Chapter 3
Fossil Fuel Resources and Use

Problem 3.1 Write down the chemical formulae for the combustion of the alkanes in Table 3.2 with n = 2 to n = 8. Determine the mass of CO_2 produced per megajoule of energy.

Solution The oxidation process is shown below

n	name	formula	combustion reaction
2	ethane	C_2H_6	$2C_2H_6+7O_2 \rightarrow 4CO_2+6H_2O$
3	propane	C_3H_8	$C_3H_8+5O_2 \rightarrow 3CO_2+4H_2O$
4	butane	C_4H_{10}	$2C_4H_{10}+13O_2 \rightarrow 8CO_2+10H_2O$
5	pentane	C_5H_{12}	$C_5H_{12}+8O_2 \rightarrow 5CO_2+6H_2O$
6	hexane	C_6H_{14}	$2C_6H_{14}+19O_2 \rightarrow 12CO_2+14H_2O$
7	heptane	C_7H_{16}	$C_7H_{16}+11O_2 \rightarrow 7CO_2+8H_2O$
8	octane	C_8H_{18}	$2C_8H_{18}+25O_2 \rightarrow 16CO_2+18H_2O$

The number of moles of CO_2 produced per mole of alkane is clearly shown. The molecular mass of the alkane is shown below. The molecular mass (M) of CO_2 (44 g/mol) can be used to determine the relative mass of CO_2 produced per unit mass of alkane. The heat of combustion is given in Table 3.2 and the amount of CO_2 per MJ heat is found.

n	R = (moles CO_2)/(moles alkane)	M (alkane)	$R\times44/M$ = (kg CO_2)/(kg alkane)	heat of combustion MJ/kg	kg(CO_2)/MJ
2	2	30	2.93	51.9	0.0565
3	3	44	3.00	50.3	0.0596
4	4	58	3.03	49.5	0.0612
5	5	72	3.06	48.7	0.0628
6	6	86	3.07	48.1	0.0638
7	7	100	3.08	48.1	0.0640
8	8	114	3.09	46.8	0.0660

Problem 3.2 Locate the current world price of oil (US$/bbl) and the current retail price of regular gasoline in your area (per liter or per gallon, as appropriate). What is the markup in the price per unit energy between crude oil and retail gasoline?

Solution World price per bbl of crude oil is \$88.94 US\$ @ 14 Sept 2011 (source: www.oil-price.net). Current price of regular gasoline in Halifax, Nova Scotia, at the same date is \$1.318 CDN/L at the exchange rate of \$1.00 CDN=1.00899 US\$. The price of gasoline is 1.33 US\$/L. The content of one bbl oil is (see Appendix III) ~159 L/bbl, so the price per L of crude oil is 0.56 US\$/L. Thus the markup in % is

$$100 \times \left(\frac{\text{gas(\$/L)}}{\text{oil(\$/L)}} - 1 \right) = 137\% \text{ mark up}$$

The answer will, of course depend on when and where prices are obtained, but this mark up is substantial and includes many factors including refining costs, oil company profits and taxes.

Problem 3.3 Locate the current world price of oil (US\$/bbl), coal (bituminous coal, per tonne), and natural gas (per 1000 m^3). For each fossil fuel, calculate the cost of energy per gigajoule assuming that the fuel can be converted to usable energy with an efficiency of 100%.

Solution From the web (at 14 September 2011) [www.oil-price.net] oil = 88.94 US\$/bbl. The price of coal is less well defined but one source gives a recent price in the US as of \$152 per tonne [http://www.alibaba.com/product-free/110812567/Met_Coal.html].
Natural gas prices are somewhat more standardized than coal prices and a recent price (Aug 2011) is \$146.13 per $10^3 m^3$
[http://www.indexmundi.com/commodities/?commodity=natural-gas].

From Appendix IV the energy content of these fuels is

oil	–	6.12×10^9 J/bbl=6.12 GJ/bbl
coal (bituminous)	–	3.10×10^{10} J/tonne=31.0 GJ/tonne
natural gas	–	3.85×10^{10} J/1000 m^3 =38.5 GJ/1000 m^3

From the prices given above the cost per GJ is

oil	–	\$14.53/GJ
coal	–	\$ 4.90/GJ
natural gas	–	\$ 3.79/GJ

Problem 3.4 Assume that all of the United States' annual electricity requirement of 3×10^{12} kWh is produced by coal-fired generating stations operating at a net overall efficiency of 40%.
(a) How many tonnes of coal are burned per second? (Assume the coal is all bituminous)
(b) Assuming that coal is 100% carbon, how many tonnes of CO_2 will be produced each year?

Solution The total coal energy needed is 3×10^{12} /0.4 = 7.5×10^{12} kWh. Averaged over the year, this is a power output of

$$\frac{7.5\times10^{12}\,\text{kWh}}{365\text{d}\times24\text{h/d}\times10^{3}\,\text{kW/MW}}=8.56\times10^{5}\,\text{MW}$$

This is 8.56×10^5 MJ per second. As the energy content of bituminous coal is 3.1×10^4 MJ/t from the Appendix IV, the number of tonnes per second is

$$(8.56\times10^5 \text{ MJ/s})/(3.1\times10^4 \text{ MJ/t}) = 27.6 \text{ t/s}$$

for the combustion process

$$C+O_2\rightarrow CO_2$$

then 1 mole of C produces 1 mole CO_2 or

$$12\,\text{g}\,(\text{C})\rightarrow 44\,\text{g}\,(\text{CO}_2)$$

so 1 t of C produces 3.67 t CO_2. Thus (27.6 t/s)×(3.67 t/t) =101 t of CO_2 per second are released.

Problem 3.5 On land, coal is transported primarily by train. A typical large coal train may be about 1.5 km long and may consist of 120 cars, each holding 110 tonnes of coal. As each tonne of coal has an equivalent energy content (in terms of the stored chemical energy it contains), a moving coal train represents a flow of (chemical) energy or a power. For a coal train traveling at 100 km/h, calculate the equivalent power in watts.

Solution One tonne of coal has energy content of 3.1×10^{10} J. The total amount of coal on the train is 120×110 tonnes = 13,200 tonnes. This has an energy content of

$$(13{,}200 \text{ tons})\times(3.1\times10^{10} \text{ J/ton}) = 4.09\times10^{14} \text{ J}.$$

100 km/h corresponds to

$$(100 \text{ km/h})\times(1000 \text{ m/km})/(3600 \text{ s/h}) = 27.8 \text{ m/s}$$

A 1.5-km long train will pass a reference point in

$$(1500 \text{ m})/(27.8 \text{ m/s}) = 54 \text{ s}$$

Thus the rate of flow of energy is

$$\frac{4.09\times10^{14}\,\text{J}}{54\text{s}} = 7.57\times10^{12}\,\text{W} = 7.57\times10^{6}\,\text{MW}$$

Problem 3.6 How many tonnes of oil shale which produces 120 L/t would be needed to produce the same energy as 1 tonne of bituminous coal?

Solution The **s**hale oil energy content per tonne is

$$(120\ \text{L/t})\times(3.85\times10^{7}\ \text{J/L}) = 4.62\times10^{9}\ \text{J/t}$$

The energy content of one tonne of bituminous coal will be

$$(1000\text{kg})\times(31\times10^{6}\,\text{J/kg}) = 3.1\times10^{10}\,\text{J}$$

Thus it will require

$$\frac{3.1\times10^{10}\,\text{J}}{4.62\times10^{9}\,\text{J}} = 6.7\ \text{t}$$

of oil shale to yield the same energy as one tonne of bituminous coal.

Problem 3.7 Assume that the total energy needs of a person in the United States (Chapter 2) is satisfied by burning coal. If each person is responsible for the mining, transportation, processing, and burning of their own coal, how much coal must each person process, on average, per day?

Solution Each person uses an average of 11,730 W. This is

$$(11730\text{W}\times24\text{h/d})/10^{3}\,\text{W/kW} = 282\ \text{kWh per day}$$

Converting this to MJ gives

$$\frac{282\text{kWh/d}\times3.6\times10^{6}\,\text{J/kWh}}{10^{6}\,\text{J/MJ}} = 1015\text{MJ}$$

For coal with an energy content of 31 MJ/kg then so (1015MJ)/(31MJ/kg)=32.6 kg per day must be processed.

Problem 3.8 If shale oil replaced coal in the United States, how many years would the U.S. resources last at the current rate of use?

Solution From Example 3.3, the annual coal use in the U.S. is 1.01×10^9 t/y. From Appendix IV the primary energy content of this coal is

$$\left(1.01\times10^9\ \mathrm{t/y}\right)\times\left(3.1\times10^4\ \mathrm{MJ/t}\right)=3.13\times10^{13}\ \mathrm{MJ/y}$$

From Table 3.12 the US resources of shale oil are equivalent to 2.59×10^{12} bbl of oil. This has an energy content at 6.12×10^3 MJ/bbl of

$$(2.59\times10^{12}\ \mathrm{bbl})\times(6.12\times10^3\ \mathrm{MJ/bbl}) = 1.59\times10^{16}\ \mathrm{MJ}.$$

At the energy use of coal per year as above, the shale oil will last for

$$(1.59\times10^{16}\ \mathrm{MJ})/(3.13\times10^{13}\ \mathrm{MJ/y}) = 508\ \text{years}.$$