Geo Factsheet

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Introduction: The carbon cycle

What is carbon and why is it important?

The element carbon is the most important out of all the elements that make up living matter. Carbon is an element with a simple atomic structure that has the ability to bond with other atoms of carbon and also atoms of other elements to create complex molecules which are the basis of all living matter. Examples are proteins, simple sugars, carbohydrates and fats. These carbon-based compounds are the building blocks of life.

Carbon compounds are found in the oceans, soils, crust and atmosphere which form the stores within the carbon cycle, linked by flows (or fluxes). The amount of carbon (as CO_2) in the Earth's atmosphere is important in terms of our global climate system, although it is less than 0.05% of our atmosphere at present. CO_2 is a potent greenhouse gas and is therefore important in the Greenhouse Effect.

The Greenhouse Effect

Figure 1. shows the Greenhouse Effect, which is a natural process. Without the greenhouse gases the planet would be too cold for us to live on, as too much solar radiation would be lost. The natural greenhouse effect (see Figure 1.) enables organic life to survive on Earth and carbon dioxide is one of the most important of the greenhouse gases, along with methane and water vapour. By slowing up the loss of the sun's energy through the atmosphere, the Earth's average temperature is 15˚C rather than -18˚C.

However, human activities on the Earth have been increasing the percentage of carbon dioxide in the atmosphere since the European Industrial Revolution of the 18th century. The increasing combustion of fossil fuels releases carbon dioxide that has been locked underground for millions of years. This releases it within very short time spans, upsetting the natural greenhouse effect. Table 2. shows how the percentage of carbon dioxide in the atmosphere has changed since then.

Figure 1. Natural Greenhouse Effect

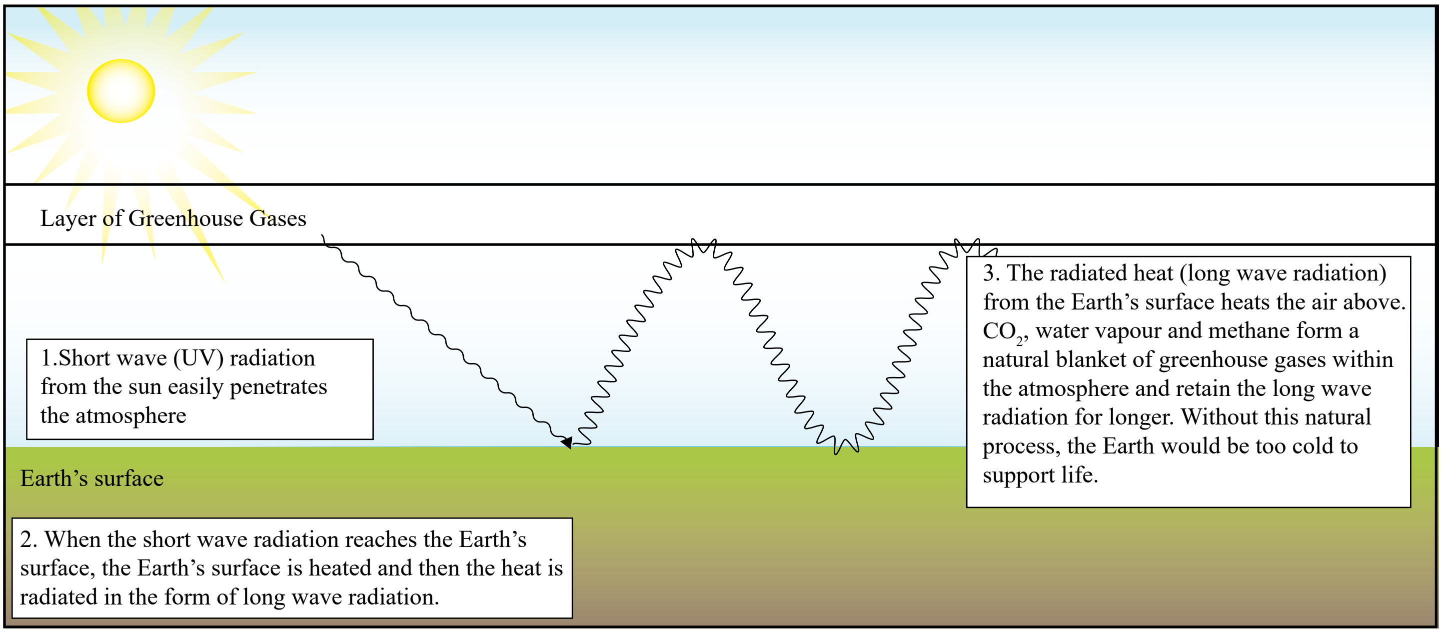

Table 1. CO_2 in the atmosphere from 1700 until 2015 in parts per million (ppm) and %

Year	Parts Per Million (ppm)	%
1700	275	0.0275
1750	278	0.0278
1800	280	0.0280
1850	288	0.0288
1900	295	0.0295
1950	312	0.0312
2000	362	0.0362
2015	402	0.0402

These figures and other research show that the amount of carbon dioxide in our atmosphere is increasing rapidly. Although it forms only a small percentage of the atmosphere, it is highly efficient at holding in long wave radiation and therefore warming the atmosphere. Over the past few decades it has become accepted by the majority of climate scientists that if we release increasing amounts of carbon dioxide into the atmosphere, not only would there be a commensurate rise in average global temperature, but there will be an increase of severe weather in many parts of the world such as hurricanes and droughts. It is thought that a warming atmosphere will also change other mechanisms of climate change such as the jet streams and ocean currents.

Figure 2. The Carbon Cycle

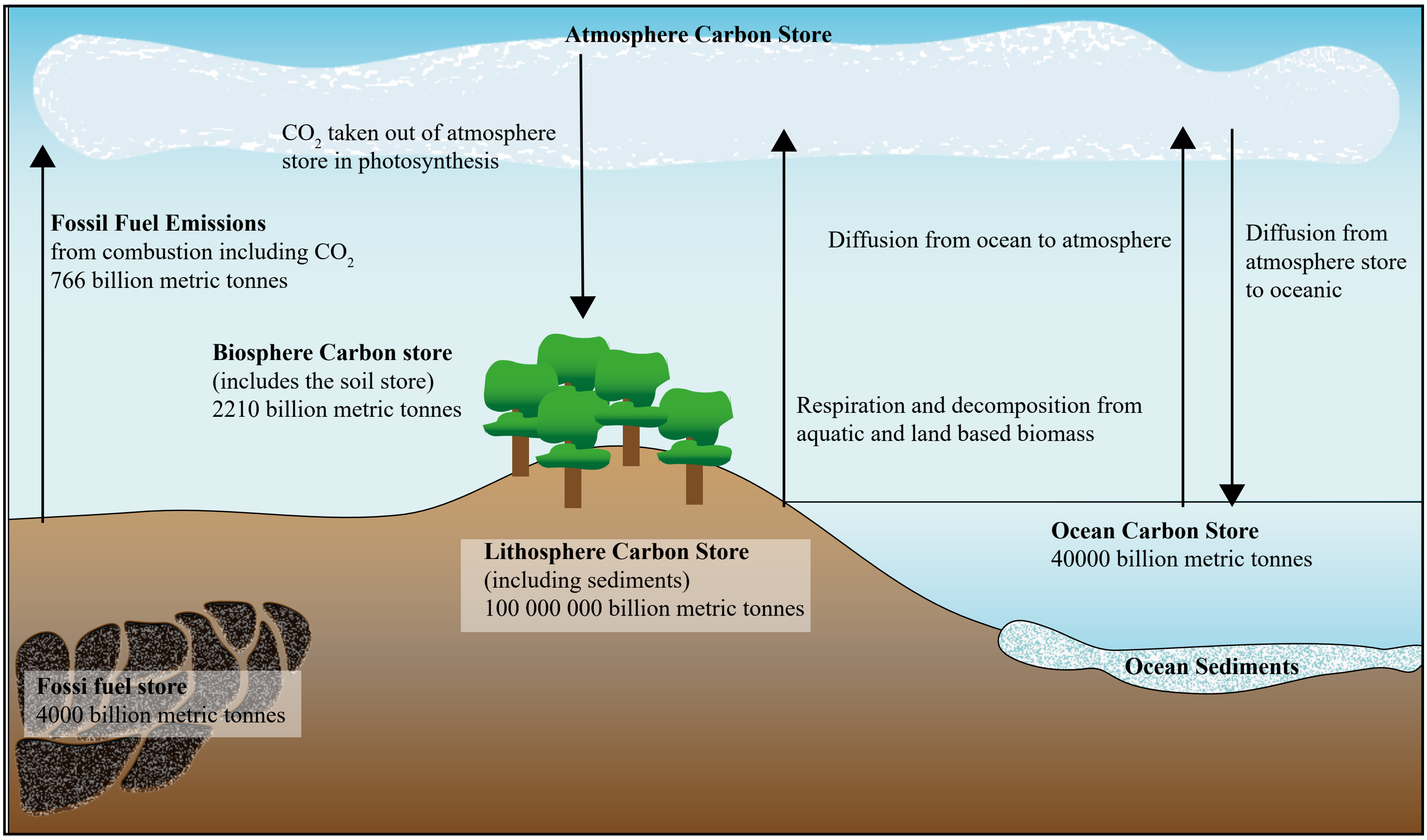

Figure 2. *(above)* shows a simplified version of the carbon cycle. CO2 can be added to the atmosphere from the stores, but also can be removed from the atmospheric store. When all the stores and flows are in balance the system is said to be in equilibrium. However, human activities over the last 200 years have significantly changed the rate of release of carbon from the stores and in some cases have reduced the ability of the Earth's systems to absorb carbon dioxide. It is important for us all to have an understanding of the carbon cycle and our impact upon it if we are not to completely disrupt the global climate system with severe consequences for our and future generations.

Carbon is stored in the following stores or sinks (see Table 2.):

Table 2.

Store	Format
Atmosphere - 766 billions of metric tons (bmt)	Stored as the gas carbon dioxide.
Biosphere - plants 610 bmt soils 1600 bmt	Stored as organic molecules in living and dead plants and animals. In the soil it is stored as organic matter from dead plant material and the activity of microorganisms. The decay process releases CO_2 back into the atmosphere.
Oceans - 40000 bmt	Stored as dissolved carbon dioxide, but also as calcium carbonate in the shells of marine life which can fall to the sea floor and become marine sediments. Much of the ocean carbon store is located at great depths. Only about 4% is found near the upper ocean surface.
Lithosphere - 100000 bmt	Stored as fossil fuels (coal, oil and gas) and also in sedimentary rocks such as limestone and chalk. The Lithosphere is the largest store of carbon.

There are various flows (fluxes) between these stores and they are summarised below (Table 3.):

Table 3.

Flow between stores (Given in billions of metric tons p/a)	**Description**
From Atmosphere into Biosphere (111 bmt/pa)	Plants (autotrophs) use carbon dioxide in the process of photosynthesis and the carbon becomes locked within plant material and can then be passed along a food chain to heterotrophs (herbivores initially and later along the food chain, carnivores). Some plant material, such as roots, are held within the soil.
From Biosphere to Atmosphere (110 bmt/pa)	Released as carbon dioxide by plant and animal organisms in the process of respiration. Dead plant material is broken down within the soil by microorganisms and CO_2 is released via respiration.
Atmosphere to Ocean (92 bmt/pa) (and Ocean to Atmosphere- 90 bmt/pa)	Carbon dioxide gradually diffuses into oceanic waters where it can remain or it can be fixed by some marine organisms and form calcium carbonate. This is used to create e.g. shells and coral. (CO_2 is also diffused from the ocean to the atmosphere).
Ocean to Lithosphere	When corals and shelled organisms die, their calcium carbonate parts sink to the bottom of the ocean and form large deposits. Over millions of years these deposits are compressed and undergo chemical changes to form sedimentary rocks.
Lithosphere to Atmosphere (Fossil fuel use 6.3 bmt/pa)	Some of the carbon stored in the lithosphere is released during volcanic eruptions. The carbon stored in fossil fuels within the lithosphere under natural conditions would slowly release carbon dioxide over hundreds of thousands of years. Human (anthropogenic) activity in burning these fuels is releasing huge amounts of carbon dioxide over extremely short time spans and is destroying the overall equilibrium of the carbon cycle.

As can be seen from above there are really two natural carbon cycles- the slow and the fast.

Slow carbon cycle
This cycle can take millions of years and involves the lithosphere store and the flow into the atmosphere store. Carbon is built up over millions of years in the laying down of sedimentary rocks and ocean sediments. This carbon dioxide is slowly released from marine deposits, the weathering of sedimentary rocks and transportation by rivers, or vented via volcanic activity. Its time scale is measured in 100s of thousands or millions of years.

Fast Carbon Cycle
This is the movement of carbon through food chains and takes place within a lifetime. Photosynthesis and the take up of carbon dioxide from the atmosphere can just take a few minutes and within seconds the plant can be giving off carbon dioxide in respiration. It is estimated that the movement of carbon through food chains is up to 100, 000 million metric tons a year.

Changes in the Carbon Cycle
The stores and flows of carbon occur continually, and until the last 200 years were in overall equilibrium. When scientists constructed carbon budgets, they measured the amount of carbon being released from a store and the amount being taken in. There is a clear excess of carbon dioxide in the atmosphere and this has been increasing since the 18^{th} century – 280ppm (0.028%) to over 402ppm (0.0402%) in May 2015.

Our atmosphere contains more carbon now than it has done for the last two million years and we are not sure what the total impact of this might be. What has caused these changes?

- During the Industrial Revolution, which began in the 18^{th} Century, humans began to burn fossil fuels (coal, oil and gas), a process which has accelerated and expanded in the following centuries. Carbon dioxide is being released as part of the fast cycle rather than the natural slow carbon cycle, when the fossil fuel deposits would slowly weather and release their carbon.
- Not all the excess carbon has gone into the atmosphere; some has been taken up by plants and the ocean, but there is evidence that these stores may be at their limit.
- The ocean is thought to have absorbed some of the excess carbon emitted by humans. This has caused higher levels of the weak carbonic acid to occur in the seas, about 30% since the beginning of the Industrial Revolution. Shell forming organisms in the ocean are finding it harder to create their protective casings and increasing acidification seems to be creating stress for coral reefs, reducing their ability to survive. It is also thought that plankton are threatened by the increasing acidification and as they form the base of most marine food chains, this will impact on fish stocks and the livelihoods of many fishermen.
- Large areas of forest have been cleared and burned, not just releasing more CO_2 into the atmosphere, but reducing one of the most important carbon stores or sinks. The forested areas may be replaced by crops such as palm oil in the tropics or by cereal crops in the temperate zones. Not only do they not store as much carbon, but they are harvested and much of the carbon is taken away for human consumption.
- As soils are exposed via agricultural activities, they often become degraded and more CO_2 is released.
- Increased climate warming in the Arctic has led to permafrost melting and the release of methane, and supplies of carbon from peatlands.
- A positive change is when humans have afforested areas that were once cleared of trees, thus creating carbon sinks.

Carbon Budgets

The carbon budget for North America is not in equilibrium. The continent is responsible for 25% of the global carbon dioxide emissions. This is partially due to vehicle fuel in countries like the USA where public transport is limited and people expect to have the freedom of their own car. The number of single occupied dwellings is increasing and thus the amount of electricity needed for heating or cooling of interiors. Most of the electricity is created from fossil fuels. The emerging superpowers of India and China have a fast growing middle class who are demanding western lifestyles and access to their own vehicles. Whereas 15 years ago the roads of Beijing were still dominated by bicycles and scooters, there are now huge traffic jams in the centre for much of the day. Stationary traffic burns fuel inefficiently and adds to the emissions of greenhouse gases. Worldwide, sales of cars with combustion engines are increasing as are traditional coal or oil fired power stations. This activity alongside the clearance of more land for agriculture means the carbon budget does not balance. We are already beyond the recommended percentage of carbon dioxide in the atmosphere if we wish to maintain a steady climate, and yet the nations are doing very little, as yet, to improve the situation by mitigation.

Can we revert to a carbon cycle in equilibrium?

- The Kyoto Protocol was a start in trying to rectify our mistakes. In Kyoto, Japan in 1997 the Kyoto Protocol was drawn up and came into force in 2005. Its aim was to reduce collective greenhouse gas emissions, especially carbon dioxide, by 5.2% when compared to the levels in 1990. As can be seen from Table 1, this has not been achieved as yet. The targets were not set the same for every country with European Union countries agreeing to an 8% reduction, Iceland to 10% and the USA to 7%. Unfortunately, the USA did not ratify the Protocol despite being one of the largest emitters of carbon dioxide and Canada withdrew from the Protocol in 2012.There is to be another round of talks in Paris in late 2015 where the stated aim is to get all countries to work towards reducing greenhouse gases by 60 % by 2050.
- There are ways in which humans can reduce their own carbon footprint. We know how to reduce our output of CO_2 by e.g. reducing car use and we know how carbon sinks can work in absorbing more of our emissions. However, it requires a change of attitude to our present fossil fuel -driven world from governments and individuals in order that the sinks and flows of carbon can once again be in equilibrium.

Conclusion

This introduction to the carbon cycle shows how important it is in supporting life and that we risk our species' future if we do not learn how and why we are impacting on it. Some scientists believe that we have reached or are about to reach a tipping point where the levels of carbon dioxide in the atmosphere will warm the oceans, melt more polar ice, absorb more solar energy, alter currents such as the North Atlantic Drift and drive us into an increasingly unstable climate system. This will create millions of Global Warming refugees as islands such as the Maldives sink beneath the rising seas and low lying countries such as Bangladesh are inundated. Where will these people go? With less land, how will they be fed?

Learning to understand the complex carbon cycles will be ever more important as we try to tackle the problems we have created.

Useful Websites

www.zerocarbonbritain.org – The research project being carried out at the Centre for Alternative Technology in Wales.
http://earthobservatory.nasa.gov/Features/CarbonCycle/ This is the Earth Observatory site of NASA and has links to many aspects of the carbon cycle.

Review Question

(a) Give a definition of the carbon cycle and outline its main stores and flows.
(b) Outline how humans can disrupt or alter the carbon cycle.

Response

(a) The carbon cycle is the movement of carbon through several stores via pathways that include photosynthesis, respiration, weathering and decomposition. Its main stores are the atmosphere, the oceans, the biosphere and the lithosphere. (Use the article to enable you to add more to the outline)

(b)
- Humans have altered the carbon cycle mainly during the last 200 years, since the Industrial Revolution. By burning fossil fuels (oil, gas and coal) the equilibrium of the carbon cycle has been upset and there is now more carbon dioxide in the atmosphere than for the previous two million years.
- We have also deforested huge areas of the planet, reducing a most important carbon sink, and replaced them with urban areas or cropland which is harvested and is inefficient as a carbon sink.
- The burning of forests as in slash and burn agriculture releases huge amounts of CO_2 into the atmosphere.
- The burning of fossil fuels has led to an increase in acid rain and the acidified water finds its way into rivers and seas altering ecosystems.
- Afforestation can increase carbon sinks.
- Changing from fossil fuel driven power to alternatives such a wind, tidal, solar etc would help return the carbon cycle to equilibrium.

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