Please note: Users may read this poster in their Web browser by zooming in on any section using the Acrobat "Zoom" tool.

When printing a copy of this poster, users are encouraged to set their page to 11x17.

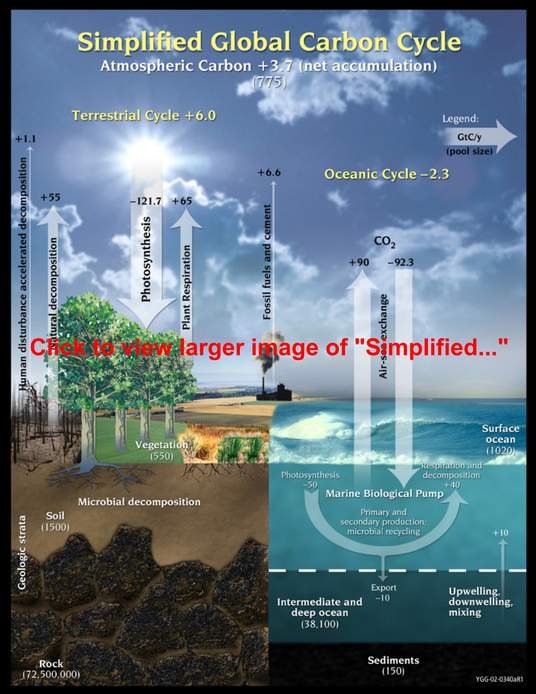
U.S. Department of Energy Office of Science

Carbon Sequestration Research Programs

Science-Based Solutions for Mitigating Global Climate Change

Office of Science U.S. DEPARTMENT OF ENERGY

25 Years of Carbon Dioxide Research at the U.S. Department of Energy



Click to view larger image of "Simplified..."

The Earth's biosphere

is a large and accessible reservoir for sequestering CO_2 already present in the atmosphere. Because natural carbon fluxes are large compared with anthropogenic emissions, even small forced changes resulting from R&D advances can be very significant. Addressing the environmental consequences of altering natural fluxes will be critical.

DOE's Office of Science focuses its carbon sequestration research efforts in four areas:

- Enhancing the Natural Terrestrial Cycle
- Microbial Genome Research
- Carbon Sequestration in the Oceans
- Sequestering Carbon in Underground Geologic Formations

Domesticated poplar trees optimized to enhance carbon storage and yield more energy- and cost-efficient products such as ethanol

Terrestrial

CO_2 is removed from the atmosphere by photosynthesis and stored in vegetation, litter, and soil organic matter. Enhancing these processes requires advances in the fundamental understanding of biological and ecological processes and the formation of soil organic matter in unmanaged and managed terrestrial ecosystems. A greater understanding of the mechanisms and magnitudes provides a scientific foundation for estimating the quantity of excess carbon that can be removed from the atmosphere by terrestrial ecosystems.

The time series of tallgrass prairie restorations at the Fermilab National Environmental Research Park is helping to define upper bounds for soil carbon sequestration potential in the Midwest.

Examples of research challenges in this program:

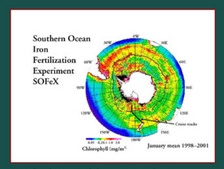
- **Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with emphasis on physiology and rates of photosynthesis of vascular plants**
- **Retaining organic matter in soils and enhancing its transformation into protected physical and chemical forms**
- **Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic carbon**
- **Increasing the capacity of degraded and underutilized lands to sequester carbon**

Sampling for Soil Carbon at the Oak Ridge National Environmental Research Park

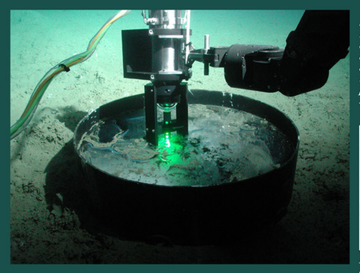
Oceanic

Oceans represent large potential sinks for sequestering CO_2 emissions. The goal of the ocean carbon sequestration research program is to provide the fundamental science to allow an objective evaluation of direct injection of CO_2 into the midwater or deep ocean and enhancement of natural ocean carbon sequestration by fertilization of phytoplankton with nutrients. The long-term effectiveness and potential environmental consequences of either strategy are unknown and are the focus of this research.

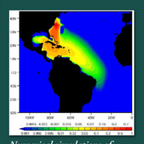
Autonomous robotic profiling floats (Carbon Explorers) deployed inside and outside the iron-treated waters assessed carbon biomass variability from the surface to 1000 meters depth and gathered information on carbon sedimentation rates near 100 meters.



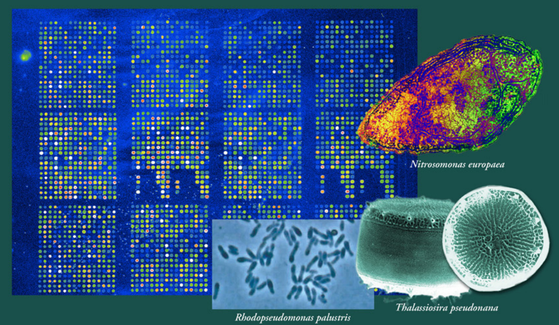
Iron fertilization of the ocean to enhance phytoplankton production is a carbon sequestration strategy requiring careful scientific assessment. Several open ocean enrichment experiments have been performed to evaluate the effects of additional iron on ecosystem structure and behavior in the equatorial Pacific and Southern Ocean. The Southern Ocean Iron Enrichment Experiment (SOFeX) is a small-scale study aimed at producing a tested model with predictive capability.



Small-scale direct injection of liquid carbon dioxide into the deep sea. Research will aid in evaluating the risks and opportunities presented by this strategy.



Numerical simulations of direct injection of CO_2 in the near and far field



Molecular techniques are used to identify key genetic and regulatory components of microbes relevant to carbon sequestration.

Microbial

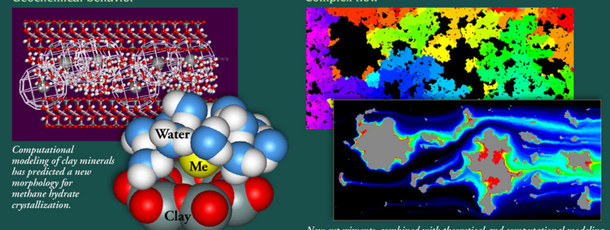
Microbes are responsible for much natural CO_2 absorption on land and at sea and are also potential sources for producing fuels such as methane and hydrogen. Sequencing the genomes of relevant microbes enables further explorations to identify key genetic and biochemical components that regulate the production or capture of these gases and eventually will add powerful new approaches to carbon management.

Obtaining greater knowledge of how particular enzymes or pathways operate, for example, will allow evaluation of their potential for producing methane or hydrogen from either fossil fuels or other carbonaceous sources, including biomass or even some waste products. Similarly, understanding in greater detail how microbes absorb CO_2 can provide clues to enhancing these ongoing natural processes.

This research capitalizes on investments made in DOE's Human Genome Program, Microbial Genome Program, and Genomes to Life Program.

Geologic

Geochemical behavior



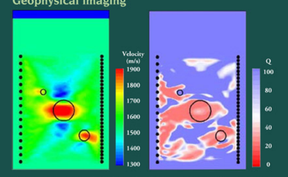
Computational modeling of clay minerals has predicted a new morphology for methane hydrate crystallization.

Structure of methane hydrate (Me) formed in clay interlayer (simulation)

Complex flow

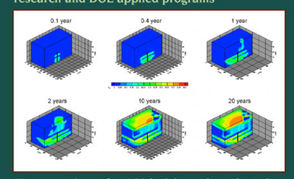
New experiments, combined with theoretical and computational modeling, have tracked the flow of two phases in fractured and porous media and have shown how both phases move in competition. Upper figure shows phase displacement in rough-walled fracture leading to entrapment of CO_2 (black); displacement order is shown in color from purple, blue, green, and yellow to red. Lower figure depicts subsequent dissolution of CO_2 (now gray) from flowing fracture; dissolved concentrations of CO_2 are shown in color from blue (0) to red (CO_2 saturated).

Geophysical imaging



Acoustic imaging of acrylic rods within a water tank provided the first laboratory images of an analog system of seismic intrinsic attenuation. These images show velocity (left) and quality factor (right) from viscoacoustic inversion of laboratory data.

A critical synergy: Office of Science basic carbon research and DOE applied programs



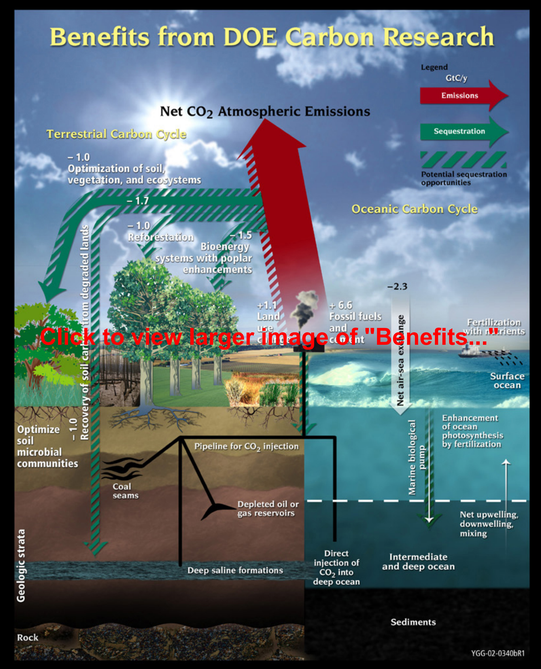
Using recent advances from BES-funded research, simulations have been performed to assess the behavior of CO_2 injected into the Frio Formation along the Upper Texas Gulf Coast (a future FE-funded sequestration demonstration test site). 3-D snapshots show the degree of gas saturation at different times for CO_2 injection into a saline aquifer associated with a heterogeneous sandstone-shale sequence.

Geological formations such as brine aquifers, oil and gas fields, and coal beds offer potentially significant large-scale opportunities for storage of CO_2. A thorough understanding of geological parameters and processes is needed so that storage capacity can be maximized and potential leakage rates minimized. In addition, geological science will be challenged to help develop tools for monitoring and performance assessment of CO_2 storage.

Key scientific needs focused on by the Office of Science include:

- **Geochemical investigations on the reaction kinetics and thermodynamics of water-rock-CO_2 interactions in mixed fluids and their multicomponent reactive transport phenomena,**
- **Computational studies leading to improved coupled hydrologic-mechanical-chemical-transport models, and**
- **Geophysical research on microseismic mechanisms and deformation modeling and scientific advances in high-resolution geophysical imaging.**

The Basic Energy Sciences Geosciences Research Program (GRP) provides cross-cutting, fundamental science supporting multiple internal DOE missions. The program specializes in building multidisciplinary teams among researchers at universities and national laboratories. GRP partially supports some applied program activities to aid "tech transfer" between basic and applied science, as in the case of the FE/NETL-funded GEO-SEQ project.



Click to view larger image of "Benefits..."

A DOE CO_2 Resource

CDIAC: Carbon Dioxide Information Analysis Center

The Carbon Dioxide Information Analysis Center (CDIAC) is the primary global-change data and information analysis center of DOE. CDIAC responds to data and information requests from users worldwide who are concerned with the greenhouse effect and global climate change.

For More Information

Office of Science Carbon Sequestration (includes details on Oceanic, Terrestrial, and Microbial)
cdiac2.esd.ornl.gov/index.html

DOE Basic Energy Sciences/Geosciences Research Program
www.er.doe.gov/production/bes/geo/geohome.html

Carbon Dioxide Information Analysis Center
cdiac.esd.ornl.gov

AmeriFlux
public.ornl.gov/ameriflux/Participants/Sites/Map/index.cfm

Free Air CO_2 Enrichment (FACE)
cdiac.esd.ornl.gov/programs/FACE/face.html

Consortium for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems (CSITE)
csite.esd.ornl.gov/

Contacts

John Houghton (Microbes and Poplar)
301/903-8288, john.houghton@science.doe.gov

Anna Palmisano (Oceans)
301/903-9963, anna.palmisano@science.doe.gov

Roger Dahlman (Terrestrial)
301/903-4951, roger.dahlman@science.doe.gov

Nick Woodward (Geologic)
301/903-4061, nick.woodward@science.doe.gov