THE CARBON CYCLE – towards becoming carbon neutral

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CARBON IN OUR WORLD

Organic Chemistry and Hydrocarbons

For more than 200 years, chemists have divided materials into two categories. Those that trace back to minerals are called inorganic and those isolated from plants and animals were classified as organic. Early chemists believed that organic compounds were fundamentally different because they contained a vital force that was only found in living systems. In fact, the common elements in all organic compounds are hydrogen and carbon. Plant and animal materials also contain oxygen, e.g. carbohydrates. When plant and animal remains are buried and subjected to geological processes the oxygen is removed and they become fossil fuels i.e. hydrocarbons.

When a hydrocarbon burns in air, it forms carbon dioxide (CO_2) and water vapour and releases energy. Likewise when plants and animals respire naturally in air carbohydrates are converted to CO_2 and water vapour and energy is released to enable the organism to live. When living things die and decay in air CO_2 is produced and the energy is lost.

"The quantities of carbon transferred are huge, but because the natural cycle is normally balanced the net transfer or flux is relatively small"

The opposite reaction is photosynthesis in which CO_2 from air and water in the atmosphere and oceans is converted to carbohydrates. This process requires energy which is provided by sunlight. The natural carbon cycle of growth and decay of plant materials on the surface of the earth is balanced. A net increase in global atmospheric CO_2 occurs in the autumn as plants die back and there is a net reduction in the spring as new growth draws CO_2 from the atmosphere via photosynthesis.

Fossil fuels

Coal, oil and gas that we call fossil fuels – because they're compressed by rock like other fossils – are just stored carbon, or ancient sunlight captured by long dead forests and other plant material. These forests were turned into fossil fuels between 150 million and 90 million years ago, so they are prehistoric. Through the action of heat and pressure over millions of centuries, they were chemically changed by processes into coal, oil, and natural gas. Likewise algae captured in sediments of seas became converted to deposits of oil and gas. Both the coal and oil-making geological processes can produce the simplest hydrocarbon, methane (CH_4) which can be trapped in porous rock as deposits of natural gas.

Because fossil fuels took so long to form, they cannot be replaced. That is why they are also called non-renewable resources. But over the last 200 years, hydrocarbons derived from fossil fuels have become not only the prime fuel source, but also the feedstock for a petrochemical industry that provides everything from plastics to farm fertiliser, from pesticides to textiles, from medicines to soap and food items.

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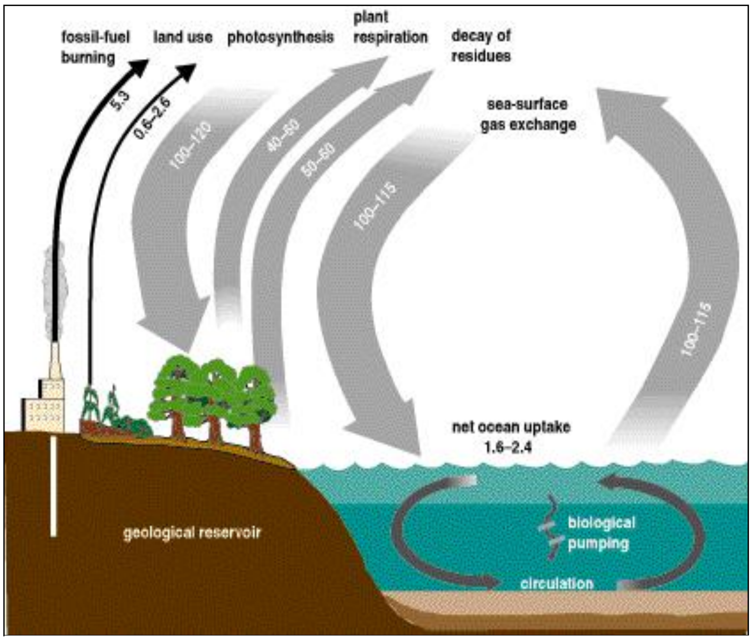
THE GLOBAL CARBON CYCLE

Sources and sinks

The diagram below of annual carbon fluxes shows that there is a natural carbon cycle in which plant photosynthesis is balanced by plant respiration and decay or residues. Carbon moves around in our world from sources like animals and plants and their decomposition, or the burning or combustion of carbon fuels to sinks such as vegetation, soils or the oceans – the largest sink of all.
The quantities of carbon transferred are huge – the figures are in billions of tonnes (gigatonnes) of carbon[1] (GtC), but because the natural cycle is normally balanced the net transfer or flux is relatively small. However onto a net natural flux of say 3 billion tonnes per year, we have been adding another 8 billion tonnes per year from human impacts such as burning fossil fuels.

Combustion



THE GLOBAL CARBON CYCLE

Figures are billions of tonnes of carbon (GtC)

Burning fossil fuels – or non-renewables – in what are often very inefficient ways has been putting back into the atmosphere, or the carbon cycle, millions of years of sequestered carbon, over a relatively short period of 150 years or so. It's no surprise that carbon dioxide levels are increasing, even though the oceans have probably soaked up about half of that increase. The present level of CO_2 in the atmosphere is already over 400 parts per million (ppm). That may not sound a lot, but for many years before the industrial revolution in 1850 the figure was only 280 ppm. Climate scientists estimate that a 'safe level' – that would allow global warming to stay below 2^{o}C – is 350 ppm but we are already above that now..

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but the overall quantity of reserves remains basically unchanged.

The allure of fossil fuels

The attraction of fossil fuels is in the high concentration of energy in a small weight and volume. For example a barrel of oil equivalent contains energy of 6.1 Gigajoules (GJ) or 1,700 kWh. That's enough energy to run a 2 kilowatt household heater for a month flat out. A day's heavy manual labour equals 10 million joules, so a barrel of oil equals 600 days labour. A litre of petrol is still equivalent to more than two days labour.

All the alternatives for generating and particularly storing energy from variable resources like wind or hydro are much more difficult. Electricity must be stored in batteries, or as potential energy by pumping water up to a higher reservoir. Alternatively energy can be stored as high pressure gas which comes with large weight penalties because of the strong metal cylinders necessary, whereas liquid petroleum fuels can use light metal or plastic containers.

[1] One kg of carbon equals 4.17 kg of CO_2. See http://ecometrica.com/white-papers/greenhouse-gases-co2-co2e-and-carbon-what-do-all-these-terms-mean/

FOSSIL FUELS & SUSTAINABILITY

Sustainability

The most widely known definition of sustainability still comes from "Our Common Future", the Brundtland report in 1987. It says that sustainable development is that which "meets the needs of the present without compromising the ability of future generations to meet their own needs." Another way of putting it is that sustainability is living in such a way that it can be carried on indefinitely.

Yet we are using fossil fuels as though they were inexhaustible rather than finite resources, meeting our wants rather than our needs in such a way that our children and grandchildren will wonder how we ever managed to burn up three trillion barrels of oil in a little under 200 years.

At the moment total global human power usage is around 20 Terawatts (TW), of which less than 5 TW (which includes hydroelectric, wind, biomass and wood) is renewable. The remaining 15 TW comes from fossil fuels. Yet the potential already exists in the world to harvest at least 16 TW from renewable sources such as the sun, hot rocks, and wind. Essentially we are living beyond our energy means by burning fossil fuels instead of using renewable sources – which is like living on a legacy without having to worry about when it runs out.[2]

Peak oil (& gas & coal)

The concept of "peak oil" was first realized by M. King Hubbard of Shell back in 1949 and is by now well known. It is the point in time when the maximum rate of petroleum extraction in a region is reached. After that the rate of production gradually reduces, and prices increase until supply equals demand. It's not about running out of oil. Although there is some debate it is generally thought that global peak oil occurred in the early 2000s. It's not just the size of the tank which matters, but the size of the tap. When the tap is full on and still not meeting demand then the price rises. New techniques like 'fracking' may delay or extend the peak, but the overall quantity of reserves remains basically unchanged. The current fall in oil and coal prices is a result of resource owners trying to realise their assets before they lose value, rather than any recognition of their scarcity value.

What is happening with oil will also happen with gas and coal and even uranium. So we have known for 60 years what would happen to finite resources.

Relying on technology to pull us out of a hole is a bit like gambling – wishing and hoping for a magic bullet is like waiting for a win on the Lottery.

Energy out over energy in

Back in the 1850s when oil was first commercialised, the ratio of 'energy out' (from refined products) over 'energy in' (the total energy cost of production) was around 100:1. Now, it has declined to somewhere between 10 and 20. Even for renewable fuels such as ethanol the ratio depends very much on the feedstock and the process, and can be as low as 1 or 2, rather than the often quoted ratio of 8 for Brazilian sugar cane ethanol. When the ratio falls below one, we are exspending more energy on production than the energy we get back, which makes no sense, even though it has a convenience factor, such as a liquid transport fuel. But it is unsustainable in the long term.

TRANSITIONING TO SUSTAINABLE ENERGY

We are now in uncharted waters. We have never been though a situation where something so crucial to the way we live, to our whole society as we have created it, will become so expensive and scarce that we will have to change the way we do things. There are two issues – carbon emissions to the atmosphere from burning fossil fuels, and the declining quantity of fossil fuels that remain and the increasing cost and environmental damage to recover them. The recent Paris conference on

[2] 'Beyond Smoke and Mirrors: Climate Change and Energy in the 21st Century', Burton Richter, Cambridge University Press 2014.

climate change (COP21) was a significant step forward to international agreement about carbon or greenhouse gas emissions but is non-binding and still has to be ratified by all the signatories.[3]

Bill McKibben[4] co-founder of 350.org promoted the idea of a carbon budget that humanity needed to stay within of roughly 560 more gigatons of carbon dioxide into the atmosphere by midcentury and still have some reasonable hope of staying below 2^{o}C global warming. Newer informaton taking into account more variables[5] indicates that "a carbon budget of 1,000 Gt of CO_2 from 2011 to give a 66% chance of staying under 2C. Subtract the roughly 150 Gt we've already burned since then and that leaves about 850 Gt for all sources of $CO_{2,}$ and we might have as little as 300 GT left for fossil fuels – which would be closer to a 10th of proven reserves."

To make goods requires energy. There is an energy payback equation for energy producing power plants, so that over the life cycle they should return far more energy than was initially invested. Even to make the transition to a sustainable world based on renewable energy sources such as solar, will require a huge investment of our remaining fossil fuels. It is time to begin prioritising how that might work so that the finite usable resource of fossil fuels is reserved for the highest and best use – lubricants, feedstocks for synthetic material and medicines, rather than as transport or power generation fuels.

Economists and the meaning of finite

Apart from a few economists like Herman Daly, the finite nature of a resource is often not acknowledged, or not considered as relevant. Economists do believe that the price of a resource is the sum of the extraction cost plus a scarcity rent, which acknowledges that a resource is in short supply. But complicated theories don't always deal with the realities that common sense tells us. For example in the past in the US oil depletion levies were used to fund more exploration, rather than used to find alternatives. Yet when the oil shocks hit in the 70s, and billions of dollars were suddenly found for research into alternatives, the demand curves at the time show how demand fell in response to measures like improving energy efficiency. Yet when the price of oil fell again, the research effort dropped away and demand again took off.

Will engineers discover a 'magic bullet'? Relying on technology to pull us out of a hole is a bit like gambling – wishing and hoping for a magic bullet is like waiting for a win on the Lottery. Some technologies may deliver solutions *in the longer term or they might not. For example* fusion power was the great hope back in the early 60s. Endless cheap power from the same reaction that fuels the sun. But 50 years later it's still "just around the corner". Similarly nanotechnology, ocean power, hot rock technology all may offer some salvation. But we seem to be wedded to coal to liquids, carbon capture and storage and other developments of conventional technologies that will allow us to carry on business as usual. Essentially for the transition period over the next 20 years, all the tools that will really help are already available.

WE CAN CHANGE OUR BEHAVIOUR

The price trend is up

The price of oil may fluctuate, and even fall as it has done recently but the inexorable trend is up. Is this just a speculator's "bubble" or a desperate attempt for fossil fuel companies to protect their bakance sheets? Futures markets may add to the fluctuations, but will not affect the basic long term trend.

Politicians are gradually coming to accept global warming – a subset of the use of fossil fuels – without necessarily understanding about "peak oil". Yet there has been a change in politicians'

[3] http://unf ccc.int/paris_agreement/items/9485.php

[4] "Do the Math" Bill McGibben, Rolling Stone, August 2012

[5] https://www.theguardian.com/environment/keep-it-in-the-ground-blog/2015/mar/25/what-numbers-tell-about-how-much-fossil-fuel-reserves-cant-burn

movement towards concepts such as emissions trading – which is largely ineffective except as a tax on emissions − and more carbon neutral electricity. The hard one to tackle is transport, which still eats up half of our energy. Electric cars may help, with countries such as New Zealand where the electricity is already 80% renewable, but globally it is still a challenge

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Invest in the transition to sustainability

With threats come opportunities, and although it might seem like a cost to invest in research and development to make us sustainable, it will pay off in the long run. When energy is renewable, usually the cost of the fuel is low or zero. If we aim for durability and low input energy, then we are investing in moving towards a low energy, low carbon and sustainable future. The quality of life is not dependent on people having more goods. It is about having the benefits of using goods that are durable and useful enough to improve the quality of life.

People want reasonably priced mobility on demand, not necessarily cars. People want communications, not necessarily a new cellphone every year. In many ways people want connectivity rather than cars. Maybe smartphones are a better alternative. If we focused on people's real needs instead of just wants or marketing strategies, on service before innovation, then life could be at least as good, or better than now

Live and buy local, but think global

The 'global village' and 'globalisation' were interesting ideas, when it seemed we could fly or ship things around the world at prices that didn't increase at the same rate as inflation. We were able to export our problems, such as pollution and high local wages to other very low priced economies – mainly due to low labour rates. But in the end the cost of fuel will render those efforts worthless. The internet may be the only surviving remnant of the global village. Having communities that are based on getting their goods and services from within a 200 kilometre radius will be the sustainable way of life for the future.

SUMMARY

Carbon and the carbon cycle is a natural part of life.

- Burning fossil fuels adds a 'tipping point' to natural cycles that we can't afford to risk.
- Becoming carbon neutral means markedly decreasing the use of fossil fuels – starting now.
- Sustainability is being able to do the things that sustain life forever – not just till oil becomes too expensive.
- Transition means increasing the use of renewables (primarily solar based) and recycling (waste minimisation − no more diluting our resources with the throwaway economy)
- Technology will help, but it cannot fight physics such as the laws of thermodynamics.
- We will have to change the way we live and do things. More durability in goods, more local produce, less pointless shipping of similar goods around the world.

A FEW USEFUL LINKS

http://esr.org.nz/

The web site of Engineers for Social Responsibility – a New Zealand based group.

http://www.350.org/

350 (ppm CO_2) is the most important number on the planet…..

http://www.theoildrum.com/

Discussions about energy and our future

http://www.earthcharter.org/

...is a declaration of fundamental principles for building a just, sustainable, and peaceful global society for the 21st century.

http://www.ucsusa.org/global_warming

Union of Concerned Scientists global warming page

This paper was peer reviewed by Dr David Painter, Consultant in Water Resources and Sustainable Management; Dr Hugh Thorpe, Research Fellow, University of Canterbury; and Steve Goldthorpe, Energy Analyst.

While the reviewers have provided comment on drafts of this article, they do not necessarily endorse it in its final form. The author is solely responsible for any errors and judgements that may exist in the published article.

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