T206 Energy for a sustainable future

Tutorial – Durham March 2008

Calculation solutions

Q.1 Outline answer

Sources: The three figures are on pages 71, 83 and 85 of Book 1. Note that the question concerns consumption, i.e. diagram (b) in each case. The associated text for each country discusses the data..

UK: Gas (40.9%). Preferred over coal or oil for heating and in the 'dash for gas' of the electricity generation industry. The North Sea gas resource is also a factor (or was, in the year 2000!).

France: Nuclear (39.6%). Negligible indigenous fossil fuel. Government decision to support nuclear in order to reduce imports (and/or to improve very poor self-sufficiency).

India: 'Other renewables' (40.8%). Principally biofuels such as wood, dried dung, etc. India is still a developing country, and per capita consumption of the 'modern' forms of energy remains much lower than in the industrialised countries. Large rural population depending on biofuels as their main energy source. [Might mention uncertainty of the data.]

Calculation of percentages not essential, but may contribute towards mark.

Q.2 Answers

Sources: Conversion efficiency is introduced in Box 3.1 on p.94 of Book 1. The relationships between energy units are introduced on pp.58 – 60, where Appendix A is also mentioned.

(a)percentage efficiency = output/input × 100

so input = output/pct efficiency × 100 = 14 000/35 × 100 = 40 000 TWh

From Table A3 in Appendix A or the DATA spreadsheet…

1 TWh = 0.0036 EJ

so 40 000 TWh = 40 000 × 0.0036 = 144 EJ

and the percentage of the total is × 100 = 34.0%

or: Convert 424 EJ to 117778 TWh and × 100 = 34.0%

(b)World population = 6.1 billion (or: 6.1 × 109)

1 TWh = 1 billion kWh, so 14 000 TWh = 14 000 billion kWh (or: 1.4 × 1013 kWh)

and per capita electricity consumption = = 2295 kWh, i.e. about 2300 kWh.

Q.3 Answers

'Capacity factor' is described in Chapter 9 on page 353 (this may require an excursion to the book index for students who are working through the questions week by week)

(a)There are 24 hours in a day, so the maximum possible daily output is
1000 MW x 24 hr = 24,000 MWh.

With a CF of 75%, the average daily output will be
0.75 x 24,000 = 18,000 MWh per day.

1 MWh is 1000 kWh, so the average daily output is 1.8 x 10^7 kWh or 18 million kWh

(b)Average daily household consumption is about 15.3 kWh.
So the number of households = 1.8 x 107 / 15.3 = **1.18 x 10^6, or about 1.2 million**.

(b) percentage efficiency = output/input × 100
so average daily input = avge daily output/pct efficiency × 100 = 18/40 × 100 = 45 million kWh

From Table A3 in Appendix A or the DATA spreadsheet…1 kWh = 0.0036 GJ

so 45 million kWh = 45 x 10^6 × 0.0036 = 162 000 GJ
and the quantity of coal required is therefore 162 000 / 27 = 6000 tonnes per day.

or: 27 GJ t-1 = 27 / 0.0036 = 7500 kWh t-1

and the quantity of coal required is therefore 45 000 000 / 7500 = **6000 tonnes per day**

Q.4 Answer

Carnot efficiency (%) = [1 – output temp / input temp] × 100
or (input temp – output temp) / input temp × 100

where the two temperatures are in degrees kelvin (K)

Temperature in K = (temperature in ºC + 273)

so input temperature = 527 + 273 = 800 K

and output temperature = 47 + 273 = 320 K)

so Carnot efficiency = [1 – 320 / 800] × 100 or (820 – 320)/800 x100 = **60%**

Q.5 Answer

(a) The equation for the combustion of methane is introduced on p.145 of Book 1, and the answer to SAQ 7 in the Week 3 Guide shows the mass calculation for methane. The propane equation (without mass calculation) is the subject of SAQ 20 in the Week 2 Guide.

For heptane, the seven Cs need seven O_2s, and the sixteen Hs need eight Os, i.e. four O_2s.

So a total of 7 plus 4 = 11 O2s are needed. The equation and the mass calculations are…

C_7H_{16}	+	$11O_2$	⇨	$7CO_2$	+	$8H_2O$
(7 × 12) + (16 × 1)	+	11 × (2 × 16)	=	7 × [12 + (2 × 16)]		8 × [(2 × 1) + 16]
100	+	352	=	308		144

So combustion of 100 kg of heptane releases 308 kg of CO_2

a**nd 1 kg of heptane therefore releases 3.08 kg of CO_2.**

(b) The best model answers are the calculations for coal and methane in SAQ 8 of the Week 3 Guide .

Warning: The calculation in Box 5.5 (p.175) starts with coal combustion, but then moves on to a coal-fired power plant and calculates the CO2 per unit of electrical energy. Not what is needed here.

48 MJ = 0.048 GJ, so the above 3.08 kg of CO2 is released in producing 0.048 GJ of heat.

The mass of CO2 released in producing 1 GJ of heat is therefore 3.08 / 0.048 = 64.2 kg (1 mark)

Table 7.8 shows 19 kg of carbon per GJ for 'oil'. As explained in the footnote to the table, the corresponding mass of CO2 would be 19 × 44 / 12 = 69.7 kg.

This is close enough to the above answer to suggest that heptane may be a significant component of 'oil'. The two figures are not identical, but 'oil' is not of course pure heptane.

Q.6 Answers

Potential energy is introduced in Chapter 4 (pp.132–133). The example in Box 4.3 should be useful.

(a) If 5% is lost, 95% remains available, i.e. 3 × 95 / 100 = 2.85 million kWh.

1 kWh = 3.6 MJ, so 2.85 million kWh = 2.85 × 3.6 = **10.26 million MJ**

(b) The energy needed to raise mass m through height H is given by E (J) = mgH

H = 190 metres, g = 10 m s^{-2} and E =10.26 million MJ = 10.26 × 10^{12} J

so m = E / g x h = (10.26 x10^{12}) / (10 x 190) = 5.40 × 10^9 kg

density = mass / volume

so volume = mass/density = 5.4 x 10^9 = 5.40 × 10^6 m^3 or 5.40 million cubic metres

(c) 3.6 km^2 is 3.6 million square metres = 3.6×10^6 m^2

either raising the level by 1.5 m would need a volume of $1.5 \times 3.6 \times 10^6$ = **5.4×10^6 cubic metres.**

or height raised = = **1.5 m**

Q.7 Answers

(a) Efficiency is defined on p.94, and unit conversions are in Tables A1 and A3 on pp.598–599.

1 TWh = 3.6 PJ = 3.6 million GJ

fuel	energy content of fuel (GJ t^{-1})	annual fuel input (Mt)	annual electricity output (TWh)	energy input (million GJ)	energy output (million GJ)	percentag e efficiency
coal	26	50	130	1300	468	36%
gas	55	20	140	1100	504	45.8%

(b) Carnot, etc., is introduced on pp.197–200 in Chapter 6. Application to the steam turbine (coal-fired power plant) is on p.221 and to the CCGT in Box 9.11 on p.382.

Answer should explain that the temperatures determine maximum possible efficiency, and that turbine gases are hotter than steam in coal-fired plant. [The ideal answer would suggest temperatures and Carnot efficiencies, but a clear explanation without this could attract the full mark.]

Q.8 Answer

Please note: In the version distributed the unit was unfortunately missing from Table 2. This has been rectified in the TMA01 and Help sub-conferences (and is not actually essential for the answer).

Students might notice that the data in Table 2 (except the final column) are shown in graphical form in Figure 7.13 (p.253). The surrounding text discusses the changes up to 2000.

Answers should include brief verbal accounts of the information in the table. For instance…

- Petrol consumption peaked in about 1990 and has fallen [by about 20%] since then
- Diesel, having changed little, has risen steeply since the 1980s [average rise about 5% per year]
- Aviation fuel consumption has risen throughout - but less rapidly after 2000 [1990-2000 annual average 5%, 2000-2004 annual average 2.5%]

Some mention of quantities is needed (e.g. 20% fall in petrol since 1990; aviation fuel up by factor 4 since 1970; diesel average rise of about 5% a year since 1980; etc.)

The text offers some explanations:

- petrol down due to improved mpg and shift to diesel
- corresponding diesel rise, and also from increased transport of goods by road
- effect of low-cost airlines, etc.
- Some mention of the period 2000-2004, not discussed in the text. [Recent media interest should surely provide something?]

Q.9 Marking notes

Box 4.6 (p.139) has the basics. Distribution voltages are discussed on p.344 in Chapter 9, Electricity.

(a) power (W) = voltage (V) × current (A)

so current = power / voltage

(i) current = $(22 \times 10^6) / (275 \times 10^3)$ = **80 A**

(ii) current = $(22 \times 10^6) / (11 \times 10^3)$ = **2000 A**

Note: The theory in Box 4.6 is for DC voltages and currents and is all that is required for an answer to this question. High voltage grid supplies will use 3-phase AC. Although the theory of 3-phase AC is introduced in Box 9.3, the equation for power is not. However, if students with a knowledge of electrical engineering use the equation Power = $\sqrt{3}$ Volts × Amps, they should not be penalised.

Q.10 Marking notes

The three figures, with associated discussions, are on pages 71, 83 and 85..

(a) The question asks about consumption, so the right-hand pie in each figure is needed. Total annual per capita consumption is given in the figure captions.

country per capita total	***UK 165 GJ***		***France 192 GJ***		***India 21 GJ***	
source	*% of total*	*contribution*	*% of total*	*contribution*	*% of total*	*contribution*
fossil fuels	89.7%	148.0 GJ	53.8%	103.3 GJ	57.0%	12.0 GJ
nuclear power	9.0%	14.9 GJ	39.6%	76.0 GJ	0.8%	0.2 GJ
renewables	1.3%	2.1 GJ	6.7%	12.9 GJ	42.1%	8.8 GJ

Note: (a) GJ y-1 equally acceptable as unit (b) the total of the pie chart for France adds to 100.1% and that for India to 99.9% due to rounding - allowance should be made for any confusion that this causes.

(b) The following are the most obvious ways in which India differs from the European countries.

- The high proportion of primary energy contributed by renewables in India [over 40% in contrast to a few percent] – reflecting the large contribution of biomass [wood, cow dung, etc.] to energy consumption, particularly in rural India.
- The much lower per capita consumption of energy from fossil fuels and/or nuclear power [India an order of magnitude or so less than the UK or France] – reflecting lower vehicle-miles, electricity consumption, etc. per person.

Q.11 Outline Answer

Note that the question is restricted to delivered energy in the 'domestic' sector, so oil use does not include transport. The main discussion of trends in UK delivered energy is on pp.115–8 in Chapter 3. SAQs 5 and 6 in the Week 2 Study Guide could also be useful.

The following are the main changes

- The dramatic reduction in solid fuel consumption [almost 90%]
- A significant increase in gas consumption [about 50%]

Reasons for the differences in the patterns of consumption might include…

- a continuing fall in the use of coal fires, with a rise in gas-fired central heating
- better heating of houses in 2005 – noting that the increase in energy from gas (5500 kWh) is greater than the reduction from solid fuel (4100 kWh), despite the greater efficiency of gas heating. (However, greater consumption in 2005 might be due to colder weather in that year, as mentioned in SAQ 5 answer.)
- An increase in the numbers of some types of electrical [and electronic] appliances or systems – dryers, dishwashers, TVs, etc.

Q.12 Answers

(a) This part requires only an understanding of kilowatt-hours.

Total power = 3 × 60 = 180 W

Annual consumption = 750 × 180 = 135,000 Wh = 135 kWh

(b) Lamp efficacies are introduced in Chapter 3 (p.104).

When lighted, the three GLS lamps produce 180 × 14 = 2520 lumens

For the same light, the three CFLs, producing 70 lumens per watt, need a total power of

2520 / 70 = 36 W

so their annual consumption is 750.× 36 = 27,000 Wh = **27 kWh**

Alternatively, the following or equivalent:

A fivefold increase in efficacy means that, for the same illumination, only one fifth of the original electrical energy is required, i.e. 135 / 5 = **27 kWh**.

(c) The annual saving in electricity is 135 – 27 = 108 kWh

The annual saving in running cast is 108 × 9.26 pence = **1000 pence = £10**

Q.13 Answers and marking notes

(a) Efficiency is defined on p.94. All other information is in the question.

Energy input per hour = fuel input per hour × energy content of fuel = 48 × 55 = 2640 GJ

Energy output per hour = 400 × 1 = 400 MWh, which is 400 × 3.6 GJ = 1440 GJ

Percentage efficiency = output/input × 100 = 1440/2640 × 100 = **54.5%**

Full mark or this or any other valid method, with quantities identified and units given.

(b) Carnot is introduced on pp.197–200 in Chapter 6. There are sample calculations in Box 6.5 (p.200), Box 9.11 (p.382) and in the answer to.SAQ13 of the Week 3 Study Guide.

Input temperature = 1400 K

Output temperature = 300 K

Carnot percentage efficiency = × 100 = × 100 = × 100 = 78.6%

Alternatively, (1 – T2/T1) × 100 = (1 – 0.214) × 100 = 78.6%

Actual efficiency = 54.5%, which is 54.5 / 78.6 × 100 = **69.4% of the Carnot efficiency i.e. just under 70%.**