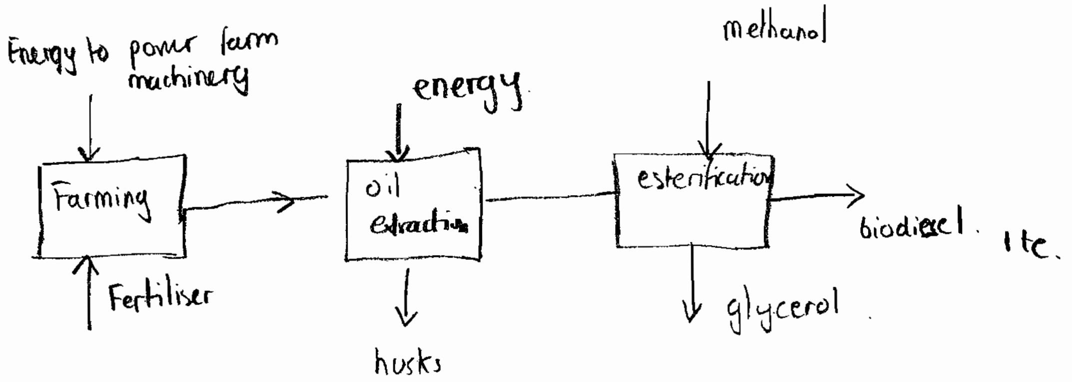
2009 PART IIB 4M15 SUSTAINABLE ENERGY
Dr S A Scott

1 a i) life cycle analysis aims to quantify the enviromental burden due to a product over the entire lifecycle of the product, ie. from raw material extraction through to product use and finally disposal. Reference systems are needed for comparison when a resource has an alternative use. In the case of bio fuels, it is important to consider what other use the land would have if it were not used for an energy crop. [2 marks]

ii)



Farming: Need 2.5 te seeds ⇒ 0.833 ha of land.

Fertiliser embodied energy $= 42 \times 0.3 \times 0.833$
$= 10.5$ GJ

Diesel embodied energy $= 42/1000 \times 50 \times 0.833$
$= 1.75$ GJ

Need to subtract the reference system, since the land would otherwise be used as fallow set aside. For set-aside

Diesel embodied energy $= 42/1000 \times 10 \times 0.833$
$= 0.35$ GJ

∴ contribution to lifecycle from farming is

$10.5 + 1.75 - 0.35 = 11.9$ GJ.

Oil extraction

Need 3.0 GJ of energy. The husks are a waste product so we don't count any energy which could be recovered from them (They are incinerated without energy recovery).

Q1

Esterification

Embodied energy of methanol = 0·1 × 45
= 4·5 GJ

In addition we require 4 GJ of energy for process.
The energy is not recovered from the glycerol

Total input to esterification process = 8·5 GJ

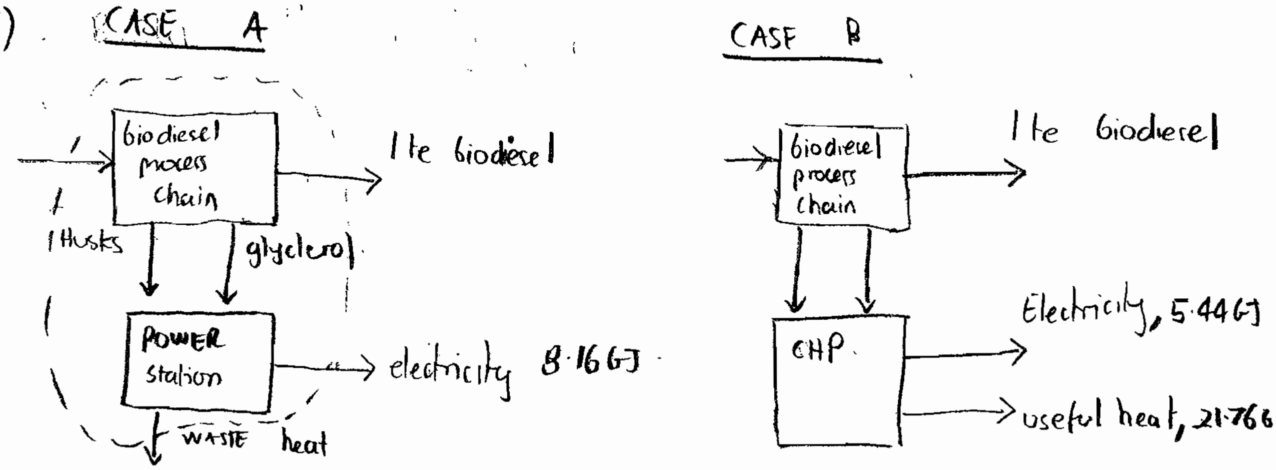
∴ embodied energy of 1te of biodiesel is

8·5 + 3 + 11 9 = 23·4 GJ / te

i.e. 23·4 MJ/ kg

[3 marks]

6i)



total energy input to powerstation or CHP is 1·5 × 17 + 0·1 × 17 = 27·2 GJ

CASE A : electricity output = 0·3 × 27·2 = 8·16 GJ

CASE B : Electricity output = 0·2 × 27·2 = 5·44 GJ
heat output = 21·76 GJ

The total enviromental burden for the process chain is 23.4 GJ; This can be apportioned by economic value.

Product	CASE A Value (£)	burden (GJ)	CASE B Value (£)	Burden (GJ)
Biodiesel	1000	14.89	1000	12.89
electricity	£571	8.51	381	4.91
heat	0		435	5.6
Total	1571	23.4	1816	23.4

∴ if allocation by price is used the new embodied energy of the bio diesel is case A = 14.9 GJ/te
CASE B = 12.89 GJ/te [3 marks]

ii) Allocation by substitution.

CASE A: The electricity produced now displaces grid electricity giving a credit of 8.16 × 2 = 16.32 GJ of fossil energy cared.
∴ new embodied energy (of the bio diesel) is 23.4 − 16.32 = 7.08 GJ/te.

CASE B: The electricity produced gives a credit of 5.44×2 = 10.88 GJ
The heat displaces natural gas so there is a credit of 21.76 GJ
∴ emboided energy of the biodiesel is 23.4 − 10.80 − 21.76 = −9.16

[4 Marks]

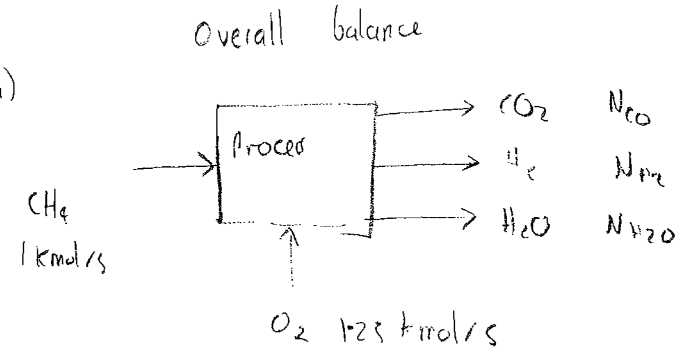
c) The calorific value of bio-diesel is 40 GJ/te, compared with the energy input of 23.4 GJ/te of fossil energy. so there is some overall benefit, but not as much as perhaps at first thought. When taking into account the co-products the analysis becomes more favourable, especially if the heat can be used. Allocation by price reflects the value society places on each product. Since we value transport fuels more than other forms of energy this method allocates most of the burden to the diesel. Bio diesel only uses a very small part of the crop, (ie the oil in the seeds), so when heat can be recovered from the waste products and we use allocation by substitution, we see a negative environment burden for the bio diesel. Allocation by substitution is recognised as the best method for allocation, so it would appear as if using a chp give use the bio-desel at negative environmetal cost. On the face of it this says, that biofuels are a good idea - especially if we can use the wastes.

However, the negative enviromental burden tells us that most of the environmental benefit comes from using the waste. If we had simply used all the seeds in a chp an not made biodiesel, we would get a larger fossil energy saving than if we made biodiesel.

Other issues which have not be considered so far

- land area required to produce biofuels is vast
- Global warming potential. If virgin grass land was ploughed up instead of fallow land a huge amount of extra green house gas would be released from the soil.
- competition for food on agricultural land
- LCA assumes activities dont affect the background system. However if bio-fuels are grown on a vast scale the current agricultural system will be significantly peturbed. [8 marks]

Q2



2a)ii)

Carbon balance:

$$N_{CO_2} = 1 \text{ kmol/s}$$

Hydrogen balance:

$$4 = 2N_{H_2} + 2N_{H_2O}$$

Oxygen balance

$$2.5 = 2N_{CO_2} + N_{H_2O}$$

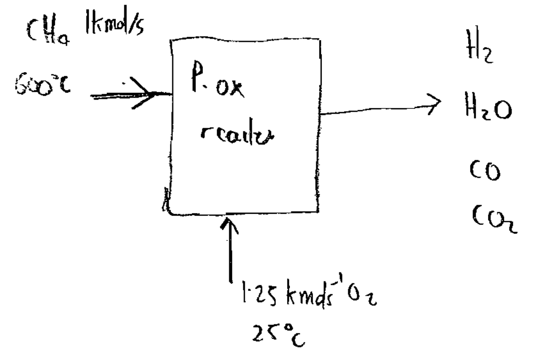
$$\Rightarrow N_{H_2O} = 0.5 \text{ kmol/s}$$

substituting into hydrogen balance,

$$N_{H_2} = \frac{4-1}{2} = 1.5 \text{ kmol/s}$$

[2 marks]

ii) The partial oxidation reactor produces syn-gas – mixture of H_2O, H_2, CO, CO_2



Need material balance to calculate molar flows out of reactor.

Carbon: $\dot{N}_{CO} + \dot{N}_{CO_2} = 1$ and $N_{CO}/N_{CO_2} = 1.2 \Rightarrow N_{CO_2} = \frac{1}{2.2} = 0.4545$

$$\Rightarrow \dot{N}_{CO_2} = \frac{1}{2.2} = 0.4545$$

$$\Rightarrow \dot{N}_{CO} = 0.5455$$

Oxygen: $2N_{CO_2} + N_{CO} + N_{H_2O} = 2.5$

$$\Rightarrow N_{H_2O} = 1.0455$$

Hydrogen balance

$2N_{H_2} + 2N_{H_2O} = 4 \Rightarrow N_{H_2} = \underline{0.9545}$

First law.

$Q = \sum N\underline{H}_{in} - \sum \dot{N}\underline{H}_{out}$

INFLOW $H_{IN} = 1 \times -44893 = -44893$ kJ/s

OUTFLOW $H_{out} = 0.9545 \times 25964$
$+ 1.0455 \times -209481$
$+ 0.4545 \times -350542$
$+ 0.5455 \times -83024$
$= -397795$ kJ/s

$\therefore Q = 352902$ kJ/s (heat output).

or $\underline{352.9}$ MJ / kmol of methane.

[4 marks]

Q2

Heat sources (Hot streams need cooling down)

Stream	heat capacity flow	Temperature	Heat load (MJ)
reactor (pox)	–	900 °C	352.9
shift reactor	–	600 °C	100
separation system		25 °C	268

heat sinks	heat capacity flow	T_{in}	T_{out}	Heat load (MJ)
CH_4		25 °C	600 °C	29.7
separation system	–		200 °C	250

Interval	heat sinks	heat sources	Net (MJ)	Cumulative heat load (MJ)
900 - 900 °C	–	−353	−353	−353
600 - 600 °C	–	−100	−100	−453
200 − 600 °C	51.7 × 400 = 20.7	0	+20.7	−432.3
200 - 200 °C	250	0	+250	−183.2
25 - 200 °C	51.7 × 175 = 9	0	+9	−173.3
25 - 25 °C	–	−268	−268	−441.3

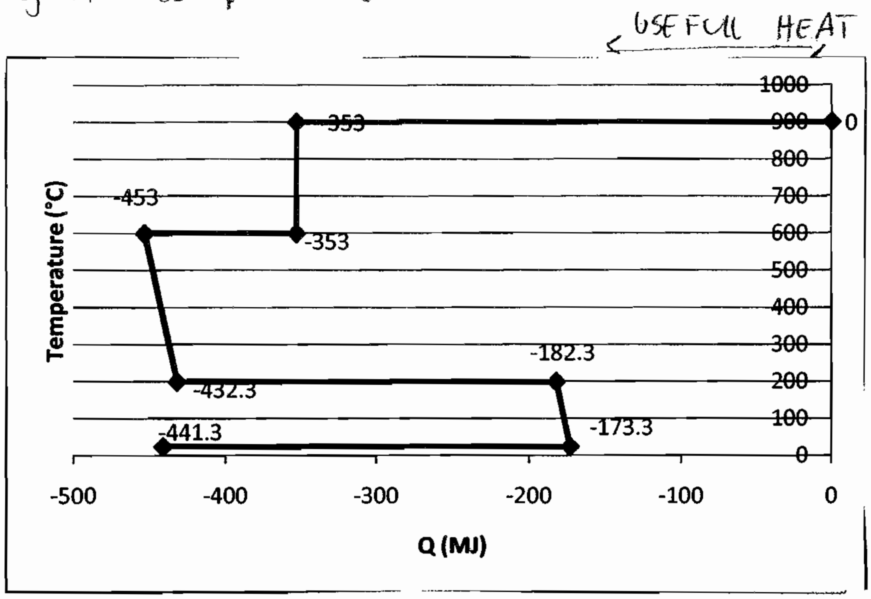
∴ No heating is required - cooling of 441.3 MJ is needed. There is no pinch and all the heat sinks can be supplied by the heat sources.

(N.B −ve ⇒ heat given out)

All of the process heating requirements can be met by heat sources with the process ⇒ heat recovered = 250 + 29.7 = 279.7 MJ

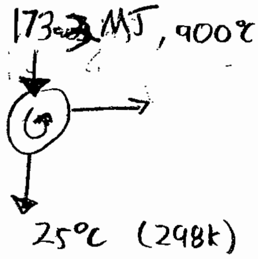
[4 marks]

ii) The grand composite curve is 4



(Nb heat release taken as -ve)

Maximum work which could be generated from the process waste heat is



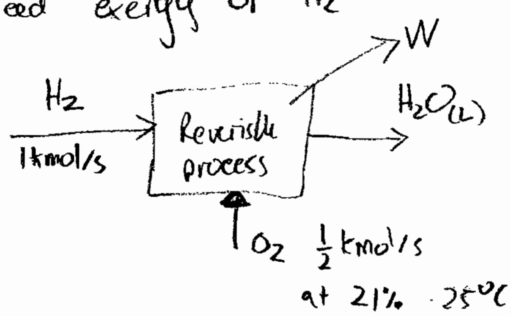
$\eta = 1 - \frac{298}{1173} = 0.745$

$\Rightarrow$ Work $= 0.745 \times 173.3 =$ 129.1 MJ

N.b, this is the exergy value of the waste heat from the process.

[4 marks]

iii) Need exergy of H_2



$H_2O_{(L)}$ 1kmol/s

Work = − Exergy of H_2

$-\text{Exergy} = W = \underline{B}_{H_2} + \frac{1}{2}\underline{B}_{O_2} - \underline{B}_{H_2O(l)}$ (where $\underline{B} = \underline{H} - T_0(\underline{S} - R\ln y)$)

$\underline{B}_{H_2} = 0 - 298.15(130.7) = -38968$ kJ/kmol

$\underline{B}_{O_2} = 0 - 298.15(205.1 - 8.314\ln 0.21) = -65019$ kJ/kmol

$\underline{B}_{H_2O(l)} = -285380 - 298.15(69.9) = -306220$ kJ/kmol

$\therefore$ Exergy $= 234742$ kJ/kmol $= 235$ MJ/kmol.

Q2

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∴ Exergetic efficiency is

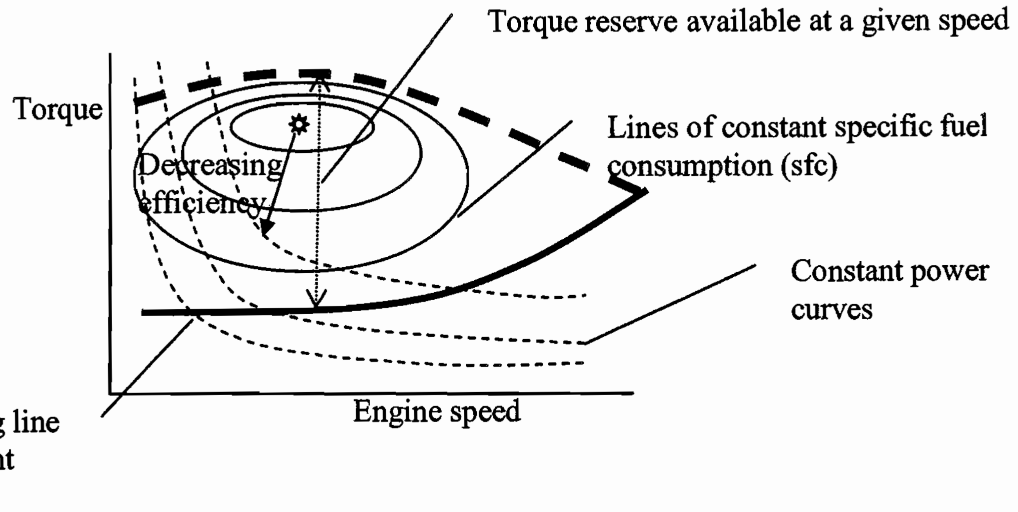
$$\frac{1.5 \times 235 + 173.3 \times 0.30}{830} = \underline{48.7\%}$$

N.b. All of the 173.3 MJ of heat rejected by the processes can be used by the steam cycle.

[6 marks]

(a) Are the battery manufacturers correct when they say that petrol and diesel engines already operate at their maximum efficiency? If not, how can cars powered by internal combustion engines be made more efficient? Explain your reasoning?

This is best explained using a sketch of the characteristics of a typical petrol engine.



An engine is sized and geared so that at a given speed (e.g. 70 mph) when cruising, the engine is running at a relatively low efficiency. The rational for this is that a torque reserve is needed should the car need to accelerate (also important for the driving experience). If the engine operates close to the maximum efficiency, then there is insufficient torque reserve. A large increase in efficiency can be achieved if the torque reserve can be provided by an alternative power source. One way to achieve this is with a hybrid drive system, where excess energy form the engine is stored in a battery, which can provide a boost in power for short durations of acceleration. Several configurations are possible. (i) Series: an engine charges a battery; the battery is then used to drive a motor connected to the wheels. (ii) Parallel: both the engine and the electric motor are connected to the wheels via a power splitter, and the engine is used to charge the battery when it is producing more power than required to drive the vehicle.

Thus, the manufactures is not correct to say that the efficiency of internal combustion engine powered vehicles cannot be improved. [6 marks]

(b) The battery manufacturer claims that if you buy the electricity to charge the electric cars using the "*Green-Nuclear*" tariff offered by *Electricity R us plc.* the cars are CO_2-neutral. In their product literature, *Electricity R Us plc.* state that they will purchase the same number of units of electricity from nuclear power generators, as a customer of the "*Green-Nuclear*" tariff uses in a year.

What the arguments for, and against the claim of CO_2-neutrality, if the electricity for the electric cars is supplied via the "green nuclear" tariff?

If the electricity were to come directly from a nuclear power station to the customer, then there would be some argument in favour of the claim. Of course, even pure nuclear electricity is not fully CO_2 neutral, but in comparison to fossil generated electricity it is very low. The material used to the build the reactors and some parts of the fuel cycle all contribute a small amount to the overall foot print. From the point of view of a lifecycle analysis, the argument against this view is that, the electricity from the nuclear power stations could have been used for other uses, so that using the nuclear electricity for cars, just causes the CO2 production associated with say coal fired stations to appear somewhere else.

In the UK, where electricity is supplied by a grid, so that there is not a direct connection between the customer and the generator. Only about 20% of the electricity in the UK comes from nuclear, the majority will come from coal or gas fired stations, which produce carbon dioxide. If a life-cycle analysis were used to calculate the CO_2 burden of the car, the electricity used for running would have a CO_2 burden equal to that of the average energy mix in the UK. It is not fair to allocate the electricity from nuclear power to the vehicles, since this electricity could displace fossil generated electricity from elsewhere (e.g. even if a new nuclear power station was build solely for charging the cars).

The electricity supplier has only promised to buy the same number of units as are used over the whole year, which is not the same as saying that the customer will always be receiving nuclear electricity. The market in the UK is such that electricity supply is based on contracts, and the amounts generated from different sources depend on the price. Nuclear electricity provides base load, so that when there is little demand for electricity (e.g. summer night time), the price of nuclear electricity is low. The energy company can simply buy units of nuclear energy when the price is low (and electricity demand is low). When the price is high, it will use the cheapest other source to provide the electricity to charge the car. In the worst case scenario, if coal were cheap so that the coal fired stations were at the top of the merit order, then plugging in one extra car, would result in all of additional electricity required being produced from a coal fired station, with a CO_2 burden significantly higher than the average. In this case, the CO_2 burden associated with the electricity is the marginal burden associated with plugging one extra car into the grid.

Thus, deciding what the CO2 burden associated with car is a complicated issue and open to some argument. One thing that is obvious though, is that if the cars "know" the electricity price, then they could choose to charge when the price is cheap, and power which is being produced by nuclear and renewables is cheap, and in some cases (if demand is very low) simply wasted. This motivates the need for smart metering of electricity, which if implement would mean that the cars could operate much closer to being CO2 Neutral.

[6 marks]

(c) Does nuclear power meet the definition of a sustainable energy technology? How do the proposed future nuclear power stations address the concerns of the 1980's?

Nuclear power is one of the electricity generating technologies which can produce energy on a scale needed by the UK at the moment. Whilst renewable sources (in the UK wind energy is probably the most promising of these), have some role to play, even the most ambitious targets for renewable use are barely comparable to even the current amount of energy generated by nuclear in the UK. From a sustainability point of view, nuclear is not sustainable in the long term. The current fuel cycle uses enriched uranium, which is processed from ores mined in e.g. Namibia or Austrailia. Estimates of the extent of this resource show that if the world were to move to a fully nuclear electricity system, the known, technically feasible nuclear resource would be relatively quickly depleted. So although, nuclear power does not produce CO_2 (and so result in a pollutant release which perturbs the carbon cycle), it faces the same resource depletion issues as fossil fuel technologies. Given the seriousness of global warming, resource depletion is perhaps less of a worry.

The major obstacle to new nuclear stations is public perception of the danger of nuclear power stations, usually in context of previous nuclear accidents (e.g. Chernobyl). This manifests itself in the planning process, which means that it is very difficult to get permission to build a nuclear station. From a technical point of view, the major is issue is what to do about the dangerous waste which is produced. There is currently no technically feasible way of rendering harmless the high level nuclear waste produced by a nuclear station. This waste have has half-life which exceeds any likely human civilisation, which leads to questions about who will be responsible for this. The two suggestions to overcome this so far are long term storage underground, or the hope that in future, some yet to be specified technology will be invented to deal with this problem.

The new generation of nuclear reactors address the issue of safety. In particular, they are designed to be intrinsically safe. A key component of a reactor is the cooling system, which in previous reactor designs has relied on pumps and active components to circulate coolant. New designs can be cooled through natural convection, so that a power failure does not result in a run away in temperature (and possible loss of containment). One suggestion uses nuclear fuel, which is encapsulated within "pebbles", whose outer shells can withstand any possible temperature excursion. The fuel in the pebble is relatively dilute and cannot be dispersed, reducing the danger of a catastrophic loss of containment. An added feature of this new type of fuel, is that they cycle is once through, i.e. spend fuel cannot easily be reprocessed to make new fuel, or more importantly the raw materials for nuclear weapons. [6 marks]

+ [2 marks] for quality of arguement