T206 Energy for a sustainable future

Tutorial – Durham March 2009

Calculation Questions

Question 1

Figures 2.7(b), 2.17(b) and 2.20(b) in Book 1, *Energy Systems and Sustainbility*, show the patterns of primary energy consumption in the year 2000 for the following three countries

(a) The UK

(b) France

(c) India

For each country, identify the main primary energy source and briefly suggest the reasons for its current importance.

Question 2

The estimated gross electrical output of all the world's power stations during the year 2000 was about 14 000 TWh.

(a) Assuming that the average power station conversion efficiency, from primary energy input to electrical output, was 35%, calculate the total primary energy (in TWh) used world-wide for electricity generation in 2000.

Express this primary energy input as a percentage of world total primary energy consumption in 2000, which was 424 EJ.

(b) If the world population in 2000 was about 6.1 billion (6100 million), what was the approximate per capita electricity consumption in that year, in kWh?

Question 3

(a) Calculate the average daily output, in kilowatt-hours, from a large 1000 MW coal-fired power station operating at a capacity factor of 75%.

(b) If the daily electricity consumption of the average UK household is about 15.3 kWh, approximately how many households could be served by the output of this power station?

(c) Suppose that the overall coal-to-electricity efficiency of the above plant is 40%, and it uses coal with an energy content of 27 GJ t-1 (gigajoules per tonne). Show that it will require an input of 6000 tonnes of coal a day when operating as described in (a) above.

Question 4

Calculate the Carnot efficiency of a system where the steam enters the first turbine at 527ºC and leaves the condenser at 47ºC. Express your answer as a percentage.

Question 5

(a) One constituent of crude oil is heptane (C_7H_{16}), a hydrocarbon whose molecules have seven carbon atoms and sixteen hydrogen atoms. Write the chemical equation for the combustion of heptane in reaction with oxygen, and use it to find the mass of carbon dioxide released in the combustion of 1 kg of heptane. (The relative atomic masses of H, C and O are 1, 12 and 16 respectively.)

(b) The combustion of 1 kg of heptane produces 48 MJ of heat energy. Using the result of (a) above, find the mass of CO2 released per gigajoule (GJ) of heat produced.

Compare your answer with the data for 'oil' in Table 7.8 on page 259 of Book 1, Energy Systems and Sustainability, noting the footnote to the table.

Question 6

The surplus overnight output of a power station is 'stored' by using it to pump water up into a high reservoir.

(a) The surplus electrical energy generated during one night is 3 million kilowatt-hours. If 5% of this is lost in the pumping process, calculate the energy available to raise the water and express your answer in megajoules (MJ).

(b) If the reservoir is 190 metres above the intake, how many cubic metres of water will be delivered during the night?

You may assume that:

density of water = 1000 kg m–3 ; acceleration due to gravity, g, = 10 m s–2.

(c) Show that, if the area of the reservoir is 3.6 km2, its surface level will rise by 1.5 m as a result of the additional volume of water.

Question 7

(a) Table 1 shows the annual contributions to UK electricity generation from coal-fired power stations and combined-cycle plants using natural gas, in a given year. Use the data in the table to calculate the overall fuel-to-electricity conversion efficiency for each system.

Table 1 Two contributions to UK annual electricity generation

fuel	energy content of fuel (GJ t^{-1})	annual fuel input (Mt)	annual electricity output (TWh)
coal	26	50	130
gas	55	20	140

(b) Explain the fundamental thermodynamic reason for the different efficiencies of the two types of power station.

Question 8

Table 2 shows UK annual consumption of transport fuels in five different years between 1970 and 2004. Discuss possible reasons for the changes in consumption of each type of fuel during this period.

Table 2 UK consumption of transport fuels, in million tonnes per year, 1970–2004

product	1970	1980	1990	2000	2004
gasoline (petrol, mainly for road vehicles)	14.4	19.2	24.3	21.6	19.5
DERV (DiEsel for Road Vehicles)	5.3	5.9	10.7	15.9	18.5
aviation fuel (for jet engines)	3.4	4.7	6.6	10.7	11.8

Question 9

(a) At peak times, the electric power demand of a small town is 22 MW. Calculate the current that will be flowing at peak times in each of the following sections of the distribution system that brings power to the town.

(i) A high-voltage Supergrid section operating at 275 kV.

(ii) The local distribution network operating at 11 kV.

(b) Explain briefly why the extra cost of high-voltage systems is justified for transmission over long distances.

Question 10

(a) Construct a table comparing the UK, France and India in the year 2000, in terms of their per capita consumption (in GJ) of primary energy from each of the following three sources: fossil fuels, nuclear power and renewable sources.

Hint: All the necessary information appears in Figures 2.7, 2,17 and 2.20 of Book 1, Energy Systems and Sustainability.

(b) Identify and comment briefly on two major differences in per capita consumption between India and the two European countries.

Question 11

Table 1 shows the average delivered energy per UK household in 1980 and in 2005. Summarise the main changes shown in the table and suggest two reasons for the differences in the patterns of consumption in these two years.

Table 1 Average annual delivered energy per UK household, 1980 and 2005

year	solid fuel	gas	oil	electricity	total
1980	4.6	11.8	1.5	4.3	22.2
2005	0.5	17.3	1.6	5.3	24.8

All data are in thousands of kilowatt-hours per year.

Question 12

(a) A staircase is currently illuminated by three 60 W GLS lamps (normal filament bulbs), controlled by one switch. In an average year, they are on for a total of 750 hours. Calculate the resulting annual electricity consumption, expressing your answer in kilowatt-hours (kWh).

(b) It is proposed to replace the three lamps in (a) by three compact fluorescent lamps (CFLs). They are to provide the same light intensity as the GLS lamps, and will be used for the same 750 hours per year. Assuming that the average efficacy of the GLS lamps is 14 lumens per watt and of the CFLs is 70 lumens per watt, find the new annual electricity consumption.

(c) Show that, if the price of electricity is 9.26 pence per kWh, the resulting annual saving in running cost should be £10.

Question 13

(a) A combined cycle gas turbine (CCGT) power station burns 48 tonnes of gas per hour when generating an output of 400 MW. Calculate the percentage fuel-to-electricity efficiency of the plant under these circumstances.

Data: Energy content of natural gas = 55 GJ per tonne. 1 MWh = 3.6 GJ.

(b) The effective input and output temperatures of the plant described in (a) are 1400 K and 300 K respectively. Calculate its Carnot efficiency and show that, operating as in (a) above, it is achieving almost 70% of this ideal.