2.83/2.813 Practice Quiz II

1. **Thermal Oxidation (25 pts);** Thermal oxidation is a semiconductor process whereby silicon (Si) is turned into SiO_2 (Quartz) by exposure to oxygen (O_2). For this problem, we will consider the inputs are only oxygen and silicon; oxygen is supplied at 100X the stoichiometric requirement. Therefore the outputs are SiO_2 and 99X of oxygen, which is wasted. Referring to Chapter 6 Thermodynamic Analysis of Resources used in Manufacturing Processes, see Figure 9. Note that the process with the highest electrical energy requirement per kilogram of material processed is a thermal oxidation process. Referring to this particular process, which is producing SiO_2 at the rate of about 5×10^{-6} kilograms per hour, estimate the degree of perfection. Clearly state the boundaries you have assumed for this analysis.

2. **Frozen Fish (25 pts);** Assume that fish caught in the Atlantic Ocean are then processed in Gloucester, Massachusetts. The processing results in a yield of only one half of the catch weight. The fish is then frozen and shipped to Chicago, Illinois. Estimate the energy requirements to a) catch the fish, b) freeze the fish (assume that the fish generally has a life in the freezer of three weeks before it is bought and consumed, and 3) to transport the fish from Gloucester, Massachusetts to Chicago, Illinois (assume 900 miles distance). This question should be answered for 1 kilogram of delivered frozen fish, you may assume fish has a density of $1 g/cm^3$, all other data should come from your readings (give references for data and possible variation if given). Give answers in MJ of primary energy.

3. **Retreading of radial truck tires (20 pts);** Referring to the remanufacturing paper from your readings consider the following problem. A new study of retreading at the ACME Corporation shows that the retreaded tires have an increase in rolling resistance of 10% compared to new radial tires, whereas their life is reduced from 100,000 miles for the new radial tires to 50,000 miles for the retreaded tires. Using the data from the paper please make a energy comparison between buying a new tire and buying retreaded tires for a service life of 100,000 miles. Which option results in lower energy use, buying new or retread? Give difference in MJ.

4. **Biomass (10 pts);** According to Smil what are the three drawbacks for large scale use of biomass to produce liquid or gas fuels and/or electricity?

5. **Efficency and Growth (10 pts);** Over recent history and for many different types of energy using activities, it has been common for increases in demand to exceed increases in efficiency, that is, $\frac{\Delta Q}{Q} > \frac{\Delta e}{e}$. Please explain why you think this has happened.

6. **Wind Power (10pts):** According to MacKay, the expected power density for land based wind farms in the UK is approximately 2.2 W/m^2 (Pg 265). In this calculation, MacKay assumes a hub-height of 32m. A new design proposal suggests increasing this to 45m, keeping everything else the same. Estimate the potential percentage change in power density if this was to be done. Comment on the potential change in the EROI.

Answers

1.

From Figure 9 we see that the power requirements are 50kW.

Using Szargut, the exergy of SiO_2 (Quartz) = 0.032 MJ / kg

$$\eta_p = \frac{\dot{B}_{product}}{\dot{B}_{electricity} + \dot{B}_{materials}} = \frac{5 \times 10^{-6}\ \frac{kg}{hr} \times \frac{hr}{3600\ sec} \times 0.032\ \frac{MJ}{kg}}{50{,}000\ \frac{J}{s}} = \mathbf{8.8 \times 10^{-10}}$$

This does not account for inefficiencies at the utilities!
The above calculation takes into account that $\dot{B}_{electricity} \gg \dot{B}_{materials}$ which is show below.

In 1 hour quantity of SiO_2 produced = 5 x 10^{-6} kg = 8.33 x 10^{-5} moles

$\dot{B}_{materials}$ = 8.33 x 10^{-5} x [0.855 (Si) + 100 x 0.00397 (O_2)] MJ/hr = 104.3 J/hr = 0.03 J/s << 50,000 J/s of electricity required.

2.

See Riding Vs Walking from Use Phase Lecture and/or p 180 from Smil ENERGY fishing can use 1kgoe/kg.

Energy for fishing = 42 GJ/t
Since the yield is 50%, **energy for fishing = 84 MJ/kg**

From p133 in Ashby, energy for freezing is 13.5 MJ/m^3 per day for electricity

Using the given density = 13.5 MJ/t per day electricity

For 3 weeks and accounting for utility efficiency:

➔ **13.5 kJ/kg / day x 3 weeks x 7 days/week x 3 (utilities) = 0.85 MJ/kg**

From Ashby, and Quiz 1 we know transportation energy = 1.6 MJ/tonne-km

Over 900 miles, **this gives 1.3 MJ/kg**

3.

Using table in the paper,

$$E_M^N = 4265\ MJ$$

$$E_M^R = 1365\ MJ$$

$$E_U^N = 35{,}640\ MJ$$

If retreaded tire live half the life then

$$E_M^R total = 2730\ MJ$$

and since rolling resistance increases by 10%

$$E_U^R = 35{,}640 \times 1.1 = 39{,}204\ MJ$$

Adding the above two for total energy for the retreaded tires to provide 100,000 miles = 41,934 MJ

On the contrary, for the new tire, the energy = 39,905 MJ
Therefore choosing the retreaded tires consumes 5% more energy than the 'NEW' option. This is equal to 2029 MJ = 563 kWh = running a 100W bulb for 1.5 years at 10 hours a day. Note that the assumptions about retreaded tire degradation, in rolling resistance and halving of life are slightly against retreading compared to what empirical data shows. For example, Michelin has reported an increase of up to 8% in the rolling resistance for retreaded tires.

4.

Refer to Pg 196 of Smil's book "Energy"

5.
Several factors can be listed:

Those that led to faster increase in Q:

- Rising population
- Rising affluence
- Rapid technological and productivity improvements

Those that led to slower increase in e:

- Low impact of energy costs on total costs
- High costs of energy improvements

- Lacking of incentives eg. regulations
- Technological / R&D limitations

6.
Use equation on p266 of the MacKay book.

Wind speed = v (hub height) α (hub height)$^{1/7}$

Factor increase in wind speed = $(45/32)^{1/7} = 1.05$

Also power α (wind speed)^3

Factor increase in power = $1.05^3 = 1.16$

So the power density will increase by 16% to **2.55 W/m^2**

EROI scales like energy produced divided by energy investment. If the new design lasts the same lifetime as the old, everything else being equal, then the energy produced should increase by 16%. The energy investment roughly scales like the weight of the materials for the wind turbine. The new height is 40% higher than the old. This will require a broader base, thicker sections etc. If the invested energy increases something like 40% then the EROI should go down.