The overall thermal efficiency is

$$\text{Overall thermal efficiency} = \frac{\text{Electricity produced}}{\text{Fuel energy consumed}} = \frac{5.063 \times 10^{12}\ \text{kWh}}{1.319 \times 10^{13}\ \text{kWh}} = 0.384 = \mathbf{38.4\%}$$

1-16 Noting that 1 TWh =1×10^9 kWh, the amount of electricity produced in OECD countries is

$$\text{Electricity produced} = (0.553)(19{,}028\ \text{tWh})\left(\frac{1\times10^9\ \text{kWh}}{1\ \text{tWh}}\right) = 1.052\times10^{13}\ \text{kWh}$$

Noting that the average thermal efficiency is 38%, the amount of energy consumed to produce this much electricity is

$$\text{Energy consumed} = \frac{\text{Electricity produced}}{\text{Thermal efficiency}} = \frac{1.052\times10^{13}\ \text{kWh}}{0.38} = 2.769\times10^{13}\ \text{kWh}$$

Now, we express this in tWh, Quad, and toe units:

$$\text{Energy consumed} = (2.769\times10^{13}\ \text{kWh})\left(\frac{1\ \text{tWh}}{1\times10^9\ \text{kWh}}\right) = \mathbf{27{,}691\ tWh}$$

$$\text{Energy consumed} = (2.769\times10^{13}\ \text{kWh})\left(\frac{3412\ \text{Btu}}{1\ \text{kWh}}\right)\left(\frac{1\ \text{Quad}}{1\times10^{15}\ \text{Btu}}\right) = \mathbf{94.48\ Quad}$$

$$\text{Energy consumed} = (2.769\times10^{13}\ \text{kWh})\left(\frac{3600\ \text{kJ}}{1\ \text{kWh}}\right)\left(\frac{1\ \text{GJ}}{1\times10^6\ \text{kJ}}\right)\left(\frac{1\ \text{toe}}{41.868\ \text{GJ}}\right) = \mathbf{2.381\times10^9\ toe}$$

1-17 The annual amount of electricity saved for 10 million households is

$$\begin{aligned}\text{Electricity saved} &= (\text{Number of homes})(\text{Old electricity consumption} - \text{New electricity consumption})\\ &= (1\times10^6)(1800-450)\text{kWh}\\ &= 1.35\times10^{10}\ \text{kWh}\end{aligned}$$

The annual operating hours of power plant is

Annual hours = (0.9)(365×24 h) = 7884 h

The additional power that would be needed to meet the extra demand is

$$\text{Additional power} = \frac{\text{Electricity saved}}{f_{\text{load}}\times\text{Annual hours}} = \frac{1.35\times10^{10}\ \text{kWh}}{(0.8)(7884\ \text{h})} = \mathbf{2.14\times10^6\ kW}$$

which is equivalent to 2140 MW.

1-18 Most energy in the world is consumed by the __________ sector.

(*a*) residential (*b*) commercial (*c*) industrial (*d*) transportation (*e*) service

Answer: (*c*) industrial

1-19 The emission from fossil fuel combustion that is *not* an air pollutant is

(*a*) CO (*b*) CO_2 (*c*) NO_x (*d*) SO_2 (*e*) PM

Answer: (*b*) CO_2

1-20 Which emission causes acid rain?

(*a*) CO (*b*) CO_2 (*c*) NO_x (*d*) SO_2 (*e*) PM

Answer: (*d*) SO_2

1-21 Which source should not be considered as a main renewable energy source?

(*a*) Wind (*b*) Hydro (*c*) Tidal (*d*) Biomass (*e*) Geothermal

Answer: (*c*) Tidal

1-22 The fastest growing renewable energy sources in the world are

(*a*) Wind and solar (*b*) Hydro and biomass (*c*) Solar and hydro (*d*) Biomass and hydro

(*e*) Geothermal and biomass

Answer: (*a*) Wind and solar

1-23 Which renewable energy source produces the greatest amount of electricity?

(*a*) Wind (*b*) Hydro (*c*) Solar (*d*) Biomass (*e*) Geothermal

Answer: (*b*) Hydro

1-24 Which renewable energy sources are only used for electricity generation?

(*a*) Wind and solar (*b*) Hydro and solar (*c*) Solar and geothermal (*d*) Wind and hydro

(*e*) Hydro and geothermal

Answer: (*d*) Wind and hydro

1-25 Which renewable energy source should not be considered as the manifestation of solar energy in different forms?

(*a*) Wind (*b*) Hydro (*c*) Wave (*d*) Biomass (*e*) Geothermal

Answer: (*e*) Geothermal

Fossil Fuels and Nuclear Energy

1-26 Main energy sources include coal, oil, natural gas, nuclear energy, and renewable energy. Among these coal, oil and natural gas are fossil fuels.

1-27 Common coal types are bituminuous (soft coal), subbituminuous, antracite (hard coal), and lignite (brown coal).

1-28 Carbon burns according to $C + ½ O_2 \rightarrow CO$ and $CO + ½ O_2 \rightarrow CO_2$ reactions. If some of carbon monoxide (CO) cannot find sufficient oxygen to burn with by the time combustion is completed, some CO is found in the combustion products. This can happen even in the presence of stoichiometric or excess oxygen due to incomplete mixing and short time of combustion process.

1-29 Coal is mostly used for electricity generation in power plants and petroleum products are mostly used as fuel in transportation vehicles.

1-30 The categories of oil used in power plants and industrial heating applications and their characteristics are:

Distillate oils: These are higher quality oils which are highly refined. They contain much less sulfur compared residual oils.

Residual oils: These oils undergo less refining process. They are thicker with higher molecular mass, higher level of impurities, and higher sulfur content.

1-31 Natural gas is mostly transported in gas phase by pipelines between the cities and countries. Sometimes, natural gas is first liquefied into about −160°C before being carried in large insulated tanks in marine ships.

1-32 Natural gas is used in boilers for space heating, hot water and steam generation, industrial furnaces, power plants for electricity production, and internal combustion engines.

1-33 The tremendous amount of energy associated with the strong bonds within the nucleus of the atom is called *nuclear energy*. The best known *fission* reaction involves the split of the uranium atom (the U-235 isotope) into other elements. When a uranium-235 atom absorbs a neutron and splits during a fission process, it produces a cesium-140 atom, a rubidium-93 atom, 3 neutrons, and 3.2×10^{-11} J of energy. Nuclear energy by *fusion* is released when two small nuclei combine into a larger one. When two heavy hydrogen (deuterium) nuclei combine during a fusion process, they produce a helium-3 atom, a free neutron, and 5.1×10^{-13} J of energy.

1-34 Vast majority of devices, equipment, and appliances used by people operate on electricity. From a thermodynamic point of view, electricity can be converted to other forms of energy (such as mechanical energy and heat) in a 100% conversion efficiency.

1-35 The incorporation of wind power and solar power into the grid involves some irregularities and uncertainties due to changing wind and solar conditions on hourly, daily, and seasonal basis. This requires a more flexible electrical grid system than the existing conventional system in order to accommodate inconsistent supply of renewable electricity. This new grid system is called *smart grid*, which is an important area of research and development for electrical engineers.

1-36 The combustiable constituents in the coal are carbon C, hydrogen H_2, and sulfur S. The higher and lower heating values of hydrogen are 141,800 kJ/kg and 120,000 kJ/kg, respectively and the heating value of carbon is 32,800 kJ/kg (Table A-7). Using their mass fractions, the higher heating value of this particular coal is determined as

$$\begin{aligned}\text{HHV} &= \text{mf}_\text{C} \times \text{HHV}_\text{C} + \text{mf}_\text{H2} \times \text{HHV}_\text{H2} + \text{mf}_\text{S} \times \text{HHV}_\text{S} \\ &= (0.7961)(32{,}800 \text{ kJ/kg}) + (0.0466)(141{,}800 \text{ kJ/kg}) + (0.0052)(9160 \text{ kJ/kg}) \\ &= \mathbf{32{,}770\ kJ/kg}\end{aligned}$$

Similarly, the lower heating value of the coal is

$$\begin{aligned}\text{LHV} &= \text{mf}_\text{C} \times \text{LHV}_\text{C} + \text{mf}_\text{H2} \times \text{LHV}_\text{H2} + \text{mf}_\text{S} \times \text{LHV}_\text{S} \\ &= (0.7961(32{,}800 \text{ kJ/kg}) + (0.0466)(120{,}000 \text{ kJ/kg}) + (0.0052)(9160 \text{ kJ/kg}) \\ &= \mathbf{31{,}750\ kJ/kg}\end{aligned}$$

The difference between the higher and lower heating values is about 3 percent.

1-37 The higher and lower heating values of hydrogen are 141,800 kJ/kg and 120,000 kJ/kg, respectively, and the heating value of carbon is 32,800 kJ/kg (Table A-7). The molar mass of carbon (C) is 12 kg/kmol and that of hydrogen (H_2) is 2 kg/kmol, respectively (Table A-1). Using the chemical formula, the higher heating value of gasoline is determined as

$$\begin{aligned}\text{HHV}_{\text{C8H15}} &= \frac{m_\text{C}\times\text{HHV}_\text{C}+m_\text{H2}\times\text{HHV}_\text{H2}}{m_\text{C}+m_\text{H2}}\\ &= \frac{(8\times 12\text{ kg})(32{,}800\text{ kJ/kg})+(15\times 1\text{ kg})(141{,}800\text{ kJ/kg})}{(8\times 12\text{ kg})+(15\times 1\text{ kg})}\\ &= \mathbf{47{,}530\ kJ/kg}\end{aligned}$$

For light diesel fuel,

$$\begin{aligned}\text{HHV}_{\text{C12H22}} &= \frac{m_\text{C}\times\text{HHV}_\text{C}+m_\text{H2}\times\text{HHV}_\text{H2}}{m_\text{C}+m_\text{H2}}\\ &= \frac{(12\times 12\text{ kg})(32{,}800\text{ kJ/kg})+(22\times 1\text{ kg})(141{,}800\text{ kJ/kg})}{(12\times 12\text{ kg})+(22\times 1\text{ kg})}\\ &= \mathbf{47{,}245\ kJ/kg}\end{aligned}$$

1-38 The higher and lower heating values of hydrogen are 141,800 kJ/kg and 120,000 kJ/kg, respectively, and the heating value of carbon is 32,800 kJ/kg (Table A-7). The molar mass of carbon (C) is 12 kg/kmol and that of hydrogen (H_2) is 2 kg/kmol, respectively (Table A-1). Using the chemical formula, the lower heating value of gasoline is determined as

$$\begin{aligned}\text{LHV}_{\text{C8H15}} &= \frac{m_\text{C}\times\text{LHV}_\text{C}+m_\text{H2}\times\text{LHV}_\text{H2}}{m_\text{C}+m_\text{H2}}\\ &= \frac{(8\times 12\text{ kg})(32{,}800\text{ kJ/kg})+(15\times 1\text{ kg})(120{,}000\text{ kJ/kg})}{(8\times 12\text{ kg})+(15\times 1\text{ kg})}\\ &= \mathbf{44{,}580\ kJ/kg}\end{aligned}$$

For light diesel fuel,

$$\begin{aligned}\text{LHV}_{\text{C12H22}} &= \frac{m_\text{C}\times\text{LHV}_\text{C}+m_\text{H2}\times\text{LHV}_\text{H2}}{m_\text{C}+m_\text{H2}}\\ &= \frac{(12\times 12\text{ kg})(32{,}800\text{ kJ/kg})+(22\times 1\text{ kg})(120{,}000\text{ kJ/kg})}{(12\times 12\text{ kg})+(22\times 1\text{ kg})}\\ &= \mathbf{44{,}355\ kJ/kg}\end{aligned}$$

1-39 The molar masses of C_8H_{18} and H_2O are 114 and 18 kg/kmol, respectively. When 1 kmol of octane (C_8H_{18}) is burned with theoretical air, 9 kmol of water (H_2O) is formed. Then the mass of water formed when 1 kg of octane is burned is determined from

$$m_{\rm H2O} = \frac{N_{\rm H2O}M_{\rm H2O}}{N_{\rm C8H18}M_{\rm C8H18}} = \frac{(9\text{ kmol})(18\text{ kg/kmol})}{(1\text{ kmol})(114\text{ kg/kmol})} = 1.421\text{ kg H}_2\text{O/kg C}_8\text{H}_{18}$$

The amount of heat released as 1.421 kg water is condensed is

$$Q_{\rm latent} = m_{\rm H2O}h_{fg} = (1.421\text{ kg H}_2\text{O/kg CH}_4)(2442\text{ kJ/kg H}_2\text{O}) = 3470\text{ kJ/kg C}_8\text{H}_{18}$$

Then the lower heating value of octane becomes

$$\text{LHV} = \text{HHV} - Q_{\rm latent} = 47{,}300\text{ kJ/kg} - 3470\text{ kJ/kg} = \mathbf{43{,}830\text{ kJ/kg}}$$

1-40 The total amount of heat input to coal plants is determined from the plant efficieny as

$$\eta_{\rm plant} = \frac{W_{\rm electric}}{Q_{\rm in}} \quad\rightarrow\quad Q_{\rm in} = \frac{W_{\rm electric}}{\eta_{\rm plant}} = \frac{1.51\times10^{12}\text{ kWh}}{0.34}\left(\frac{3600\text{ kJ}}{1\text{ kWh}}\right) = 1.599\times10^{16}\text{ kJ}$$

The amount of coal consumed per year is

$$Q_{\rm in} = m_{\rm coal}\text{HV}_{\rm coal} \quad\rightarrow\quad m_{\rm coal} = \frac{Q_{\rm in}}{\text{HV}_{\rm coal}} = \frac{1.599\times10^{16}\text{ kJ}}{25{,}000\text{ kJ/kg}} = \mathbf{6.395\times10^{11}\text{ kg}}$$

1-41 Which one cannot be considered as a fossil fuel?

(*a*) Coal (*b*) Natural gas (*c*) Oil (*d*) Hydrogen (*e*) None of these

Answer: (*d*) Hydrogen

1-42 Which is not a fuel?

(*a*) Oil (*b*) Natural gas (*c*) Coal (*d*) Carbon monoxide (CO)

(*e*) Carbon dioxide (CO_2)

Answer: (*e*) Carbon dioxide (CO_2)

1-43 Which is *not* a coal type?

(*a*) Bituminuous coal (*b*) Subbituminuous coal (*c*) Antracite coal (*d*) Lignite
(*e*) Green coal

Answer: (*e*) Green coal

1-44 Which coal type is of the lowest quality?

(*a*) Bituminuous coal (*b*) Subbituminuous coal (*c*) Antracite coal (*d*) Lignite
(*e*) Hard coal

Answer: (*d*) Lignite

1-45 Electricity is mostly produced from _________ burning power plants in the world.

(*a*) Coal (*b*) Natural gas (*c*) Oil (*d*) Nuclear (*e*) Solar

Answer: (*c*) Coal

1-46 The most common use of petroleum products is

(*a*) Motor vehicles (*b*) Electriciy generation (*c*) Space heating
(*d*) Steam generation (*e*) Industrial furnaces

Answer: (*a*) Motor vehicles

1-47 Which fuel is the most polluting fuel and the largest contributor to global carbon dioxide emissions?

(*a*) Coal (*b*) Natural gas (*c*) Oil (*d*) Nuclear (*e*) Solar

Answer: (*c*) Coal

1-48 Which fuel has the highest heating value?

(*a*) Coal (*b*) Natural gas (*c*) Oil (*d*) Hydrogen (*e*) Sulfur

Answer: (*d*) Hydrogen