Prof M Kelly

4M18 2016 Cribs

Note: 34 Part II students and 38 MPhil students (from several degree courses) took this examination. Students were warned that essay type answers were expected. All candidates handled the exam well, and the most cogent answers scored highest. The examination covered most aspects of the course. Too many candidates did not answer the precise question as asked, but rather poured out whatever they knew about the general area: e.g. talking only about the UK in question 2 or about domestic buildings and building operations in question 3(a).

CRIBS:

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2.. Scale
Over 90% of energy used since 1800 has been based on fossil fuels, and today 88% of primary energy use is based on fossil fuels.

Energy generation and distribution is about 10% of all world GDP, and infrastructure has evolved over >100 years in major developed countries.
Since the oil shocks in the 1970s, all renewables – solar, wind, tidal etc have grown from virtually nothing to of order 1% of world energy supply or 2% of electricity. It is 40 years since that event and less than 40 years until 2050 – it will be hard for renewables to get more than 10%, with 3-4% of primary energy provision by 2035 according to BP.
40 years + lifetime of fossil fuel plants, renewables so far 20-25 years, still to be tested in full.
EROI on solar and wind not high enough on their own to permit a sophisticated society.
Building retrofits – to long a payback time, and too much embedded carbon in UK – large workforce needed and probably a command economy.
35% of all world energy used heating/cooling air/water in buildings.
Electrifying transport would require developed countries grid sizes to double, but only likely to happen when the method of electrification (not renewables) drives demand for grid growth.
Urgent need over next 20 years – to lift 2B from poverty to 'middle class' by World Bank Standard – will require another 40% growth of world energy demand and only fossil fuels and nuclear have the capacity.
Nuclear being rejected by some advanced countries.
Many more such points covered in the lectures. ……….

3(a) The main driver of emissions associated with commercial construction is the use of steel and concrete. Many options exist to reduce the need for these materials, but none are currently commercially attractive. The intention of this question is therefore to check that students can identify contrasting options and can evaluate them in the context of the wider decisions which lead to today's patterns of material use.

Six possible proposals (and others are possible) are:

1. Don't build anything – keep using existing buildings for longer. This is technically straightforward, as most buildings are replaced before they wear out, so using them for longer requires no intervention. However, the reason for replacement is that land in the UK is expensive, and the owner of the land can earn more rent by having a different building design instead of the current one. Typically the change might be to have a building with more floors, different ceiling heights or a different layout. The barrier to maintaining the building for longer is therefore that the land owner will lose income as a result.

2. Refurbish/Adapt an existing building rather than replace it. This is a natural response to the first proposal, and occasionally proves possible – as with King's College adding a garret level of lightweight modular rooms on top of Keynes court, or Anglia Water's experience in extending existing pumping stations rather than replacing them. However, most buildings today were not designed with adaptation in mind, so it may prove very expensive. The University Arms refurbishment in Cambridge at present looks like an adaptation – but actually only the outer surface of the old building is being

maintained, for aesthetic reasons, and a whole new buildings is being constructed within it. The key challenge to adaptation is to change the heights of ceilings or the number of vertical columns in a building. However, both challenges could be made quite simple in future buildings, if the columns (which have only a small fraction of the material in the building in them) are over-specified and are designed to allow subsequent vertical re-configuration.

3. Use half the material in new buildings. Surprisingly this looks to be technically quite easy to achieve. The bulk materials (steel and cement) are made so efficiently that they are extremely cheap, and therefore minimum cost design tends to prioritise saving labour costs: if it's possible to save labour by adding more material, it makes economic sense to do so. As a result, evidence suggests that we may be over-specifying buildings by a factor of around two, even before questioning the safety factors applied to building design, which are known to be conservative. The barrier is the cost of labour over materials, so using less material would cost more, and in time this may be overcome by more intelligent construction techniques, such as off-site modular construction with a high degree of control over material use.

4. Select less emitting materials. In theory, wood and stone could be used in place of steel and cement, and this might save some emissions. Both are less versatile materials, although wood is gaining popularity. However, there is significant uncertainty about the true emissions impact of using wood: although tree growth can be "carbon-neutral" – the carbon absorbed during growth equalling that released when the wood is burnt – most wood used in construction has been dried in a kiln, and the energy required to do this is sufficient to leave the emissions intensity of wooden construction similar to that using steel.

5. Reuse old material. This is an excellent idea – as old buildings are not worn out when they are replaced, the materials in them could be extracted by deconstruction instead of demolition, and re-used. This has been applied in a few cases for steel sections, although it is rare, but is currently difficult for concrete which is largely poured on site. Future designs could aid component re-use by using modular concrete components mechanically jointed on site, and using demountable shear studs between concrete and steel. However, the main barrier for now is to do with timing: if the old building can be taken down only when all contracts for its replacement have been signed, then the contractor must remove all the old material as rapidly as posssible, and this mitigates against slower deconstruction. A further barrier today is that old steel must be re-certified (re-tested) prior to re-use, which is currently costly, although this could be resolved with simple technology developments.

6. Reduce the emissions intensity of the materials by using renewable electricity supplies. For concrete this is difficult, as the chemical reaction of creating concrete releases emissions regardless of the energy supply used for heating. For steel it is possible, and in the USA structural steel is made by recycling old scrap. One barrier to

supplying structural steel by recycling in the UK is to control the quality of scrap sufficiently, in particular to avoid contamination by copper, to ensure the quality of the recycled material. This can be overcome by various means, but a wider barrier is that there is no excess supply of renewable electricity at present, and it is unlikely that we will ever have sufficient renewable supply to meet all needs, including expanded use in industry for more steel recycling.

3(b) Nuclear forces are much stronger than electromagnetic forces which dominate the formation of chemical bonds in fossil fuels. Gravity is much weaker than electromagnetism. Fuels must be transported to where they are used. A few tons of uranium ore can be concentrated to give typically a few tens of kg of nuclear fuel for a year. Several hundred tonnes of coal are needed for a power station. Several cubic kilometres are needed annually for a hydroelectricity plant.
Fossil fuels in liquid form dominate transport for compactness and convenience.
Coal and gas dominate heating/cooling and industrial applications, with nuclear able to back up the these providing base load electricity.
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4. (a)

- Deviations in frequency can be used as a measure of discrepancy between supply and demand as the latter will cause the rotating machines to either accelerate or decelerate. Therefore feedback mechanisms that adjust the power generated such that the frequency returns to its nominal value will equalize supply and demand at steady state.

  A main challenge in the implementation of such mechanisms are stability issues when aggressive feedback policies are used. These can lead to inter-area oscillations that propagate throughout the network and affect its efficient and reliable operation. The fact that the control policies are decentralized also makes their design a nontrivial task.

- “Optimal power flow” is an optimization problem solved regularly in a power system that determines how much power to produce by each generating unit in the network such that the aggregate generation cost is minimized while satisfying the various network constraints. This can be seen as a mechanism for balancing supply and demand at a slower time-scale (timescale of hours), whereas frequency control operates at a much faster time-scale (timescale of seconds/minutes).

- Demand-side management schemes whereby the demand is adjusted so as to equalize the supply. These can be implemented by means of dynamic pricing schemes that aim to shift demand to off-peak periods. Furthermore, smart appliances/loads could contribute to frequency control as a form of demand-side management at faster timescales, i.e. appliances detect deviations in frequency and adjust their duty cycle accordingly.

- Storage: Use storage facilities as a means of dealing deal with the fluctuations in supply from renewable generation, i.e. store the energy produced so as to use it at a later stage as needed.

4(b) This is an open ended question. However a good answer would be expected to cover the following points.

Scale: CCS is an industrial scale solution to reducing CO2 emissions from power stations. Very large amounts of electricity can be de-carbonised by fitting the CO2 separation equipment to power stations (large concentrated sources of CO2), so that the CO2 can be captured and stored. This contrasts with other renewable technologies which are often more distributed and therefore difficult to scale to cover entire industrial sectors.

Sectors: CCS cannot reduce emissions to zero since you can only really apply it to large concentrated sources of CO2. This is partly due to cost, but also because you need the infrastructure to transport and store the CO2. It would be difficult to apply it to the transport and domestic sector without first converting these sectors to use entirely electricity.

Cost: It is incorrect to say that you could ever have zero costs CCS. The power-stations are already running at as high an efficiency as possible and doing anything else can only ever add cost and complexity. There is the additional capital cost of building the capture unit, the transport system and capital equipment needed for injection into storage reservoirs. The CCS system imposes an energy penalty, which whilst it can be minimised, can never be zero. There is a minimum amount of separation work needed to remove the CO2 from the flue gases. Current technologies, such as amine scrubbing divert steam from the power cycle and uses this heat to provide this separation work. This particular system operates no where near the optimum as the heat it rejects cannot be easily recovered, so there is potential for some improvement. Once separated, there is also the energy cost required to compress the CO2 for transport and storage; little improvement in this can be expected. These energy penalties mean that more fuel must be combusted per unit of electricity generated, significantly reducing the net efficiency of power generation.

Policy/Society and permanence: The CO2 must be stored for generations, making it very difficult for the private sector to operate. Government could take responsibility for the stored CO2. The energy penalty is also a very large drag on an economy and hence CCS won't be implemented unless the leading world economies all agree to implement it. CCS can only every be a transitional solution since there is a finite amount of storage space for CO2, and fossil fuels would eventually run out. CCS adds only cost and generates no revenue, so won't be implemented without some form of government intervention (e.g. a carbon tax).

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