Carbon Cycling and Biosequestration Workshop Participants and Agendas

March 2008

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DOE Carbon Cycling and Biosequestration Workshop
Agenda for March 4, 5, and (6), 2008
Hilton Executive Meeting Center and Hotel, Rockville, Maryland

Tuesday, March 4

8:00 a.m. Welcome, Program Goals: Jerry Elwood

8:30 a.m. Workshop Objective, Agenda, and Output:
Sharlene Weatherwax, Joe Graber, Jeff Amthor, Roger Dahlman, Mike Knotek, Betty Mansfield

9:00 a.m. Plenary Presentations:

Jae Edmonds, Pacific Northwest National Laboratory
"Biotechnology, Energy, and a Climate-Constrained World"

Scott Denning, Colorado State University
"Global Biogeochemical Cycles and the Climate of the 21st Century"

10:30 a.m. Break

10:45 a.m. Introduction of Working Groups' Scopes, Discussion Points:

Working Group 1: Terrestrial Plant Productivity and Carbon Biosequestration
Cochairs: Dan Bush and Stan Wullschleger

Working Group 2: Biological Cycling of Carbon in Terrestrial Environments
Cochairs: Mary Firestone and Don Zak

Working Group 3: Biological Cycling of Carbon in Ocean Environments
Cochair: Scott Elliott (Other Cochair, Ginger Armbrust, during March 17–18 workshop in Denver)

Working Group 4: Effects of Climate Change on Carbon Cycling and Biosequestration
Cochairs: Jim Ehleringer and Rich Norby

Working Group 5: Crosscutting Science, Technology, and Infrastructure
Cochairs: Jim Fredrickson and Scott Elliott

12:00 noon Box Lunch Meeting with Assigned Working Groups

3:00 p.m. Group Break

3:30 p.m. Working Group Sessions Resume, Continue Discussion

6:00 p.m. Group Dinner

7:00 p.m. Working Group 5: Crosscutting Meeting;
Working Groups 1, 2, and 4 Continue Independent Work

Wednesday, March 5

8:00 a.m. Group Writing and Discussions of Basic Research Needs Plans and Transformational Challenges

12:00 noon Working Lunch

1:00 p.m. Plenary Outbriefs and Discussion

3:00 p.m. Working Groups Reconvene; Final Discussions

4:00 p.m. Main Meeting Adjourns

Thursday, March 6

8:00 a.m. Working Group 5 and Cochairs and Writers for Working Groups 1, 2, and 4 Continue Discussions, Writing

12:00 noon Workshop Adjourns

Detailed March 4–6 Agenda: General Process Flow for Working Group Sessions

Day 1, Tuesday, March 4		
Time Slot	**Activity**	**Product**
12:30 – 2:30	Frame topical area: Presentations and discussions	Consensus systems definition of problem area: System diagram
2:30 – 4:00	Create prospective list of Basic Research Need Plans (BRNPs)	Prospective list of items End-to-end systems analysis: Definition of critical-path biology items
4:00 – 6:00	Cull list and identify research requirements	Consensus list and completed BRNP forms ~5:00 p.m.: Each session provides topic list (electronic) for printing and intergroup comparison over dinner.
6:00 – 7:30: All groups together for dinner	Discuss BRNPs that transcend groups	Assignments of transcending BRNPs to specific groups
Evening	Continue defining research requirements and outlining thoughts for write-ups Crosscutting Working Group meets for discussions	Consensus items and research areas with prioritization Beginning definition of crosscutting portfolio
Day 2, Wednesday, March 5		
8:00 – 12:00	Group writing of BRNPs Group chairs audit process, discuss items as needed	Draft and refine BRNPs
12:00 – 1:00	Lunch	All files (including presentations) provided electronically to ORISE staff for printing
1:00 – 3:00	Plenary outbriefs and discussions	Presentations and comments
3:00 – 4:00	Working group sessions reconvene Final group discussions	Final modifications
4:00: Main workshop adjourns Working Group 5 and cochairs and writers from Working Groups 1, 2, and 4 continue working		Copies of all draft files, organized by group, provided by ORISE staff to participants. Electronic files can be loaded on thumb drives.
3:00 – 6:00: Remaining working group participants meet	Working Group 5: Discuss and coalesce common crosscutting capabilities, confirm with other groups as needed, assess gaps, and make writing assignments Working Groups 1, 2, and 4: Identify gaps, make writing assignments	Consensus output of targets; refined outlines
6:00 – 7:00: Dinner	Cochairs dine together	Identification of issues and problems
Evening	Work and discuss as appropriate; individual work time	Refined work products
Day 3, Thursday, March 6		
8:00 – 11:00	Working groups continue writing	Second drafts for comparison
11:00 – 12:00	Groups convene in plenary session for ad hoc presentations for intercomparison and review of output.	Strategy adjustments; new assignments
12:00	Workshop Adjourns	Electronic and hard-copy files shared among groups, with ORISE assistance Agreement as to additional items needed, follow-up process, and assignment schedules Final files emailed to all participants and available on website

DOE Carbon Cycling and Biosequestration Workshop: Biological Cycling of Carbon in Ocean Environments

Agenda for March 17–18, 2008

Courtyard Marriott Denver Airport, Denver, Colorado

Monday, March 17

8:00 a.m.	Welcome, Program Goals, Workshop Objectives: Joe Graber, Dan Drell, Mike Knotek, and Betty Mansfield
8:30 a.m	Summary of Previous Carbon Cycling and Biosequestration Workshop Sessions: Scott Elliott
9:00 a.m	Carbon Cycling in Ocean
12:00 noon	Lunch
1:00 p.m.	Reconvene; Continue Discussion
3:00 p.m.	Group Break
3:30 p.m.	Reconvene; Continue Discussion
6:00 p.m.	Main Workshop Adjourns
6:00 p.m.	Dinner for Cochairs, Writers, and DOE Staff

Tuesday, March 18

8:00 a.m.	Writing Group Convenes
12:00 noon	Workshop Adjourns

Detailed March 17–18 Agenda: General Process Flow

Time Slot	Activity	Product
Day 1, Monday, March 17		
9:00 – 12:00	Frame topical area: Discussion	Consensus definition of topical areas: System diagram
1:00 – 3:00	Create prospective list of Basic Research Need Plans (BRNPs)	Prospective list of items Definition of critical-path biology items
3:30 – 6:00	Group writing of BRNPs: Cull list and identify research requirements	Consensus list and completed BRNP forms
6:00 – 7:30: Dinner	Discuss writing assignment	Writing Assignments
Evening	Cochairs, writers work independently	Consolidation and prioritization of BRNPs (first drafts)
Day 2, Tuesday, March 18		
8:00 – 12:00	Group Writing: Compare first drafts, discuss, and adjust strategy as necessary	Consolidation of group output Development of additional materials
12:00	Workshop adjourns	Shared electronic and hard-copy files Agreement as to additional items needed; follow-up process, and assignment schedule Final files distributed to all participants via website

Glossary

adsorption: Accumulation of molecules or cells on the surface of a substance.

aerobic: Requiring oxygen.

aerosols: Airborne solid or liquid particles (typically no larger than a few micrometers) that can remain in the atmosphere for hours to days. Aerosols impact climate by scattering or absorbing radiation, initiating cloud formation, or altering the optical properties of clouds.

albedo: Proportion of light or radiation reflected by a surface.

alfisols: Fertile soils in temperate forests with an underlying clay horizon.

algae: Photosynthetic, aquatic, eukaryotic organisms that contain chlorophyll but lack terrestrial plant structures (e.g., roots, stems, and leaves). Algae can exist in many sizes ranging from single cells to giant kelps several feet long.

algorithm: Formal set of instructions that tells a computer how to solve a problem or execute a task. A computer program typically consists of several algorithms.

anaerobic: Lacking or not requiring oxygen.

andisols: Volcanic soils containing ash and volcanic glass.

anthropogenic: Resulting from human activity.

archaea: Single-celled prokaryotic microbes that are structurally and metabolically similar to bacteria but share some features of their molecular biology with eukaryotes.

aridisols: Dry desert soils with a prominent clay horizon.

atomic force microscopy: Technique that uses a mechanical probe to characterize and magnify surface features with atomic detail.

ATP (adenosine triphosphate): A multifunctional nucleotide responsible for cellular energy transfer and storage.

autotroph: An organism that biochemically synthesizes its own organic materials from inorganic compounds using light or chemical energy.

bacterioplankton: Bacteria that inhabit marine and freshwater environments.

Bayesian approach: Use of statistical methods that assign probabilities or distributions to future events based on knowledge of prior events.

biochar: Biomass-derived black carbon.

biogeochemical model: A type of ecosystem model used to represent biologically mediated transformations and flows of carbon and other materials within an environment.

biogeochemistry: Study of how interactions among biological and geochemical processes influence the global cycling of such essential elements as carbon, nitrogen, phosphorus, and sulfur.

biogeographical model: A type of ecosystem model used to determine how populations in a particular region change over long time scales.

bioinformatics: Science of managing and analyzing biological data using advanced computing techniques.

biological pump: Collection of biological ocean processes that regulate the uptake, storage, transformation, and release of carbon.

biome: A terrestrial region (e.g., grasslands, tropical forests) characterized by dominant vegetation and climate characteristics in terrestrial ecosystems. In aquatic environments, a biome is defined by a particular range of depths and biogeochemical properties.

biopolymer: A large biological molecule formed by the linking together of smaller subunit molecules.

biosequestration: Biologically mediated uptake and conversion of carbon dioxide to inert, long-lived, carbon-containing materials.

biosphere: All living organisms.

bole: Stem or trunk of a tree.

C_3 plant: Plants (e.g., soybean, wheat, and cotton) whose carbon-fixation products have three carbon atoms per molecule. Compared with C_4 plants, C_3 plants show a greater increase in photosynthesis with a doubling of CO_2 concentration and less decrease in stomatal conductance, which results in an increase in leaf-level water use efficiency.

C_4 plant: Plants (e.g., maize and sorghum) whose carbon fixation products have four carbon atoms per molecule. Compared with C_3 plants, C_4 plants show little photosynthetic response to increased CO_2 concentrations above 340 ppmv but show a decrease in stomatal conductance, which results in an increase in photosynthetic water use efficiency.

CO_2 fertilization: Increase in plant growth due to a higher-than-normal carbon dioxide concentration in the environment.

Calvin cycle: A series of photosynthetic chemical reactions that do not require light to occur. The Calvin cycle uses energy produced by light-dependent reactions of photosynthesis to incorporate carbon from carbon dioxide into organic compounds used to make sugars, starches, and other biological molecules.

carbon allocation: See *carbon partitioning.*

carbon cycle: The complex carbon flows and transformations among major Earth system components (atmosphere, oceans, and terrestrial systems). The global flow of carbon from one reservoir (carbon sink) to another. Each carbon exchange among reservoirs is mediated by a variety of physical, biogeochemical, and human activities.

carbon dioxide: Gas that is an important part of the global carbon cycle. CO_2 is emitted from a variety of processes (e.g., cellular respiration, biomass decomposition, fossil fuel use) and taken up primarily by the photosynthesis of plants and microorganisms. CO_2 is a greenhouse gas that absorbs infrared radiation and traps heat in the Earth's atmosphere.

carbon fixation: Conversion of inorganic carbon dioxide to organic compounds by photosynthesis.

carbon flux: Rate of carbon movement as it flows from one carbon reservoir to another in the global carbon cycle. For the global carbon budget, carbon flux is usually expressed in gigatons of carbon per year (GT C/yr).

carbon partitioning: Partitioning to different parts of a plant (e.g., leaf, stem, root, and seed) versus carbon allocation (partitioning between biomass and respiration).

carbon sequestration: Biological or physical process that captures carbon dioxide and converts it into inert, long-lived, carbon-containing materials.

carbon sink: A pool (reservoir) that absorbs or takes up released carbon from another part of the carbon cycle. For example, if the net exchange between the biosphere and the atmosphere is toward the atmosphere, the biosphere is the source, and the atmosphere is the sink.

carbon source: A pool (reservoir) that releases carbon to another part of the carbon cycle.

carbon use efficiency (CUE): Ratio of net primary productivity to gross primary productivity.

chemoautotroph: An organism that biochemically synthesizes its own organic materials from inorganic compounds using chemical energy.

chemostat: Apparatus for the continuous cultivation of bacteria. Chemostats keep bacterial cultures in an optimal growth state by continually adding media and removing old cells.

chlorophyll: A type of green pigment used to harness light energy in the chloroplasts of plants and other photosynthetic organisms.

chloroplast: An organelle in the cells of green plants. It contains chlorophyll and functions in photosynthesis and protein synthesis.

climate: Average weather conditions over a time period, usually several decades. Climate is largely determined by local geographical features, latitude, altitude, land- and sea-masses, and atmospheric circulation patterns.

climate model: Mathematical model used to understand, simulate, and predict climate trends by quantitatively analyzing interactions among Earth system components (e.g., land, ocean, atmosphere, and biosphere).

coccolithophore: A type of single-celled marine algae distinguished by its production of intricate, microscopic shells that are aggregates of calcium carbonate discs called coccoliths.

cofactor: An organic or inorganic substance required by an enzyme to function.

community: All the different species of organisms living together and interacting in a particular environment.

copepod: A type of microscopic marine and freshwater crustacean that has an elongated body and a forked tail.

crenarchaea: A phylum of archaea distinguished from other phyla based on rRNA sequence. Crenarchaea are the most abundant type of marine archaea.

cyanobacteria: Division of photosynthetic bacteria found in many environments, including oceans, fresh water, and soils. Cyanobacteria contain chlorophyll a and other photosynthetic pigments in an intracellular system of membranes called thylakoids. Many cyanobacterial species also are capable of nitrogen fixation.

cytoplasm: All cellular contents surrounding the nucleus of a membrane-bound eukaryotic cell.

denitrification: Anaerobic conversion of nitrate or nitrite to nitrogen gas (N_2) by denitrifying bacteria. A small portion of nitrate or nitrite may be converted to nitrous oxide (N_2O), a potent greenhouse gas.

desorption: Removal of a substance in the reverse of absorption or adsorbtion.

detritus: Remnants of biological material.

diatom: Type of microscopic, photosynthetic algae known for its intricately designed, silica-containing shell. Thousands of diatom species are known; most are unicellular, but some form colonies. Diatoms are responsible for a large portion of photosynthetic carbon assimilation in marine and freshwater environments.

dinoflagellate: Any of a group of eukaryotic microorganisms containing both plant-like and animal-like species that lives in marine and freshwater environments. These unicellular microorganisms use a pair of dissimilar cellular appendages called flagella for motility.

disturbance: Any abrupt event that drastically changes ecosystem characteristics such as population diversity, behavior, or climate response.

DNA (deoxyribonucleic acid): Molecule that encodes genetic information. DNA is a double-stranded molecule held together by weak bonds between base pairs of nucleotides. The four nucleotides in DNA contain the bases adenine (A), guanine (G), cytosine (C), and thymine (T).

dynamic global vegetation model (DGVM): Biogeographical model used to study how general categories of plant functional types are established and respond to competition, disturbances, and other factors.

Earth System Model (ESM): A type of complex, global model that combines physical climate models, global biological processes, and human activities.

ecophysiology: Study of the physiological functions of organisms as they pertain to their ecology or interactions with each other and their environment.

ecosystem: Set of living organisms (plants, animals, fungi, and microorganisms) and the physical and chemical factors that make up a particular environment.

ectomycorrhizae: A type of mycorrhizal fungus that surrounds a plant root tip but does not penetrate the cell walls of the root with its hyphae.

edaphic: Related to or determined by soil characteristics (e.g., soil texture, composition, drainage).

El Niño: An irregular variation of ocean current that flows off the west coast of South America, carrying warm, low-salinity, nutrient-poor water to the south. El Niño events, which occur every 4 to 12 years, can cause die-offs of plankton and fish and unusual weather patterns by altering jet stream winds and storm tracks.

electron acceptor: Substance that gains electrons from another substance in an oxidation-reduction reaction.

electron donor: Substance that loses electrons to another substance in an oxidation-reduction reaction.

endomycorrhizae: A type of mycorrhizal fungus that surrounds a plant root tip and uses its hyphae to penetrate the cell walls of the root. Endomycorrhizal fungi form vesicle-like structures at the root cell surface that enhance the transport of substances between a plant and fungus.

endophyte: Any organism (usually a fungus or microbe) that lives inside another organism and establishes a parasitic or mutualistic relationship with its host.

entisols: Undifferentiated soils of recent origin found in river valleys and deltas.

epiphyte: Any organism that grows upon or attaches to a living plant for physical support but not for nutrients.

eukaryote: A single-celled or multicellular organism (e.g., plant, animal, or fungi) with a cellular structure that includes a membrane-bound, structurally discrete nucleus and other well-developed subcellular compartments. See also *prokaryote*.

euphotic zone: The layer of a body of water that receives sufficient sunlight for photosynthesis. The depth of this layer, which is about 80 m, is determined by the water's extinction coefficient, its cloudiness, and the sunlight's angle of incidence.

extremophile: An organism that can survive in physically or chemically extreme conditions that are not livable to most other organisms.

exudates: See *root exudate*.

feedback: An interaction mechanism between processes in the Earth system that occurs when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

flow cytometry: A method for analyzing and separating cells or chromosomes based on light scattering and fluorescence. Also known as flow sorting.

gas chromatography: An automated method for separating a substance into its components. The substance is volatilized and carried by a stream of gas through a column containing an inert solid or liquid matrix that separates each component before reaching a detector device.

gelisols: Cold surface soils with underlying permafrost.

gene: Fundamental physical and functional unit of heredity. A gene is an ordered sequence of nucleotides, located in a particular position on a particular chromosome, that encodes a specific functional product (i.e., a protein or RNA molecule).

gene expression: Process by which a gene's coded information is converted into structures present and operating in the cell. Expressed genes include those transcribed into mRNA and then translated into proteins, as well as those transcribed into RNA but not translated into proteins [e.g., transfer (tRNA) and ribosomal RNA (rRNA)].

gene product: Biochemical material, either RNA or protein, resulting from expression of a gene. The amount of gene product is used to measure a gene's level of activity.

gene regulatory network: Intracellular network of regulatory proteins that control the expression of gene subsets involved in particular cellular functions. A simple network would consist of one or more input signaling pathways, regulatory proteins that integrate the input signals, several target genes (in bacteria a target operon), and the RNA and proteins produced from those target genes.

genera: A taxonomic category of organisms that ranks between family and species. Genera (singular: genus) for higher organisms generally consist of species with similar characteristics.

general circulation model (GCM): A class of computer-driven models (sometimes called global circulation models) that provide weather forecasts and climate projections. GCMs integrate a variety of fluid dynamical, chemical, and biological equations that represent processes in Earth system components (e.g., land, ocean, atmosphere, and biosphere).

genome: All the genetic material in the chromosomes of a particular organism. Most prokaryotes package their entire genome into a single chromosome, while eukaryotes have different numbers of chromosomes. Genome size generally is given as total number of base pairs.

genome sequence: Order of nucleotides within DNA molecules that make up an organism's entire genome.

genomics: The study of genes and their function.

genotype: An organism's genetic constitution, as distinguished from its physical characteristics (phenotype).

gigaton (GT): One billion metric tons; a metric ton is a unit of mass equal to 1000 kg (about 2200 lb).

greenhouse gas: Heat-trapping gas such as carbon dioxide, methane, nitrous oxide, or dimethyl sulfide released into the atmosphere as a result of human activities (primarily fossil fuel combustion) and natural processes (e.g., cellular respiration, biomass decomposition, volcanic activity).

gross primary productivity (GPP): Total amount of organic matter created by photosynthesis over a defined time period (total product of photosynthesis).

haplotype: A segment of DNA containing closely linked gene variations that are inherited as a unit.

hemicellulose: Any of several polysaccharides (e.g., xylans, mannans, and galactans) that cross-link and surround cellulose fibers in plant cell walls.

heterotroph: Organism that obtains organic carbon by consuming other organisms or the products of other organisms.

hexose: A type of sugar molecule that contains six carbon atoms (e.g., glucose, fructose).

high throughput: Done on a massive, automated scale.

histosols: Poorly drained soils in swamps and bogs that contain more than 20% organic matter.

homeostasis: Tendency of an organism or a cell to maintain its internal conditions regardless of external changing conditions.

homology: Similarity in DNA sequence or structure based on descent from a common ancestor.

humus: Long-lived mixture of organic compounds derived from the microbial decomposition of plant and animal matter in soils.

hydrometeoric: Relating to atmospheric phenomena that depend on water vapor.

hydrophilic: Having the ability to readily interact with water.

hydrophobic: Incapable of interacting with water.

hydrotropism: Ability of a plant to sense and grow toward water.

hyphae: Branching, threadlike filamentous cells of a fungus.

in silico: Using computers to simulate and investigate natural processes.

in situ: In a natural environment.

in vivo: Within a living organism.

inceptisols: Variable soils with horizon development in early stages.

interaction network: Diagram that shows numerous molecular interactions of a cell. Each point or node on the diagram represents a molecule (typically a protein), and each line connecting two nodes indicates that two molecules are capable of interacting.

interactome: Molecular interactions of a cell, typically used to describe all protein-protein interactions or those between proteins and other molecules.

isotope: Atom that has the same number of protons as another atom but a different number of neutrons and hence atomic mass. For example, ^{13}C is an isotope of carbon that has one more neutron than the most common isotope of carbon, ^{12}C.

La Niña: An irregular variation of ocean current that flows off the west coast of South America, carrying cool, nutrient-rich water to the surface. La Niña typically follows El Niño events, which occur every 4 to 12 years.

lateral gene transfer: Exchange of genetic material between two different organisms (typically different species of prokaryotes). This process gives prokaryotes the ability to obtain novel functionalities or cause dramatic changes in community structure over relatively short periods of time.

lignin: Complex, insoluble polymer whose structure, while not well understood, gives strength and rigidity to cellulose fibers in the cell walls of woody plants. Lignin makes up a significant portion of the mass of dry wood and, after cellulose, is the second most abundant form of organic carbon in the biosphere.

liquid chromatography: An automated method used to separate, identify, and quantify the components of a liquid solution. A sample is carried by a mobile liquid phase through a column packed with solid particles that separates each component before reaching a detector device.

loci: Chromosomal locations of genes or genetic markers. (singular: locus)

macroaggregates: Large (greater than 250 micrometers in size) mineral–organic matter complexes in soils that physically protect organic matter from degradation.

marine snow: Aggregates of mostly organic materials that sink to the ocean floor from the photosynthetically active surface layers.

mass spectrometry: Method involving specialized instruments for measuring the mass and abundance of molecules in a mixture and identifying mixture components by mass and charge.

membrane: Semipermeable biological barrier consisting of lipids, proteins, and small amounts of carbohydrate. Membranes control the flow of chemical substances (e.g., nutrients, protons, ions, and wastes) in and out of cells or cellular compartments. They also serve as structural supports for systems of membrane-embedded proteins that mediate important biological processes such as photosynthesis and cellular respiration.

mesofauna: Any animal of intermediate size (e.g., insects, earthworms).

mesophyll: Internal, irregularly-shaped, photosynthetic tissue within a leaf.

messenger RNA (mRNA): RNA that serves as a template for protein synthesis. See also *transcription* and *translation*.

metabolic flux analysis (MFA): Method for measuring all the metabolic fluxes of an organism's central metabolism; ^{13}C-labeled substrate is taken up by an organism, and the distribution of ^{13}C throughout the metabolic network enables the quantification of labeled metabolite pools.

metabolism: Collection of all biochemical reactions that an organism uses to obtain the energy and materials it needs to sustain life. An organism uses energy and common biochemical intermediates released from the breakdown of nutrients to drive the synthesis of biological molecules.

metabolites: Small molecules (<500 Da) that are the substrates, intermediates, and products of enzyme-catalyzed metabolic reactions.

metabolomics: Type of global molecular analysis that involves identifying and quantifying the metabolome—all metabolites present in a cell at a given time.

metadata: Data that describe specific characteristics and usage aspects (e.g., what data are about, when and how data were created, who can access the data, and available formats) of raw data generated from different analyses.

metagenomics: Study of the collective DNA isolated directly from a community of organisms living in a particular environment.

metaomics: High-throughput, global analysis of DNA, RNA, proteins, or metabolites isolated directly from a community of organisms living in a particular environment.

metaproteomics: High-throughput, global analysis of proteins isolated directly from a community of organisms living in a particular environment. Metaproteomics can reveal which genes are actively translated into functional proteins by a community.

metatranscriptomics: High-throughput, global analysis of RNA isolated directly from a community of organisms living in a particular environment. Metatranscriptomics can reveal which genes are actively expressed by a community.

methane clathrates: Ice crystals that contain large amounts of methane. Massive quantities of methane clathrates have been found under sediments in the ocean floor.

microaggregates: Small (50–250 micrometers in size) mineral–organic matter complexes in soils that physically protect organic matter from degradation.

microarray: Analytical technique used to measure the mRNA abundance (gene expression) of thousands of genes in one experiment. The most common type of microarray is a glass slide onto which DNA fragments are chemically attached in an ordered pattern. As fluorescently labeled nucleic acids from a sample are applied to the microarray, they bind the immobilized DNA fragments and generate a fluorescent signal indicating the relative abundance of each nucleic acid in the sample.

microbiome: A community of microorganisms that inhabit a particular environment. For example, a plant microbiome includes all the microorganisms that colonize a plant's surfaces and internal passages.

microorganism: Any unicellular prokaryotic or eukaryotic organism, sometimes called a microbe.

mixotrophic: Having both autotrophic and heterotrophic capabilities.

model: Mathematical representation used in computer simulations to calculate the evolving state of dynamic systems.

model ecosystem: A specific type of ecosystem that is widely studied in great detail by a community of researchers to provide insights into the processes controlling the behavior of other ecosystems.

model organism: Organism studied widely by a community of researchers. Biological understanding obtained from model-organism research is used to provide insights into the biological mechanisms of other organisms. Microbial model microorganisms include the bacteria *Escherichia coli*, the yeast *Saccharomyces cerevisiae*, and the mustard weed *Arabidopsis thaliana*.

modeling: Use of statistical and computational techniques to create working computer-based models of biological phenomena that can help to formulate hypotheses for experimentation and predict outcomes of research.

molecular machine: Highly organized assembly of proteins and other molecules that work together as a functional unit to carry out operational, structural, and regulatory activities in cells.

mollisols: Grassland soils with a thick, dark organic-surface horizon.

mycelium: Mass of hyphae that make up the body of a fungus.

mycorrhizae: Fungi that establish symbiotic relationships with plant roots.

nano-SIMS: Imaging technique that uses a nanoscale secondary ion mass spectrometer (nano-SIMS) and cells labeled with stable isotopes of carbon and/or nitrogen to identify areas of active growth and follow nutrient fluxes between cells.

net biome productivity (NBP): Amount of organic carbon that remains in a biome after accounting for carbon losses or gains from disturbances such as fire, disease, and human land use.

net ecosystem productivity (NEP): Amount of organic carbon (e.g., plant biomass, soil organic matter) that remains after respiration by photosynthetic organisms, heterotrophs, and decomposers.

net primary productivity (NPP): Fraction of photosynthetically fixed energy that remains after accounting for cellular respiration. NPP also is defined as the total amount of photosynthetic biomass created annually.

nitrification: Transformation of ammonium ions to nitrate by nitrifying bacteria.

nitrogenase: Enzyme that catalyzes the conversion of atmospheric nitrogen (N_2) to nitrate in nitrogen-fixing bacteria and archaea.

nitrogen fixation: Process carried out by certain species of bacteria and archaea in which atmospheric nitrogen (N_2) is converted to organic nitrogen-containing compounds that can be used by other organisms.

nuclear magnetic resonance (NMR): Technique used to study molecular structure by analyzing the absorption of electromagnetic resonance at a specific frequency in atoms subjected to strong magnetic field.

oligotrophic: Term used to describe lakes or other bodies of water that lack nutrients and plant life and have high concentrations of dissolved oxygen.

omics: Collective term for a range of new high-throughput biological research methods (e.g.,transcriptomics, proteomics, and metabolomics) that systematically investigate entire networks of genes, proteins, and metabolites within cells.

orthologs: Similar gene or gene segments appearing in the genomes of different species but resulting from speciation and mutation.

oxidation: Loss of one or more electrons from a chemical substance.

oxisols: Tropical soils rich in iron and aluminum oxides.

pathway: Series of molecular interactions that occur in a specific sequence to carry out a particular cellular process (e.g., sense a signal from the environment, convert sunlight to chemical energy, break down or harvest energy from a carbohydrate, synthesize ATP, or construct a molecular machine).

PCR (polymerase chain reaction): Rapid technique for generating millions or billions of copies of any piece of DNA. PCR also can be used to detect the existence of a particular sequence in a DNA sample.

pelagic zone: Open ocean that is not near the coast or ocean floor.

perennial: Plant that lives from year to year.

pH: Scale used to specify acidity or alkalinity. The hydrogen ion (H^+) concentration of a sample determines its pH (pH = –log10 [H^+]); the higher the H^+ concentration, the lower the pH. A solution with a pH value of 7 is neutral; less than 7 is acidic; and greater than 7 is alkaline or basic.

phenology: Study of recurring biological phenomena.

phenomics: Collective study of multiple phenotypes (e.g., all phenotypes associated with a particular biological function).

phenotype: Physical characteristics of an organism.

phloem: Vascular tissue that distributes sugars and nutrients throughout a plant.

photosynthate: Organic carbon produced by photosynthesis.

photosynthesis: Process by which plants, algae, and certain types of prokaryotic organisms capture light energy and use it to drive the transfer of electrons from inorganic donors (e.g., water) to carbon dioxide to produce energy-rich carbohydrates.

photosystem: Large, membrane-bound molecular complex consisting of multiple proteins containing pigment molecules (e.g., chlorophylls) that absorb light at a particular wavelength and transfer the energy from the absorbed photon to a reaction center that initiates a series of electron-transport reactions.

phototroph: Organism capable of photosynthesis.

phylogeny: Evolutionary history that traces the development of a species or taxonomic group over time.

physicochemical: Relating to both physical and chemical properties.

physiology: Study of the functions of living organisms and the factors that influence those functions.

phytoplankton: Free-floating, microscopic photosynthetic organisms (e.g., algae, cyanobacteria, dinoflagellates) found in the surface layers of marine and freshwater environments.

phytosiderophores: Chemical compounds released from the roots of certain plants (e.g., grasses) to sequester iron from the environment.

polymer: A large molecule formed by the linking together of smaller subunit molecules.

population: Collection of organisms of the same species living together in a given area. A community comprises several different populations.

primary production: Production of organic compounds from carbon dioxide, primarily through photosynthesis.

prokaryote: Single-celled organism lacking a membrane-bound, structurally discrete nucleus and other subcellular compartments. Bacteria and archaea are prokaryotes. See also *eukaryote*.

promoter: DNA site to which RNA polymerase will bind and initiate transcription.

protein: Large molecule composed of one or more chains of amino acids in a specific order; the order is determined by the base sequence of nucleotides in the gene that codes for the protein. Proteins maintain distinct cell structure, function, and regulation.

protein complex: Aggregate structure consisting of multiple protein molecules.

proteome: Collection of proteins expressed by a cell at a particular time and under specific conditions.

proteomics: Large-scale analysis of the proteome to identify which proteins are expressed by an organism under certain conditions. Proteomics provides insights into protein function, modification, regulation, and interaction.

proteorhodopsin: Light-dependent proton pumps in marine bacteria.

protozoa: Single-celled, eukaryotic microorganisms that use cellular appendages called flagella to propel them through their environments.

radioisotope: Unstable isotope of an element that releases radiation as it decays to a stable form.

Redfield ratio: Optimal ratio of carbon, nitrogen, and phosphorus for phytoplankton growth (106C:16N:1P) based on molecular concentrations.

reduction: Electron-transfer reaction in which a substance gains one or more electrons.

regulatory elements: Segments of the genome (e.g., regulatory regions, genes that encode regulatory proteins, or small RNAs) involved in controlling gene expression.

regulatory region or sequence: Segment of DNA sequence to which a regulatory protein binds to control the expression of a gene or group of genes that are expressed together.

respiration: Series of biochemical redox reactions in which the energy released from the oxidation of organic or inorganic compounds is used to generate cellular energy in the form of ATP.

rhizosphere: Narrow zone of soil surrounding a plant root.

ribosomal RNA (rRNA): Specialized RNA found in the catalytic core of the ribosome, a molecular machine that synthesizes proteins in all living organisms.

RNA (ribonucleic acid): Molecule that plays an important role in protein synthesis and other chemical activities of the cell. RNA's structure is similar to that of DNA. Classes of RNA molecules include messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA), and other small RNAs, each serving a different purpose.

root exudate: Chemical substance released from the root of a plant.

RuBisCo (Ribulose-1,5-bisphosphate carboxylase/oxygenase): Enzyme that catalyzes the first major step of photosynthetic carbon fixation by adding a molecule of carbon dioxide to a short 5-carbon sugar called ribulose bisphosphate. The resulting 6-carbon sugar is split into two 3-carbon molecules that can be used to build larger sugar molecules. RuBisCo also catalyzes photorespiration, which releases CO_2.

senescence: Process of aging.

simulation: Combination of multiple models into a meaningful representation of a whole system that can be used to predict how the system will behave under various conditions. Simulations can be used to run in silico experiments to gain first insights, form hypotheses, and predict outcomes before conducting more expensive physical experiments.

solubility pump: System of physical processes [e.g., changes in water temperature, ocean circulation, and gradient of carbon dioxide (CO_2) spanning the ocean depth] that influences the ocean's uptake of CO_2 from the atmosphere. In combination with ocean circulation, the solubility pump results in net CO_2 emissions at the equator and net CO_2 drawdown at high latitudes.

species: Taxonomic group of closely related organisms sharing structural and physiological features that distinguish them from individuals belonging to other species. In organisms capable of sexual reproduction, individuals of the same species can interbreed and generate fertile offspring. For microorganisms, a species is a collection of closely related strains.

spodosols: Acidic soils—typically found in coniferous forests—containing organic matter, aluminum oxides, and iron oxides.

stable isotope: Isotope that does not undergo radioactive decay.

stochastic: Relating to a series of random events.

stoichiometry: Ratio of molecules in a structural complex or chemical reaction.

superoxide dismutase: Enzyme that protects cells from oxidative damage by catalyzing the transformation of superoxide (a harmful species of oxygen) into oxygen and hydrogen peroxide.

symbiosis: Ecological relationship between two organisms in which both parties benefit.

synchrotron: Research facility that accelerates charged particles and uses an increasing magnetic field to keep the particles in a circular path. Electromagnetic radiation emitted by the high-energy, accelerated particles can be used in a variety of scientific applications.

systems biology: Use of global molecular analyses (e.g., measurements of all genes and proteins expressed in a cell at a particular time) and advanced computational methods to study how networks of interacting biological components determine the properties and activities of living systems.

taxa: Categories (e.g., phylum, order, family, genus, or species) used to classify animals and plants (singular: taxon).

taxonomy: Hierarchical classification system for naming and grouping organisms based on evolutionary relationships.

transcript: RNA molecule (messenger RNA, or mRNA) generated from a gene's DNA sequence during transcription.

transcription: Synthesis of an RNA copy of a gene's DNA sequence; the first step in gene expression. See also *translation*.

transcription factor: Protein that binds to regulatory regions in the genome and helps control gene expression.

transcriptomics: Global analysis of expression levels of all RNA transcripts present in a cell at a given time.

translation: Process in which the genetic code carried by mRNA directs the synthesis of proteins from amino acids. See also *transcription*.

troposphere: Region of the atmosphere closest to the Earth's surface.

tussock: A tuft or clump of grass or other vegetation.

ultisols: Acidic, clay-containing soils with strong horizons found in temperate humid and tropical regions.

Van der Waals bonds: Weak intermolecular bonds resulting from the attraction between electron-rich regions of one molecule and electron-poor regions of another.

vertisols: Seasonally dry soils with a high clay content that swell when moist and then crack when dry.

virus: Noncellular biological entity that can replicate only by infecting a host cell and using its reproductive capabilities.

windthrow: Trees uprooted by wind.

zooplankton: Free-floating, microscopic animals that drift with water currents.

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