A Survey of Measurement, Mitigation, and Verification Technologies for Carbon Sequestration and Roadmap Development

Third Annual Conference on Carbon Sequestration

May 5, 2004

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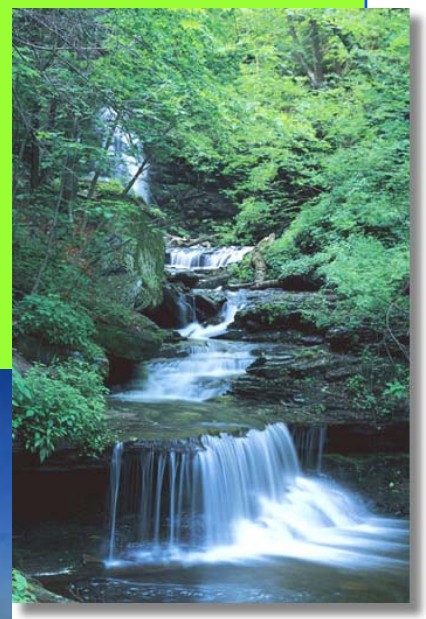
Overview

- What is Measurement, Mitigation, and Verification (MM&V)?
- What are the drivers for the DOE's Fossil Carbon Sequestration Program and how does MM&V form a major component of the program?

  What are DOE's MM&V Roadmap goals?
- Status of Terrestrial MM&V DOE R&D
- Status of Geologic MM&V DOE R&D
- Summary



What is MM&V?

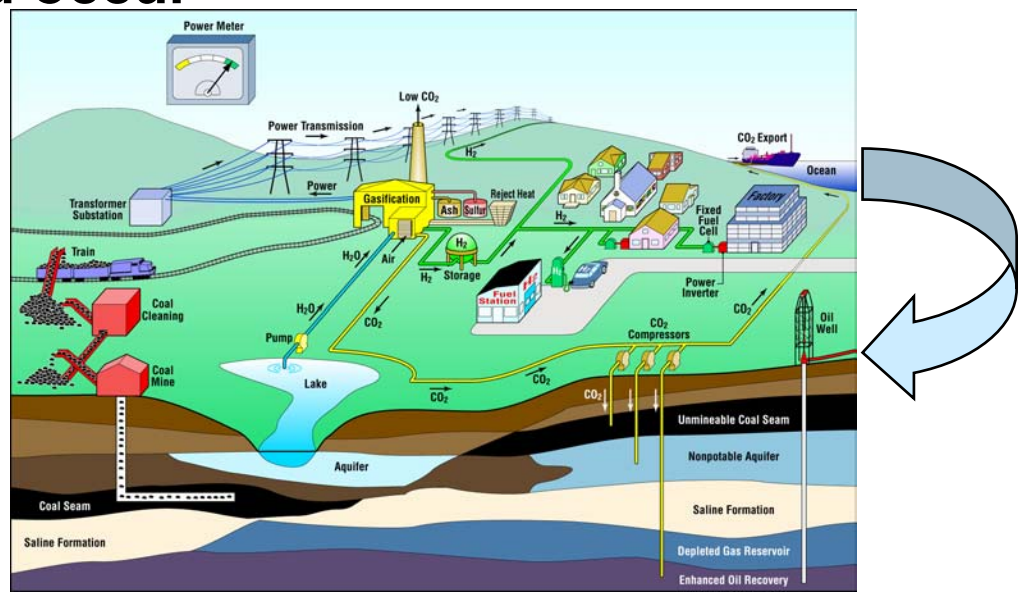
- **MM&V – The capability to:**

✓ **Measure the amount of CO_2 stored at a specific sequestration site**

✓ **Monitor the site for leaks/deterioration over time to verify the CO_2 storage is permanent and not harmful to the ecosystem**

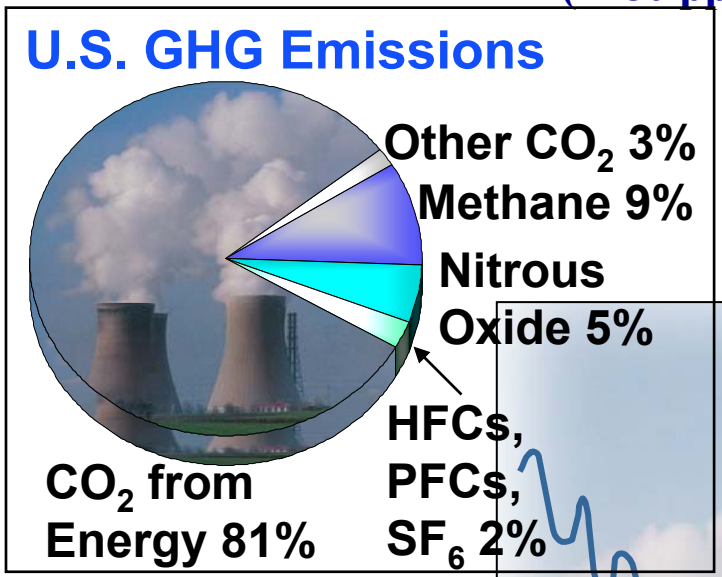
✓ **Provide mitigation capabilities to respond to CO_2 leakage or ecological damage if it should occur**

- **MM&V forms an integral part of the sequestration program**
- **DOE is currently developing a roadmap for MM&V**



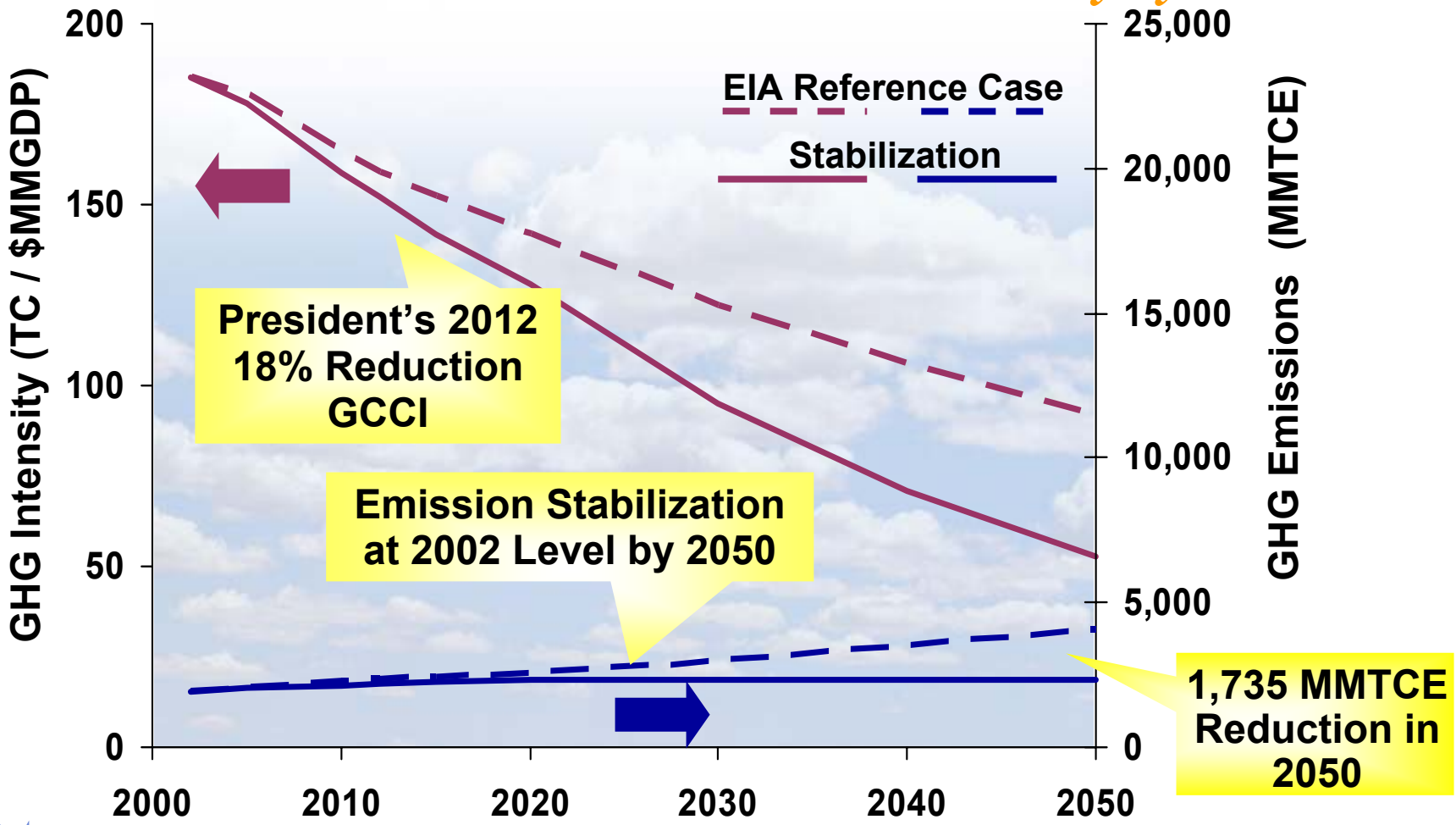
Global Climate Change:

CO_2 Concentrations On The Rise
(~280 ppm to 370 ppm over last 100 years)



Pathway to Carbon Stabilization

Global Climate Change Initiative Goal(GCCI): 18% Reduction in Greenhouse Gas Intensity by 2012



EIA Annual Energy Outlook 2002; EPA special studies; DOE/FE/NETL Sequestration Benefits Model

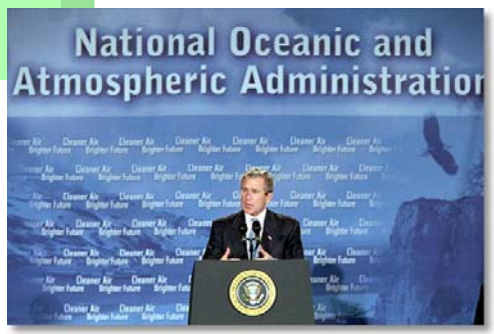
President's Response to Climate Change Issues

June 11, 2001, National Climate Change Technology Initiative

"We all believe technology offers great promise to significantly reduce emissions -- especially carbon capture, storage and sequestration technologies."

- ✓ *Public-private partnerships in applied research to expedite innovative, cost-effective approaches to reduce greenhouse gas emissions*
- ✓ *Enables continued use of domestic energy resources & infrastructure*

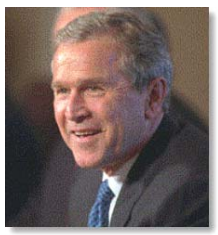
February 14, 2002, Global Climate Change Initiative



- ✓ *Reduce GHG intensity by 18% in next 10 years*
- ✓ *Sustain economic growth*

January 28, 2003, Hydrogen Fuel Initiative

"Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles."



February 27, 2003, FutureGen Initiative

"…the United States will sponsor a $1 billion, 10-year demonstration project to create the world's first coal-based, zero-emissions electricity and hydrogen power plant …"

White House photo: Paul Morse

Approaches to Sequester Carbon

Capture and Storage

Enhance Natural Processes

Unmineable Coal Seams

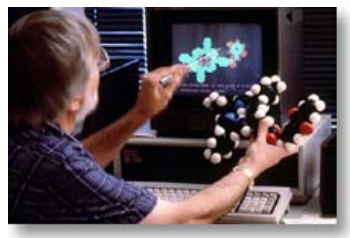
Ocean Uptake

Depleted Oil / Gas Wells, Saline Reservoirs

Mineral Carbonation

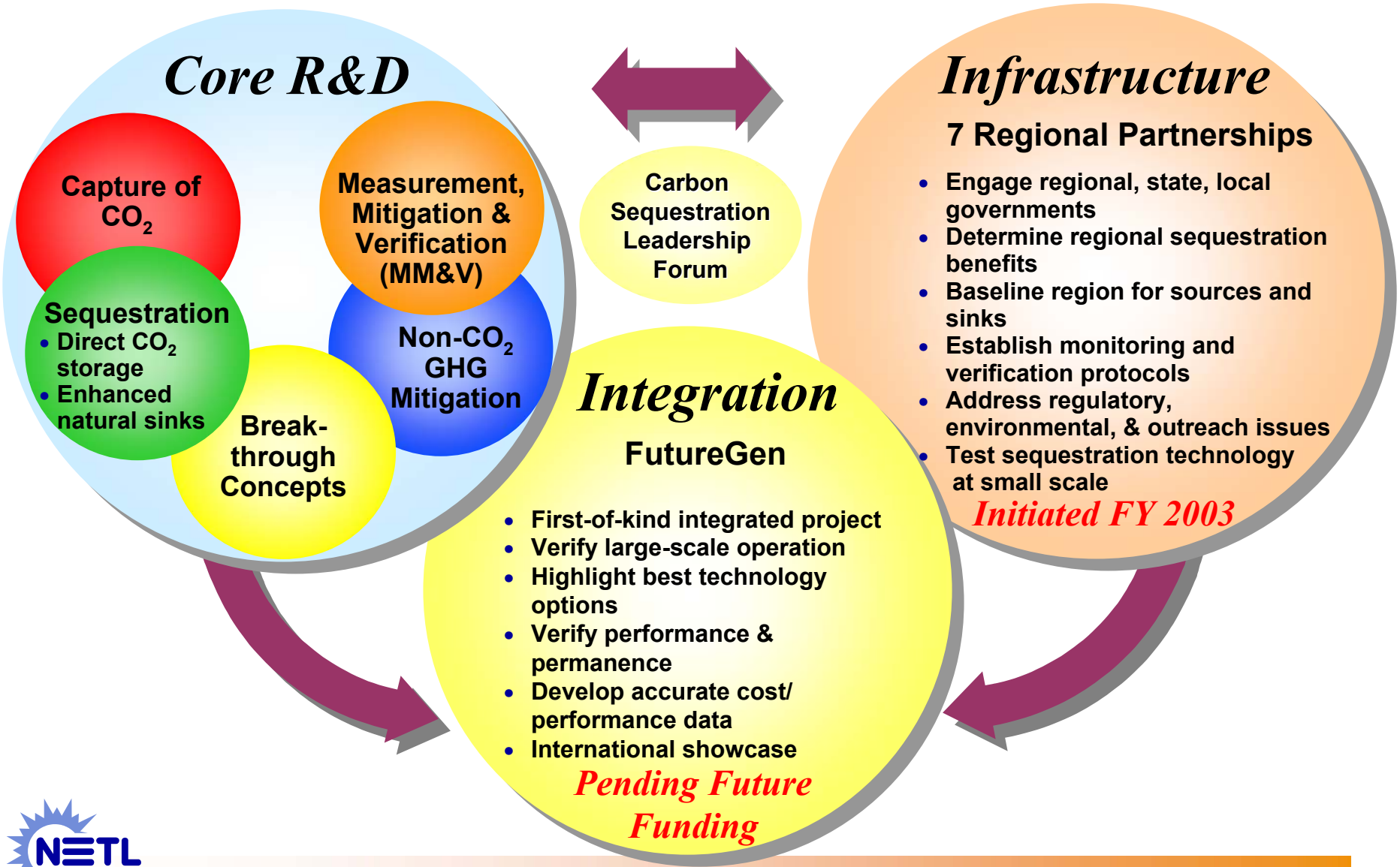
Iron or Nitrogen Fertilization of Ocean

Forestation

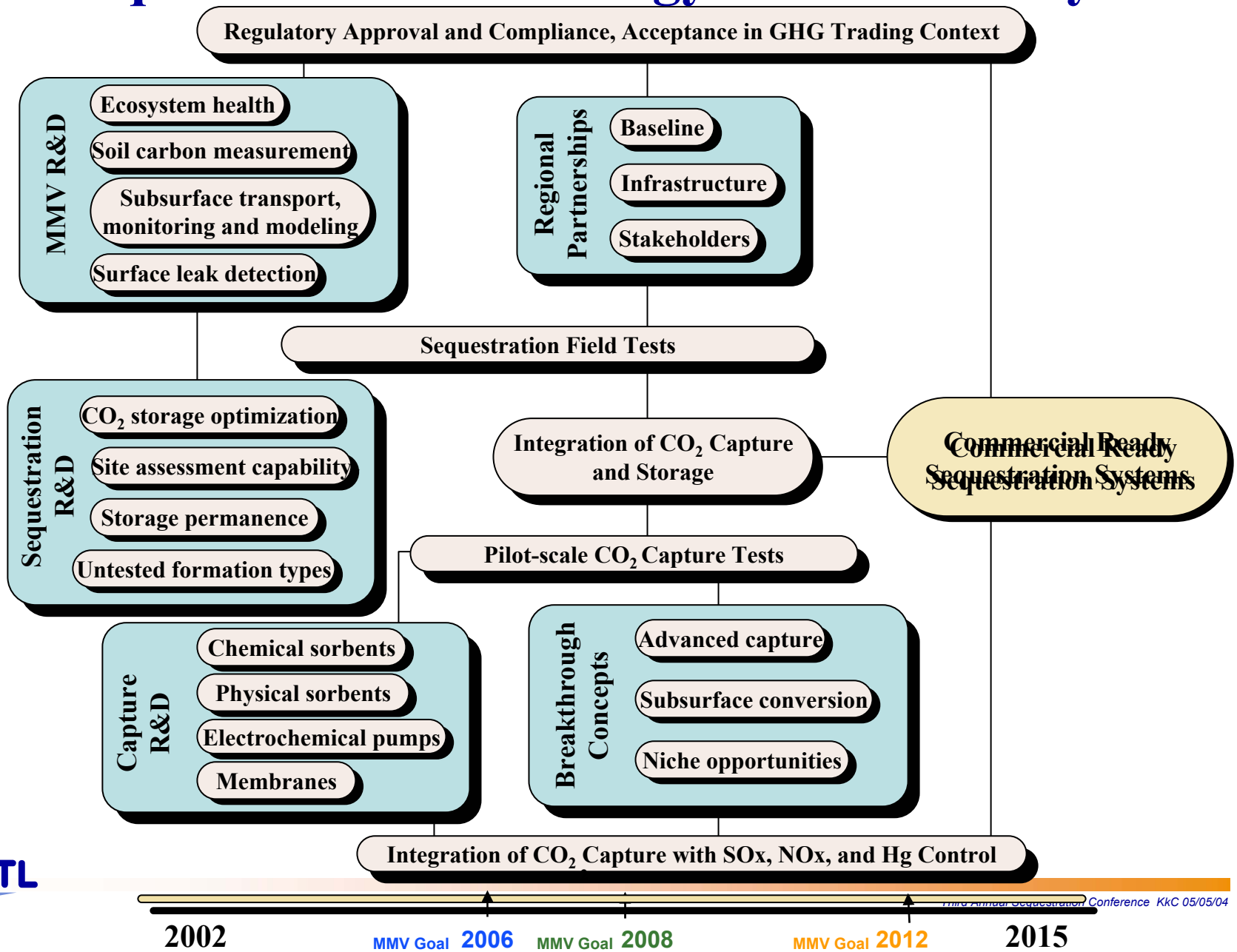


Enhanced Photosynthesis

Carbon Sequestration Program Structure



Sequestration Technology R&D Pathways



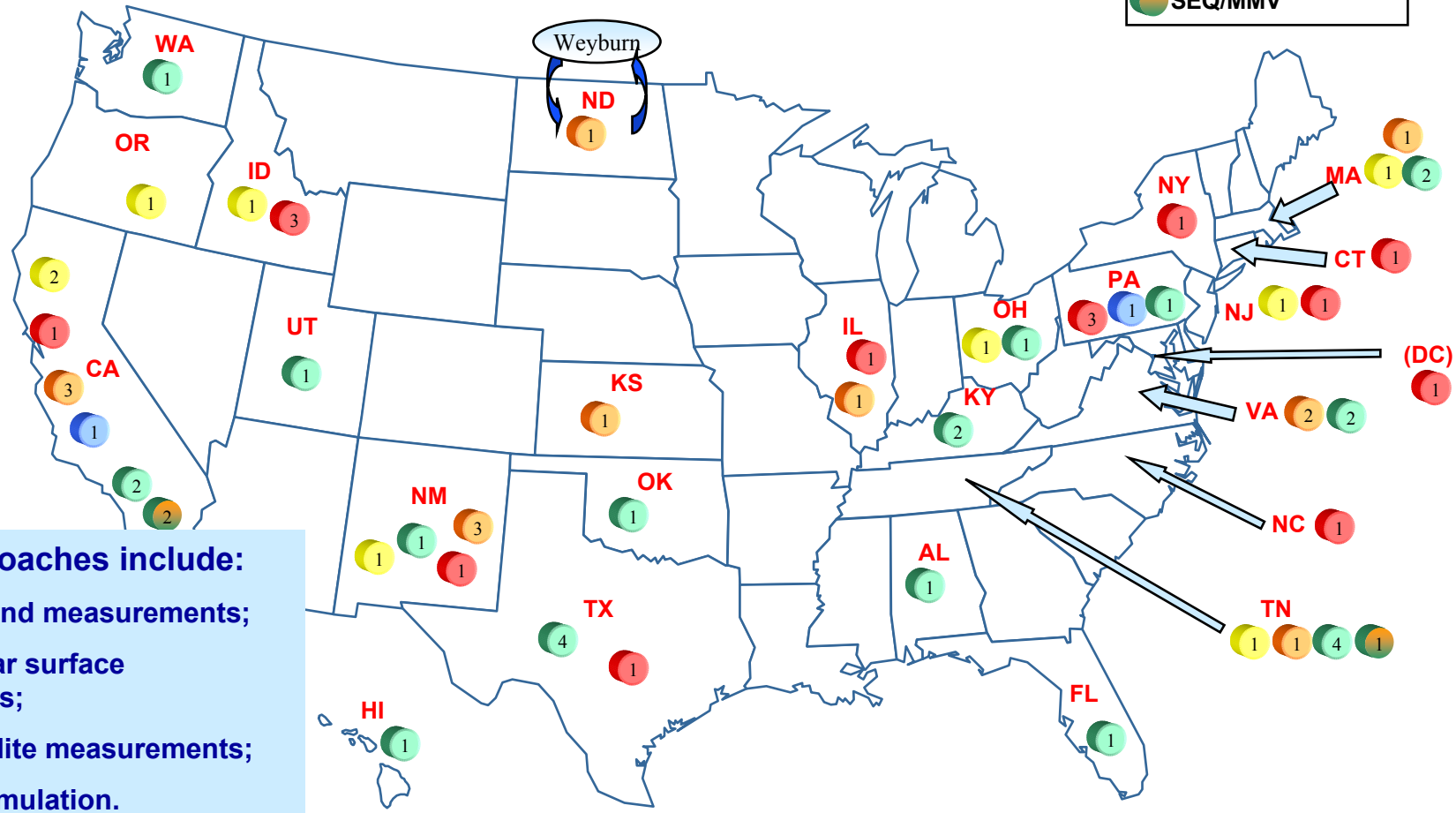
DOE's Sequestration MM&V Roadmap Goals

- **2006 - Apply promising MM&V technologies to several field tests or commercial applications.**
- **2008 - MM&V protocols enable 95% of CO_2 uptake in a terrestrial ecosystem to be credited and represents no more than 10% of the total sequestration cost.**
- **2012 - MM&V protocols enable 95% of CO_2 injected into a geologic reservoir to be credited and represents no more than 10% of the total sequestration cost.**

West Pearl Queen Injection Test Site

NETL

Carbon Sequestration Projects With Focus on MM&V Studies



MM&V approaches include:

- ✓ Below ground measurements;
- ✓ Surface/near surface measurements;
- ✓ Aerial/satellite measurements;
- ✓Modeling/simulation.

*Includes BP. Doesn't include NETL

Measurement, Mitigation, and Verification

R&D Goals for Terrestrial Sequestration

- **Reduce cost of MM&V and develop protocols**
- **Improve soil carbon measurements**
  - Decrease sample time and count
  - Develop measurement protocol
- **Improve regional MM&V**
  - Remote sensing opportunities
  - Vegetation carbon databases for calibration
- **Partner with USDA and other organizations**

R&D Goals for Geologic Sequestration

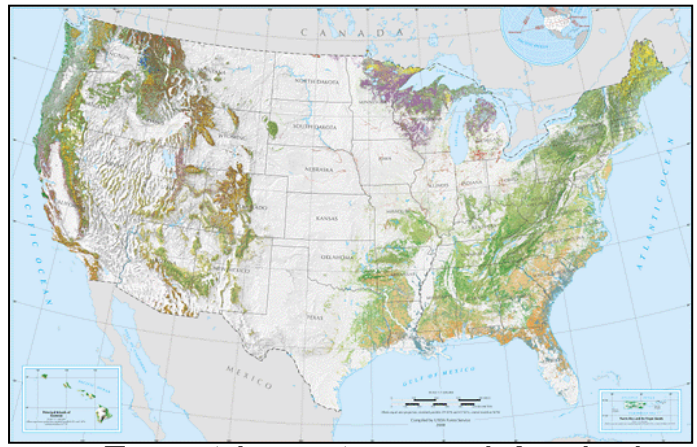
- **Reduce cost of MM&V and develop protocols**
- **Improve measurement accuracy**
  - Develop tools for surface-level measurements
  - Improve existing tools for in-reservoir MM&V
  - Ensure protection of human and ecosystem health
- **Create infrastructure**
  - Develop universal MM&V protocols
  - Assist regulators in developing guidelines

NETL

Terrestrial MM&V Strategies

- **Develop hierarchical system to integrate sequestration measurements of different system components …and for a range of scales**
  - Soils → organisms→ ecosystems
  - Plot → landscape→ regional →worldwide

- **To provide a net accounting of CO_2 inventories, emissions, and sinks**

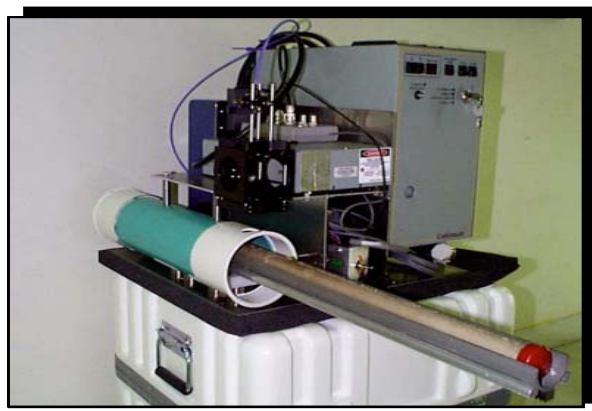


Forest Inventory and Analysis Program Coverage Map

Below-ground Terrestrial Measurements

Participant: Los Alamos National Laboratory

- Laser Induced Breakdown Spectroscopy (LIBS) to measure carbon in soil
- Flashlight-sized laser device to analyze soil samples in the field
- Portable and fast
- Long-term goals: verifying data collected by satellite, establishing a global productivity index



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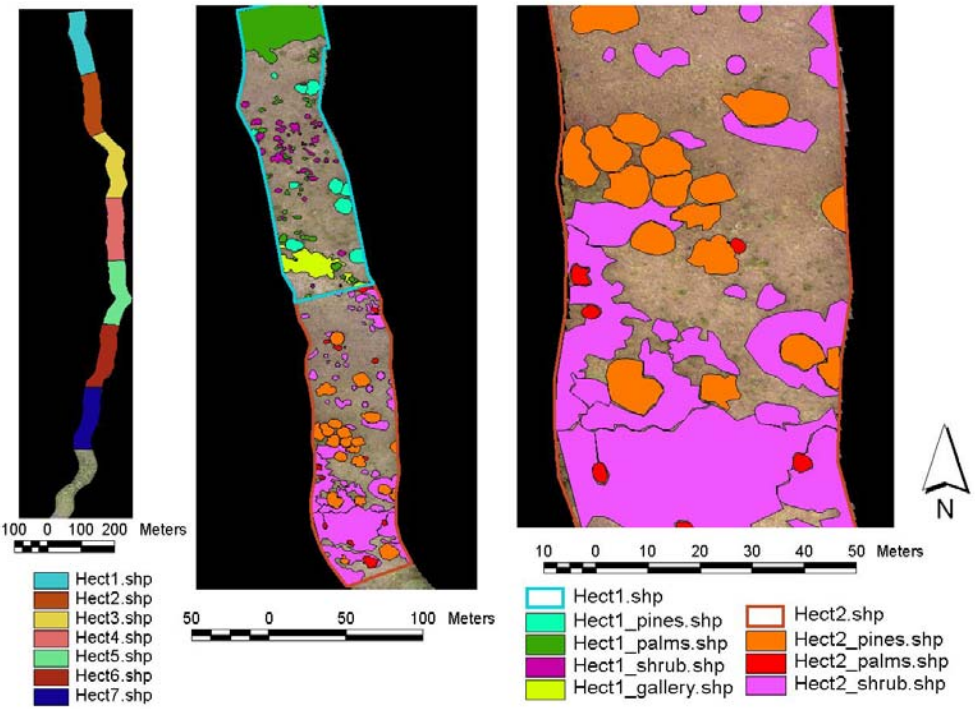
Above-Ground Terrestrial Measurement Project:

Advanced Videography

A New MMV Tool for Remote Monitoring of Terrestrial Seq.



Advanced Videography results shown are from Rio Bravo Project in Belize on the Pine Savanna

- Estimate carbon on the ground by flying over a project site
- Cameras, a pulse laser, and GPS sensor
- 3D model of terrestrial ecosystem during a flyover
- Reduce costs of MM&V for terrestrial sequestration
- Using TNC's sequestration projects as proving grounds

Participants: The Nature Conservancy, Winrock

NETL

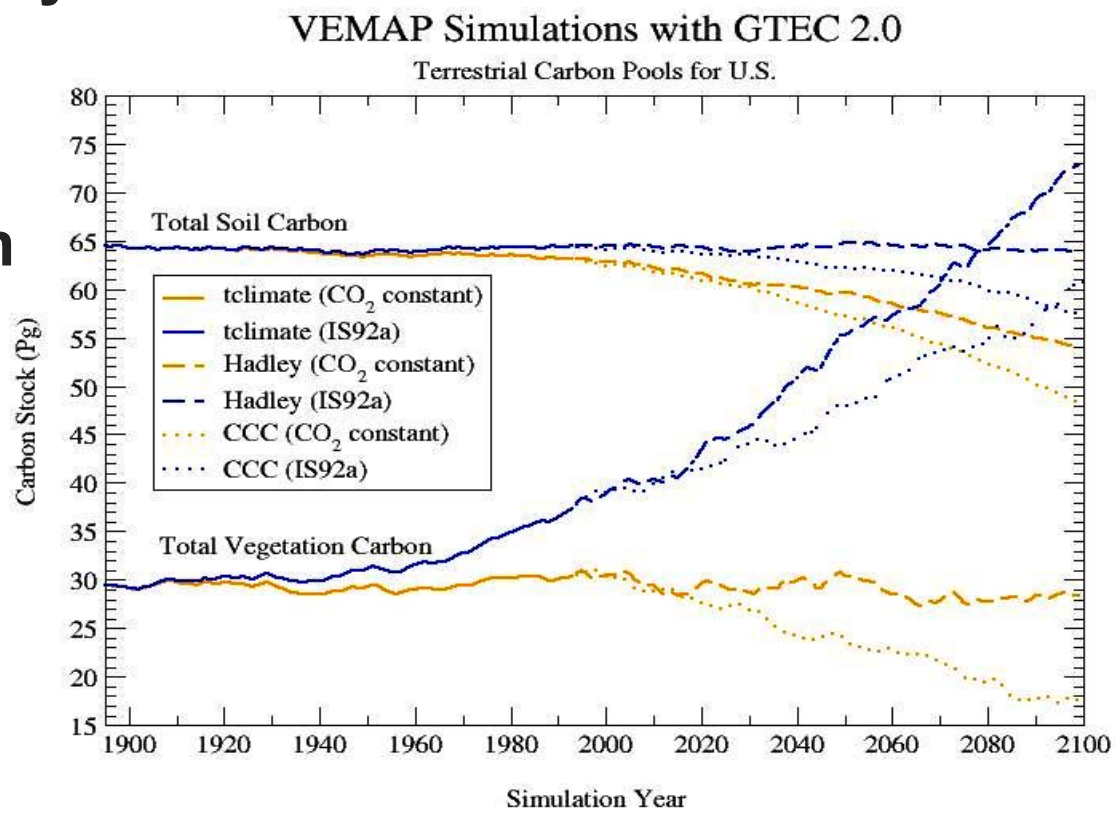
Terrestrial Ecosystem Models

- Models provide the baseline values and benchmark values for terrestrial projects
- High spatial and temporal resolution global terrestrial carbon cycle models
- Examples:

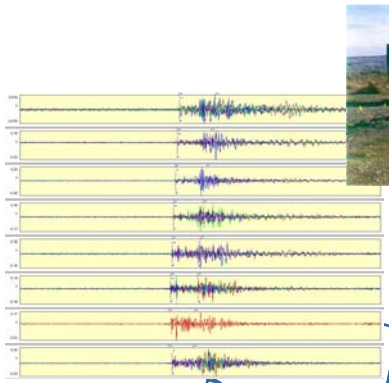
  -Global Terrestrial Ecosystem Carbon Model (GTEC)

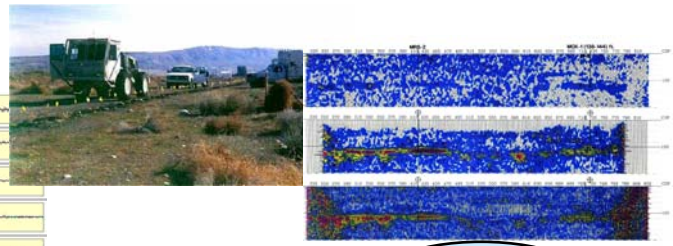
  -Terrestrial Ecosystem Model (LoTEC)

GTEC Sample data

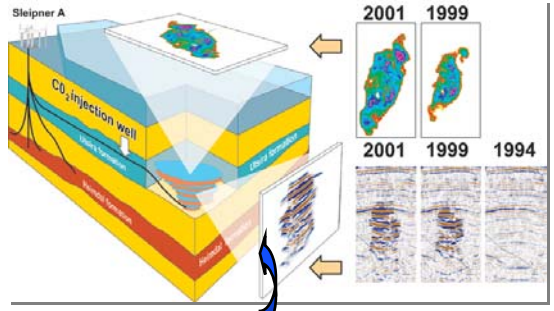


Geologic MM&V Field Projects

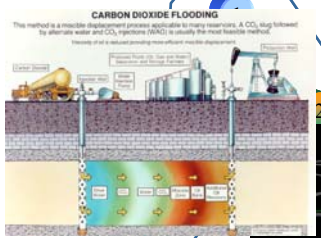




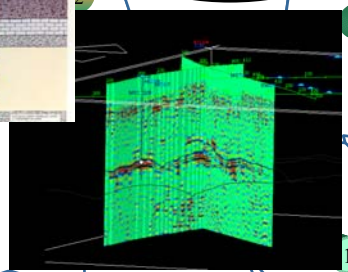
Weyburn Field



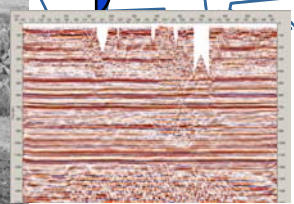
Sleipner Field
North Sea



West Pearl
Queen Field, NM



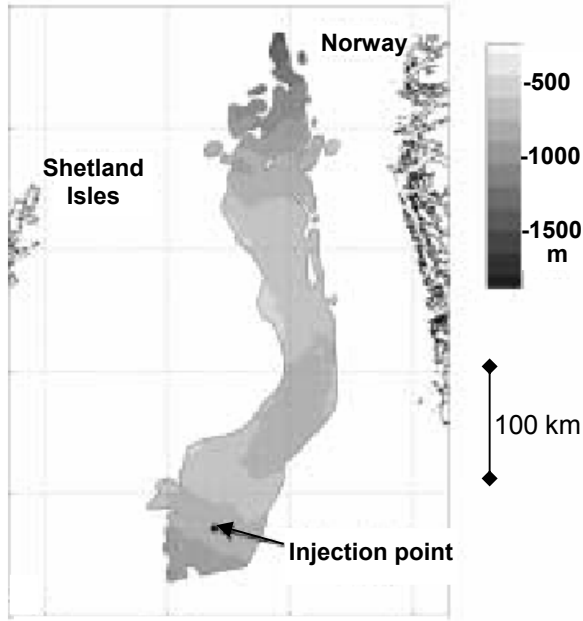
Frio Fm, Tx

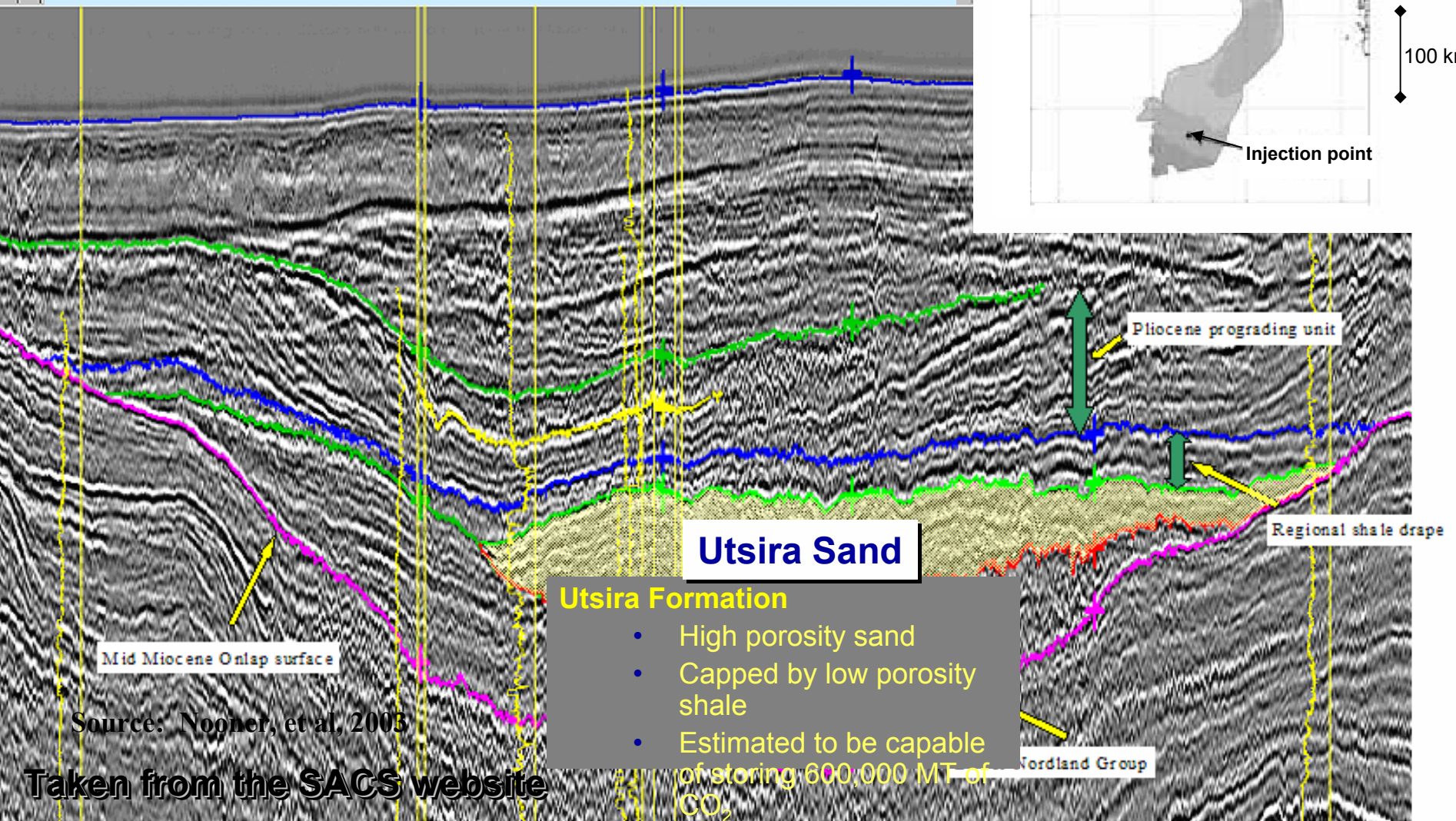


*Includes BP. Doesn't include NETL

Sleipner

- Located in the North Sea between Norway and Great Britain
- Natural gas recovered with 7% excess CO_2
- ~1 MT of CO_2 injected per year





Utsira Sand

Utsira Formation

- High porosity sand
- Capped by low porosity shale
- Estimated to be capable of storing 600,000 MT of CO_2

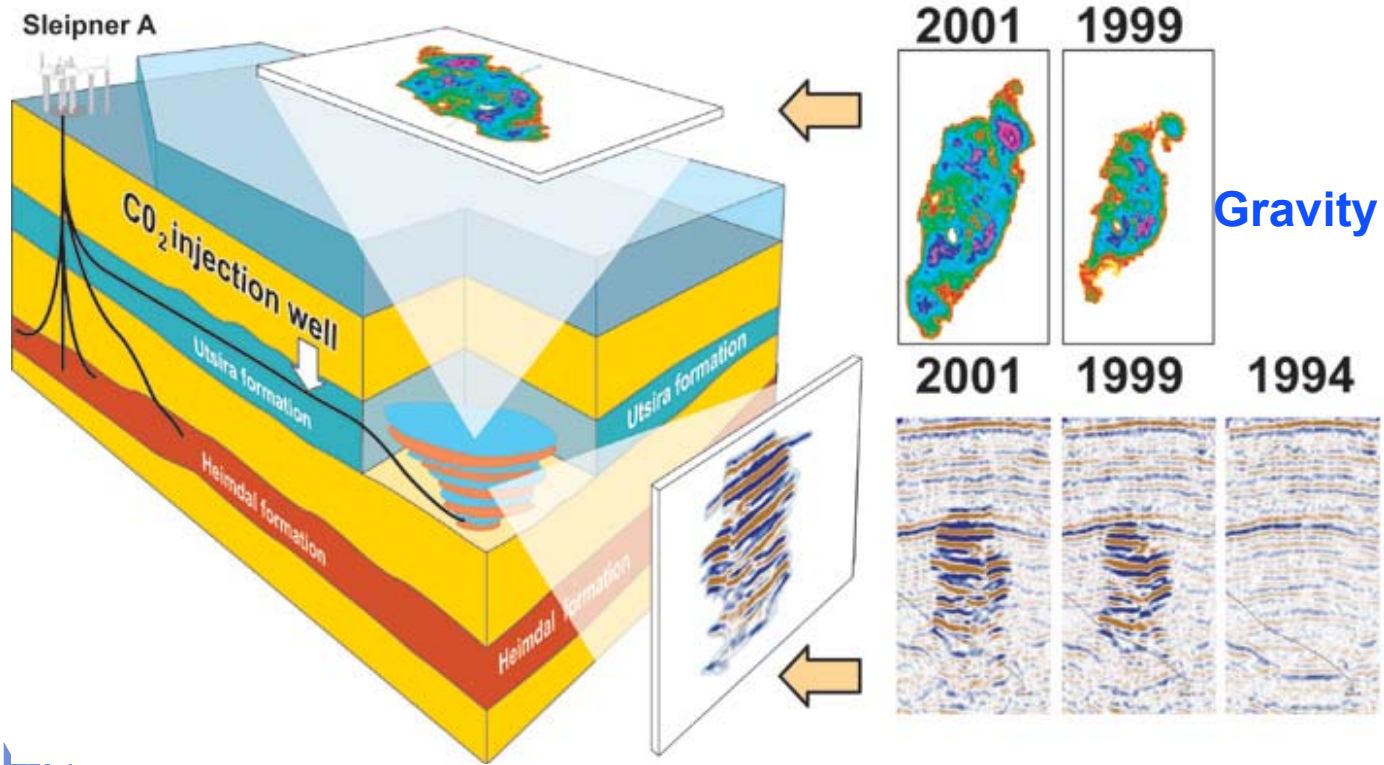
Source: Nooner, et al, 2003

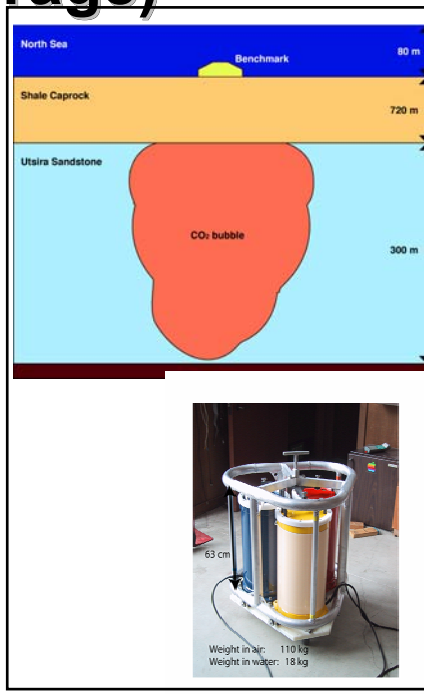
Taken from the SACS website

CO2 Monitoring efforts

Undertaken by SACS (Saline Aquifer CO_2 Storage) and CO2STORE

- 4-D seismics
- Time-lapse seafloor gravimetry





Source: Nooner, et al, 2003

Source: White, et al, 2003

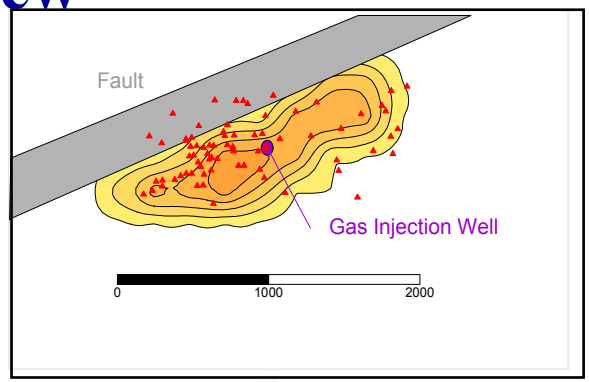
Weyburn Field, Canada

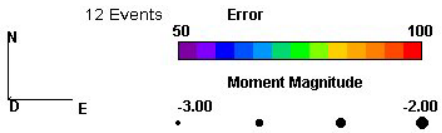
Weyburn Unit:

Field Size: 70 sq. miles

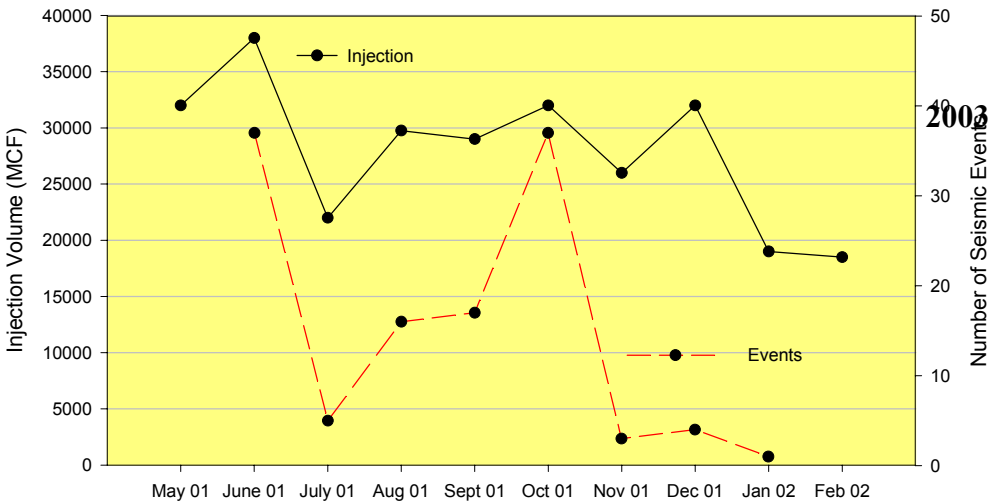
Oil Recovered: 370 million bbls

Injection Rates and Preliminary Weyburn Microseismic Monitoring: Map View





Observation Well
101/06-08-006-13W2/0



192/09-06-006-13W2/0

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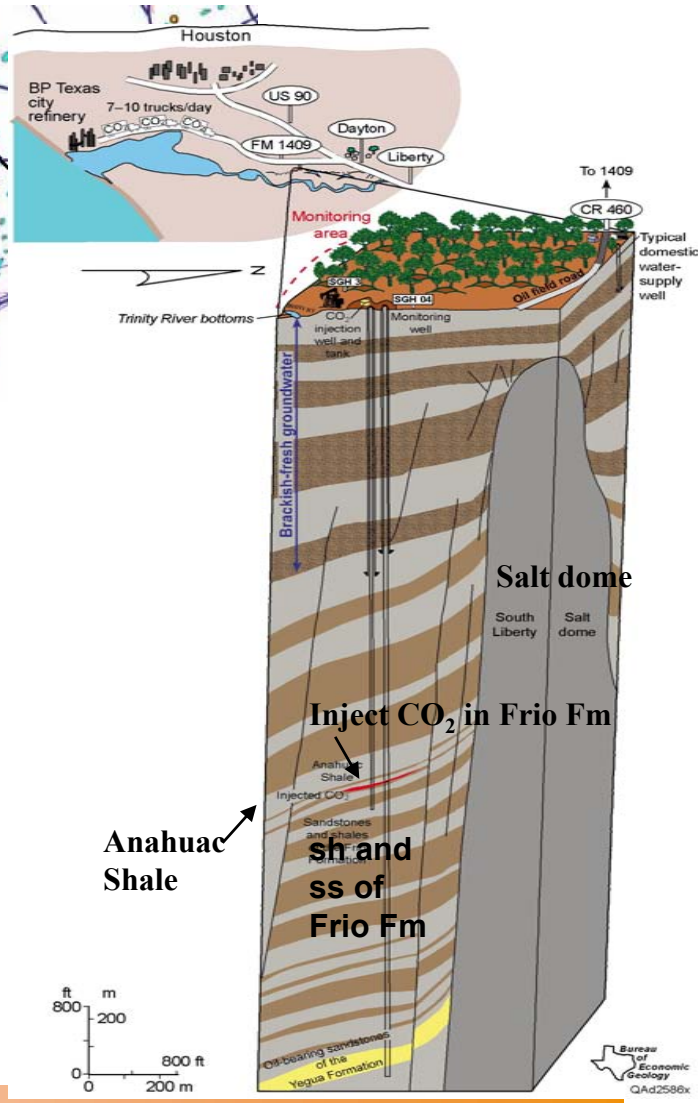
Source: White, et al, 2003

Frio Formation Texas Test Site

Small Scale Injection Provides Baseline Experience for Future Large Scale Tests and MM&V Studies

- 3,000 tons of CO_2 injected at depth of 1,500 m into a brine saturated sandstone
- Containment formed by **Anahuac** shale and growth faults
- Focus on MM&V methods to quantitatively monitor plume movement and CO_2 saturation

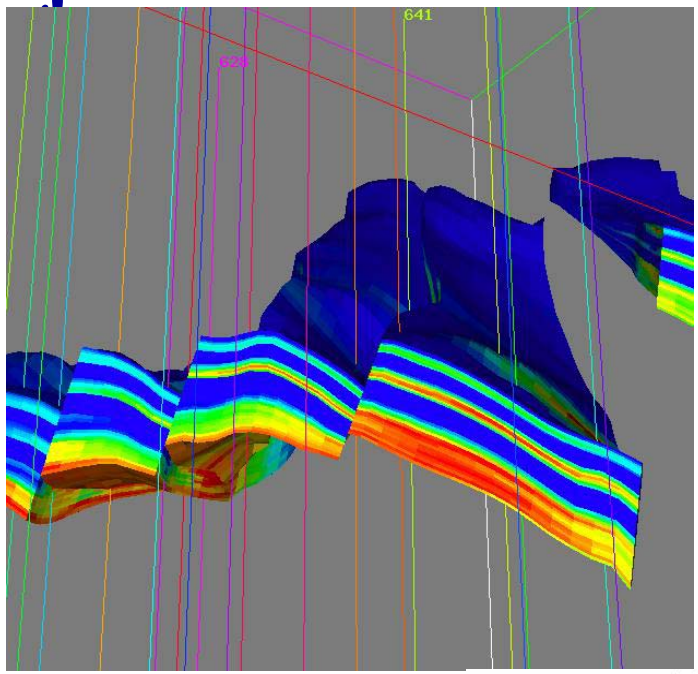


Baseline soil gas monitoring performed

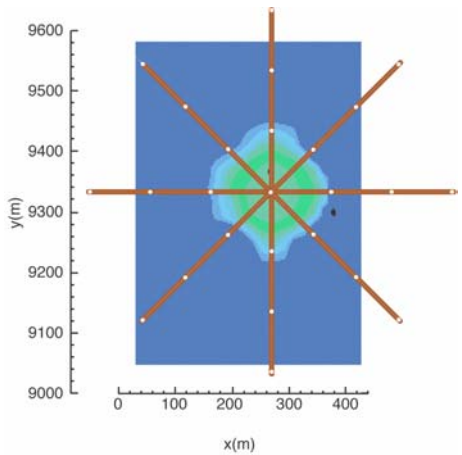
Source: Myer, et al, 2003

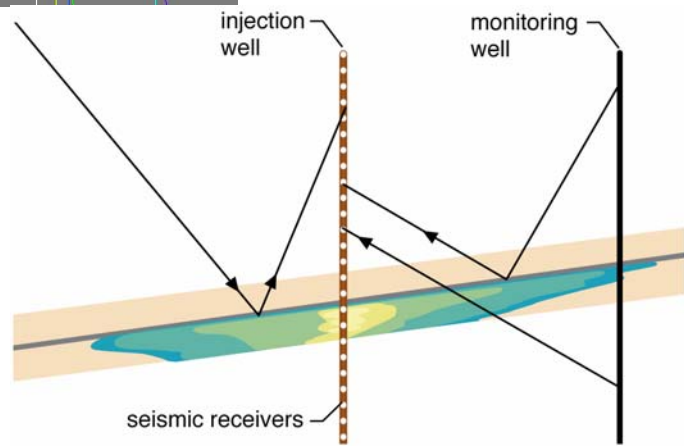
Frio Formation: Baseline MM&V and Post-Injection MM&V

- 3-D seismic, well logs, core, and other geologic data used to develop baseline geologic model
- Porosity map of section of Frio Fm containing A, B, and C sands
- Monitoring approach combines various methods:
  - *-Well Logging*
  - *-Vertical Seismic Profiling (VSP)*
  - *-Crosswell Seismic*
  - *-Streaming Potential*



- Surveys before and after CO_2 injection
- Surface dynamite for VSP

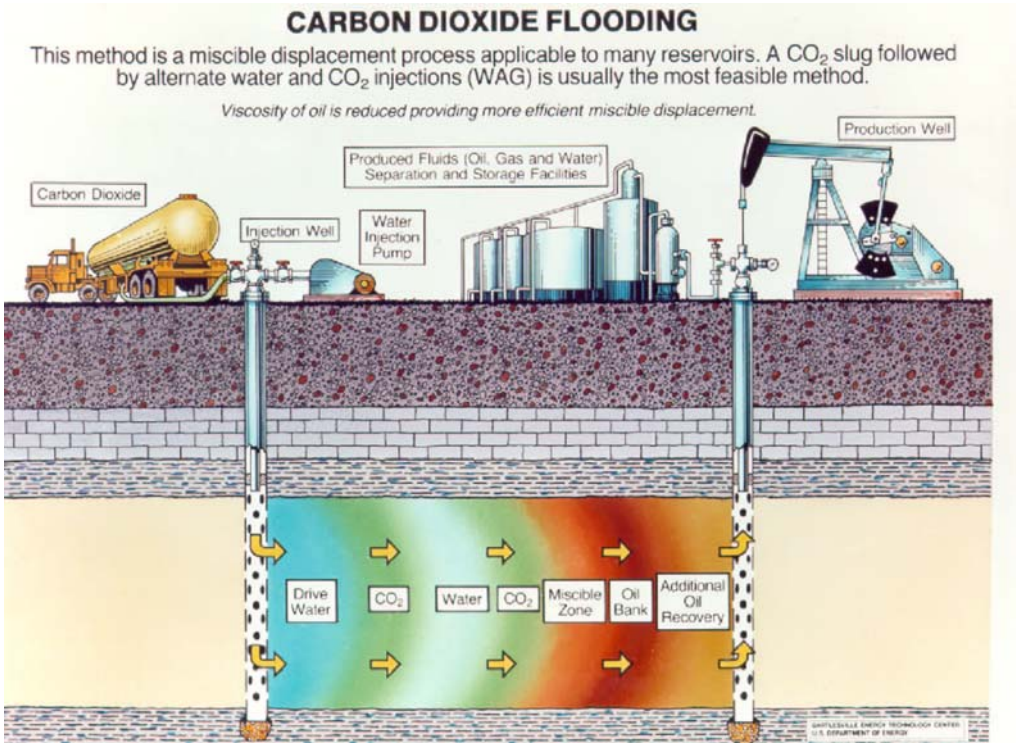




Source: Myer, et al, 2003

Geologic Sequestration MM&V Modeling and Simulations

West Pearl Queen Injection Test Site



Summary

❖Measurement, Mitigation, and Verification (MM&V) technologies comprise a primary component of DOE's Fossil Fuel Carbon Sequestration Program Roadmap. MM&V is defined as the capability to:

- Measure the amount of CO_2 stored at a specific sequestration site;
- Monitor the site for leaks/ deterioration over time to verify the CO_2 storage is permanent and not harmful to the ecosystem; and
- Provide mitigation capabilities to respond to CO_2 leakage or ecological damage if it should occur.

❖Major Roadmap goals include:

2006 - Apply promising MM&V technologies to several field tests or commercial applications.

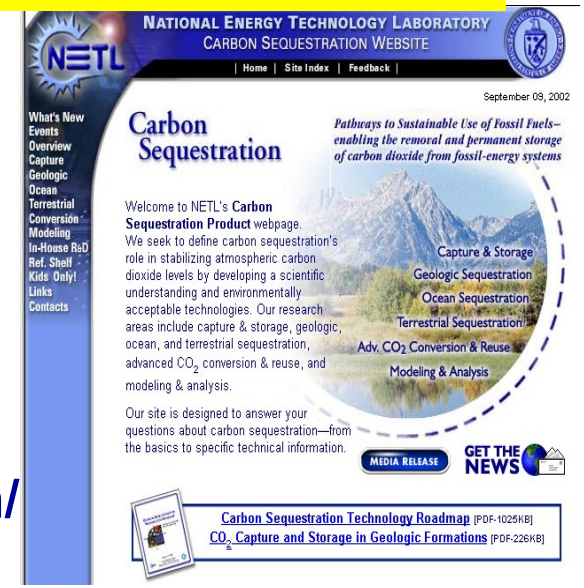
2008 - MM&V protocols enable 95% of CO_2 uptake in a terrestrial ecosystem to be credited and represents no more than 10% of the total sequestration cost.

2012 - MM&V protocols enable 95% of CO_2 injected into a geologic reservoir to be credited and represents no more than 10% of the total sequestration cost.

Summary, cont./Questions

- **MM&V research is ongoing in terrestrial and geologic sequestration projects, achieving accomplishments to meet DOE's Program Roadmap goals. Terrestrial/Geologic MM&V technology strategies include:**
  - ✓**Surface/near surface measurements;**
  - ✓**Subsurface measurements;**
  - ✓**Modeling and simulations; and**
  - ✓**Aerial measurements and satellite imagery.**

- **Examples include carbon measurements in soil by laser induced breakdown spectroscopy (LIBS) and a myriad of seismic techniques.**



Visit Our NETL Sequestration Website
www.netl.doe.gov/coalpower/sequestration/