The Carbon Journey

What are the scientific challenges that must be met?

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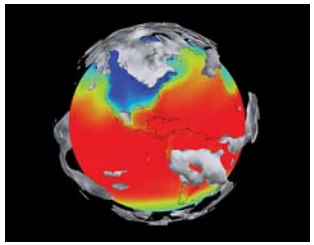
U.S. DEPARTMENT OF ENERGY

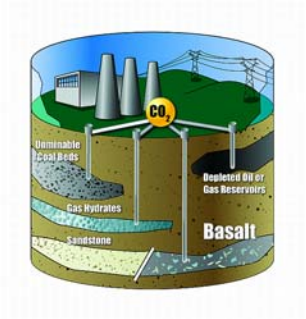
Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Three key scientific challenges



Understanding natural and anthropogenically induced changes in earth systems

Developing new, economically viable materials and processes to capture and utilize carbon dioxide



Predicting with confidence the performance of carbon storage reservoirs

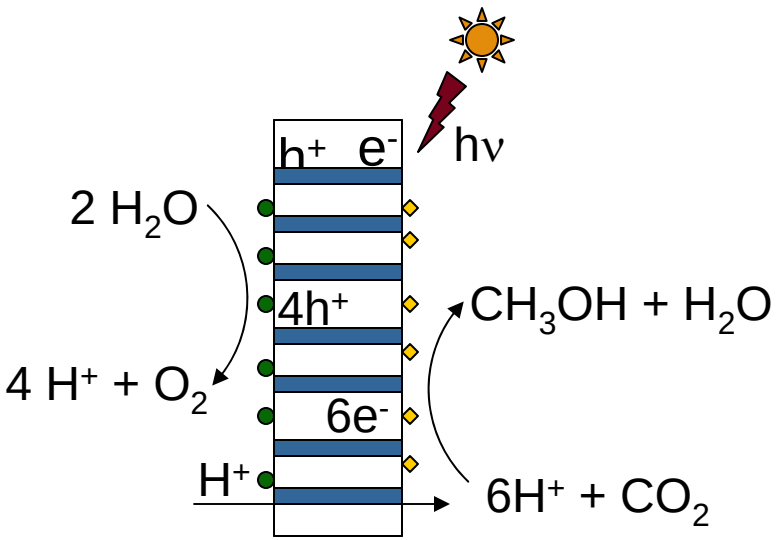
Challenge #1: Understanding natural and anthropogenically induced changes in earth systems

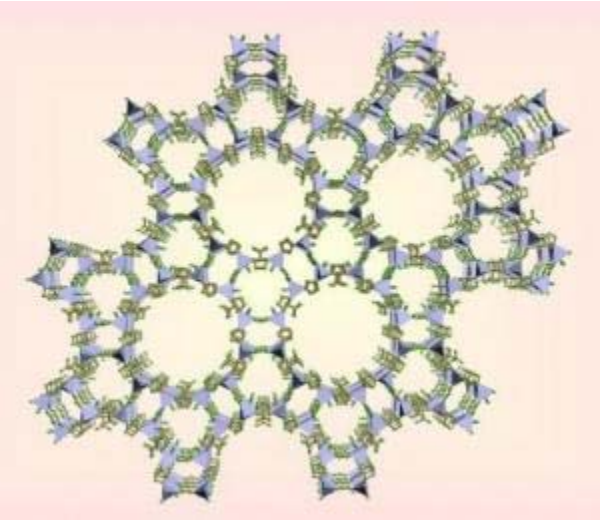
How accurately can we predict natural and anthropogenically induced changes in earth systems – including impacts?

Are there “tipping points”?

What are the impacts as a function of the forcing terms?

Challenge #2: Developing new, economically viable materials and processes to capture and utilize carbon dioxide





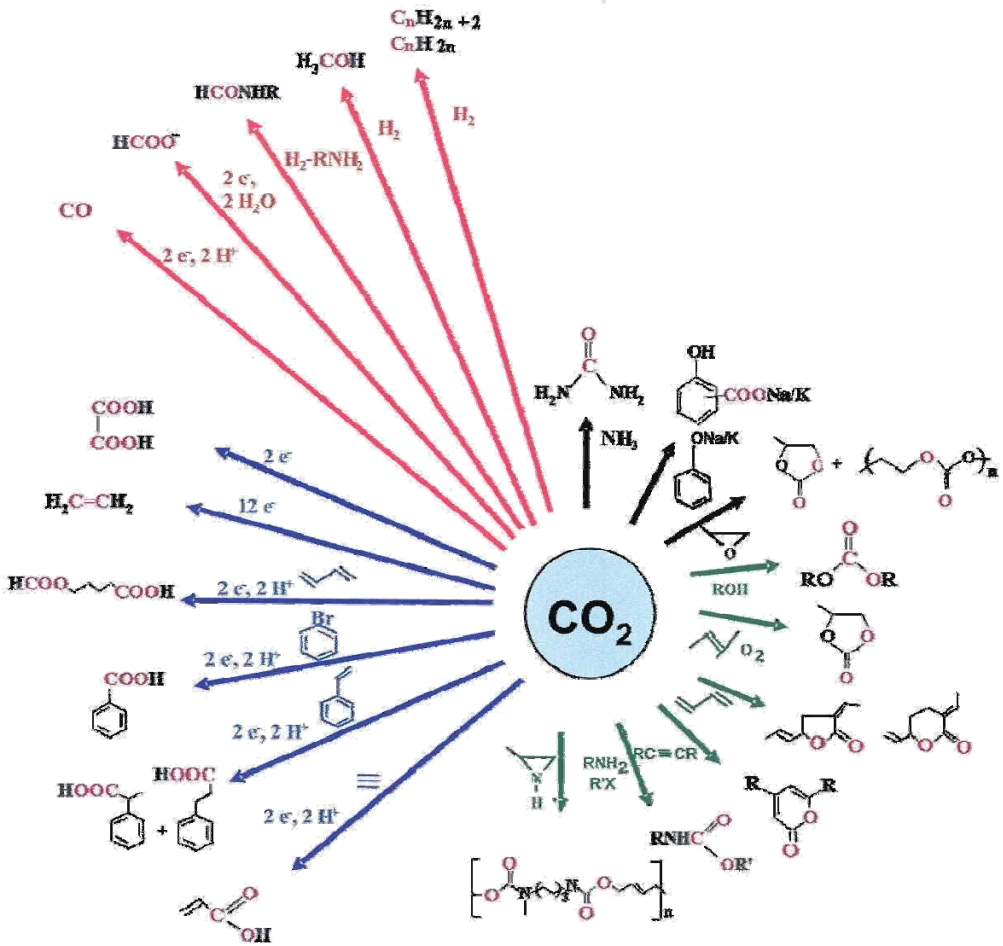
proton channel

semiconductor electrode

H_2O oxidation catalyst

CO_2 reduction catalyst

Can we economically synthesize fuels and chemicals from CO_2?

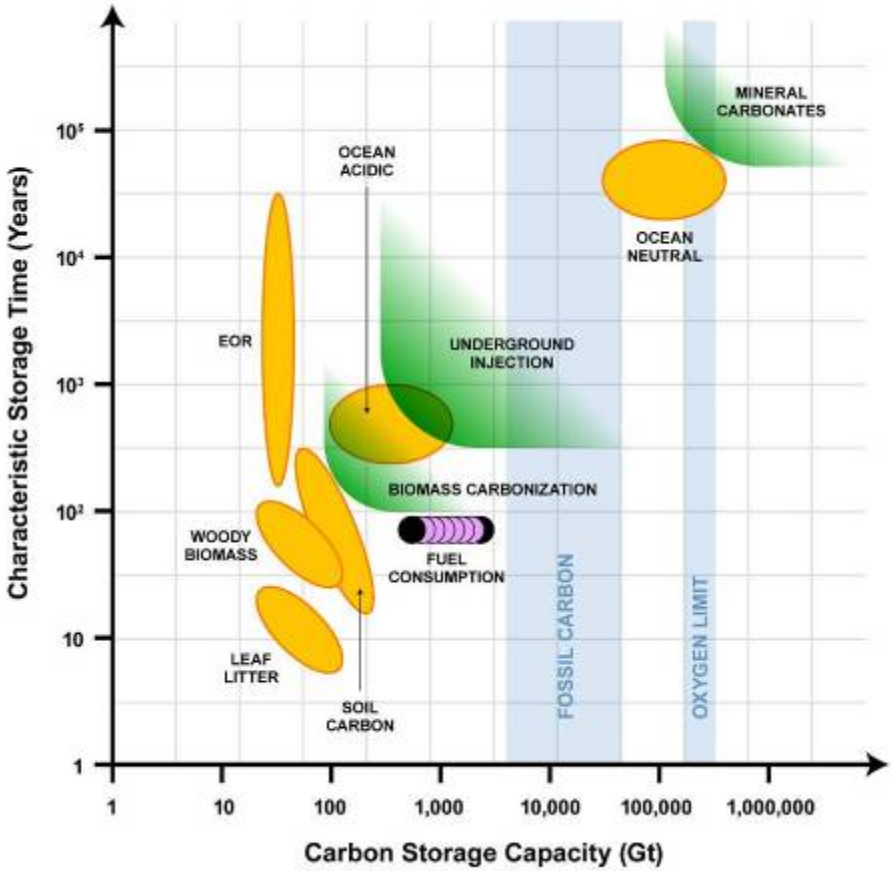


Scientific challenges in

- ***Catalyst design***
- ***Assembly and integration of catalytic components***
- ***Charge transport***
- ***Design and synthesis of multifunctional nanostructured materials***

Marks, T.; Aresta, M. et al
Chem Rev **2001,** 101, 953-996

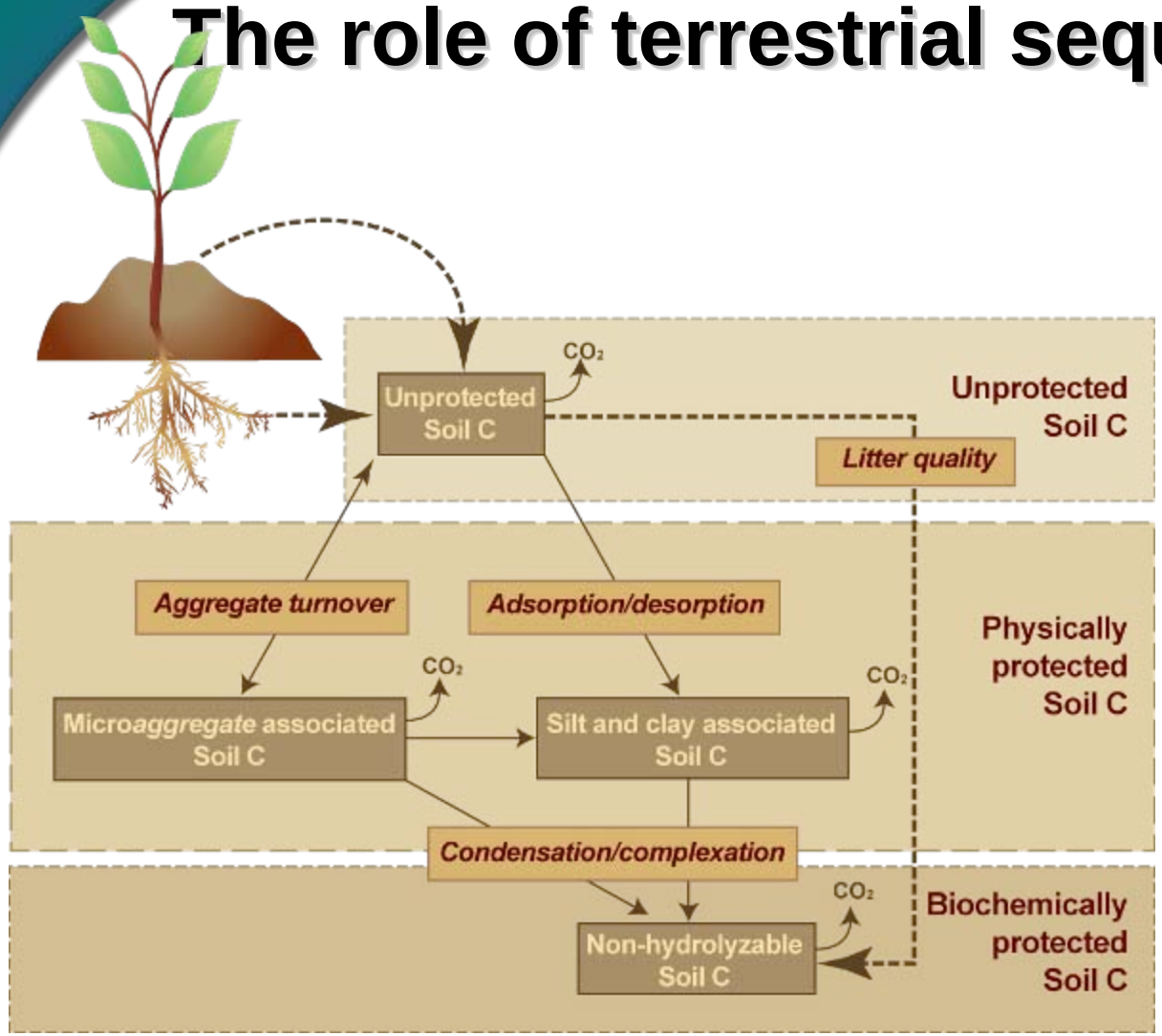
Challenge #3: Predicting with confidence the performance of carbon storage reservoirs



Modified after KS Lackner, *Science*, 300, 1677 (2003)

- ***How much for each type of reservoir?***
- ***What are the effects of changing conditions ?***
- ***What is the time-frame for storage?***
- ***Uncertainties?***

The role of terrestrial sequestration



Six et al. (2002)

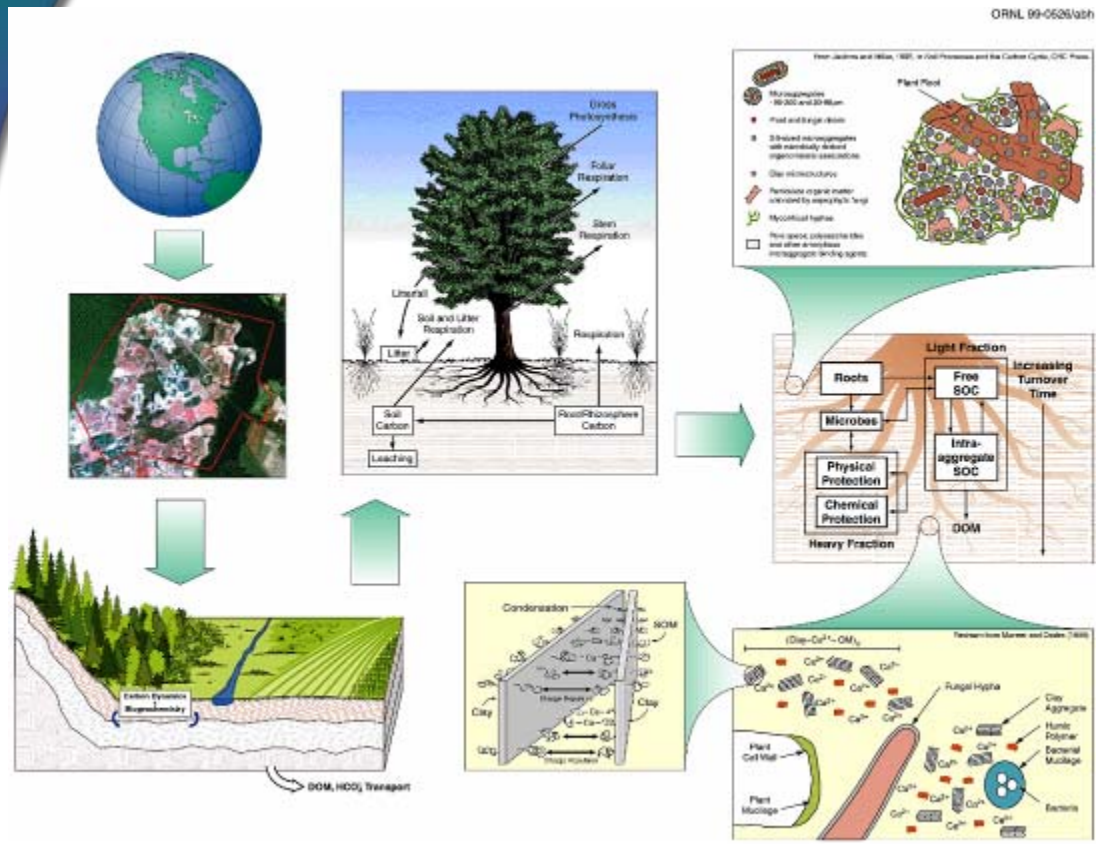
Role of plants and microbes?

Fundamental control mechanisms?

C movement in the soil?

C sequestration enhancement?

Science challenges – terrestrial sequestration



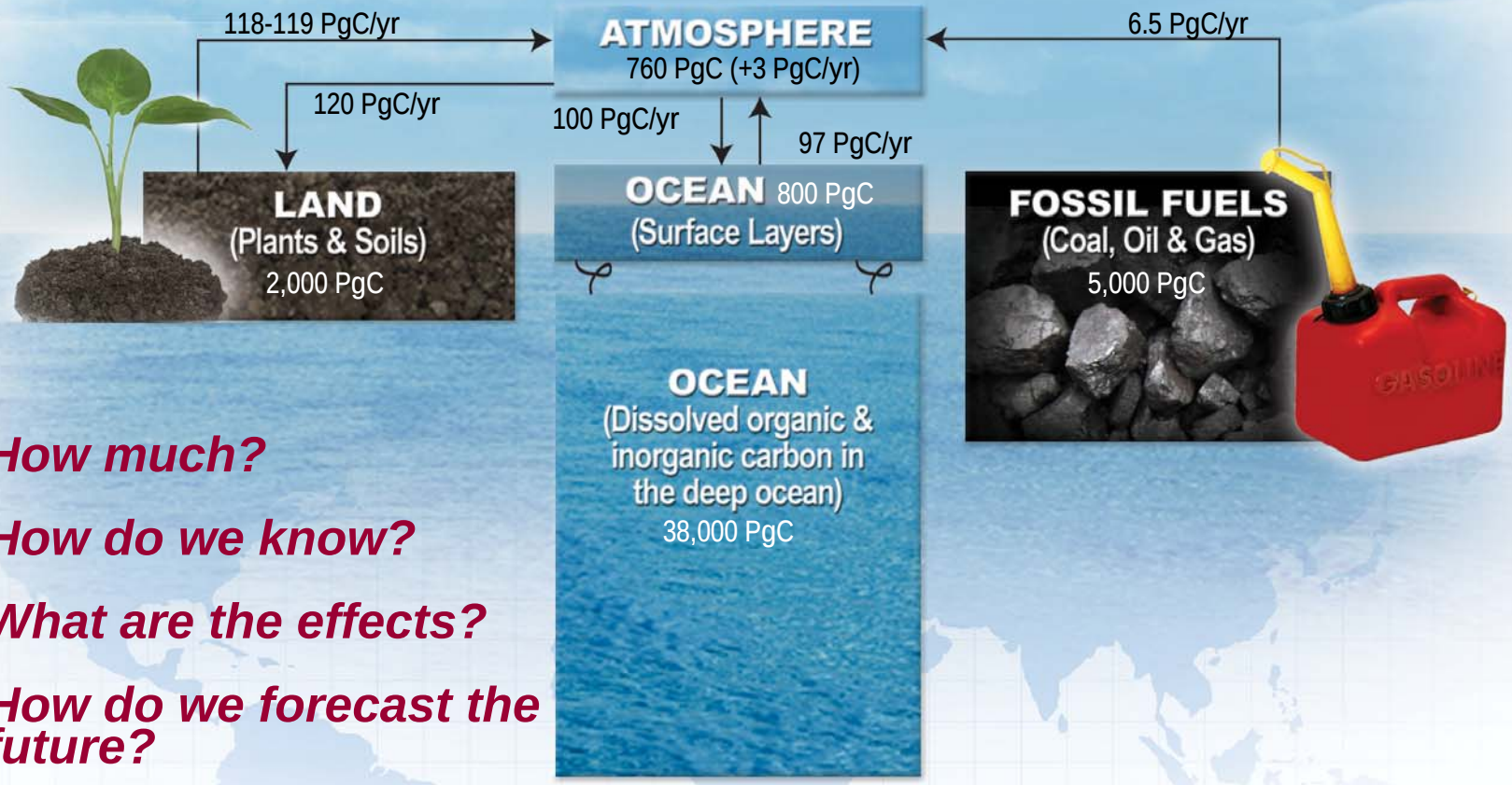
Altering carbon capture and sequestration mechanisms from molecular to landscape scales

Developing conceptual and simulation models for extrapolation across spatial and temporal scales

Assessing environmental and economic consequences of sequestration

Ocean sequestration – many issues

Global Flows of Carbon



How much?

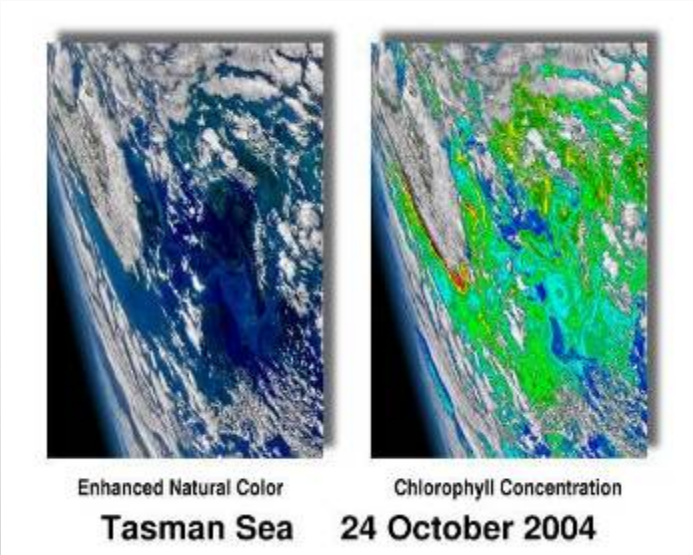
How do we know?

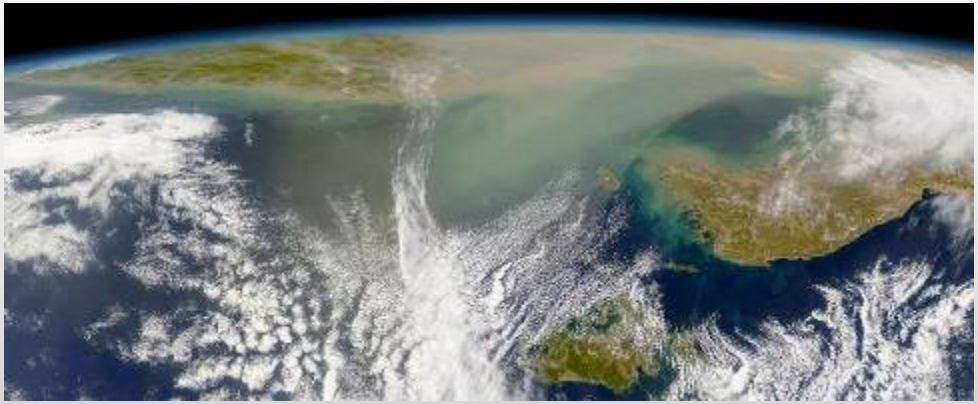
What are the effects?

How do we forecast the future?

Source NASA Science:
http://science.hq.nasa.gov/oceans/system/carbon.html

Science challenges – ocean sequestration





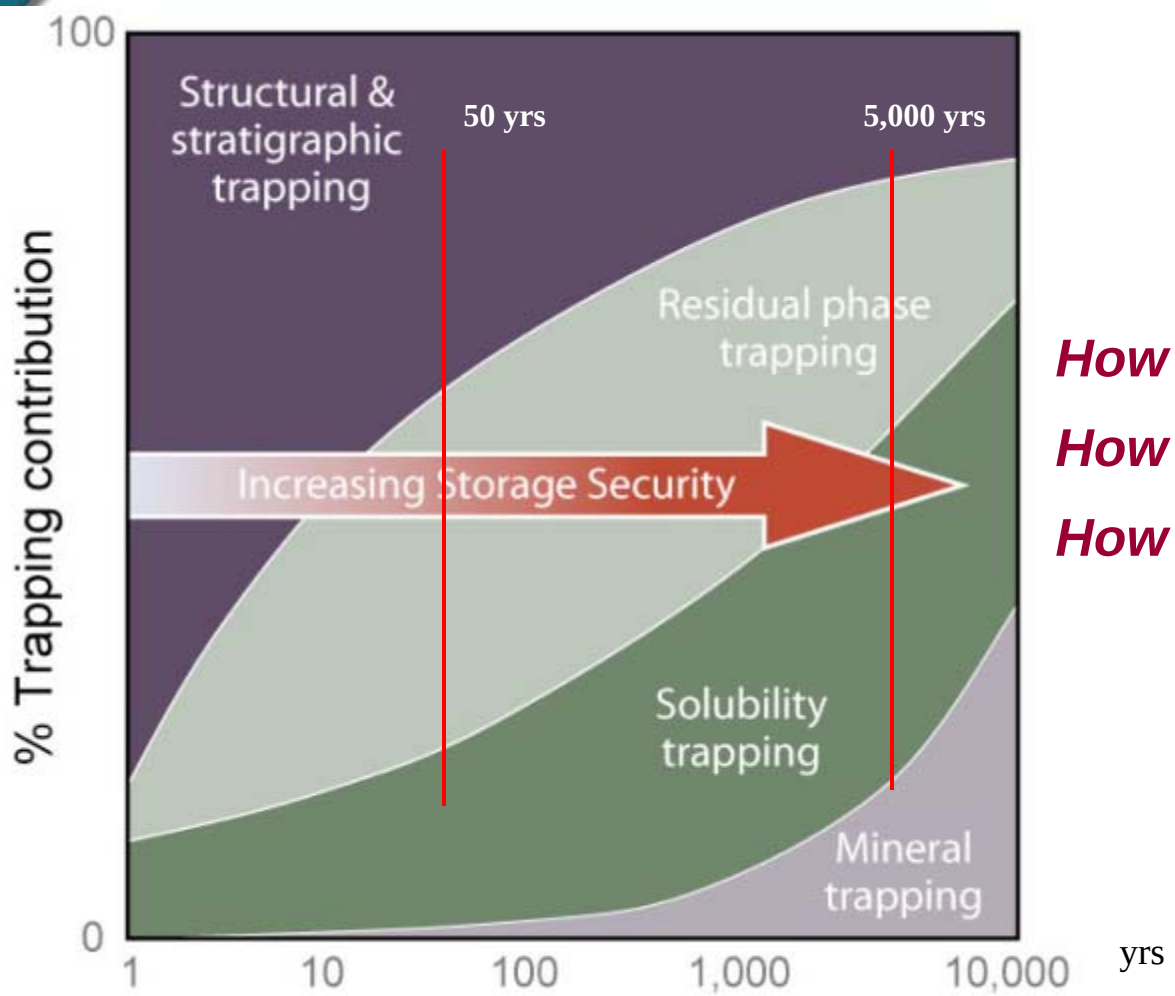
Understanding of the physical and biological aspects of ocean carbon cycling

Mechanistic investigations of primary ocean processes and changes caused by ocean circulation

Accurate measurements of CO_2 fluxes, dissolved and particulate carbon, and ocean productivity on multiple spatial and time scales

Images from: The Ocean Color Image Gallery: http://oceancolor.gsfc.nasa.gov/

What happens to CO_2 at depth?



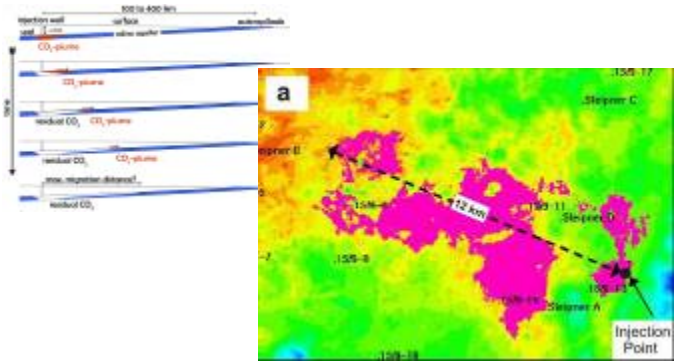
How much?

How permanent?

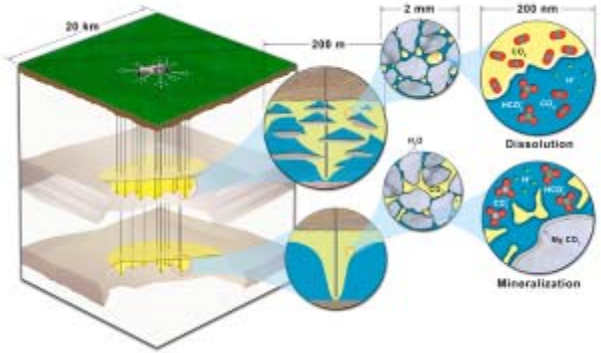
How do we know?

Multiple trapping mechanisms of Geological Carbon Sequestration. Over time the physical processes of residual trapping and chemical processes of solubility and mineral trapping *are expected to* increase in importance. *After Benson & Cook (2005)*

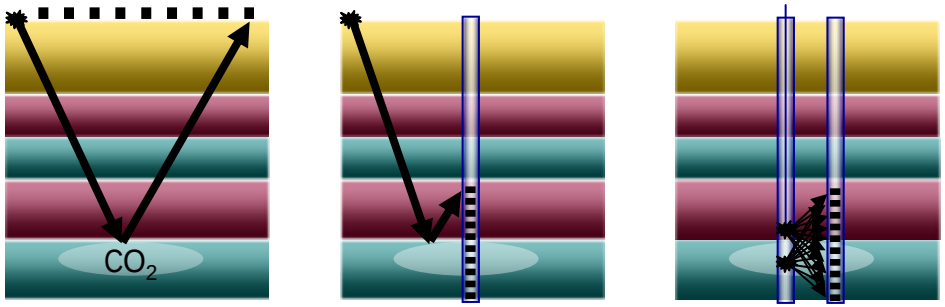
Science challenges – deep geologic sequestration



Fluid Flow: Field scale of CO_2 sequestration - large footprint, multiple subsurface processes and rates



Geochemistry: Mineral-Fluid and Fluid-Fluid Interactions



Surface Seismic 2-D, 3-D, and 4D | **Vertical Seismic Profile (VSP)** | **Cross-Well Tomography**

Geophysical monitoring, measurement and Verification

Basic Research Needs for Geosciences Workshop Conclusions

Grand Challenges

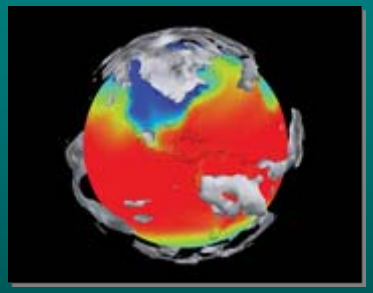
1. Computational thermodynamics of complex fluids and solids
2. Integrated characterization, modeling, and monitoring of geologic systems
3. Simulation of complex multi-scale systems for ultra-long times

Priority Research Directions

1. Mineral-water interface complexity and dynamics
2. Nanoparticulate and colloid physics and chemistry
3. Dynamic imaging of flow and transport
4. Transport properties and *in situ* characterization of fluid trapping, isolation, and immobilization
5. Fluid-induced rock deformation
6. Biogeochemistry in extreme and perturbed environments

Cross cutting issues

1. The microscopic basis of macroscopic complexity
2. Highly reactive subsurface materials and environments
3. Thermodynamics of the solute-to-solid continuum



Questions? Comments?