School of Engineering and Built Environment

Energy Resources, Generation and Utilisation

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Task Exercise No: 3

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Section 3: Global warming and carbon sequestration

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Section 3: Global warming and carbon sequestration

In the previous section we identified a need to develop alternative energy sources because the dwindling fossil fuel reserves may soon result in problems matching supply with demand. In this section we look at the environmental effects and global consequences of fossil fuel consumption and present this as another argument for moving towards sustainable power generation.

The greenhouse effect

The conventional greenhouse effect occurs because glass transmits visible light readily but is a relatively poor conductor of heat. On a sunny day, light enters the glasshouse and is absorbed by the floor. The floor warms up and re-radiates the energy as heat (infrared radiation). The heat radiation cannot easily escape through the glass, consequently the glasshouse heats up.

Something similar (but not identical) happens on the Earth where the atmosphere acts as blanket over the surface. The sun radiates an energy **spectrum** or energy range with the peak output at the electromagnetic frequency corresponding to green light. Visible light passes largely unimpeded through the atmosphere and reaches the surface where the energy is absorbed by the soil, water, buildings, plants etc. As a consequence, the surface heats up after which energy is re-emitted upwards as longer wavelength infrared radiation (just as in the glasshouse).

However, certain gases in the atmosphere though transparent to light can absorb heat very effectively, notably water vapour, carbon dioxide, methane, and ozone. The heat leaving the surface that would otherwise escape into space is absorbed by these molecules. Since a molecule will only retain absorbed energy for a short time (because of spontaneous emission), after which the captured energy is released. The important point is that the energy is re-radiated in every direction, including downwards - it does not just continue its journey upwards through the atmosphere. It will eventually escape into space, but only after millions of absorptions and re-emission events. The energy radiated from the surface is therefore “held up” and warms the atmosphere.

This is like trying to move through a crowd of people going in all directions. You are eventually going to get through (probably after many 'collisions') but you will be held up for some time.

As a consequence of this effect, the Earth is warmer than it would be, were there no water or carbon dioxide in the atmosphere. This is the atmospheric greenhouse effect and the temperature elevation is strongly dependent on the concentration of water and carbon dioxide in the atmosphere. The average temperature on the surface of the Earth is 15^{o}C: Without the greenhouse effect, the temperature on the surface would be -18^{o}C or 'snowball Earth'. With too much greenhouse gas, we could have a situation similar to that on our sister planet Venus where the surface temperature is 450^{o}C because of its runaway greenhouse effect. This is a vision of 'fireball Earth'.

Task 3.1

When a greenhouse floor absorbs light, why is the energy re-radiated, and why is it re-radiated as heat rather than as visible light?

HINT: Compare it with the way a large drop of water falling on the ground is split into smaller drops on impact; or how the mechanical energy supplied by the engine of a car ultimately ends up as heat due to friction with air or the road surface.

Carbon dioxide

Carbon dioxide (CO_2) is a molecule formed when two oxygen atoms bond to one carbon atom. It is produced by heating carbon or its compounds to a high temperature in the presence of oxygen. The reaction releases energy and the CO_2 gas normally escapes into the atmosphere.

Plants extract CO_2 from the air and combine it with water to form organic compounds. Energy is required to 'fix' CO_2 (take it out of the atmosphere) and this is supplied by sunlight in the photosynthesis process. If the plant material is consumed (by animals or bacteria for example) the CO_2 is released back into the air as a by-product of respiration. Dead plant material may instead sink into the soil and eventually (through pressure and over time) form rock such as coal. Burning these fossil fuels releases the CO_2 back into the atmosphere. The constant recycling of carbon through the biosphere is referred to as the **carbon cycle**.

Natural processes maintain the level of CO_2 in the atmosphere at about 280 parts per million (ppm). You should appreciate there is very little CO_2 in the air - there are about 600 oxygen molecules for every single carbon dioxide molecule.

Since the industrial revolution, human activity, primarily the burning of fossil fuels in huge quantities, has changed the balance and the present concentration of CO_2 is up to 380 ppm. It is quite difficult to predict how the level will change in the future because there are many different mechanisms at work which remove CO_2 from the air, and all are sensitive to the concentration. Trying to model the process and make future predictions is difficult. Climate modellers are sure the concentration of CO_2 will continue to rise if current fossil fuel consumption trends continue, but it is less certain by how much.

If we were to globally stop burning fossil fuels and allow forests and vegetation to regenerate, natural processes will bring the concentration back to the equilibrium pre-industrial levels of 280 ppm. However one should be aware there may exist a 'tipping point' beyond which recovery is impossible.

An analogy is stretching a rubber band - when the force is removed, the band will return to its original length, but if too great a force is applied the band will break. This is the transition from a reversible to an irreversible process.

To find the mass of CO_2 in the atmosphere in kg, multiply the concentration (in ppm) by 7.8×10^{12}. The current mass of CO_2 in the atmosphere is $7.8 \times 380 \times 10^{12}$ kg = 3.0×10^{15} kg.

You should note that one atom of carbon weighs 12 atomic units, but one molecule of CO_2 weighs 44 units (because of the two extra oxygen atoms weighing 16 units each) hence the atmosphere contains $12 / 44 \times 3.0 \times 10^{15}$ kg = 8.2×10^{14} kg of carbon. This is 820,000 million tonnes. We are now consuming annually 8,000 million tonnes of carbon from fossil fuel which is adding around 1% to the total in the atmosphere.
[en.wikipedia.org/wiki/Image: Global_Carbon_Emission_by_Type.png]

Task 3.2

Does all the carbon being burnt each year really accumulate in the atmosphere as implied in the text above, or are there processes that respond to the raised carbon dioxide levels by removing some of the material? Use date from the website below to investigate the above.

Open cdiac.ornl.gov/trends/emis/tre_glob.html -> Click on Digital Data (ASCII Comma Delimited) -> Open in Excel -> Delete columns C to G, Delete rows 2 to 208-> Open **cdiac.ornl.gov/ftp/trends/co2/maunaloa.co2** -> Copy the block of numbers to the rectangle C2:Q48 -> Delete rows C to P, Delete row 2 -> Change column headings.

Effect on global temperature and climate

We have seen that burning fossil fuel (and to an extent deforestation) has increased atmospheric CO_2 concentration. Using current projections, the concentration may eventually rise to 600 ppm by 2100. Since CO_2 is a greenhouse gas, the rising concentration will enhance the greenhouse effect and cause a global temperature increase. The effect is magnified because there will be more water vapour in the atmosphere of a warmer Earth from increased evaporation, and water vapour is itself a greenhouse gas and can cause further warming (this is **positive feedback**). Burning fossil fuel therefore has the potential to change the environment. To understand the global consequences of fossil fuel consumption there are two critical questions to answer:

(i) What is the exact relationship between CO_2 concentration and temperature?
(ii) What is the effect of an overall temperature rise on climate?

We have already seen a significant rise from 280 ppm to 380 ppm over 100 years so there is already some data available on how a rise in concentration affects temperature. Though not conclusively proven, there is strong evidence for a strong link between a global temperature rise and dramatic climate change.

Global mean temperature has fluctuated over the past 2000 years, rising by about 0.5 oC over the last 50 years. This appears to follow the rise in CO_2 concentration. However, this is the subject of some debate. A robust and provocative criticism by Christopher Monckton of the Sunday Telegraph on 05/11/2006 suggests that data is being manipulated by **selection bias**. He makes the (dubious?) point that deliberately exaggerating the threats from environmental change ('biblical droughts') is used to justify a 'world government' to deal with global issues.

If there is bias in the data presentation, the motive is just as likely to be concern for the planet.

With due regard to the counter arguments, the most probable explanation for the recent temperature rise, ie '**global warming**', is rising CO_2 levels. Many models assume a linear relationship and predict the future temperature rise accordingly. Some models predict a rise of as much as 5 oC over the next century. What effect would such a temperature rise have on the climate? Again the models are very complex though a number of worst-case scenarios have emerged. It is predicted that most of the polar ice will melt adding to global warming because the ice plays the important role of reflecting some of the incident solar radiation.

The melting ice will result in rising sea levels making low-lying coastal regions vulnerable to flooding. The increased amount of evaporation will make the weather much warmer but wetter. Dynamical processes such as the Gulf Stream will also be affected.

Extreme weather events such as hurricanes and droughts are expected to become more common. Look at www.ukcip.org.uk to see how regions in the UK are thought likely to become affected.

Task 3. 3

Determine if the global temperature rise over the last 50 years is related to the carbon dioxide concentration. Does the activity of the sun as indicated by the number of sunspots per year affect the temperature [data available from https://www.ngdc.noaa.gov/stp/solar/solardataservices.html]?

Mitigating actions

It is likely that the world climate will change significantly over this century as a result of burning fossil fuels. One option is to do nothing and rely on market forces and our ability to adapt to change to make a smooth transition to an altered world (remember the hype about the 'millennium bug'?).

However ecosystems may be devastated and flora and fauna will be threatened because animals cannot adapt to rapid environmental change, and it is likely that not all people will be affected to the same extent - the poorest areas of the world are likely to suffer the most. A more responsible response to threatened climate change is to take reasonable steps now to reduce the rate at which we put CO_2 into the atmosphere. This can be achieved by improving efficiency in energy end-use and eliminating casual waste, generating energy by renewable means, improving conventional generation and distribution techniques, technological improvements and innovation, and perhaps most difficult, lifestyle changes to reduce our individual carbon footprint. Table 3.1 lists possible actions.

Table 3.1: Mitigating actions (from 'A plan to keep carbon in check' in "Energy Solutions for a Sustainable Future", Scientific American, Special Issue September 2006).

End-user efficiency and conservation	**Run cars for 5,000 miles pa instead of 10,000 miles**
	Increase car fuel economy
	Cut electricity use by 25%
Power generation	Raise coal power plant efficiency from 40 to 60%
	Replace coal power plants with gas plants
Carbon capture and storage (CSS)	Install CSS at all coal plants that produce hydrogen for vehicles
	Install CSS at all coal plants
	Install CSS at all syngas plants
Alternative energy	Increase nuclear output capacity
	Increase wind power
	Increase solar power
	Wind power to hydrogen
	Create biofuels
Agriculture and forestry	Expand conservation tillage
	Stop deforestation

We have already seen that energy is used very inefficiently and there is vast scope for improving efficiency without even impacting on economic performance. The term **mitigation** is used in this context; it means taking action to avoid a predicted but undesirable outcome. But significant mitigation as a nation tries to meet agreed worldwide targets will inevitably affect GDP. It is therefore uncertain whether the economic cost of mitigating action is greater or less than the costs associated with adaptation to climate change.

And it is apparent even now that international cooperation/control is essential to make this work. If for example some countries reduce fossil fuel consumption, the commodity price will fall and countries that are not part of an agreement may therefore consume more, with no net world reduction. The Kyoto Agreement is an attempt to mobilise global action.

Undoubtedly the greatest potential for carbon saving is at the point of electricity generation because a lot of fossil fuel is consumed at a specific location. It is therefore feasible to install **carbon sequestration** technology. This means trapping the carbon dioxide from combustion and binding it in some way to prevent release into the atmosphere. There are a variety of methods possible, but all involve additional cost which must be added onto the price of electricity for the consumer. Geological sequestration involves injecting CO_2 in underground reservoirs such as depleted gas and oil wells, and coal mines. It is also possible to use hydroxides that combine with CO_2 to form stable carbonates.

CO_2 can also be forcibly dissolved in water, but carbonic acid then forms (H_2CO_3) in a 1%:99% equilibrium, and can affect an ocean ecosystem by significantly increasing the acidity. This effect will occur naturally in the world's oceans as the atmospheric carbon dioxide level rises and is an example of **natural sequestration**.

Task 3.4

Make a list of what actions could be taken to reduce energy use on a personal level. In each case, state to what extent this would impact on your standard of living and/or quality of life.

With reference to your own area, do you think people will return to a simpler lifestyle characteristic of a generation ago, voluntarily or through economic necessity?

Can you find anything positive about the threat of global warming?

Notes

Composition of the atmosphere

The atmosphere is a mixture of non-interacting gases. The density falls steadily with height. Air is about 1,000 times less dense than a solid material: Nevertheless, a column of air with a base area of 1 m^2 exerts the same force on the surface as a 10 tonne mass.

The main constituents of the atmosphere are:

Gas	**Fraction by volume**	**Molecular weight**
Nitrogen (N_2)	78.08 %	28
Oxygen (O_2)	20.94 %	32
Argon (Ar)	0.93 %	18
Carbon dioxide (CO_2) (= 380 parts per million)	0. 038 %	44
Water vapour (H_2O)	≈ 1 %	18
Other (including methane, CH_4, and ozone, O_3)	0.002 %	

The CO_2 concentration is very low but the molecule is very effective at absorbing infrared radiation. CO_2 is heavier than air and has a slight tendency to sink to ground level where it is used by plants for photosynthesis. The reason is that the bonding of these molecules cause a positive charge to form on one part of the molecule and a negative charge on another. The molecular vibration of this type of polarised molecule is able to interact with electromagnetic radiation.

The contribution to the 'greenhouse effect' described in the text from water vapour in the atmosphere is approximately 65%, 25% from carbon dioxide, 7% from methane and 3% from ozone. See Wikipedia Greenhouse gas for more detailed information.
[https://en.wikipedia.org/wiki/Greenhouse_gas]