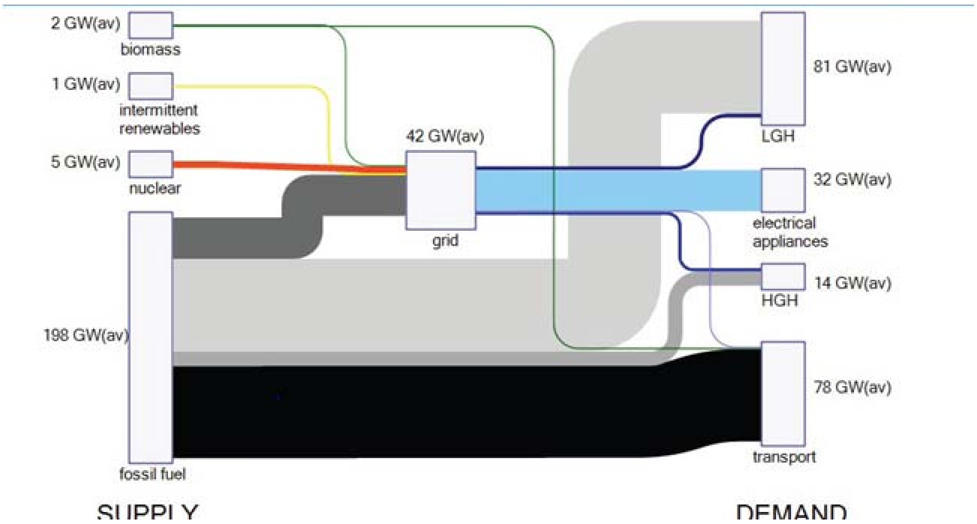
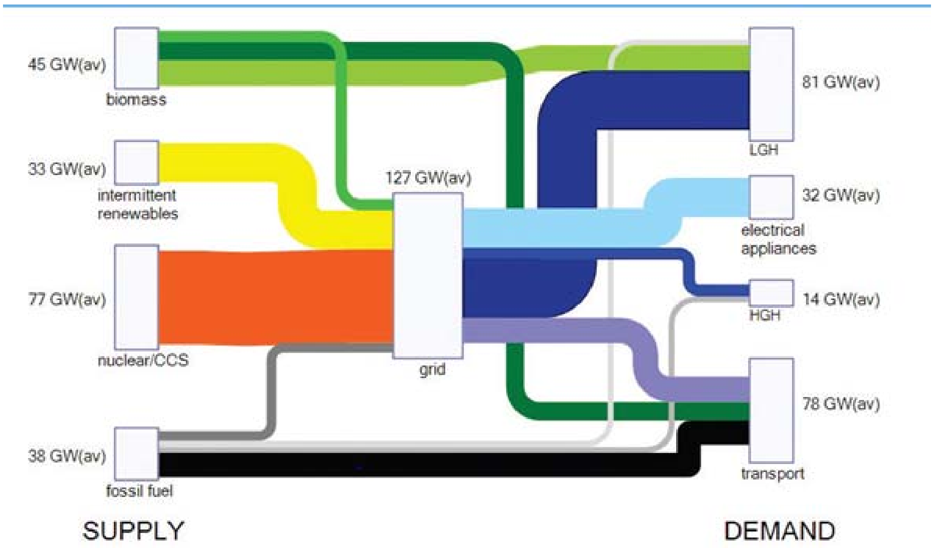
CRIBS FOR 4M18 PRESENT AND FUTURE ENEGRY SYSTEMS

Q1(a) KELLY



In 2050 there are several possible diagrams depending on total energy consumption and reserving the remaining fossil fuels for transport or low grade heat. As per RAEng report used in lecture 12, it could be :

Level demand in 2050:



1(b) ALLWOOD The four forms of efficiency mentioned are:

- “Theoretical efficiency” – current energy use is compared with the absolute theoretical limit to the minimum that could ever be used. Typically this is reported using an exergy measure
- “Practical efficiency” – current energy use is compared with the best performance of known solutions – for example against “best available technology”, or pre-commercial demonstrations of new technologies.
- “Economic efficiency” – current energy use is compared with the best performance of the best alternative solution providing the same service while also remaining profitable. Options that show a negative marginal cost on “marginal abatement curves” fall into this category.
- “Service efficiency” – current energy use is compared with the performance that could be achieved by a different way of delivering the same service – for example where intelligent heating controls avoided heating unused rooms in a building.

For the petrol engine car, examples of these measures and their implementation challenges might include:

- Theoretical: extracting electrical energy directly from the petrol at room temperature using a fuel cell to avoid the irreversibilities of combustion. However, at present fuel cells for this conversion are not available, or exist only at laboratory scale
- Practical: VW’s L1 concept car weighs around 380kg, so with fuel consumption strongly correlated with vehicle weight, the efficiency of all cars could be raised to around 160mpg through reducing their weight. Unfortunately customers prefer big cars to small ones, and small ones would suffer in a collision with big ones, so extra safety measures would be required.
- Economic: most cars perform better if the top speed is constrained to nearer 60mpg than 80mph, so journey costs could be reduced if completed with a lower top speed. However, most drivers prefer travelling faster, so would not voluntarily choose this option, even though it would save them money.
- Service: typical occupancy of UK cars is 1.6 passengers, but the cars average 5 seats. The average fuel consumption per passenger mile would be reduced if more people shared the same vehicle. However, at present, people prefer to set off on journeys without the planning that would be required to find others going in the same direction.

2(a) KELLY RETROFIT Data given.

45% energy consumed heating air and water in buildings, 27% in homes. The energy sue from homes could be more than halved by going to passivhaus standards, but at of order £50 per house to go part way to that, with more internal and external cladding, modern appliances, and treble or vacuum glazing, this added up to of order £1T over 40 years, to which the supply chain costs and the non-domestic building bring this to something like £1.7T. Largest civil engineering project ever considered in UK peacetime, and finance unlikely to be forthcoming on the scale and time. The workforce is of the scale of the NHS when the supply chain (which would have to be trebled over what we have today just to cope with retrofitting) and all is taken over, and on a pro-rata basis over the whole country , the capacity would be such that the conversion of Cambridge would take 6 weeks.

Several other points of detail might come up: personal behaviour is key, and can serve to thwart or reinforce any engineering. More serious in the UK, compared with Sweden or Spain where the thermal envelope is a vital first order design element from buildings. There is evidence that retrofit work poorly done is worse than no work being done at all particularly with insulation measures.

There has been steady progress on a business as usual basis since 1990, as of order £33Bpa is spent on all forms of buildings upgrades and additions.

2(b) PALMER

(i) Care is needed on this as the axis is 4000-7500. This indicates a pretty heavy load at all times of (say) 5500MW. The evening peak is as expected or domestic dinner cooking and heating pumps. There is also around 1000MW daytime load. Again, one can mention light industry, heating, computers, food refrigeration etc.

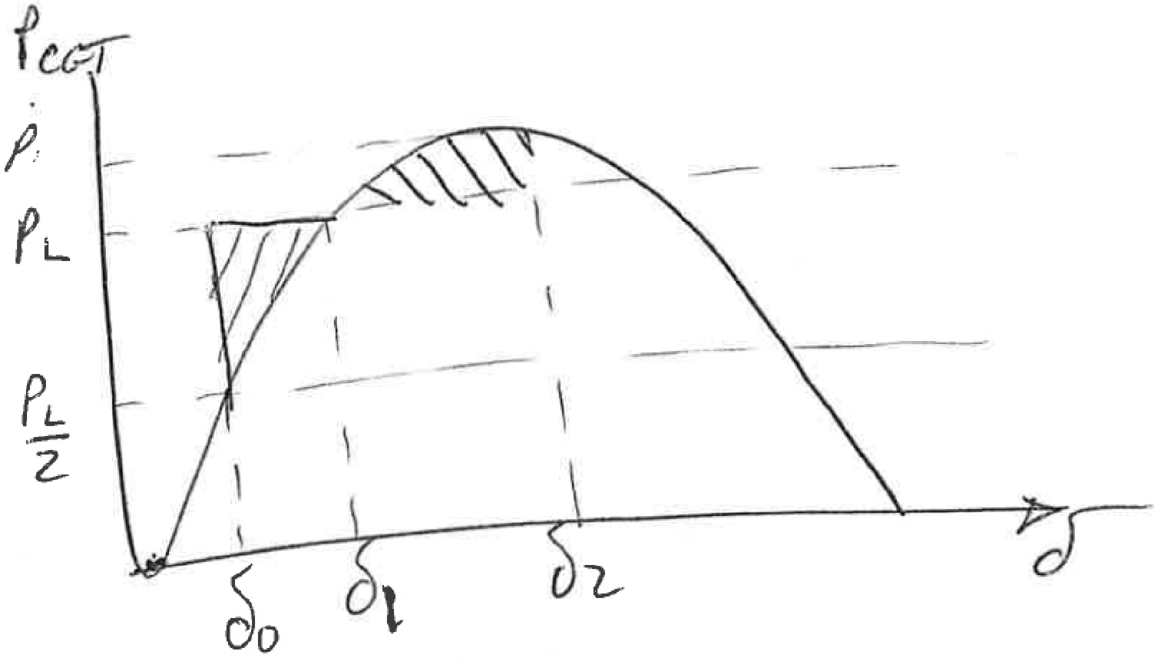
(ii) Clearly the heavy load implies some extraction industry or refining. Placing a generator near this if possible would reduce losses. Spinning reserve is needed for the evening period. Fuel mix can also be estimated given the start-up times. Hydro is available could become pumped storage to flatten out the curve entirely.

(iii) The 3 sigma boundaries are some way away from the measured losses indicating uncertainty. Difficult to measure power accurately (2V's and 2I,s, and losses = P_{gen}-P_{load}. The daytime peak of say 7500MW is 2000MW higher than the 5500MW, or 136%. Power losses related to current have a fixed percentage of the load (if we neglect reactive power). There are very little fluctuations here. So either the transformers and generators are oversized with large fixed losses or reactive power is also high during the lower load periods, which seems a little unlikely. Losses are mostly in transformers and transmission lines. Transformers have fixed losses, transmission lines do not, so it is mostly the transformers which are oversized. A curve for London would have a much lower load in proportion and bigger peaks morning and evening, as it lacks heavy industry mostly and has a high proportion of 9-5 office workers.

3(a) PALMER

(i) CB might open for: Loss of volts at VA; loss of frequency at A; trip fo any generator, disconnection of any large loads.

(ii) Sketch an equal area diagrams for the CGT on opening of CB in the case where $|P_G|=|P_L|/2$:



(iii) 1: Must be able to produce PL (i.e. $P_{peak} > P_L$)
2: Must have margin to produce the second area fso machine/impedance transformer must eb carefully chosen.
3: Machine must have damping to avoid oscillations remaining
4: Protection thermally when running at high power P_L (short term to avoid oversized machine?)
5: Reacrive power of the plant (unknown) therefore power factor correct at plant

3(b) LESTAS (i)Discrepancies between load and supply accelerate/decelerate generators and hence lead to fluctuations in frequency. Frequency control schemes readjust the power command signals at the generating units so as to suppress these fluctuations and thus maintain the nominal frequency. This is in general a nontrivial task as the control schemes are decentralized, and stability of the system can be compromised when these feedback schemes are too aggressive.

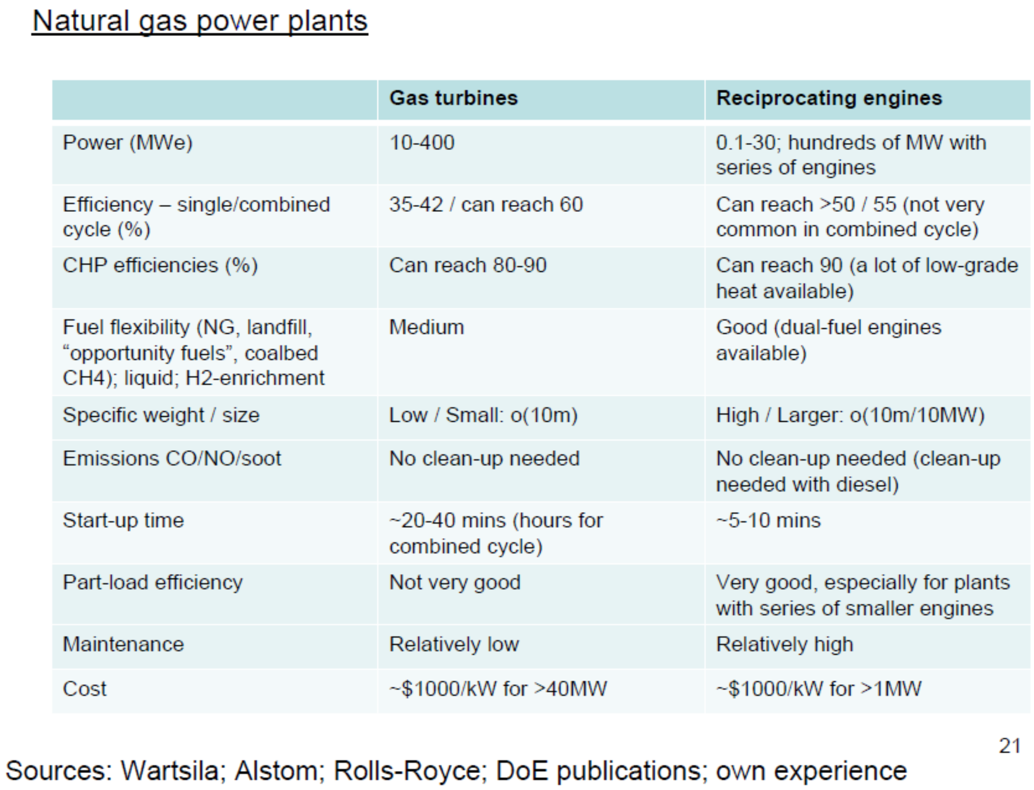
(ii) A load disturbance causes a transient in the rotor angles. This hence leads to disturbances in the power transfer between regions, which propagate throughout the network, and normally get attenuated by means of frequency control schemes. Larger disturbances (e.g. due to faults) can lead to instabilities.

(iii) "Economic Dispatch Problem" (EDP): how much energy to produce at each generator such that operation cost is minimized and network constraints are satisfied (e.g. limits on power that can be generated, voltage constraints, transmission line restrictions, power flow constraints).

EDP sets the operating point for the frequency control schemes.

Differences: EDP is a static optimization (no dynamics taken into account). Also in frequency control economic considerations are not taken into account when power command signals are automatically readjusted.

4(a) MASTORAKOS



Natural gas power plants

	Gas turbines	Reciprocating engines
Power (MWe)	10-400	0.1-30; hundreds of MW with series of engines
Efficiency – single/combined cycle (%)	35-42 / can reach 60	Can reach >50 / 55 (not very common in combined cycle)
CHP efficiencies (%)	Can reach 80-90	Can reach 90 (a lot of low-grade heat available)
Fuel flexibility (NG, landfill, "opportunity fuels", coalbed CH4); liquid; H2-enrichment	Medium	Good (dual-fuel engines available)
Specific weight / size	Low / Small: o(10m)	High / Larger: o(10m/10MW)
Emissions CO/NO/soot	No clean-up needed	No clean-up needed (clean-up needed with diesel)
Start-up time	~20-40 mins (hours for combined cycle)	~5-10 mins
Part-load efficiency	Not very good	Very good, especially for plants with series of smaller engines
Maintenance	Relatively low	Relatively high
Cost	~\$1000/kW for >40MW	~\$1000/kW for >1MW

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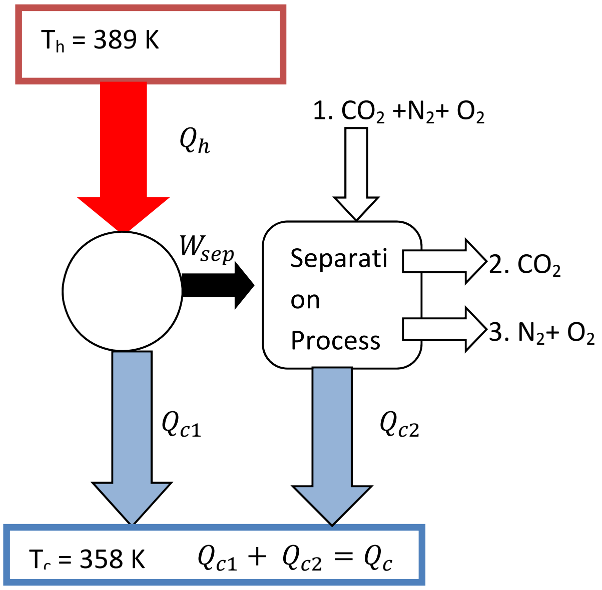
Sources: Wartsila; Alstom; Rolls-Royce; DoE publications; own experience

4(b) SCOTT

The amine scrubbing unit (responsible for wsep) uses heat diverted from the main power cycle to run the separation process. CO_2 is absorbed at low temperature (and heat rejected), and the amine (with CO_2 absorbed) is then send to a separate reactor where it is heated (taking in heat at a higher temperature) to release pure CO_2 and regenerated the amine (which is recycled).

Work is required to do the separation, not heat. However heat transferred across a temperature difference has a work value. Thus the amine scrubbing system can be though as a two stage process with work being generated by diverting heat through a Carnot cycle, and the resulting work being used to separate the gases (as shown in the sketch below). Note that either the separation process must reject heat, or the outlet gases will be at a different temperature to the inlet gas stream.



The minimum work to separate gases can be calculated from the first and second law applied to a control volume, just around the separation process,

i.e.

compare this to a process which uses work, and rejects heat also to T_c (e.g. as in (b))

$$0 = \dot{H}_1 - \dot{H}_2 - \dot{H}_3 + W_{sep} - Q_{c2}$$

And

$$0 = \dot{S}_1 - \dot{S}_2 - \dot{S}_3 - Q_{c2}\left(\frac{1}{T_c}\right)$$

Multiply by the entropy equation by Tc and subtract from the first law to give

$$W_{sep} = -\left(\dot{H}_1 - T_c\dot{S}_1\right) + \left(\dot{H}_2 - T_c\dot{S}_2\right) + \left(\dot{H}_3 - T_c\dot{S}_3\right) \qquad (*\,2)$$

Which, if the gases enter an leave at the same temperature, is equal to the free energy change ΔG. Note that then DH would be zero and the only to contribution to the separation work will be the entropy change.

The work can then be provided by the carnot engine, so that the

$$Wsep = Q_h\left(1 - \frac{T_c}{T_h}\right)$$

Thus, an amount of heat Qh must be taken from the power cycle, typically by diverting steam from the steam cycle; steam that would otherwise have gone through a turbine and generate useful work.

You would divert the lowest quality steam possible to reduce the penalty, is take it from the LP turbine at a temperature just above the upper temperature of the amine scrubbing system. Note that the opportunity cost, i.e. the max work you could have generated from the heat if it hadn't been diverted to the scrubbing system would be

$$Wsep = Q_h\left(1 - \frac{T_{env}}{T_{extract}}\right)$$

Where Th is the extraction temperature of the heat, and T_{env} is the temperature at which the power cycle rejects heat. Obviously this is all a bit approximate as the real power cycle isn't a perfect Carnot cycle.