Carbon Sequestration Research Supported by the DOE Office of Science

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Geosciences Research Program
Office of Basic Energy Sciences
Office of Science

Fourth Annual Conference on Carbon Capture and Sequestration
Hilton Alexandria Mark Center
Alexandria, Virginia
May 5, 2005

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Office of Science Programmatic Criteria

Excellence –

Innovative high-quality research

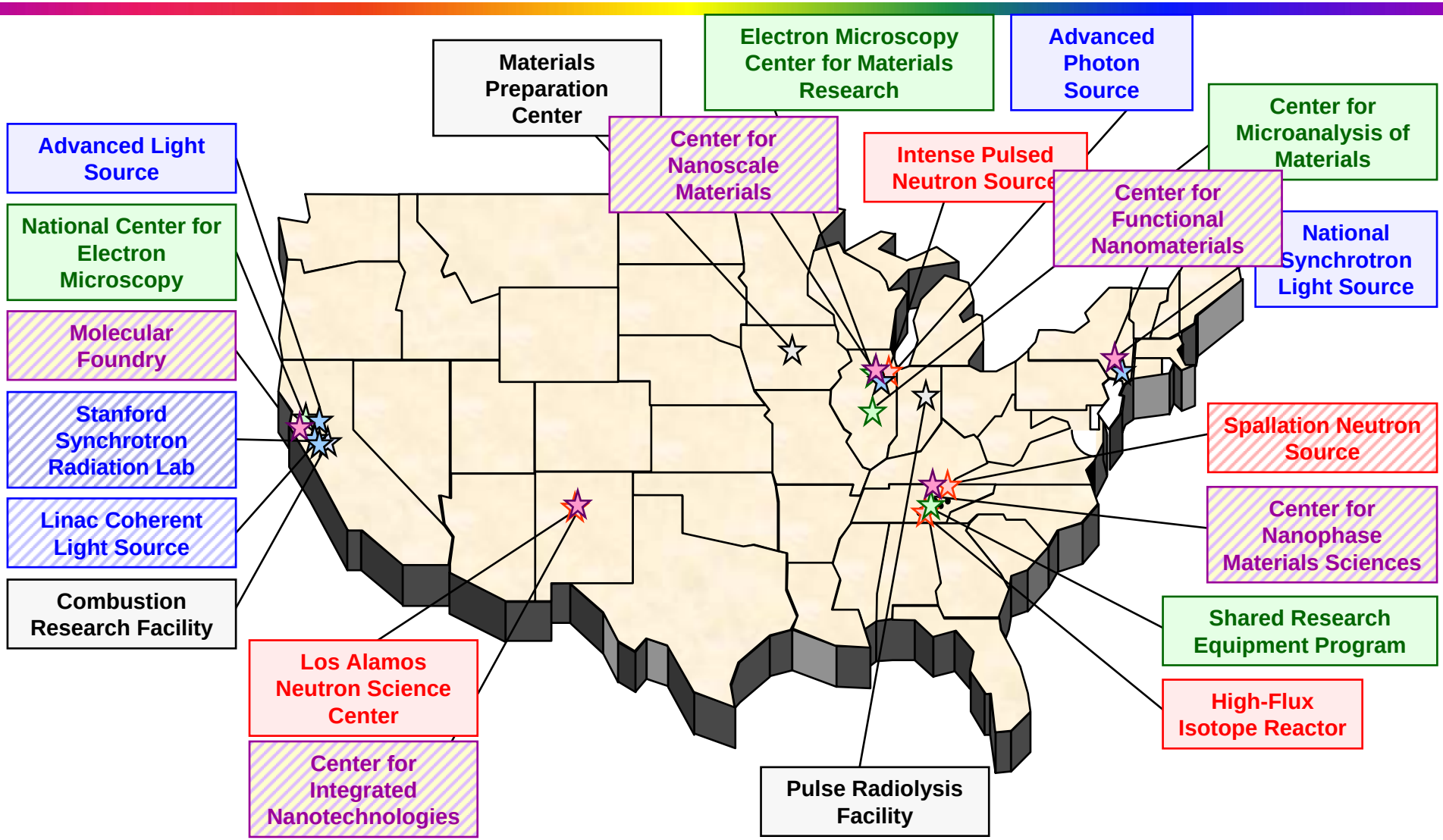
Relevance

Importance in supporting long-term DOE mission objectives

Stewardship

Using DOE facilities and supporting DOE laboratory capabilities

Office of Science - BES User Facilities



- *1 Linac Coherent Light Source (PED)*
- *3 Special Purpose Centers*
- *4 Synchrotron Radiation Light Sources*
- *4 High-Flux Neutron Sources (SNS under construction)*
- *4 Electron Beam Microcharacterization Centers*
- *5 Nanoscale Science Research Centers (PED and construction)*

Research Objectives

Research does two things:

It expands the RANGE OF OPTIONS, and

It provides the basis for WISE CHOICES among options.

Office of Science R&D - Carbon Sequestration

Fundamental science on geologic, ocean, and terrestrial sequestration, and advanced biological concepts for sequestration

Basic research on sequestration includes:

Experimental investigations, process studies, and modeling to enable:

- **Improvement of existing concepts and approaches;**
- **Development of advanced concepts and strategies;**
- **Assessment of monitoring and measurement strategies to demonstrate effectiveness**
- **Assessments of potential consequences of proposed solutions**

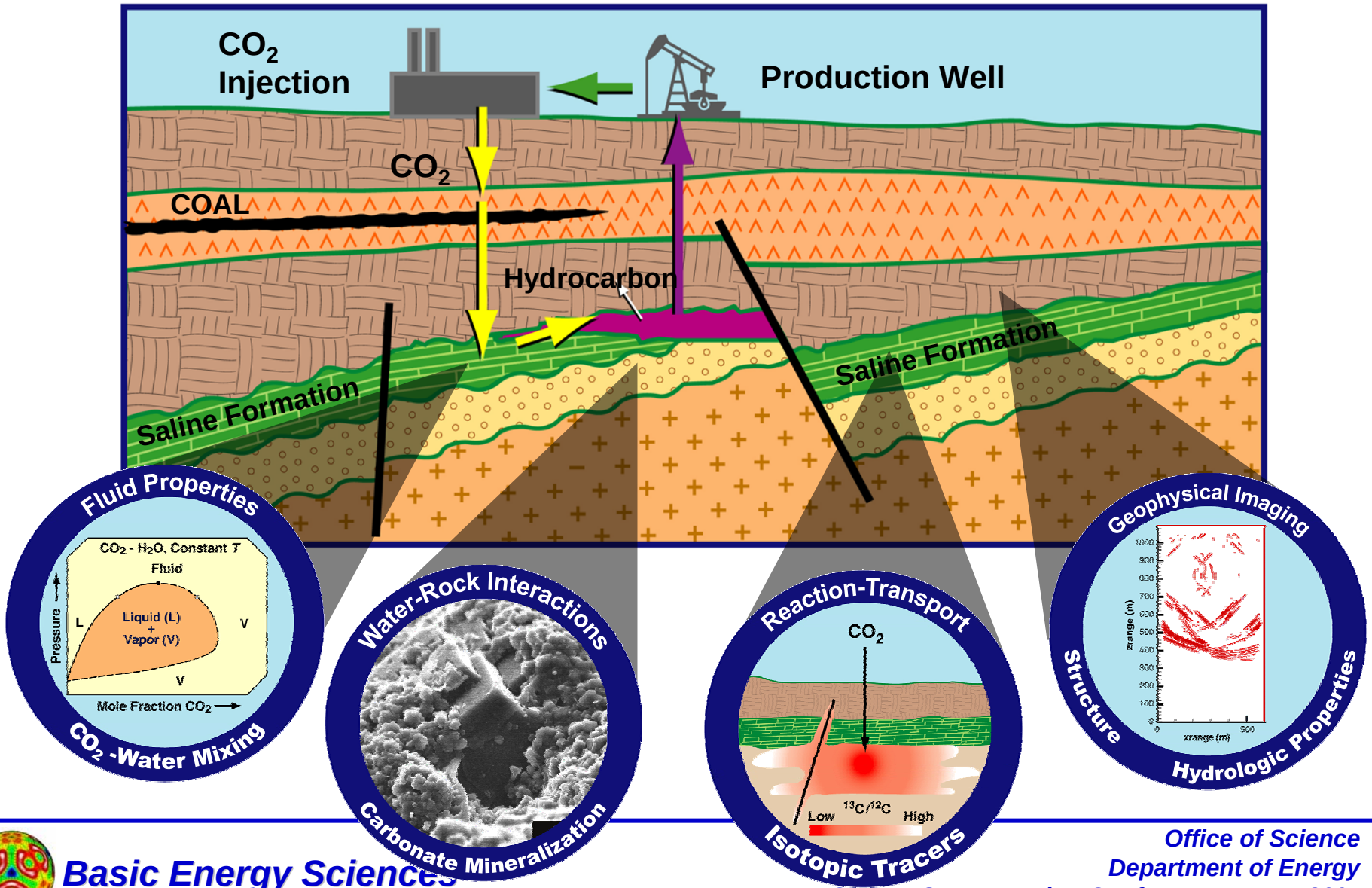
Office of Science R&D - Carbon Sequestration

Geologic sequestration research – Office of Basic Energy Sciences

Research that will help provide a sound scientific basis for both assessing long-term storage security and risks and defining performance requirements.

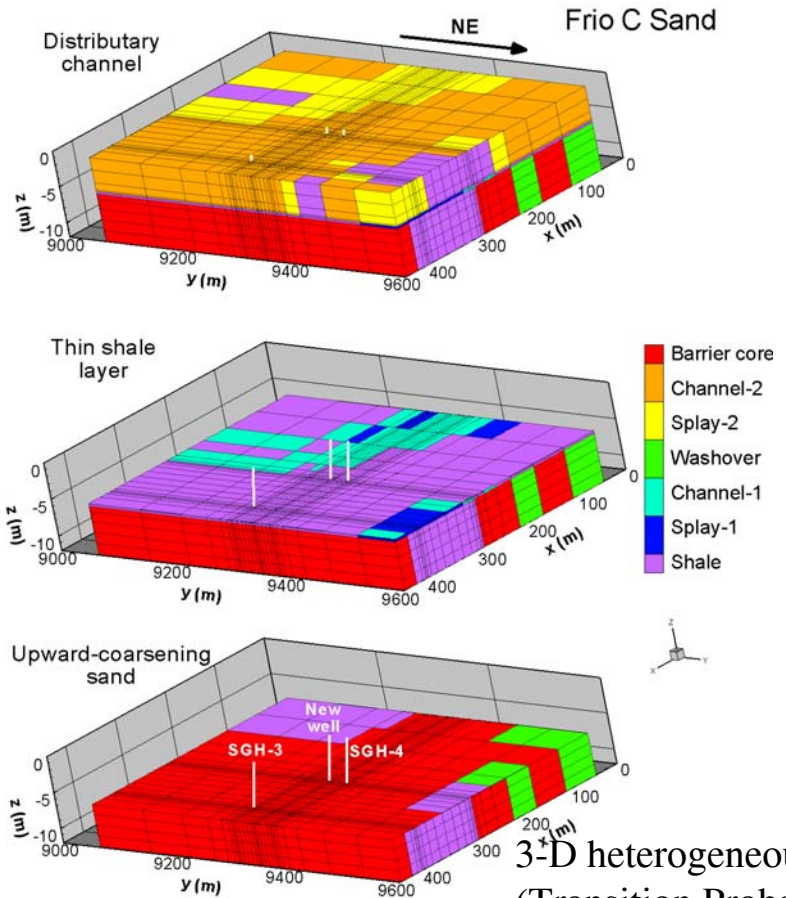
- **Geochemical investigations of rock-water interactions; how CO_2 disposal would change the geological and hydrological stability of subsurface formations**
- **Hydrological, mechanical, and chemical numerical modeling of the physics of subsurface fluid flows, e.g., flow of injected CO_2**
- **High resolution geophysical imaging to understand and track potential impacts of injected CO_2**

Office of Science R&D - Carbon Sequestration

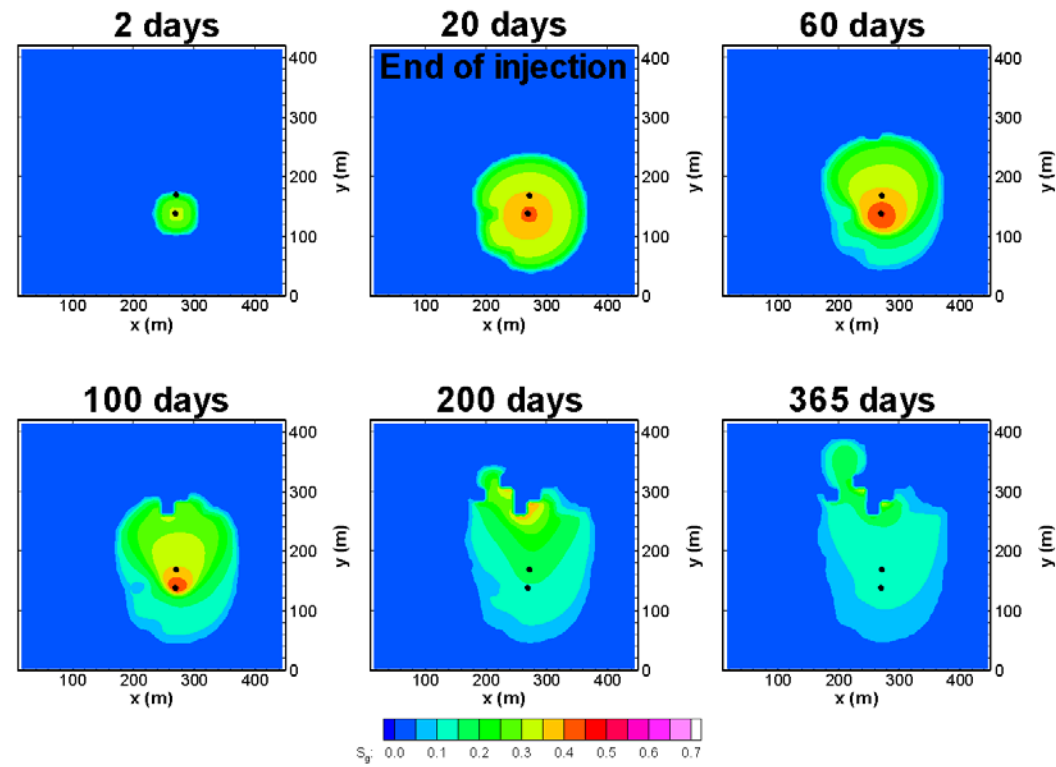


Office of Science R&D - Carbon Sequestration

How well does CO2 Disposal in Saline Aquifers work? Models are Critical for Evaluating the Feasibility of CO_2 Storage. Simulating the Coupled Effects of Fluid Flow + Heat Flow + Chemistry + Geomechanics



3-D heterogeneous reservoir model (Transition Probability Geostatistics)

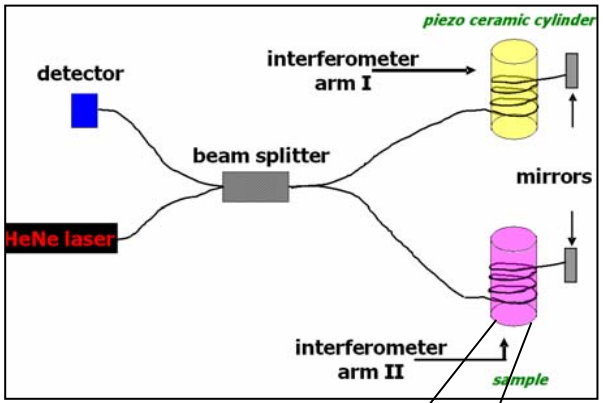


Gas saturations at top of upward-coarsening sand

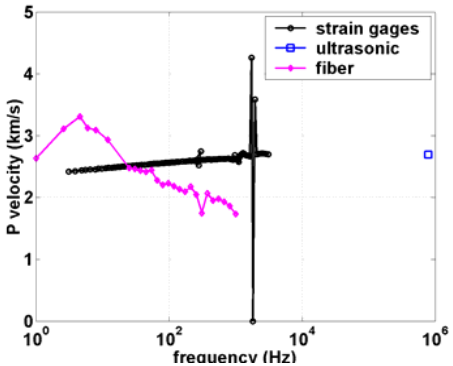
Office of Science R&D - Carbon Sequestration

Seismic Velocity and Attenuation: 1Hz to 1kHz: Optical Measurements of Velocity and Attenuation at Seismic Frequencies: Increasing Sensitivity and Accuracy

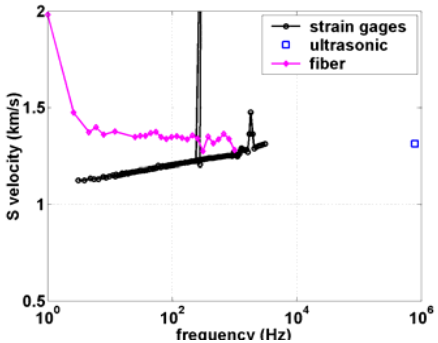
Fiber-Optic Strainmeter



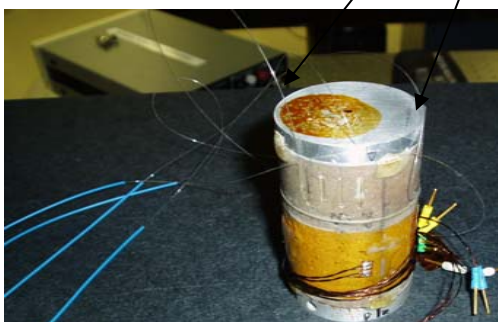
Velocity: p-wave



Velocity: s-wave

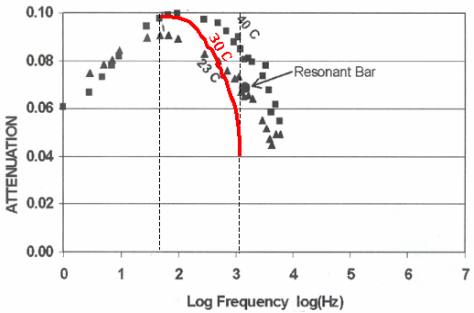


Rock Core



Frequency dependence of velocity and attenuation is controlled by the permeability, fluid type and saturation of the heterogeneous rock core.

Attenuation



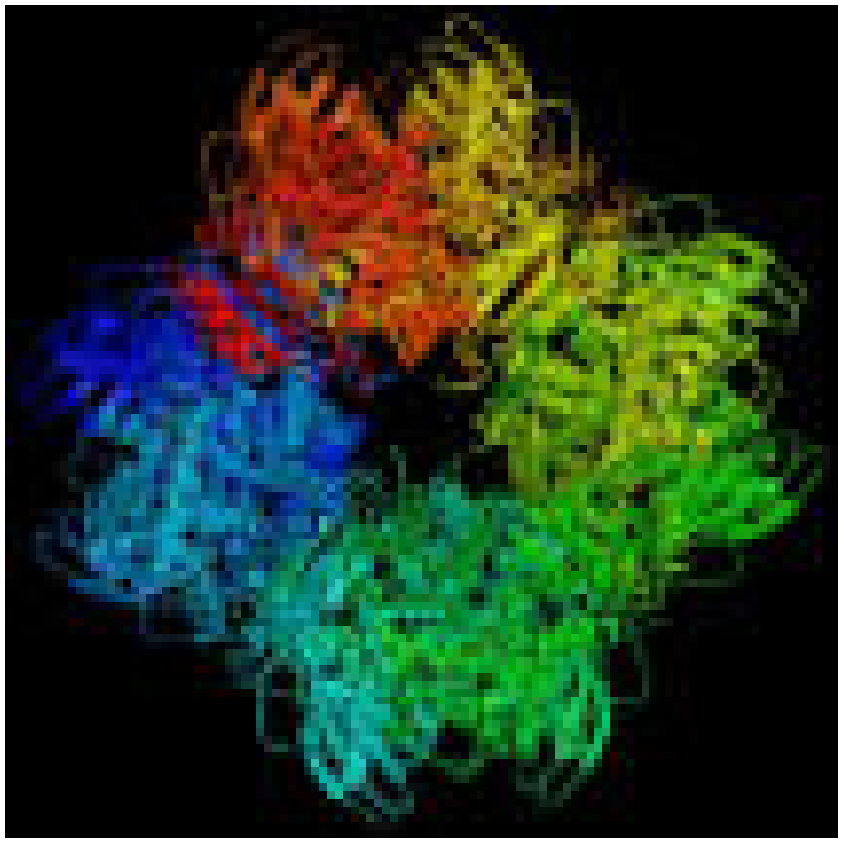
Office of Science R&D - Carbon Sequestration

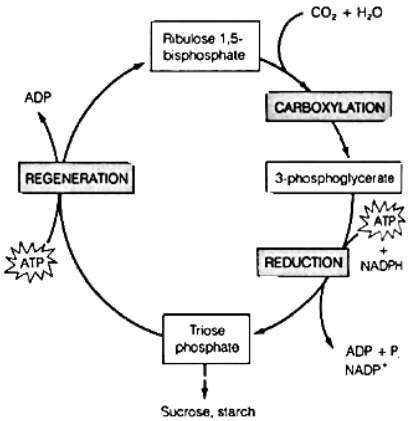
Energy Biosciences Sequestration Research – Office of Basic Energy Sciences

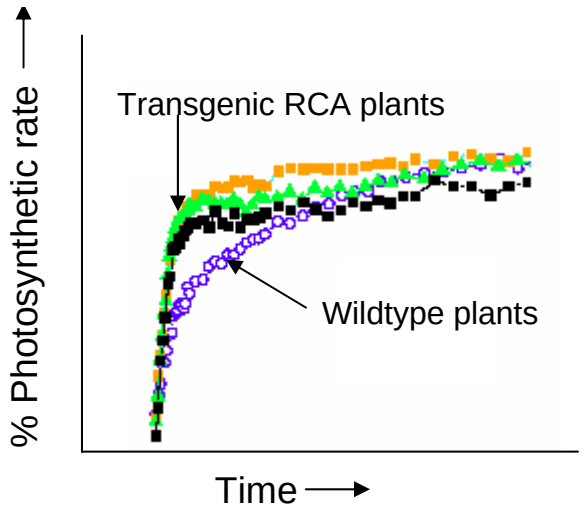
- **Research to understand biological regulatory mechanisms for more efficient synthesis and utilization of carbon-containing materials by plants and microbes**
- **Understanding biochemical and metabolic pathways of assembly of stable macromolecules by plants and microbes**
- **Carbon fixation and its subsequent assimilation, storage, and mobilization for growth by plants and microbes**

Office of Science R&D - Carbon Sequestration

Improving Carbon Fixation Altering Regulation of Rubisco, the enzyme in plants that fixes atmospheric CO2 during photosynthesis







A potential design principal for enhancing the ability of plants to remove CO_2 from the atmosphere.

Office of Science R&D - Carbon Sequestration

Terrestrial Sequestration –

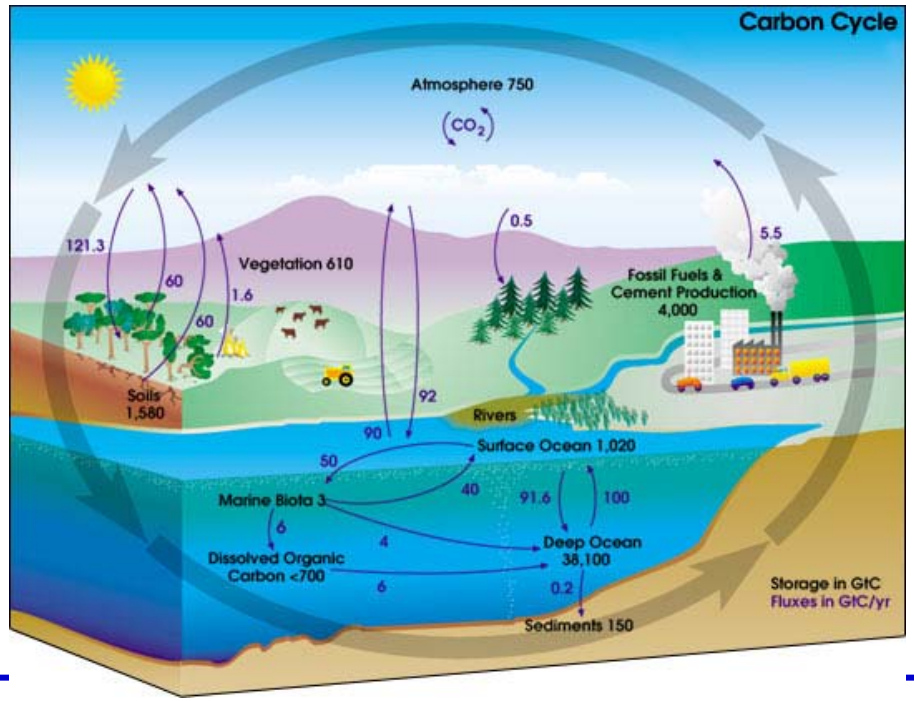
Office of Biological and Environmental Research

Research to develop approaches for enhancing carbon sequestration in terrestrial ecosystems – long-lived vegetation and soil pools

- **Field and lab studies to identify processes controlling carbon sequestration in terrestrial ecosystems**
- **Geochemical and biological process studies on how to modify natural processes to enhance carbon sequestration in long-lived vegetation and soils**
- **Develop new, reliable methods for measuring and monitoring carbon sequestration in terrestrial systems**

AmeriFlux – Processes Controlling Sources and Sinks

- ~ 80% of CO_2 taken up by photosynthesis at >30 flux sites is returned to the atmosphere by respiration
- Net sequestration of carbon averages 20% of gross photosynthesis in some mature forests(Law et al. Agric. For. Meteorol. 2002)

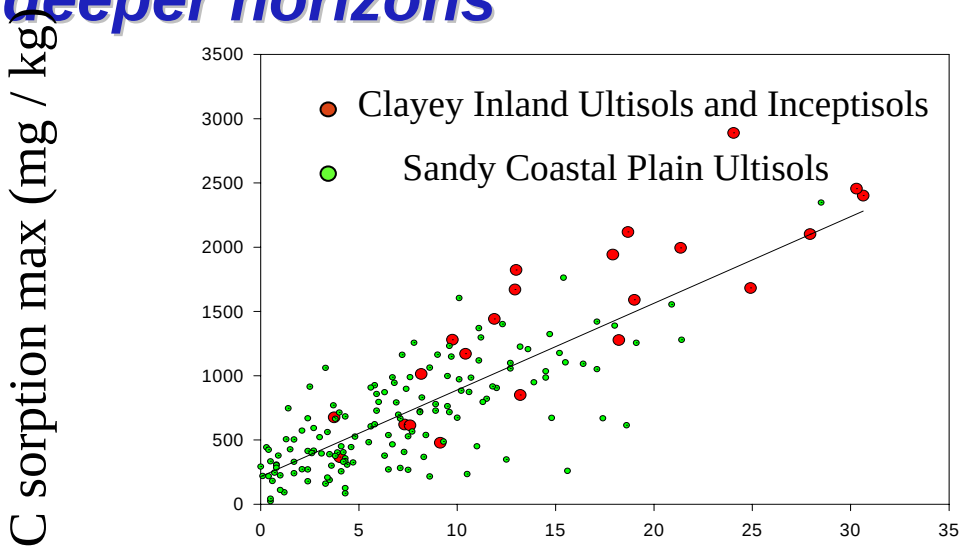


Office of Science R&D - Carbon Sequestration

Terrestrial Carbon Sequestration - Soil Manipulation: Mobilization to deeper horizons

- Enhance iron oxide content
- More carbon input to deep soil profile
- Quantify root-microbiology processes

Rhizotron Observation of Root-Soil Interaction



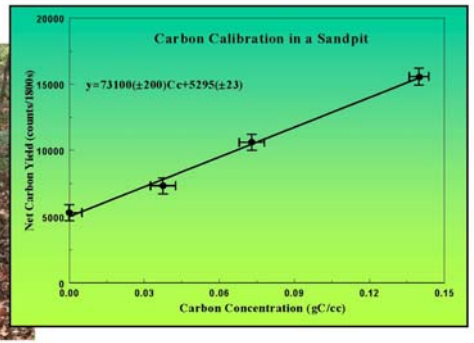
Mobilized Carbon in Tropical Soil Profile

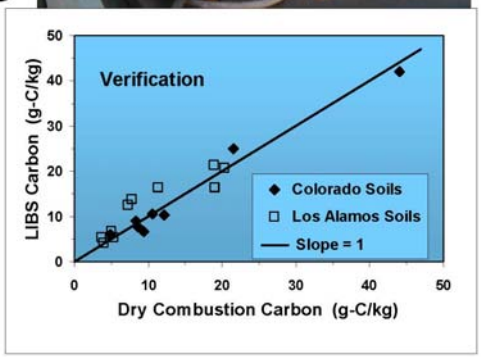
Measuring Soil Carbon

Better, faster, cheaper? (pick 1 or 2)

- **Laser-Induced Breakdown Spectroscopy (Ebinger et al)**
  - **Fast, high spatial resolution, invasive**

- **Inelastic neutron scattering (Wielopolski et al)**
  - **Fast, bulk analysis, non-invasive**





Poplar Trees for Carbon Sequestration

A poplar plantation

Greenhouse testing of poplar germplasm

The BER "*Poplar Genome Based Research for Carbon Sequestration in Terrestrial Ecosystems*" program is building on the recently completed genomic sequence of a female black cottonwood tree* to obtain the fundamental understanding needed to select, breed, or manage trees to meaningfully enhance sequestration of carbon in tree biomass and/or the underlying soil.

*** *Populus balsamifera* L. ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw, clone Nisqually-1**

Office of Science R&D - Carbon Sequestration

Ocean Sequestration – Office of Biological and Environmental Research

Fundamental research on efficacy and consequences of enhancing the "biological pump" and of direct injection of CO_2 at depth

- **Experimental studies on iron fertilization of the ocean surface to assess the efficacy of enhancing the oceanic "biological pump" – eliminate a constraint of nutrient supply on carbon fixation**
- **Experimental studies of impacts on ocean chemistry and biology of injecting a pure stream of CO_2 into the deep ocean – chemical changes in seawater will likely affect marine ecosystems near injection points**
- **Numerical modeling of ocean biogeochemistry and ocean circulation to project long-term fate of CO_2 injected into deep ocean and of carbon sequestered by an enhanced biological pump**

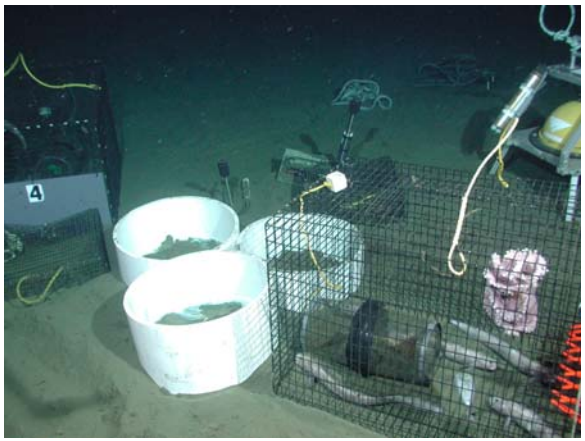
Ocean Carbon Sequestration - Southern Ocean Iron Enrichment Experiments (SOFeX)

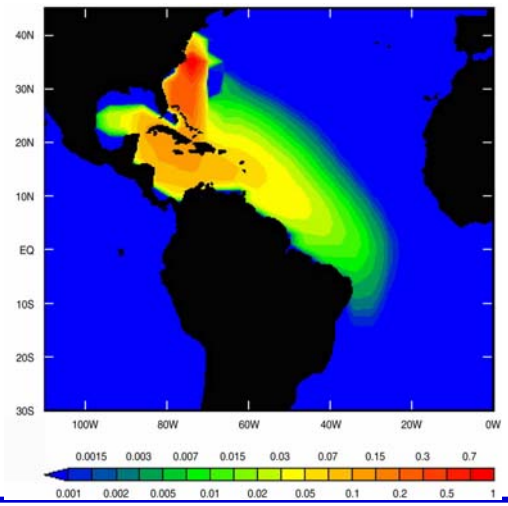
Iron added to the surface ocean (100 times background levels) triggered massive phytoplankton blooms

Phytoplankton from outside (left) and inside (right) a patch of ocean fertilized with iron

***In* situ measurements of the vertical profiles of particulate organic carbon outside and inside a patch of ocean artificially enriched with iron indicated that some of the enhanced carbon assimilation by phytoplankton did sink to deeper water — where it would have the potential to remain for a considerable period**

Ocean Carbon Sequestration - Direct Injection





Laboratory and deep sea experiments (photo is of experimental system at 3000+ m depth) on effects of direct injection of liquid CO_2 – effects on water chemistry and marine biology. Some marine organisms are quickly killed by added CO_2.

Simulated distribution over time of CO_2 injected at depth off the east coast. How long will injected carbon remain in the ocean? A very long time.

Ocean Carbon Sequestration

Decision makers need:

Information about quantitative effectiveness of carbon sequestration methods – how well will they work

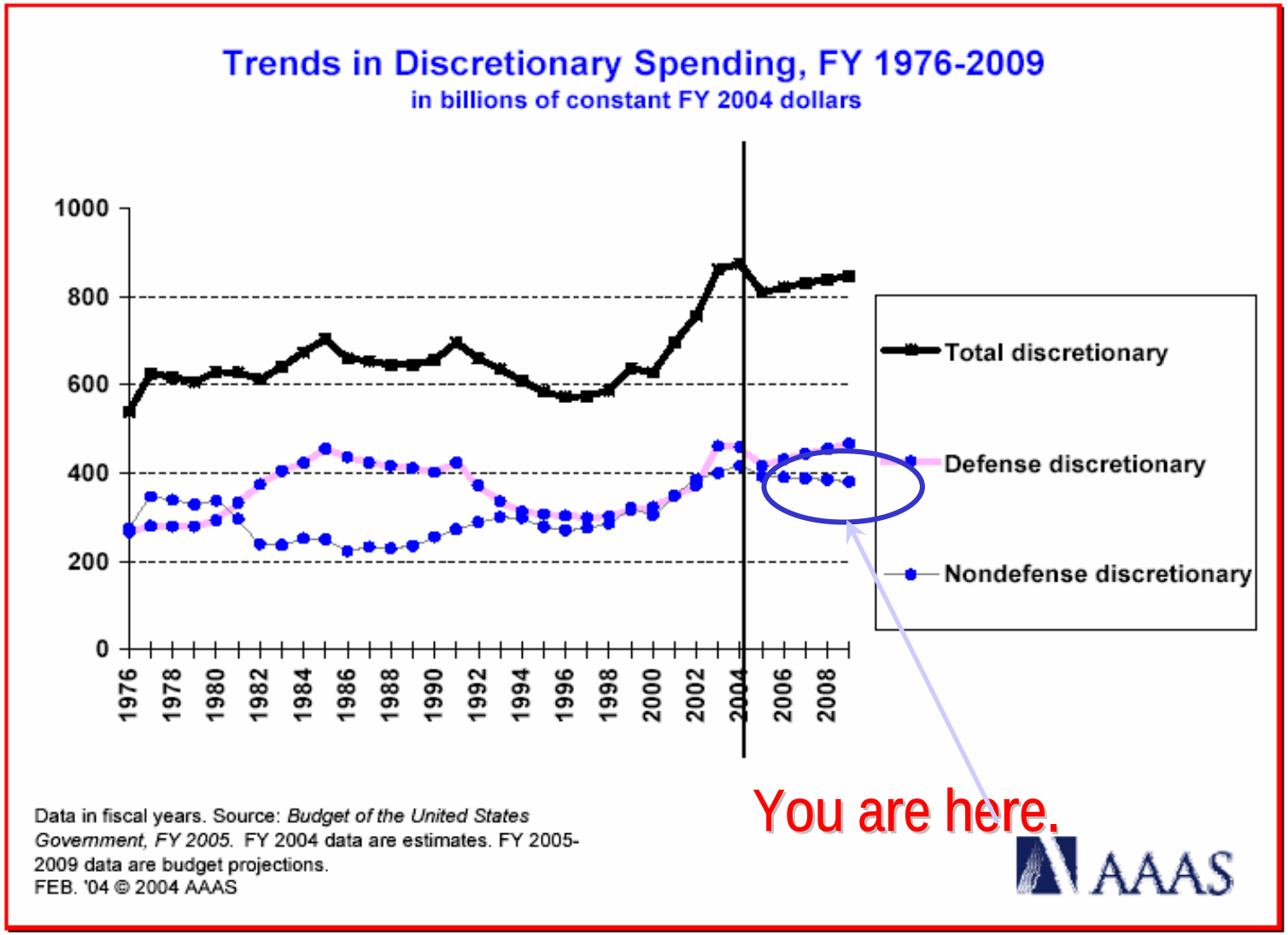
Hard data on ecological trade-offs of carbon sequestration approaches

- **Is it worth the carbon storage to kill the animals on the ocean floor near injectors?**
- **Will ocean basin-scale changes in pH be largely detrimental to ocean biology?**
- **Will iron fertilization cause undesirable changes in general ocean biogeochemistry and biology?**

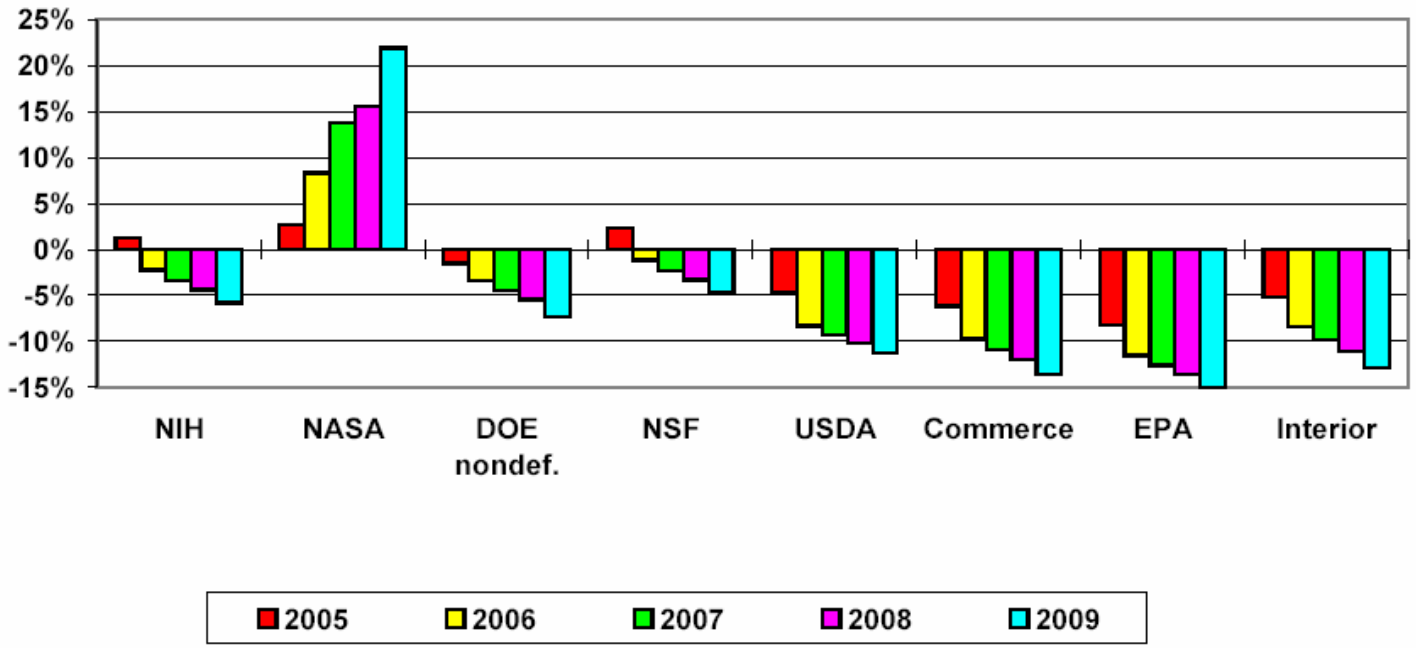
Advanced biological concepts for carbon sequestration

- **Functional genomics and proteomics of microbes, poplar and other plant species that will enable development of new and more effective strategies for carbon capture and sequestration**
- **Functional genomics of microbes in plant rhizosphere that affect transfer of carbon between roots and soil**
- **Advance concepts – search for genes and gene functions in microbes with potential applications in carbon sequestration**

Future Budget Prospects -- AAAS Analysis 2005-2009



Future Budget Prospects -- AAAS Analysis 2005-2009



Source: AAAS analysis *Projected Effects of President's FY 2005 Budget on Nondefense R&D*
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