Glasgow Caledonian University

School of Engineering and Built Environment

Energy Resources, Generation and Utilisation

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Task Exercise No: 2

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Section 2: Energy balance and new energy sources

Having identified a realistic level of energy consumption that represents an equitable division of resources and offers reasonable growth for developing economies, we now have to consider if the primary energy demand can be supplied using fossil fuels, and, if not, whether there are alternative energy sources available.

Fossil fuel reserves

Proven reserves

Proved reserves are reserves from known locations that geological and engineering data demonstrate, with reasonable certainty, to be recoverable with current technological means and economic conditions. Undiscovered recoverable resources are quantities of fuel that are thought to exist in favourable geologic settings. These resources would be feasible to retrieve with existing technological means, although they may not be feasible to recover under current economic conditions.
[www.libraryindex.com/pages/163/Energy-Reserves-Oil-Gas-Coal-Uranium.html]

Fossil fuel is highly concentrated solar energy and the natural production process is so slow as to be considered non-renewable, hence the consumption of fossil fuel at the current rate is clearly unsustainable. When will it run out? This really depends on how much there is in the ground. To answer this question properly we have to factor in the difficulties of extraction.

The economical-to-extract reserves (**proven reserves**) and reserves known to exist but only theoretically recoverable with new technology (**probable reserves**) may differ wildly. As the conveniently-accessible reserves become depleted, the price of fuel will inevitably rise making reserves that are currently considered uneconomic, viable. Thus, the actual amount of fossil fuel is not a scientific but an economic question. There are also reserves deduced only from geological considerations but not yet found (**possible reserves**).

OPEC is an organisation made of countries that work together to control oil production and price. In 2006 OPEC reckoned that more than three-quarters of the world's oil reserves were located in OPEC countries (992 billion barrels in OPEC countries and 273 billion barrels in non-OPEC countries). Note that a 'barrel of oil' is 0.146 toe, and about 7 barrels are needed to get one tonne of oil equivalent energy. The proven oil reserves http://en.wikipedia.org/wiki/Oil_reserves in 2016 is about 200 Gtoe (though this relies on the countries reporting their reserves truthfully).

Extrapolating the data from the North Sea where the geology and the technology is well understood (2006: Proven - 479 Mtoe, Probable - 221 Mtoe, Possible - 370 Mtoe), the global figure of 200 Gtoe can safely be doubled to give an estimate of the total reserves, and applying Caspian Sea projections along with potential deep-sea wells could give a final total of 1,000 Gtoe available in the ground. There is also oil shale and oil sand which is discussed later. The proven coal reserves is 700 Gtoe, though the possible coal reserves is again likely to be many times greater than this (en.wikipedia.org/wiki/Coal). The proven natural gas reserves where Sub-Saharan **Africa** produced 1.69 trillion cubic feet of **natural gas** in 2011, accounting for 1% of total global **natural gas** production. Sub-Saharan **Africa** has 221.6

trillion cubic feet of proved **natural gas reserves**.
https://www.eia.gov/pressroom/presentations/howard_08012013.pdf

There may also be 1,000 Gtoe of peat accessible
https://www.worldenergy.org/

Crudely adding up all the energy sources, the total energy equivalent of the combined *proven* fossil fuel reserve is 2,080 Gtoe. We can estimate how long it would last on the assumption that energy consumption levels off at 2.0 toe *pc* by 2050 and that the world population peaks at 10.8 billion around 2080. The projection is shown in Fig. 2.1.

By this calculation, all the fossil fuel will be consumed by 2115. Of course, the *possible* reserves may be much greater, hence an upper time limit for the depletion of all fossil fuel is more likely around the year 2200.

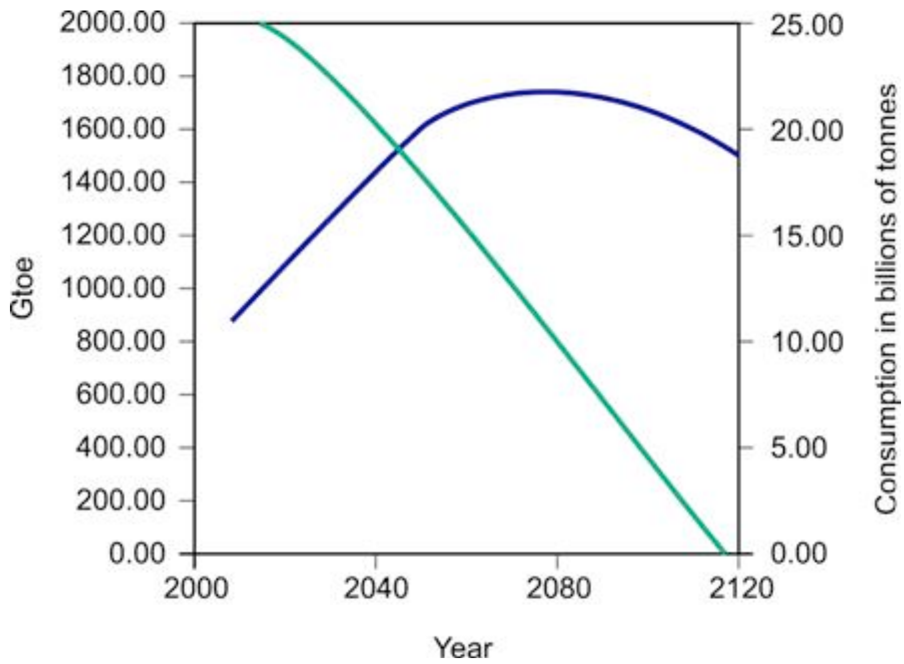

Figure 2.1: A projection of how long before the world runs out of fossil fuel - based on a population peaking at over 10 billion in 2050 each consuming 2 toe pc.

Task 2.1

The calculation made above where all fossil fuels were lumped together is not realistic. The transport sector places the greatest demands on energy supply and only oil will do. A more likely - and sooner - crisis point is associated with the depletion of oil. Based on current consumption figures of 4,000 Mtoe per annum, calculate how long the proven oil reserves will last. Repeat the calculation to include probable and possible oil reserves. Discuss the results.

The energy balance

The previous calculations indicated that if care is taken to limit consumption, the remaining oil will last for a long time. So where is the problem? To understand the concerns, it is necessary to work with a more sophisticated model that takes into account supply and demand (production and consumption). The production history of an oil well, or field, or even a country or a region, can be described by using the Hubbert curve (Fig. 2.2). This is similar to a normal distribution or bell curve.

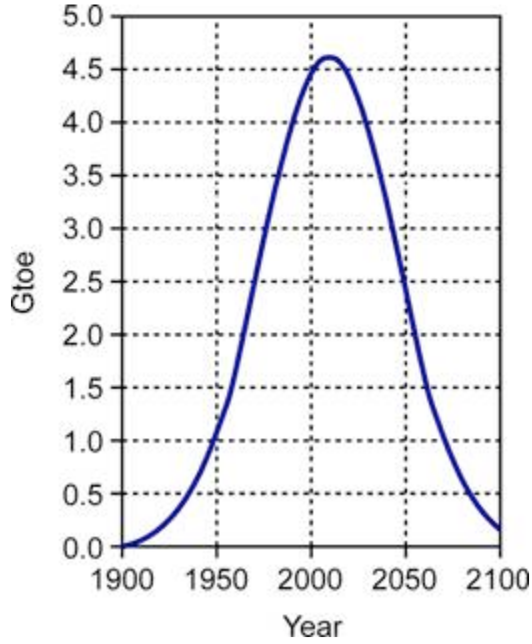

Figure 2.2: The Hubbert Curve. This shows how a resource will develop. Production rises as the technology is deployed then after a sharp peak, there is a rapid decline.

Once a field is ready for exploitation, production increases rapidly as oil wells are sunk and the distribution infrastructure is built up. Production peaks at a point referred to as **'peak oil'**, then steadily declines as the remaining oil becomes progressively harder to extract. Eventually, one toe of energy is required to extract one toe of oil when extraction is impractical regardless of the price of oil.

Fig. 2.3 traces the world production history and suggests we are already near the peak oil point. The more optimistic estimate by OPEC places peak oil at 2015 with a peak annual production of 5 Gtoe. If more oil is produced than is used, the excess is stored, but in the oil industry, the storage capacity is small and production tends to match consumption. If we assume consumption now at the annual rate of 4 Gtoe and increasing by between 0.25% and 1% annually, the supply and demand curves are plotted in Fig. 2.3.

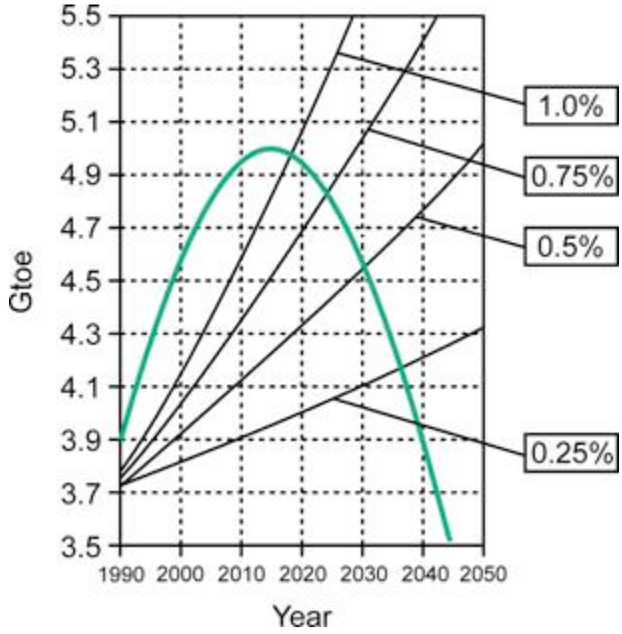

Figure 2.3: Points where demand exceeds supply for some plausible oil consumption growth scenarios.

It is clear that there will be a problem sometime between 2018 and 2035. This theory predicts a probable oil shortage in about 20 years with serious political and economic implications. What energy source can then be used for transportation? Forcing the wells in order to increase production is not an option; wells are then damaged and do not release all the oil potentially available. There is really no solution except to *reduce* oil consumption to delay the crisis point, or find an alternative power or fuel mechanism for vehicles. Oil can be synthesized by laboratory means or from coal, oil sand or oil shale, or produced from crops (biofuel). Reducing fuel use is certainly not the current trend and would be difficult to achieve.

However, if consumption is to be cut, we must look in detail at the energy balance and find where there is waste, and try to eliminate this.

Task 2.2

Do you think the views on the impending oil crisis presented by researchers at the University of Rochester and quoted at **www.unisci.com/stories/20012/0625012.htm** are valid?

New energy sources

We have seen there is the probability of an impending energy crisis arising from the excessive consumption of oil. One reaction might be to reduce consumption, but the most realistic long-term solution is to move to a diverse range of alternative and sustainable energy sources, sources that are replenished as least as fast as they are consumed.

It would be possible to rely for a while almost entirely on nuclear power, but the basic fuel, uranium-235, is not plentiful: The current estimate is only 100 years supply. Since this could be extended to 10,000 years by transforming the more plentiful and stable uranium-238 into plutonium in a fast-breeder reactor. Creating such a dangerous material as plutonium as well as the difficulty in dealing even with lower grade radioactive decay products makes this, for most people, a last-ditch solution, plan 'C'. Note that nuclear power can mitigate the effect of declining oil supplies even though the output of a nuclear reactor is electricity - it is possible to produce synthetic oil http://en.wikipedia.org/wiki/Synthetic_oil by a variety of processes assuming a plentiful supply of electricity.

Consequently, the transport sector would be required to change very little in this scenario. Another possibility is to rely on some new technology such as **fusion**, the process by which the Sun releases energy. The basic fuel is hydrogen, plentiful in water, but though experimental systems have been constructed, commercial exploitation is 30 to 50 years away. A breakthrough in solar cell technology is another possibility.

Potentially the most attractive alternative energy sources are wind power, wave power, tidal power, hydroelectricity, solar power, geothermal energy and biomass production. These are **renewable energy sources**, and all could be exploited to produce energy from natural processes in real time.

The pros and cons of each method will be considered in detail in later sections, but we can make some general points at this stage. The cost of energy generation from renewable energy is greater than using fossil fuel. However the balance is liable to shift as the cost of fossil fuels rise.

The other problem is that we have limited control over natural processes and it becomes a problem matching supply with demand. It is important to balance production and consumption and if they cannot be matched, a storage mechanism is required to act as a buffer to maintain continuity of supply at times when generation is inadequate. **Pumped-storage** is one possibility, but another approach is to produce hydrogen gas by **electrolysis**.

The hydrogen is stored until required. It may be burnt for heat or converted directly to electricity using a **fuel cell** or used to run an adapted vehicle. This is one vision of the hydrogen economy http://en.wikipedia.org/wiki/Hydrogen_economy

Hydrogen in this context is an **energy carrier**, not an energy source, because hydrogen is merely storing energy produced by other means. Whilst using hydrogen for energy storage overall is potentially 80-90% efficient, fuel cells and electrolysers now are respectively only 50% and 75% efficient.

Task 2.3

Compare the efficiency of using electricity to drive an electric car and drive a hydrogen vehicle. Note that a battery and electric motor are about 90% energy efficient. A combustion engine is about 10-25% efficient.

Policies on alternative energy

We will later consider in detail environmental aspects of fossil fuels consumption and the installation of renewable energy systems, but at this stage it is useful to provide an overview of the government and local policies on energy generation and consumption.

It is widely accepted that the reduction of non-renewable energy use is a critical objective, if only because the limited fossil fuel supply. This is promoted at the highest level by the **Kyoto protocol**, an agreement ratified by 174 countries on 11th December 1997 to control carbon dioxide emissions. The basic target for EU countries is the equivalent to the reduction of fossil fuel energy consumption to 8% below the 1990 level during the period up to 2012.

A consequence of this is a drive by government to promote the construction and installation of both small-scale and large-scale renewable energy systems. There are several problems though. As pointed out earlier, the generation cost of energy by renewable means is not competitive with generation by fossil fuels (or nuclear). Consequently government subsidies are needed, but because the technologies are relatively new, the real costs are not accurately known hence, even with grants and subsidies, there are unresolved economic issues.

Another problem is that the technology of renewable energy systems is not sufficiently developed. For example, fuel cells and electrolysers have poor efficiencies in comparison with established low-capacity storage technologies, and there is still no effective device that will exploit the enormous amount of energy in ocean waves. Prototype systems that have been effective in extracting energy are vulnerable to damage under storm conditions.

The third problem is that renewable energy devices have a significant effect on the environment and often come up against competing interests. This is especially true of large wind farms where there are obvious environmental and social conflicts. It is very difficult to objectively weigh up the advantages and disadvantages in cases like these, with the result that an assessment of a scheme may be highly subjective with competing parties entrenched in their views holding up developments. This is quite right of course, and it should be no other way, as the views of affected parties must be embedded as a critical element within the decision-making process, but the result is that it is hard for national energy-saving targets to be achieved.

Even on a small scale, the installation of domestic renewable energy systems are *currently* subject to normal planning laws and the same degree of scrutiny.

For these reasons, the wide-scale adoption of renewable energy is a slow process even in terms of the remaining lifetime of the fossil fuel resource. However, as the cost of energy from fossil fuel rises, one would expect normal economic forces to accelerate the shift towards renewable energy.

Task 2.4

Investigate the grants and regulations in your own area / country concerning the installation of small-scale renewable energy systems

www.energysavingtrust.org.uk,

www.scotland.gov.uk/Topics/Environment

https://www.usaid.gov/powerafrica/newsletter/dec2014/smarter-power-in-africa

Notes

Working in scientific notation

Many of the calculations related to energy involve large numbers. Numbers are conveniently shortened using prefixes such as G, M or k, but these are best used to represent a conclusion or final result. It is not convenient to perform calculations using prefixes. This is illustrated below where we have to convert 11,000 Gtoe per year, the current world primary energy consumption to the average amount of energy used per second (the mean power). There are 31.5 Ms (s being short for seconds) in one year and 1 toe is 42 GJ.

To complete the calculation, you would have to have known that giga times giga divided by mega was tera, and that tera times 1,000 is peta. Clearly this is unsatisfactory.

It is better to express numbers in scientific notation (or standard form). A number is expressed as a **mantissa** and an **exponent**, a power of 10 which indicates the number of zeros to the place we move the decimal point, or the number of places the decimal point was moved to the left. This is illustrated below.

The advantage of using this notation is that when multiplying two numbers the mantissas are multiplied and the exponents are added. A correction may have to be applied to bring the mantissa back to a number between 1 and 10. If mantissas are expressed to one decimal place eg 1.3, then the result of the multiplication should also be rounded to 1 decimal place (eg 1.3 x 1.3 ≈ 1.7).

If one number in scientific notation is divided by another, divide the mantissa and subtract the exponents. If the resulting exponent is 0, the 10^0 is just the same as 1. If the exponent is negative, the result is a fraction: 10^{-1} is the same as $1/10^1$ which is 0.1.

In scientific notation,

11,000 G = 11,000,000,000,000
= 1.1×10^{13}

Mantissa — Exponent

42 G = 42,000,000,000
= 4.2×10^{10}

31,5 M = 31,500,000
= 3.15×10^{7}

11,000 G x 42 G =
= $1.1 \times 10^{13} \times 4.2 \times 10^{10}$
= 4.6×10^{23}

11,000 G x 42 G / 31. 5 M
= $4.6 \times 10^{23} / 3.15 \times 10^{7}$
= 1.5×10^{16}

Thus

$P = 1.5 \times 10^{16}$ W

Basic engine thermodynamics

The method of obtaining electricity from fossil fuel is usually by burning the material and using the heat produced to perform work, in this case to turn a generator. However thermal power plants are not able to convert all the energy in the original fuel source (the primary energy) into useful work. The efficiency of a typical power plant is about 36% (25% for a car engine), and although heat recovery methods can be applied to use some of the waste heat, this represents very poor efficiency, and is the major cause to the current high level of energy consumption.

Unfortunately the waste is largely unavoidable because machines that rely on a temperature difference to do work are subject to the constraints imposed by the **laws of thermodynamics**.

The maximum possible efficiency is achieved by going through an ideal engine process called a **Carnot Cycle**. The efficiency is then calculated using the equation shown on the left. The Carnot cycle cannot be achieved in practice because of real effects like friction neglected in the theoretical cycle.

A **fuel cell** does not burn its hydrogen fuel and is not subject to these limits.

Maximum efficiency = 1 - exhaust temperature / working temperature
= 1 - 473 / 1073
= 55.9%

The Carnot cycle for an engine where the fuel burns at 800 ^{o}C and the exhaust gas has a temperature of 200 ^{o}C. The temperatures must be converted to kelvin degrees (K) by adding 273.

Summary

The world is heavily reliant on hydrocarbons to provide energy. We have seen that to continue with this reliance is unsustainable in the long term. In the short term, the huge dependence on oil and the enormous rate at which it is consumed presents the most pressing problem. It is apparent that alternative and sustainable energy sources need to be developed for transportation as a matter of urgency.

The crisis can be delayed by reducing consumption through efficiency measures and minimising waste, but not averted.