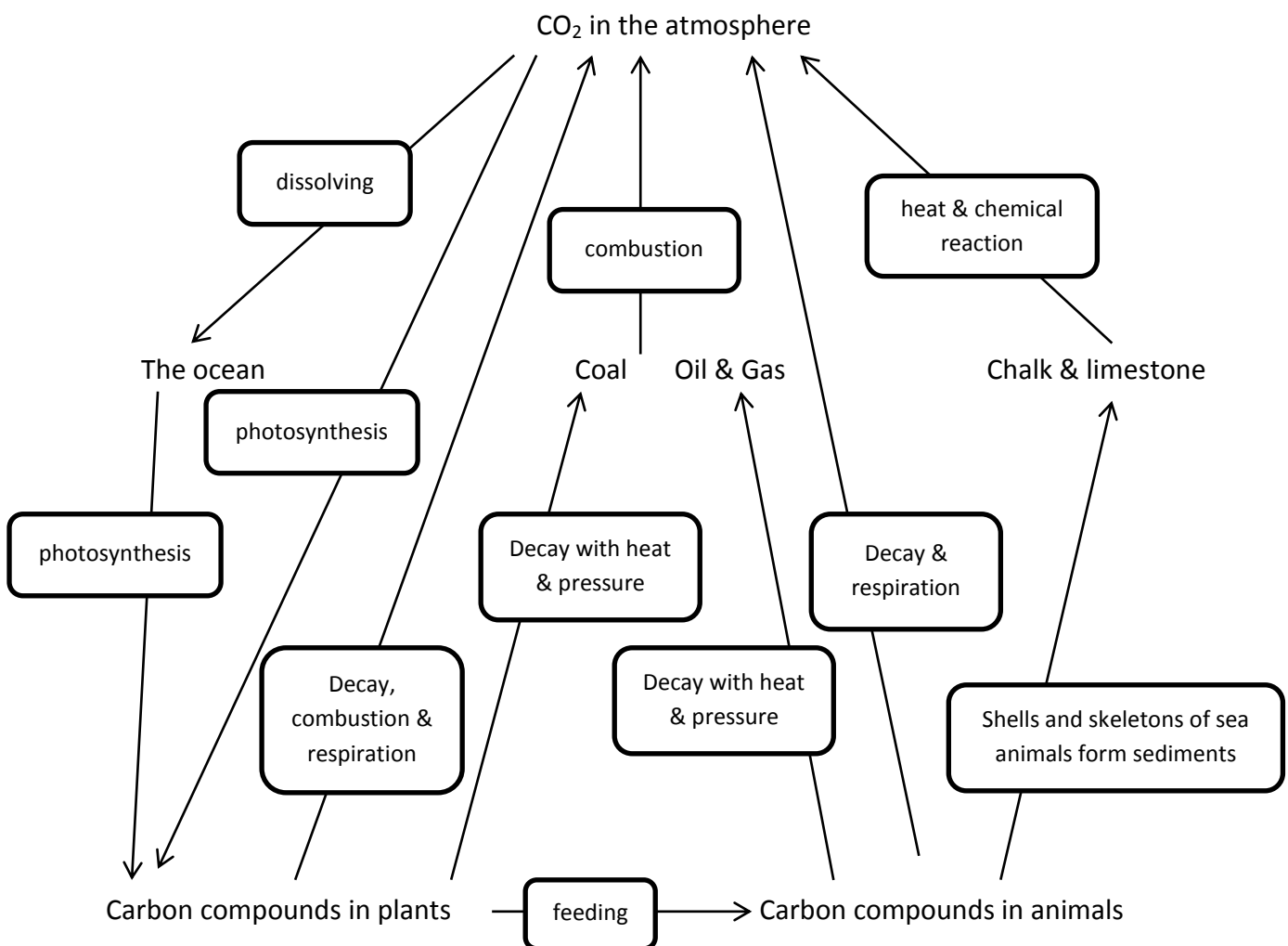


The Carbon Cycle

Carbon is an important part of many molecules that make up organic and inorganic matter.

The movement of carbon, in its many forms, between the atmosphere, oceans, biosphere (all the living organisms on Earth), and geosphere (the solid portion of Earth, including the crust and mantle) is described by the carbon cycle. The carbon cycle is one of the most important cycles of the Earth.

Carbon is the fourth most abundant element in the Universe. Most of Earth’s carbon is stored in rocks. The rest is in the ocean, atmosphere, plants, soil, and fossil fuels. Carbon flows between each sink or store in an exchange called the carbon cycle. Carbon is constantly entering the atmosphere, mainly in the form of carbon dioxide gas CO₂ and methane gas CH₄. At the same time, it is being removed by green plants, and the oceans. It is also stored for long periods of time (in sediments, fossil fuels, the ocean, and in carbonate rocks and other carbon-rich rocks) or for short periods of time (in forests and phytoplankton).



Addition of carbon to the atmosphere

Respiration & excretion. Carbon dioxide enters the atmosphere through respiration. Plants, animals and microbes break down carbon containing compounds to gain energy. When oxygen is present, aerobic respiration occurs, which releases carbon dioxide into the surrounding air or water. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. The living things excrete carbon dioxide as waste.

Decay. Fungi and bacteria (decomposers) break down the carbon compounds in dead animals and plants and convert the carbon compounds into carbon dioxide if oxygen is present (aerobic respiration) or into methane if not. Anaerobic respiration releases methane into the surrounding environment, as marsh gas or flatulence from animals such as sheep and cattle.

Combustion. If plant material, e.g. wood, is burned, oxygen combines with the stored carbon to release water, carbon dioxide, and energy. This reaction is combustion. Burning of biomass (e.g. forest fires, wood used for heating, anything else organic) can transfer substantial amounts of carbon to the atmosphere. Burning fossil fuels (formed very long ago from plant or animal remains that were buried, compressed, and transformed into oil, coal, or natural gas), releases carbon that has been stored in the geosphere for millions of years.

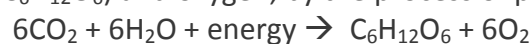
Volcanic activity.

Volcanic gases are primarily water vapour, carbon dioxide and sulfur dioxide. Seafloor spreading pushes the sea floor down in the process of subduction. When rocks containing carbon, such as limestone, are pushed deeper into the earth by tectonic forces they heat up, eventually melt, and can rise back up to the surface, where the carbon is released as CO_2 and returned to the atmosphere. This return to the atmosphere can occur through volcanic eruptions, or more gradually in vents, and CO_2 -rich hot springs.

Removal of carbon from the atmosphere

Photosynthesis.

Carbon is removed from the atmosphere by photosynthesis. Plants and phytoplankton (microscopic organisms in the ocean) take carbon dioxide from the atmosphere by absorbing it into their cells. Using energy from the Sun, they combine carbon dioxide (CO_2) and water to form sugar ($C_6H_{12}O_6$) and oxygen, by the process of photosynthesis.



The simple sugars are then converted into other molecules such as starch, fats, proteins, enzymes, and DNA/RNA i.e. all of the other molecules in living plants. Through food chains, the carbon that is in plants moves to the animals that eat them. Animals that eat other animals get the carbon from their food too.

Dissolving in water

Carbon dioxide enters the waters of the ocean by simple diffusion. Carbon is removed from the atmosphere by dissolving in water. Carbon dioxide is slightly soluble and is absorbed into bodies of water such as the ocean and lakes. A rough, cold sea is able to dissolve a greater amount of carbon dioxide; the warmer the water the less carbon dioxide remains in the water. Once dissolved in seawater, the carbon dioxide can remain as is or can be converted into carbonate (CO_3^{2-}) or bicarbonate (HCO_3^-). Some carbon dioxide is used by algae and phytoplankton through the process of photosynthesis. Certain forms of sea life can use bicarbonate with calcium (Ca^{2+}) to produce calcium carbonate (CaCO_3). The carbon is locked up in calcium carbonate “plates” or shells or other body parts by organisms such as coral, clams, oysters, some protozoa, and some algae. (The dissolved calcium in the oceans comes from the chemical weathering of calcium-silicate rocks.)

Storage of carbon

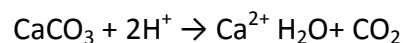
Short term storage

Forests. Carbon dioxide from the atmosphere is absorbed by plants during photosynthesis and used to produce food or other carbon rich compounds. Carbon is locked up in plants short term. Plants lock up carbon dioxide as sugar which they convert to starch and animals eat the starch and release the carbon dioxide for plants to use again. A longer cycling of carbon dioxide occurs when the trees lock up carbon dioxide into timber (as structural materials cellulose and lignin). Some timber is burnt as fuels but carbon can be locked into many trees over a long period of time. When the trees die the carbon dioxide is released by decomposition back into the atmosphere. However if the plant matter is turned into coal then it becomes a long term store of carbon.

Long term storage

Sediments:

In the atmosphere, carbonic acid forms by a reaction with atmospheric carbon dioxide (CO_2) and water. As this weakly acidic water reaches the earth as rain, it reacts with minerals at the earth’s surface, slowly dissolving them through the process of chemical weathering.



These dissolved substances are carried in streams and rivers eventually to the ocean, where they precipitate out as minerals like calcite (CaCO_3). Carbon is removed from seawater when the shells and bones of marine animals and plankton collect on the sea floor. As the shelled organisms die, bits and pieces of the shells fall to the bottom of the oceans and accumulate as carbonate-rich deposits. The shells can become compressed over time as they are buried. After long periods of time, these deposits are physically and chemically altered into the sedimentary rock limestone, which is the largest reservoir of carbon in the carbon cycle. The carbon may stay locked up in limestone sediments for millions of years.

Over long periods of time, the sediments may be raised up as dry land to expose the carbon rich rocks which release the carbon into the atmosphere by weathering and erosion.

Coal, oil and natural gas:

Under certain geological conditions, organic matter can be buried and over time form deposits of the carbon-containing fuels coal, oil and gas. It is the non-calcium containing organic matter that is transformed into fossil fuel. Fossil fuel formation is a long-term sink for atmospheric CO₂. The carbon is said to be "fixed" in place and is essentially locked out of the natural carbon cycle. Coal is an example of a long-term storage of carbon because it was formed by the compression of ancient plant material millions of years ago that was buried, compressed and metamorphosed. The ancient plants would have originally obtained their carbon dioxide from the atmosphere. This was locked away until exposed by mining or mountain uplift (natural process).

Humans intervene during by burning the fossil fuels and carbon dioxide is released back into the atmosphere. We have burnt a lot of these fossil fuels and have hence released a lot of this long term carbon storage, raising the levels of carbon dioxide in the atmosphere at a faster rate than has ever happened in earth's geological history

Subduction resulting in carbon-rich metamorphic and igneous rocks:

Subduction of sediments and rocks, the formation of magma, and eruption of volcanoes, can all return carbon dioxide to the atmosphere. Some of the calcium carbonate (limestone) is converted to marble (a metamorphic rock) at the subduction zones. Conversion to silicates can lead to the release of carbon dioxide. $\text{CaCO}_3 + \text{SiO}_2 \rightarrow \text{CO}_2 + \text{CaSiO}_3$.

The sediments may be melted to form magma. Carbon is released again from volcanoes as carbon dioxide gas and methane which goes back into the atmosphere. Volcanoes produce very large amounts of carbon dioxide.

Useful website:

<http://www.sciencelearn.org.nz/Contexts/The-Ocean-in-Action/Sci-Media/Animations-and-Interactives/Carbon-cycle>