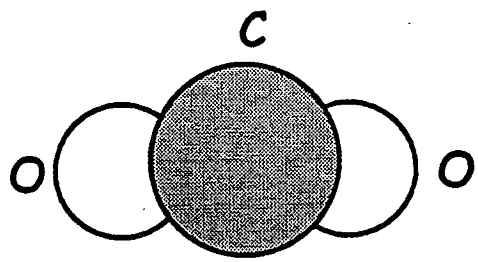
Teacher Background Information: Carbon Dioxide

Carbon dioxide (CO_2), a colorless, odorless gas, is an important molecule in the basic physiological processes carried out by all living organisms. *Respiration* involves the consumption of oxygen (O_2) and the release of CO_2 in a series of complex chemical reactions. The benefit to the organism is that it allows access to the energy stored in food molecules. This energy is then used to repair cells, move muscle, repair injuries, combat disease and many other functions necessary for survival. Both plants and animals carry out respiration as an energy releasing mechanism.

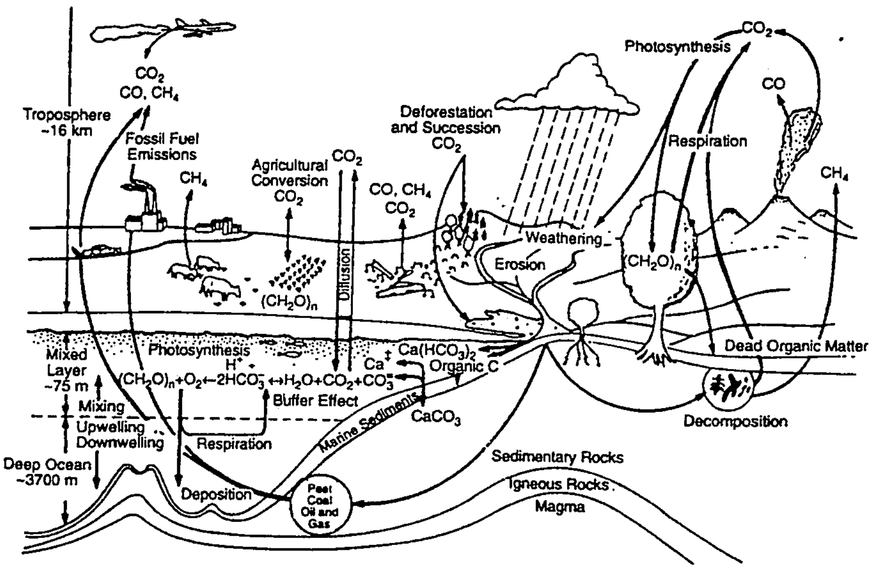


A carbon dioxide molecule

All plants consume CO_2 in the process of photosynthesis. This process, initiated by sunlight, changes CO_2 and water (H_2O) through a series of reactions which release oxygen (O2) as a by-product and produces sugars and several other organic substances. The organic material is the essence of plant matter, including the stems, leaves, roots and flowers. Indirectly, they are the essence of animal matter as well, since plants are the ultimate food source for all animals, even meat-eaters. For that reason, plants have been labeled the "primary producers". It can be said that respiration and photosynthesis are complementary processes with respect to O_2/CO_2 production and consumption.

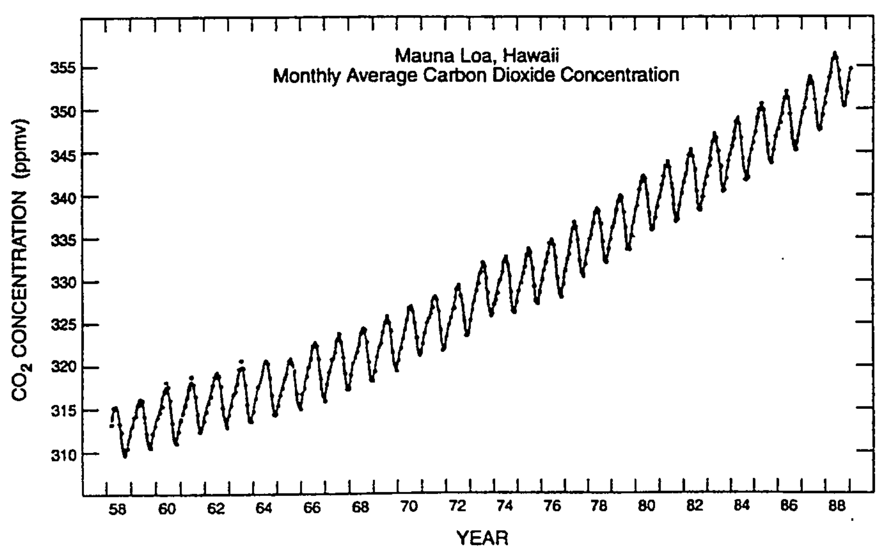
The important factor about these two processes is that the carbon atoms, in the form of CO_2, are being "cycled" from one form to another, from CO_2 in the air, to glucose and other organic substances in plant and animal tissues, and then back again as the process of decomposition is involved. There is interaction between the *abiotic* part of the Earth system, the atmosphere, and the *biotic* part, the biosphere. This and other similar interactions involving CO_2 are easily seen in a drawing of the *carbon cycle.*

In addition to its physiological value, carbon dioxide is important as a *greenhouse gas* and for that reason, increases in its concentration are cause for concern. Human activities have seriously altered the cycle of carbon storage and release. The use of organic (fossil) fuels like oil, coal and natural gas, and the process of deforestation free the carbon atoms stored in the fuel and forests and release them into the atmosphere as carbon dioxide in the combustion process. By doing so, the natural storage time for carbon is being disrupted and the concentration in the atmosphere is increasing as the processes that normally remove it from the atmosphere (dissolution in the oceans and uptake by plants) cannot keep pace.



The Earth's global carbon cycle today

There is irrefutable evidence that global levels of carbon dioxide are increasing in the Earth's atmosphere. This trend was first observed in the CO_2 record from the Mauna Loa Observatory in Hawaii in 1958. Since then, monitoring of atmospheric CO_2 levels has been rigorously maintained. In addition to showing an overall increase in amount of carbon dioxide, they also show annual oscillations due to seasonal variations in the amount of CO_2 caused by increased vegetative activity in the summer and decreased activity in winter. Satellite images give a clear picture of the "greenness" of vegetation, which outside of the tropical regions can be seen to wax and wane during a year, with the cycles of the Northern and Southern Hemispheres opposing each other in perfect symmetry.



Increased CO_2 concentration over time, 1958 -1990

Because carbon dioxide is essentially a food material for plants, it is safe to assume that changes in its concentration in the atmosphere will have some effect on the biosphere. Much research is now being done into this possibility:

- On the level of individual plants, scientists know that photosynthesis and growth are stimulated by higher concentrations of CO_2, as effect known as "CO_2 fertilization". A consequence of this effect is increased water use efficiency, owing to the fact that because the plants can get sufficient CO_2 without opening their pores as widely, they lose less water from the interior.

- Another response to increased CO_2 in the atmosphere might be changes in the basic machinery of photosynthesis between C_3 and C_4 plant types, allowing one to gain an advantage over the other and causing shifts in the mixture of species within communities.

- **The reproduction and flowering of plants might also be affected by carbon dioxide concentrations in the atmosphere. Studies have shown that the flowering time of certain species is advanced by increased CO_2 as well modifications in the number and rate of flower production, the longevity of the flower and the seed weight. These changes could in turn have serious impact on the relationship between flowers and their insect pollinators. If the insects could not adapt to the changes in the plant such as flowering time, reproduction of the plant could be jeopardized.**

Many of the possible response of plants to increased CO_2 could have effects on the animals that depend on them for food, shelter or mating sites. Changes in species composition, or a general decline in species diversity could undermine the health of an ecosystem.

- Plants grown in high CO_2 environments contain less nitrogen and proteins in their plant material, meaning lower nutritional value for the animals that feed on it. In order to compensate for the decreased protein content of the plant, herbivores would have to feed more or grow less. Therefore, although the photosynthetic rate may increase, increases in herbivore grazing may offset any gains in growth. This could translate into population declines for first level feeders and eventually affect organisms higher up on the food chain.

Changes in carbon dioxide could also affect marine life. Carbon dioxide reacts with water to form bicarbonate and carbonate ions which play a major role in maintaining the stabilized pH of sea water, around 8.0 - 8.2. More CO_2 could cause the oceans to become more acidic than at present, a seemingly minor change which will alter the concentration of essential nutrients and trace metals required by phytoplankton for the process of photosynthesis. A change in phytoplankton photosynthetic rates will ultimately find its way to higher levels in the food chain. The fishing industry is very familiar with this phenomenon; it occurs when the natural occurrence known as El Nino alters the supply of nutrients in the surface waters of the eastern Pacific and decimates natural marine fisheries.

In addition to directly affecting the natural biotic processes within the biosphere, higher levels of CO_2 are expected to impact the physical climate, which in turn would affect living organisms in various ways. These are considered to be "indirect effects", since the greenhouse gas molecule itself is not what the biota is responding to. The impacts will no doubt be felt at varying levels in every ecosystem of the planet; the magnitude and speed of the changes will determine the ability of individual species to adapt and survive. Increased CO_2 concentrations, increased or decreased temperatures and rainfall, will be the most obvious changes, with droughts, floods, changes in life zones, famine and disease being secondary responses. Each of these has the potential to alter the fundamental physiological, economic and social functions of the planet in one or more ways.

Despite several major uncertainties, what happens to the CO_2 when it reaches the atmosphere is extremely important. The average carbon atom spends its life being shunted from one place to another - from fossil fuel to the air, from the air to the oceans (in the form of dissolved carbonates), from the oceans to fish and other marine organisms, from them to the sea bed, from there to the surface again, and then to the atmosphere where it may be used by plants, enter the soil and eventually end up again as a fossil fuel. The effect of burning fossil fuels on atmospheric levels of CO_2 can be accurately assessed only if the workings of the entire carbon cycle are understood. As yet they are not - although they are understood sufficiently to provide a useful guide as to what might happen as more fossil fuel is burned. So far, most of the projections that have been made assume that roughly one half of the CO_2 released into the atmosphere stays there- they other half being absorbed by plants and the ocean.

The future of the Earth's climate relies, in part, on how much the concentration of carbon dioxide increases in the future. This should depend on how much fossil fuel is burned and how much land is deforested. Unfortunately, things are rarely that simple and many complex feedback mechanisms in the Earth system are likely to be involved. Conducting experiments on the scale of a whole ecosystem is quite difficult, and yet it is crucial to be able to understand the kinds of changes that might occur in addition to temperature. Computer models are one tool that has been used to try to extend our understanding to larger temporal and spatial scales. These models ultimately rely on experimental information for their input, but even with this limitation they can be particularly useful as a way to identify which processes need further study.