Carbon Cycling and Biosequestration

Integrating Biology and Climate through Systems Science

March 2008 Workshop Report

http://genomicsgtl.energy.gov/carboncycle/

One of the most daunting challenges facing science in the 21st Century is to predict how Earth's ecosystems will respond to global climate change. The global carbon cycle plays a central role in regulating atmospheric carbon dioxide (CO_2) levels and thus Earth's climate, but our basic understanding of the myriad tightly interlinked biological processes that drive the global carbon cycle remains limited. Whether terrestrial and ocean ecosystems will capture, store, or release carbon is highly dependent on how changing climate conditions affect processes performed by the organisms that form Earth's biosphere. Advancing our knowledge of biological components of the global carbon cycle is crucial to predicting potential climate change impacts, assessing the viability of climate change adaptation and mitigation strategies, and informing relevant policy decisions.

Workshop Purpose

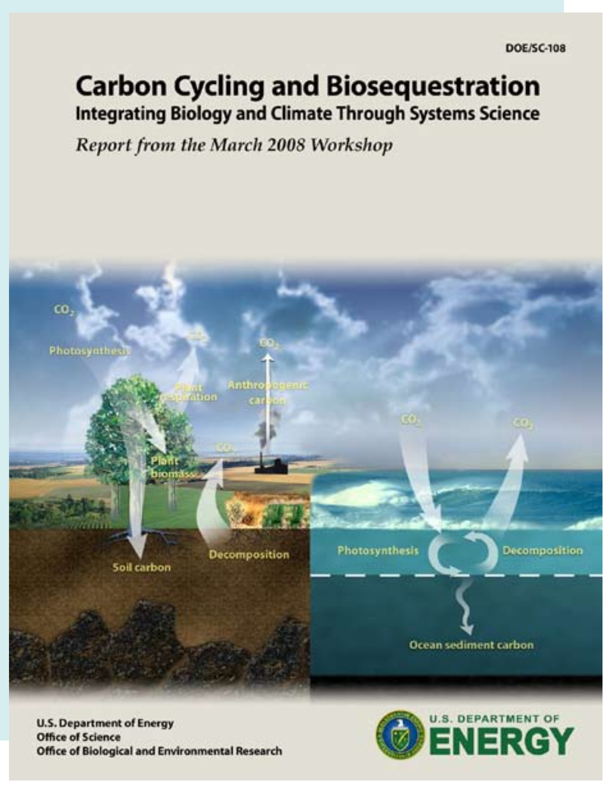
To develop research objectives aimed at better understanding and predicting the processes of the global carbon cycle, the U.S. Department of Energy's (DOE) Office of Biological and Environmental Research (OBER) hosted the Carbon Cycling and Biosequestration Workshop in March 2008. Scientists at the forefront of microbiology, plant biology, ecological research, and biogeochemical modeling identified research requirements necessary to (1) advance understanding of the biological processes that drive the global carbon cycle, (2) achieve greater integration of experimental biology and biogeochemical modeling approaches, (3) assess the viability of potential carbon biosequestration strategies, and (4) develop novel experimental approaches to validate climate model predictions.

A Science Strategy for the Future

Understanding and predicting processes of the global carbon cycle will require bold new research approaches aimed at linking global-scale climate phenomena; biogeochemical processes of ecosystems; and functional activities encoded in the genomes of microbes, plants, and biological communities. This goal presents a formidable challenge, but emerging systems biology research approaches provide new opportunities to bridge the knowledge gap between molecular- and global-scale phenomena. Systems-level research emphasizes studies on the underlying principles of intact, complex systems and facilitates scaling of concepts and data across multiple levels of biological organization. Applying this approach to the global carbon cycle will require multifaceted but highly integrated research that incorporates experimentation on model organisms and systems, collection of observational data on communities and ecosystems, and mechanistic modeling of processes ranging from metabolic to global scales (see Components of the Global Carbon Cycle, inside pages, and Table 1. Annual Fluxes in Global Carbon, back page).

Some Key Research Objectives

- Apply diverse scientific approaches to natural and model ecosystems, observations and experimentation, and modeling.
- Obtain a more detailed understanding of major carbon pools.
- Characterize and ultimately predict biological response to climate change with genomics and systems biology.
- Design experiments addressing multiple climate factors.
- Link carbon, nutrient, and water cycles.
- Address multiple scales of time and space for processes underlying climate change.
- Apply advanced instrumentation and methods.
- Understand the interactive genomic, environmental, and climatic influences on plant productivity.
- Determine the role of disturbance in ecosystem dynamics.



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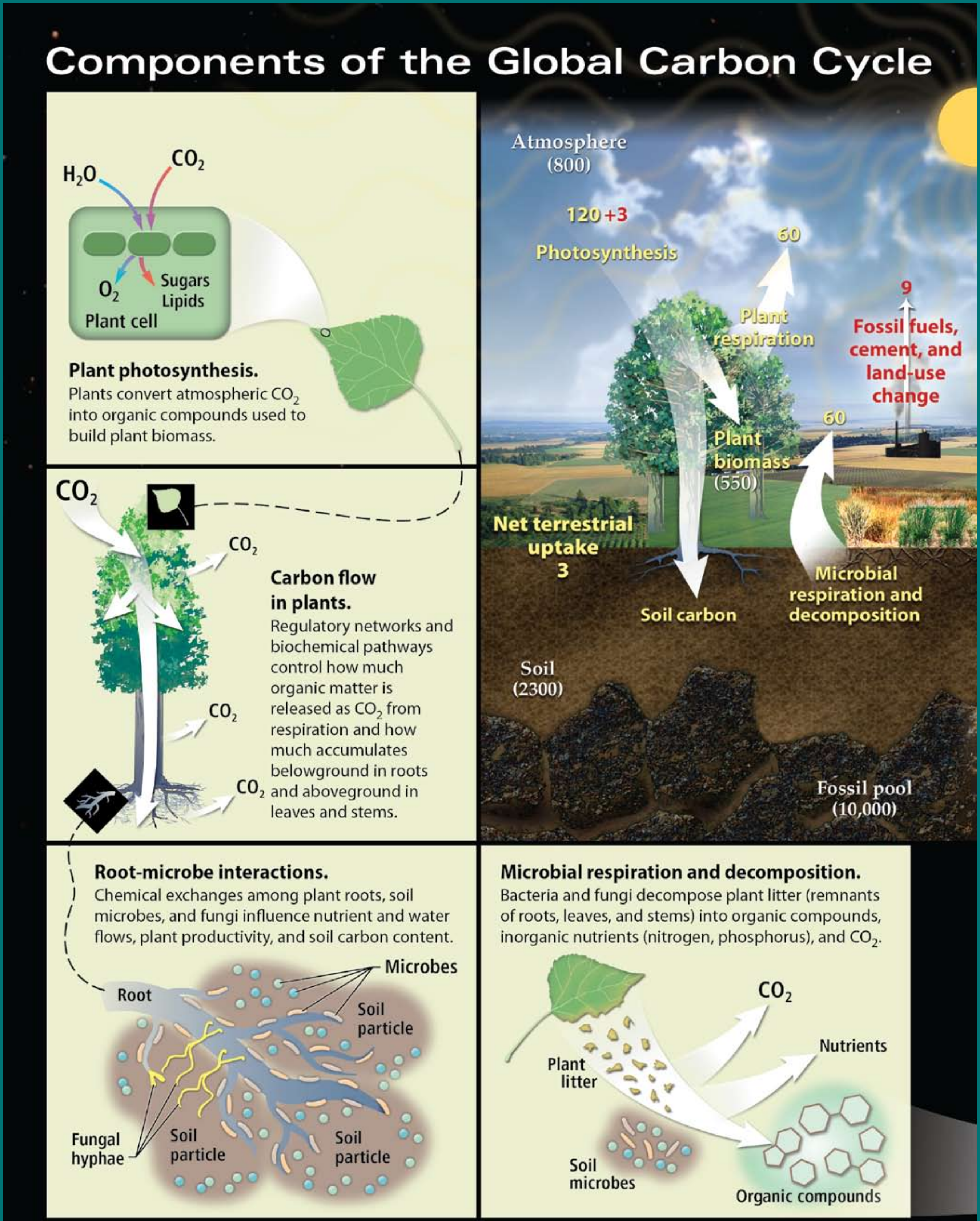
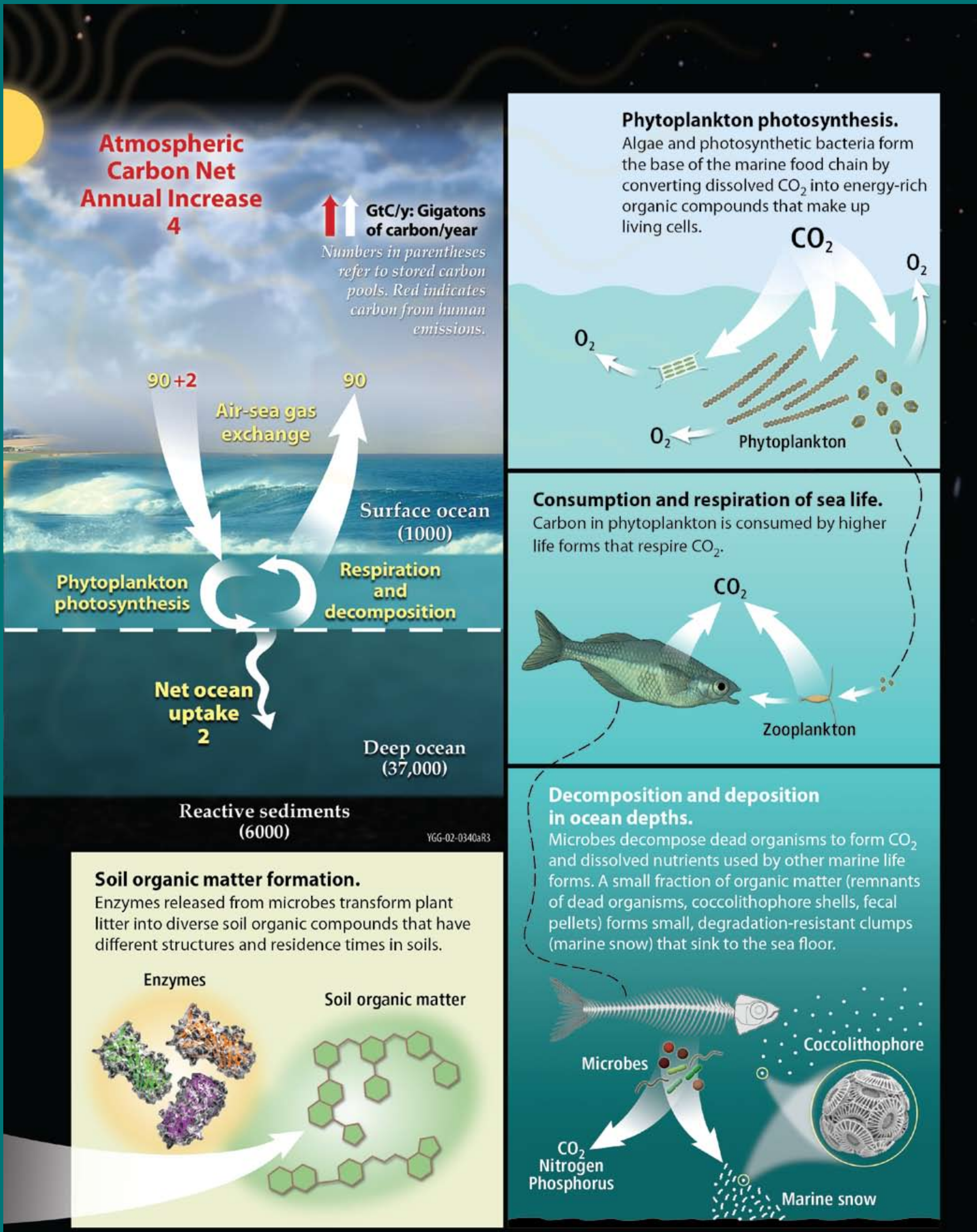


Components of the Global Carbon Cycle. A simplified representation of the contemporary global carbon cycle is shown in the center of this figure. Values in parentheses are estimates of the main carbon reservoirs in gigatons (GT).[1] The natural flux between the terrestrial biosphere and the atmosphere is about 120 GT of carbon per year, and that between the oceans and atmosphere is about 90 GT per year.[2] In the terrestrial biosphere, photosynthesis removes about 120 GT of carbon from the atmosphere; decomposition of biological material and respiration from plants and soil microbes return 120 GT of carbon.

In the oceans, the marine biosphere does not take up CO_2 directly from the atmosphere. Each year the oceans absorb and release about 90 GT of carbon largely via diffusion across the air-ocean interface. The physical processes controlling the sinking of CO_2 into colder, deeper waters (where CO_2 is more soluble) and the mixing of ocean water at intermediate



depths are known collectively as the "solubility pump." Phytoplankton photosynthesis converts CO_2 into organic carbon that is largely returned to ocean water as CO_2 via microbial respiration and decomposition. The "biological pump" refers to the small fraction of organic carbon that forms into degradation-resistant clumps and sinks to the ocean floor. Together the solubility and biological pumps control the amount of carbon transported to ocean depths and the exchange of CO_2 between ocean and atmosphere.

Human activities (primarily fossil fuel use) emit about 9 GT of carbon each year. About 4 GT of this human-contributed carbon remain in the atmosphere; 3 GT are taken up by natural terrestrial processes, and another 2 GT are removed by the ocean.[3]

Peripheral boxes describe some of the biological processes (photosynthesis, partitioning, respiration, and organic-matter formation) discussed in this report that play key roles in regulating the flow of carbon in and out of terrestrial and ocean ecosystems.

Meeting the Challenge with OBER Fundamental Research

Now widely recognized is the need to confront expanding global energy needs while simultaneously reducing carbon emissions and minimizing negative climate impacts. Transformational breakthroughs are required to increase the accuracy and resolution of climate change models that inform policy decisions, open new avenues to innovation in climate change adaptation and mitigation strategies, and assess the validity of potential solutions. Achieving an exponential increase in our understanding of the interwoven systems that control the ultimate fate of carbon in Earth's ecosystems is integral to meeting these challenges.

Operating within DOE's Office of Science, OBER is uniquely positioned to lead new national research initiatives aimed at achieving predictive, systems-level understanding of organisms, biological communities, ecosystems, and the global climate. OBER research has been crucial in advancing modern genomics-based systems biology, understanding community and ecosystem-scale responses to climate change variables, and developing increasingly sophisticated models of global climate processes.

Table 1. Annual Fluxes in Global Carbon (Gigatons of carbon per year)

Gross Natural Land-Atmosphere Carbon Fluxes[2]	
From atmosphere to plants	120
To atmosphere from plants	60
To atmosphere from soils	60
Gross Natural Ocean-Atmosphere Carbon Fluxes[2]	
From atmosphere to oceans	90
To atmosphere from oceans	90
Anthropogenic Carbon Emissions[3]	
To atmosphere from fossil fuel use	7.6
To atmosphere from land-use change	1.5
Total	9.1*
Fate of Anthropogenic Carbon Emissions[3]	
Added to atmosphere	4.1*
Absorbed by natural processes on land	2.8*
Absorbed by natural processes in oceans	2.2*

*Rounded to whole numbers in figure on inside pages.

[1]Houghton, R.A. 2007. "Balancing the Global Carbon Budget," *Annual Review of Earth and Planetary Sciences* **35**, 313–47.

[2]IPCC. 2007. *Climate Change 2007, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Released in four sections: *Working Group I Report: The Physical Science Basis; Working Group II Report: Impacts, Adaptation, and Vulnerability; Working Group III Report: Mitigation of Climate Change*; and *The Synthesis Report: Summary for Policymakers.* Cambridge University Press, New York.

[3]Canadell, J.G., et al. 2007. "Contributions to Accelerating Atmospheric CO_2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks," *Proceedings of the National Academy of Sciences of the United States of America* **104**(47), 18,866–870.

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