

## *Earth Cycles*

# The Carbon Cycle: What Goes Around Comes Around

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### Terms you should know



**atmosphere** : the collective mass of gases that surrounds Earth or another planet.

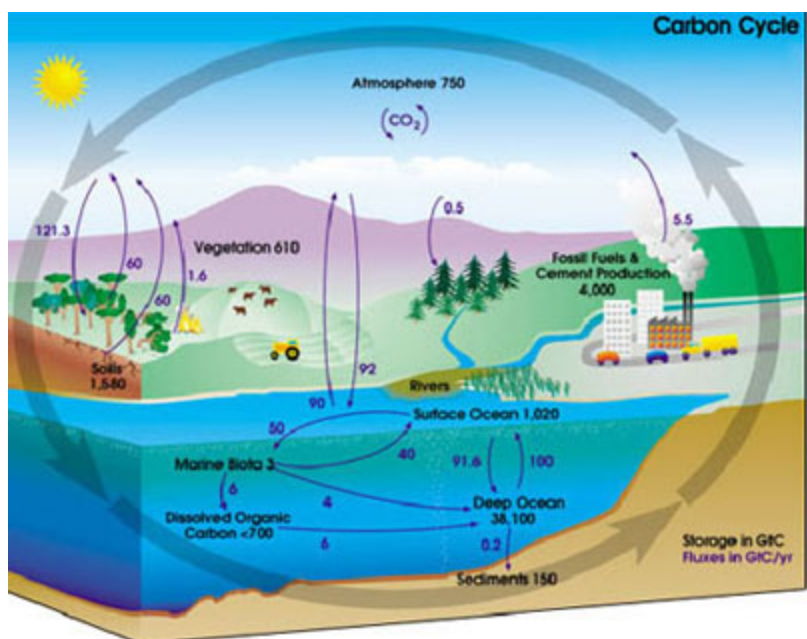
**organic** : originating from a living organism; a compound that contains hydrocarbons

**species** : a distinct type of plant or animal; a related group of living things that can produce offspring

Carbon is the fourth most abundant element in the universe, and is absolutely essential to life on Earth. In fact, carbon constitutes the very definition of life, as its presence or absence helps define whether a molecule is considered to be organic or inorganic. Every organism on Earth needs carbon either for structure, energy, or, as is the case of humans, for both. Discounting water, you are about half carbon. Additionally, carbon is found in forms as diverse as the gas carbon dioxide (CO<sub>2</sub>), and in solids like limestone (CaCO<sub>3</sub>), wood, plastic, diamonds, and graphite.

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The movement of carbon, in its many forms, between the atmosphere, oceans, biosphere, and geosphere is described by the carbon cycle, illustrated in Figure 1. This cycle consists of several storage carbon reservoirs and the processes by which the carbon moves between reservoirs. Carbon reservoirs include the atmosphere, the oceans, vegetation, rocks, and soil; these are shown in black text along with their approximate carbon capacities in Figure 1. The purple numbers and arrows in Figure 1 show the fluxes between these reservoirs, or the amount of carbon that moves in and out of the reservoirs per year. If more carbon enters a pool than leaves it, that pool is considered a *net carbon sink*. If more carbon leaves a pool than enters it, that pool is considered *net carbon source*.



**Figure 1:** A cartoon of the global carbon cycle. Pools (in black) are gigatons (1Gt =  $1 \times 10^9$  Tons) of carbon, and fluxes (in purple) are Gt carbon per year. Illustration courtesy NASA Earth Science Enterprise.  
image © NASA

The global carbon cycle, one of the major biogeochemical cycles, can be divided into geological and biological components. The geological carbon cycle operates on a timescale of millions of years, whereas the biological carbon cycle operates on a timescale of days to thousands of years.

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## The geological carbon cycle

The geological component of the carbon cycle is where it interacts with the rock cycle in the processes of weathering and dissolution, precipitation of minerals, burial and subduction, and volcanic eruptions (see The Rock Cycle module for information). In the atmosphere, carbonic acid forms by a reaction with atmospheric carbon dioxide (CO<sub>2</sub>) and water. As this weakly acidic water reaches the surface as rain, it reacts with minerals at Earth's surface, slowly dissolving them into their component ions through the process of chemical weathering. These component ions are carried in surface waters like streams and rivers eventually to the ocean, where they precipitate out as minerals like calcite (CaCO<sub>3</sub>). Through continued deposition and burial, this calcite sediment forms the rock called limestone.

This cycle continues as seafloor spreading pushes the seafloor under continental margins in the process of subduction. As seafloor carbon is pushed deeper into the Earth by tectonic forces, it heats up, eventually melts, and can rise back up to the surface, where it is released as CO<sub>2</sub> and returned to the atmosphere. This return to the atmosphere can occur violently through volcanic eruptions, or more gradually in seeps, vents, and CO<sub>2</sub>-rich hot springs. Tectonic uplift can also expose previously buried limestone. One example of this occurs in the Himalayas where some of the world's highest peaks are formed of material that was once at the bottom of the ocean. Weathering, subduction, and volcanism control atmospheric carbon dioxide concentrations over time periods of hundreds of millions of years.


### COMPREHENSION CHECKPOINT

Carbonic acid reaches the Earth's surface by way of

- volcanic eruptions.
- rain.

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## The biological carbon cycle

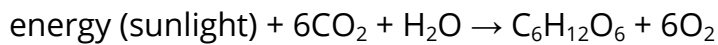
Biology plays an important role in the movement of carbon between land, ocean, and <sup>Top </sup> atmosphere through the processes of photosynthesis and respiration. Virtually all

multicellular life on Earth depends on the production of sugars from sunlight and carbon dioxide (photosynthesis) and the metabolic breakdown (respiration) of those sugars to produce the energy needed for movement, growth, and reproduction. Plants take in carbon dioxide (CO<sub>2</sub>) from the atmosphere during photosynthesis, and release CO<sub>2</sub> back into the atmosphere during respiration through the following chemical reactions:

### **Respiration:**



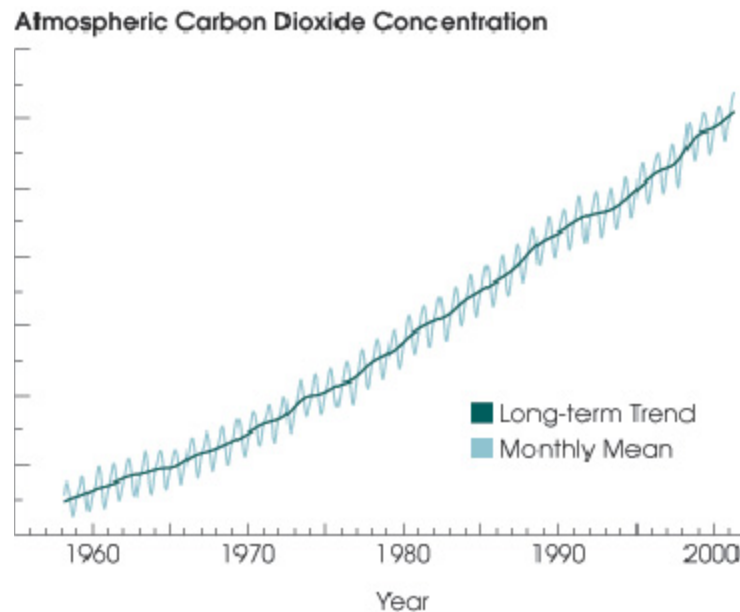
### **Photosynthesis:**



Through photosynthesis, green plants use solar energy to turn atmospheric carbon dioxide into carbohydrates (sugars). Plants and animals use these carbohydrates (and other products derived from them) through a process called respiration, the reverse of photosynthesis. Respiration releases the energy contained in sugars for use in metabolism and changes carbohydrate "fuel" back into carbon dioxide, which is in turn released back to the atmosphere. The amount of carbon taken up by photosynthesis and released back to the atmosphere by respiration each year is about 1,000 times greater than the amount of carbon that moves through the geological cycle on an annual basis.

On land, the major exchange of carbon with the atmosphere results from photosynthesis and respiration. During daytime in the growing season, leaves absorb sunlight and take up carbon dioxide from the atmosphere. At the same time plants, animals, and soil microbes consume the carbon in organic matter and return carbon dioxide to the atmosphere. Photosynthesis stops at night when the sun cannot provide the driving energy for the reaction, though respiration continues. This kind of imbalance between these two processes is reflected in seasonal changes in the atmospheric CO<sub>2</sub> concentrations. During winter in the northern hemisphere, photosynthesis ceases when many plants lose their leaves, but respiration continues. This condition leads to an increase in atmospheric CO<sub>2</sub> concentrations during the northern hemisphere winter. With the onset of spring, however, photosynthesis resumes and atmospheric CO<sub>2</sub> concentrations are reduced. This cycle is reflected in

the monthly means (the light blue line) of atmospheric carbon dioxide concentrations shown in Figure 2.



**Figure 2:** The "Keeling Curve," a long-term record of atmospheric CO<sub>2</sub> concentration measured at the Mauna Loa Observatory (Keeling et al.). Although the annual oscillations represent natural, seasonal variations, the long-term increase means that concentrations are higher than they have been in 400,000 years (see text and Figure 3). Graphic courtesy of NASA's Earth Observatory.  
image © NASA

In the oceans, phytoplankton (microscopic marine plants that form the base of the marine food chain) use carbon to make shells of calcium carbonate (CaCO<sub>3</sub>). The shells settle to the bottom of the ocean when phytoplankton die and are buried in the sediments. The shells of phytoplankton and other creatures can become compressed over time as they are buried and are often eventually transformed into limestone. Additionally, under certain geological conditions, organic matter can be buried and over time form deposits of the carbon-containing fuels coal and oil. It is the non-calcium containing organic matter that is transformed into fossil fuel. Both limestone formation and fossil fuel formation are biologically controlled processes and represent long-term sinks for atmospheric CO<sub>2</sub>.

The major biological exchange of carbon with the atmosphere is from

- a. photosynthesis and respiration.
  - b. burning carbon-containing fuels like coal and oil.
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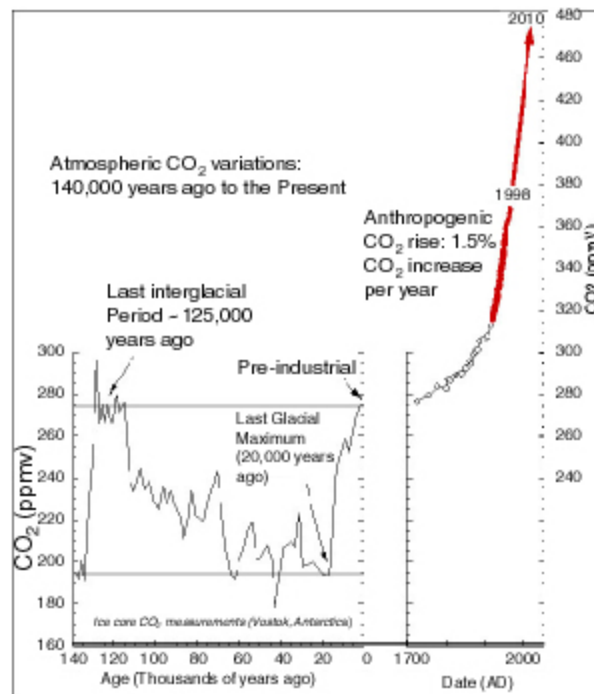
## Human alteration of the carbon cycle

Recently, scientists have studied both short- and long-term measurements of atmospheric CO<sub>2</sub> levels. Charles Keeling, an oceanographer at the Scripps Institute of Oceanography, is responsible for creating the longest continuous record of atmospheric CO<sub>2</sub> concentrations, taken at the Mauna Loa observatory in Hawaii. His data (now widely known as the "Keeling curve," shown in Figure 2) revealed that human activities are significantly altering the natural carbon cycle. Since the onset of the industrial revolution about 150 years ago, human activities such as the burning of fossil fuels and deforestation have accelerated, and both have contributed to a long-term rise in atmospheric CO<sub>2</sub>. Burning oil and coal releases carbon into the atmosphere far more rapidly than it is being removed, and this imbalance causes atmospheric carbon dioxide concentrations to increase. In addition, by clearing forests, we reduce the ability of photosynthesis to remove CO<sub>2</sub> from the atmosphere, also resulting in a net increase. Because of these human activities, atmospheric carbon dioxide concentrations are higher today than they have been over the last half-million years or longer.

Because CO<sub>2</sub> increases the atmosphere's ability to hold heat, it has been called a "greenhouse gas." Scientists believe that the increase in CO<sub>2</sub> is already causing important changes in the global climate. Many attribute the observed 0.6 degree C increase in global average temperature over the past century mainly to increases in atmospheric CO<sub>2</sub>. Without substantive changes in global patterns of fossil fuel consumption and deforestation, warming trends are likely to continue. The best scientific estimate is that global mean temperature will increase between 1.4 and 5.8 degrees C over the next century as a result of increases in atmospheric CO<sub>2</sub> and other greenhouse gases. This kind of increase in global temperature would cause a significant rise in average sea-level (0.09-0.88 meters), exposing low-lying coastal cities or cities located by tidal rivers, such as New Orleans, Portland, Washington, and Philadelphia, to increasingly frequent and severe floods. Glacial retreat and species <sup>↑</sup> range shifts are also likely to result from global warming, and it remains to be seen

whether relatively immobile species such as trees can shift their ranges fast enough to keep pace with warming.

Even without the changes in climate, however, increased concentrations of CO<sub>2</sub> could have an important impact on patterns of plant growth worldwide. Because some species of plants respond more favorably to increases in CO<sub>2</sub> than others, scientists believe we may see pronounced shifts in plant species as a result of increasing atmospheric CO<sub>2</sub> concentrations, even without any change in temperature. For example, under elevated CO<sub>2</sub> conditions, shrubs are thought to respond more favorably than certain grass species due to their slightly different photosynthetic pathway. Because of this competitive inequality, some scientists have hypothesized that grasslands will be invaded by CO<sub>2</sub>-responsive grass species or shrubby species as CO<sub>2</sub> increases.



**Figure 3:** CO<sub>2</sub> over the past 140,000 years as seen in an ice core and in the modern Mauna Loa record. The red line represents predicted concentrations. Figure courtesy of : Rebecca Dorsey, University of Oregon.

## COMPREHENSION CHECKPOINT

Carbon dioxide is considered a "greenhouse gas" because

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- a. it is released primarily by plants grown in greenhouses.
  - b. it traps heat in the atmosphere.
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## How scientists study past atmosphere and climate

In an attempt to understand whether recently observed changes in the global carbon cycle are a new phenomenon, or have instead occurred throughout geologic history, scientists have devoted considerable effort to developing methods for understanding Earth's past atmosphere and climate. These techniques include analysis of gas bubbles trapped in ice, tree rings, and ocean and lake floor sediments for clues about past climates and atmospheres. Together, these techniques suggest that over the past 20 million years, the Earth's climate has oscillated between relatively warm and relatively cold conditions called interglacial and glacial periods. During interglacial periods, atmospheric CO<sub>2</sub> concentrations were relatively high, and during glacial periods, CO<sub>2</sub> concentrations were relatively low. We are currently in an interglacial warm period, and human activities are pushing CO<sub>2</sub> concentrations higher than they have been for hundreds of thousands of years (Figure 3).

Understanding and mitigating negative impacts of atmospheric CO<sub>2</sub> enrichment constitute two of the most central challenges that environmental scientists and policy makers currently face. In order to address this issue, the scientific community has formed the Intergovernmental Panel on Climate Change (IPCC), an international, interdisciplinary consortium comprised of thousands of climate experts collaborating to produce consensus reports on climate change science. Many nations have agreed to conditions specified by the Kyoto Protocol, a multilateral treaty aimed at averting the negative impacts associated with human-induced climate change. The United States, which is currently responsible for approximately one quarter of global CO<sub>2</sub> emissions, has so far declined to participate in the Kyoto Protocol.

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## Summary

Carbon, the fourth most abundant element in the universe, moves between the atmosphere, oceans, biosphere, and geosphere in what is called the *carbon cycle*. This module provides an overview of the global carbon cycle, one of the major [Top](#)  biogeochemical cycles. The module explains geological and biological components of



the cycle. Major sources and sinks of carbon are discussed, as well as the impact of human activities on global carbon levels.

## Key Concepts

- The presence of carbon determines whether something is organic or inorganic; all living things require carbon to live.
  - Carbon cycles through the ecosystem in various ways, from photosynthesis and respiration to weathering and other geologic processes.
  - Many factors, such as seasons and human activities, influence the concentration of carbon in the global atmosphere.
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## NGSS

HS-C1.5, HS-C5.2, HS-C7.2, HS-ESS2.A1, HS-ESS2.A3, HS-ESS2.D3, HS-LS2.B3

## Further Reading

Energy

Carbohydrates

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*John Arthur Harrison, Ph.D. "The Carbon Cycle" Visionlearning Vol. EAS-2 (3), 2003.*