A brief introduction to the carbon cycle

Background information for those assisting with the “State of the Carbon Cycle Report”
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Life on Earth depends on the cycling of carbon through myriad transformations and transfers among the atmosphere, the oceans, plants and animals, soils, and even rocks and sediments deep beneath the surface. The “carbon cycle” encompasses many cyclic processes, including, for example, the daily cycle of animal feeding and metabolism, the seasonal cycle of plant growth and decay, and the geologic cycle of sediment burial and weathering. All of these processes are ultimately linked to carbon exchange with the atmosphere, where carbon exists primarily in the form of the gas carbon dioxide (CO_2).

The concentration of atmospheric CO_2 is increasing. It is now one third higher than it was during the eighteenth century, and significantly higher than at any time during the last several hundred thousand years. Because CO_2 is an important “greenhouse” gas, there is growing concern that this increase in CO_2 concentrations is causing significant warming and other changes in global climate by altering the heat and water balances of Earth’s surface and atmosphere. Research on the carbon cycle has enabled scientists to attribute the rising CO_2 concentrations primarily to human activities, especially the burning of coal, gas, and oil (“fossil fuels”). As scientists attempt to anticipate future trends in atmospheric CO_2 and climate, they are challenged by the need for a more complete understanding of the carbon cycle.

Atmospheric CO_2 is cycled naturally through other forms of carbon over time scales ranging from seconds to millennia and longer. Carbon from atmospheric CO_2 is converted by photosynthesis in plants to carbon in leaves, stems, roots, and other organic matter. Some of this carbon is taken up in the bodies of plant-eating animals, but much of the organic carbon produced by plants is respired by both plants and animals to produce the energy they need for survival. The organic carbon consumed during respiration is converted to CO_2 and cycled back to the atmosphere. When dead plant matter is buried in soils or sediments, it becomes a food source for microorganisms, yielding not only recycled CO_2 but also a supply of nutrients required for continuing plant life. In the oceans, the CO_2 needed for photosynthesis is supplied from the atmosphere in dissolved form by exchange of air at the ocean surface. Marine plants comprise the base of the oceanic food chain, which eventually returns respired CO_2 to the ocean surface and the atmosphere.

Under certain conditions, carbon buried in soils or in marine sediments may not be cycled back to the atmosphere and oceans for millions of years. These deposits comprise the limestone and organic rock formations (including coal, gas, and oil deposits) that are naturally cycled very slowly through the Earth’s interior by geologic processes. Exposure to weathering ultimately returns rock carbon to the atmosphere and oceans. Even these very slow modes of carbon cycling play a central role in the long-term sustenance of life on Earth.

Human activities are altering a broad range of carbon-cycle processes. Agriculture, forestry, and other forms of land management vastly change Earth’s land cover and direct significant quantities of plant growth to the production of food, clothing, and shelter. Deforestation and soil degradation enhance the production of CO_2 from soils and dead plant material. The burning of fossil fuels produces atmospheric CO_2 from organic carbon that has been stored in rocks for periods as long as hundreds of millions of years. Although some human activities remove carbon from the atmosphere, their overall net effect is to increase the production of CO_2.

The rate of increase in atmospheric CO_2 has accelerated markedly in recent decades, paralleling the accelerating rate of net CO_2 production by human activities. Yet the increase in atmospheric CO_2 accounts for only about 40% of the CO_2 produced by deforestation, soil degradation, and fossil fuel consumption. Where does the rest of this CO_2 go? Research has shown that some of the CO_2 produced by human activities (sometimes termed "anthropogenic" CO_2) is being dissolved in the oceans, and some is apparently being taken up by forest growth and other changes on land. A primary objective of carbon-cycle research is to account for the complete mass balance or "budget" of anthropogenic CO_2, and to anticipate potential future changes in the CO_2 budget and the carbon cycle. A full accounting of the CO_2 budget includes identifying not only its sources, but also the processes that remove it from the atmosphere ("carbon sinks"), and the places and forms in which the carbon from CO_2 is stored ("carbon reservoirs"). Recent findings point toward the likelihood of significant terrestrial carbon sinks in northern temperate latitudes. Thus, efforts to understand the anthropogenic CO_2 budget now include a particular focus on the continents of the northern hemisphere and their adjacent ocean regions. The first "State of the Carbon Cycle Report" will reflect a research emphasis on the North American CO_2 budget and its significance to the global carbon cycle.

This "State of the Carbon Cycle Report" should be viewed as part of the ongoing effort to synthesize and assess scientific information about climate change. Understanding climate change depends on understanding the role of the carbon cycle and its responses to human activities. Conversely, one of the most significant uncertainties in projecting future change in the carbon cycle is its potential response to climate change. Thus, the changing carbon cycle is viewed not only as a primary driver of climate change, but also as a primary source of uncertainty in projecting future climate trends. Research directed toward improving projections of climate change is increasingly intertwined with research directed toward improving projections of the carbon cycle.

In response to public concern about the potential effects of changes in climate and in the carbon cycle, scientists are also studying possible ways to mitigate these changes through reductions in CO_2 emissions and/or augmentation of carbon sinks. This research requires extension beyond the traditional boundaries of physical and biological science to encompass the "human dimensions" of factors that affect fossil fuel consumption, energy and agriculture technologies, and land management. Some scientists are exploring the feasibility of new methods of deliberate carbon storage ("carbon sequestration"), including enhancement of plant growth, enrichment of soil carbon storage, and injection of CO_2 into the deep ocean and into subsurface rock formations. Like the effects of current human activities, potential future carbon management will involve significant changes in the global carbon cycle. Scientists now face not only the difficulties of understanding the carbon cycle and the CO_2 budget, but also the challenge of expanding and communicating their research in ways that are more responsive to societal needs. The "State of the Carbon Cycle Report" is a response to that challenge.