U.S. DEPARTMENT OF ENERGY

Fossil Energy Sequestration Program

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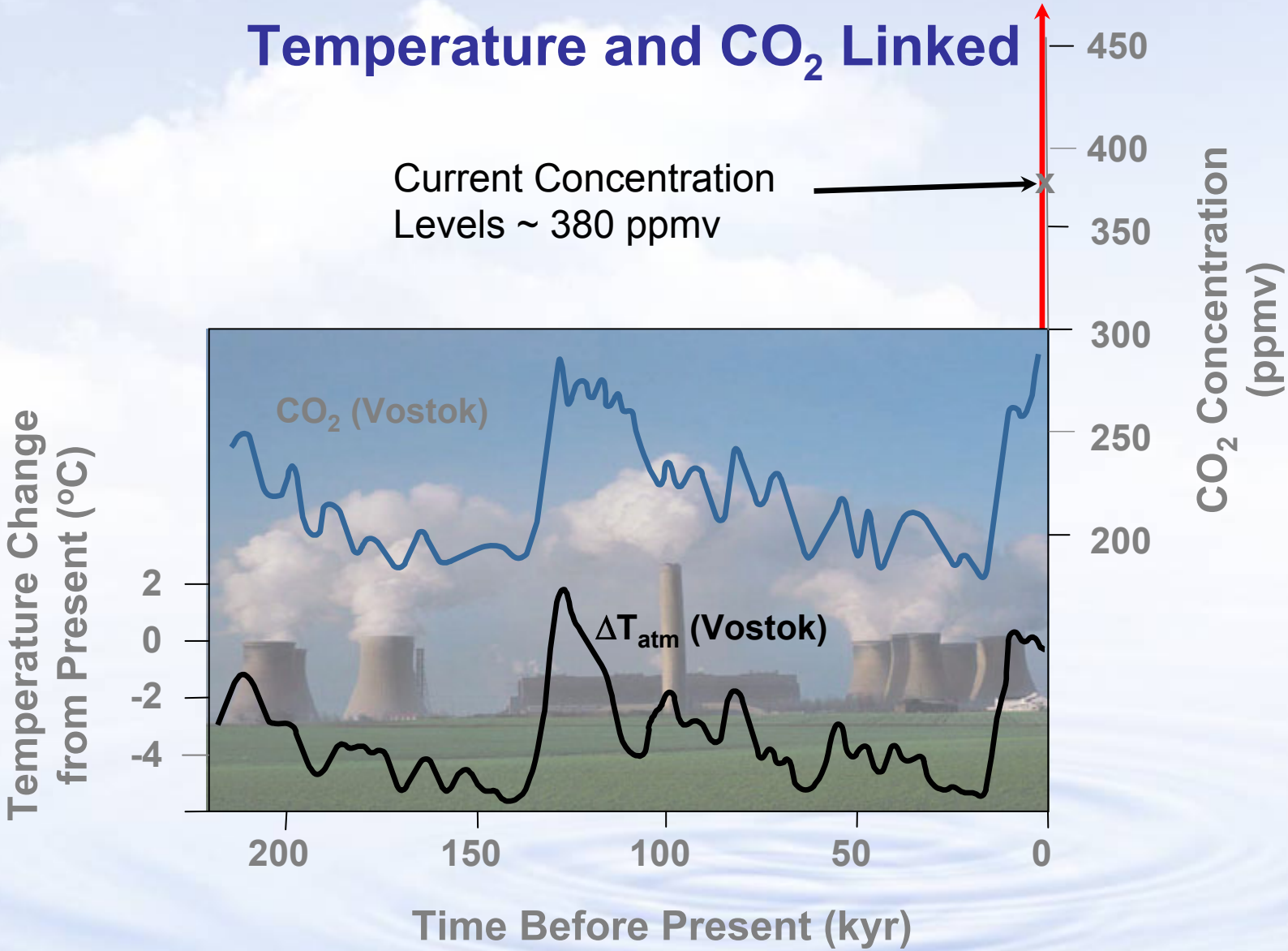
2006 DOE Hydrogen Program
Merit Review and Peer Evaluation Meeting

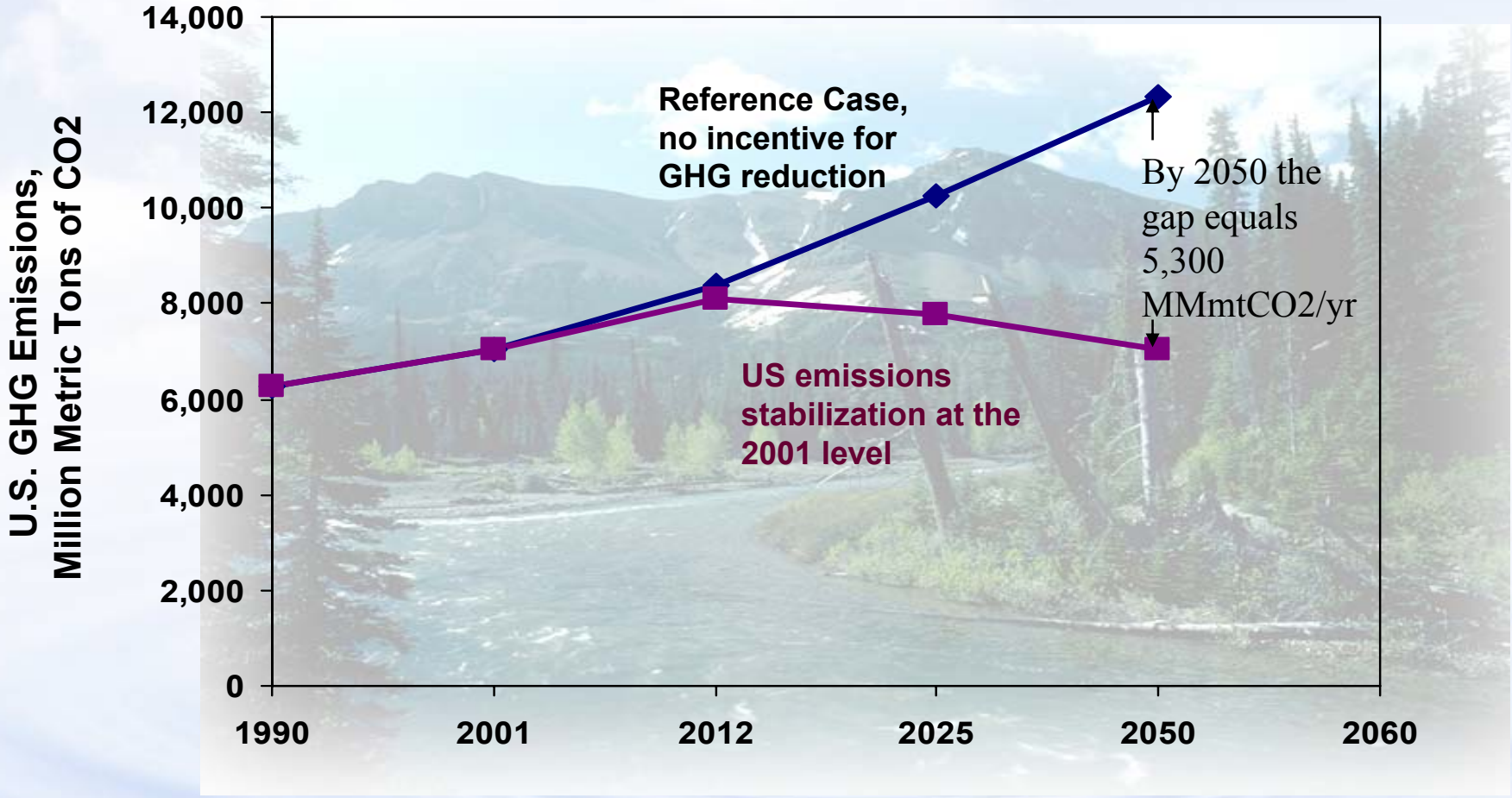
May 16, 2006

Temperature and CO_2 Linked



"Historical CO_2 Record From the Vostok Ice Core" J.M. Barnolo et al, August 1999
www.cdiac.esd.ornl.gov/ftp/trends/co2/vostok.icecore.co2
Oak Ridge National Laboratory Current Greenhouse Gas Concentrations
http://cdiac.ornl.gov/pns/current_ghg.html

U.S. Emissions of GHG Under the Reference and Stabilization Scenarios



Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

Sequester Carbon

- Capture & Store
- Enhance Natural Sinks

All options needed to:

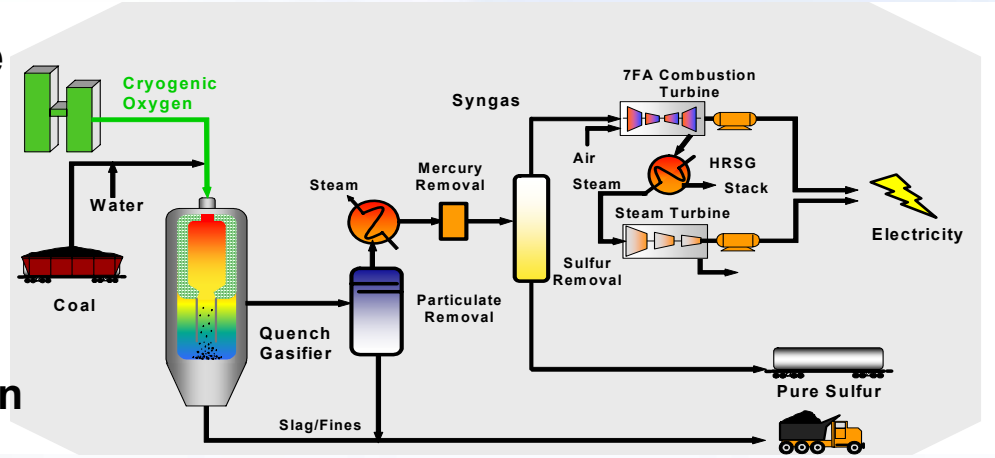
- **Affordably meet energy demand**
- **Address environmental objectives**

What is Carbon Capture

Separation and concentration of CO_2 from flue streams:

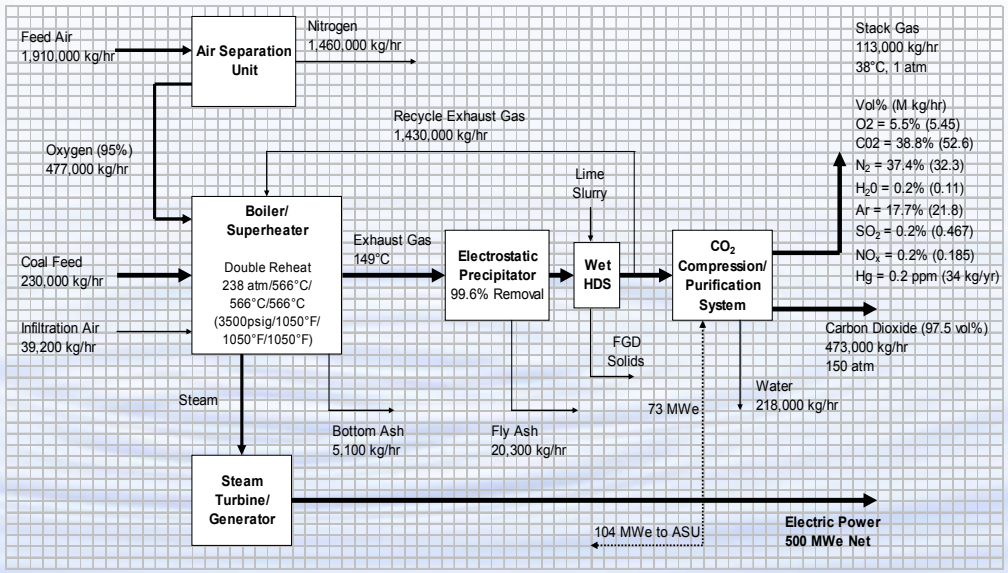
Three general classes of capture technology:

- **Post-combustion (e.g., amine scrubbing; adv. membranes)**
- **Pre-combustion (e.g., H_2O-gas shift; hydrate separation)**
- **Oxy-firing combustion (recirculation of the flue stream)**



Very expensive (40-80% in C.O.E.)

Primary research goal – cost reduction



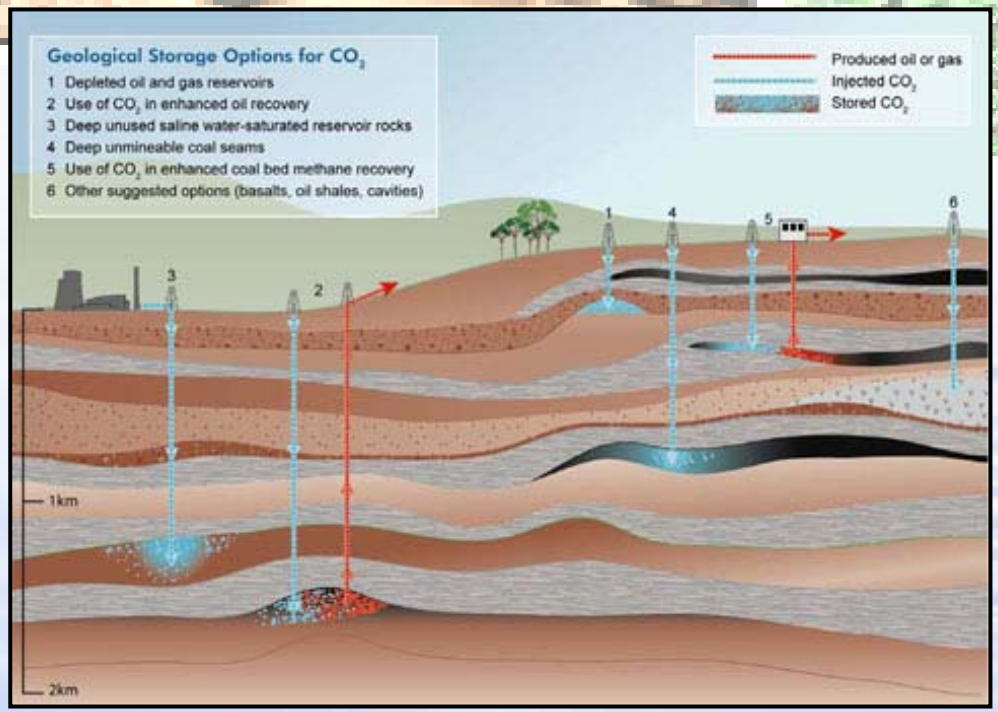
What is Sequestration

Geologic

Placement of CO_2 into an underground formation where it will remain isolated from interactions with the Earth's atmosphere for hundreds to thousands of years

Terrestrial

Enhancement of the uptake of CO_2 by plants that grow on land and in freshwater as well as enhancement of carbon storage in soils



Carbon Storage – How does it work?

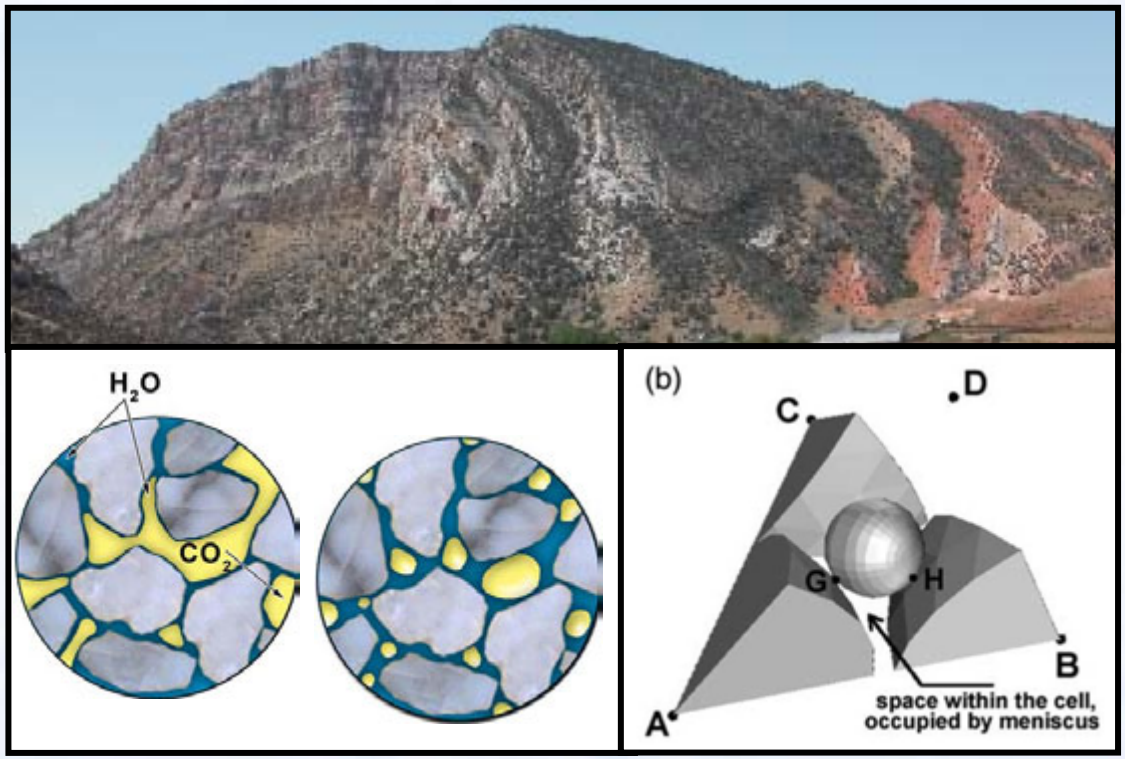
Storage mechanisms vary by target class; generally multiple processes which improve over time

Physical trapping
- Impermeable cap rock
- Either geometric or hydrodynamic stability

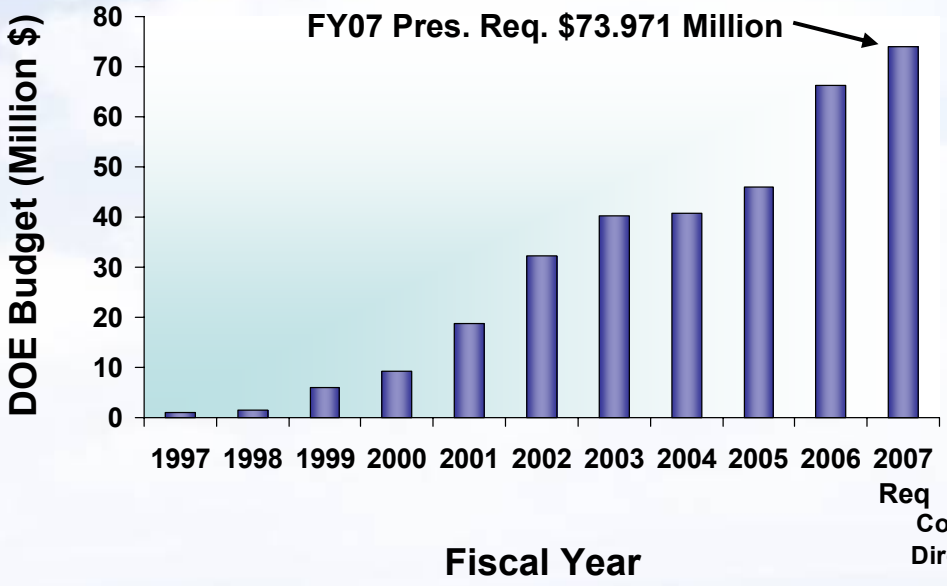
Residual phase trapping
- Capillary forces immobilized fluids
- Sensitive to pore geometry (<25% pore vol.)

Solution/Mineral Trapping
- Slow kinetics
- High permanence

Gas adsorption
- For organic minerals only (coals, oil shales)

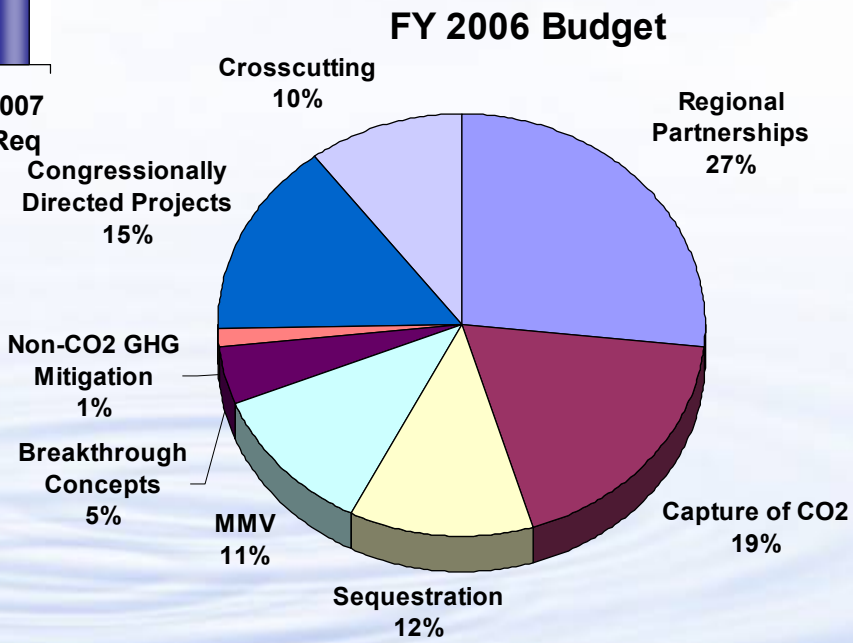


Sequestration Program Statistics FY2006



Strong industry support
~ 39% cost share on projects

Federal Investment to Date
~ $260 Million



Diverse research portfolio

~ 70 R&D Projects

Sequestration Program Goals

Develop Technology Options for GHG Management That...

- **Are safe and environmentally acceptable**
- **Separation and Capture R&D Goals**
  - ➔ 2007 have two technologies < 20% increase in Cost of Energy ***
  - ➔ 2012 developed two technologies < 10% increase Cost of Energy
- **Sequestration/Storage R&D Goals**
  - ➔ 2012 predict CO_2 storage capacity with +/- 30% accuracy
  - ➔ Develop best practice reservoir management strategies that maximize CO_2 trapping
- **Monitoring, Mitigation & Verification**
  - ➔ 2012 ability to verify 95% of stored CO_2 for credits (1605b)
  - ➔ CO_2 material balance to >99%

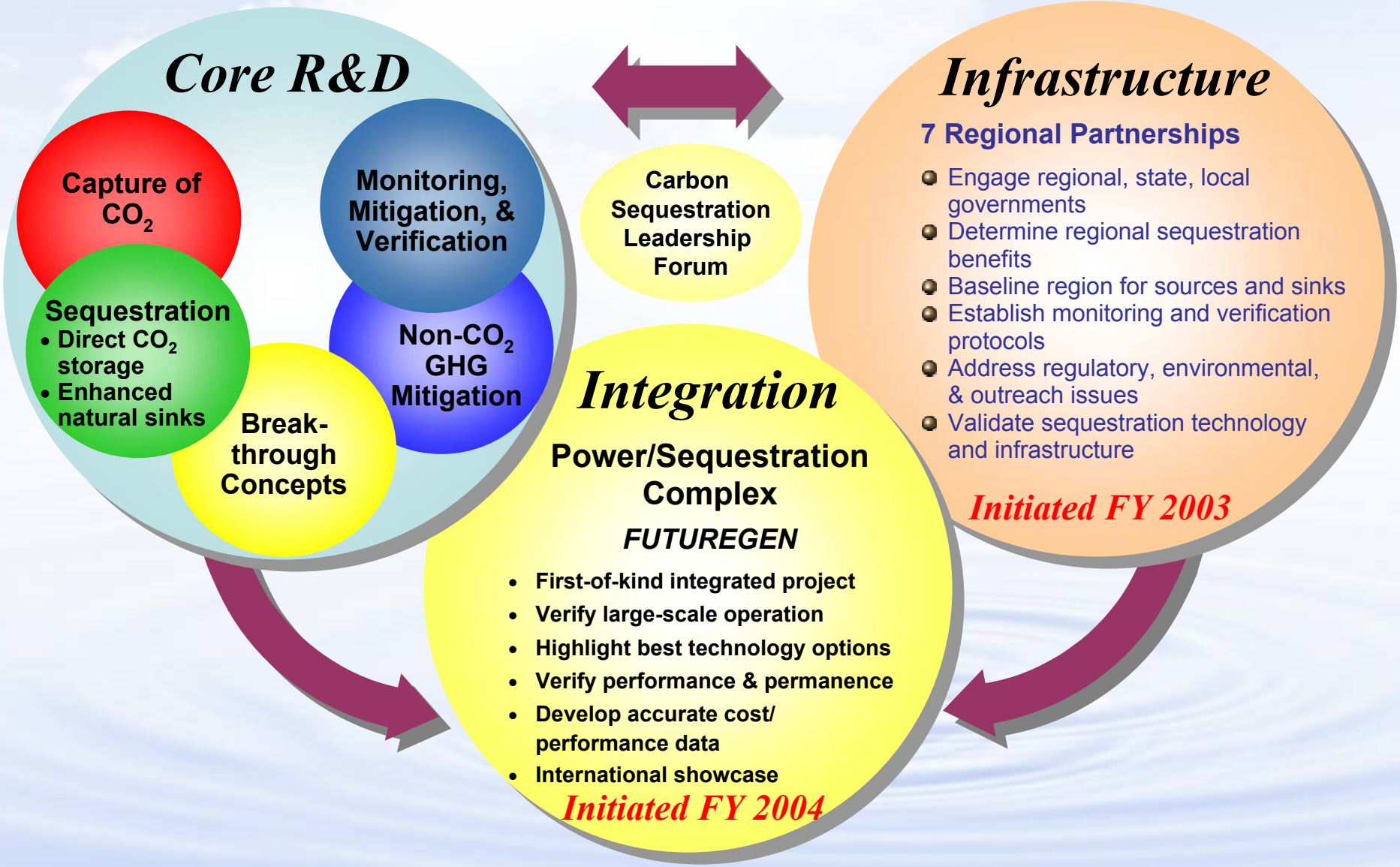
Cost Performance Goals

Year	COE Penalty IGCC Plants (% Increase)	COE Penalty PC Plants (% Increase)
2002	30	80
2007	20	45
2012	10	20
2015	<10	10
2018*	0	0

*Cost/Energy offset from sequestering CO_2 with criteria pollutants NOX, SOx, H2S (gasification)

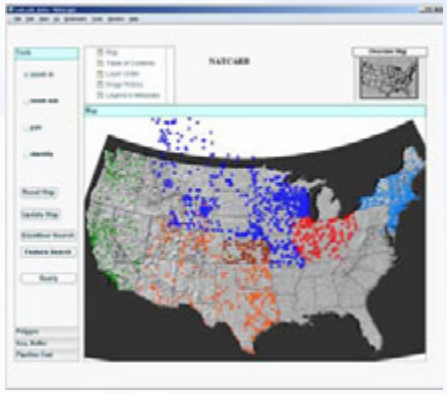
*** **technologies identified and ready to move to demonstration (~ 4yrs) and then deployment (~4 yrs) – IGCC 20% and PC 45%**

Carbon Sequestration Program Structure



Regional Partnership Update

"Developing the Infrastructure for Wide Scale Deployment"



Phase I (Characterization)

- 7 Partnerships (40 states)
- 24 months (2003-2005)

Phase II (Field Validation)

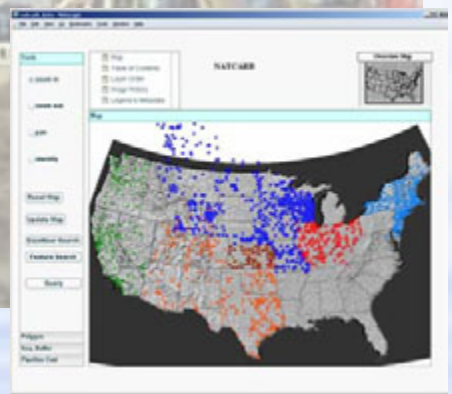
- 4 years (2005 - 2009)
- All seven Phase I partnerships continued
- $100 million federal funds
- $45 million in cost share

Phase III (Deployment)

- 8 years (2009-2017)
- Large Scale Injection Tests

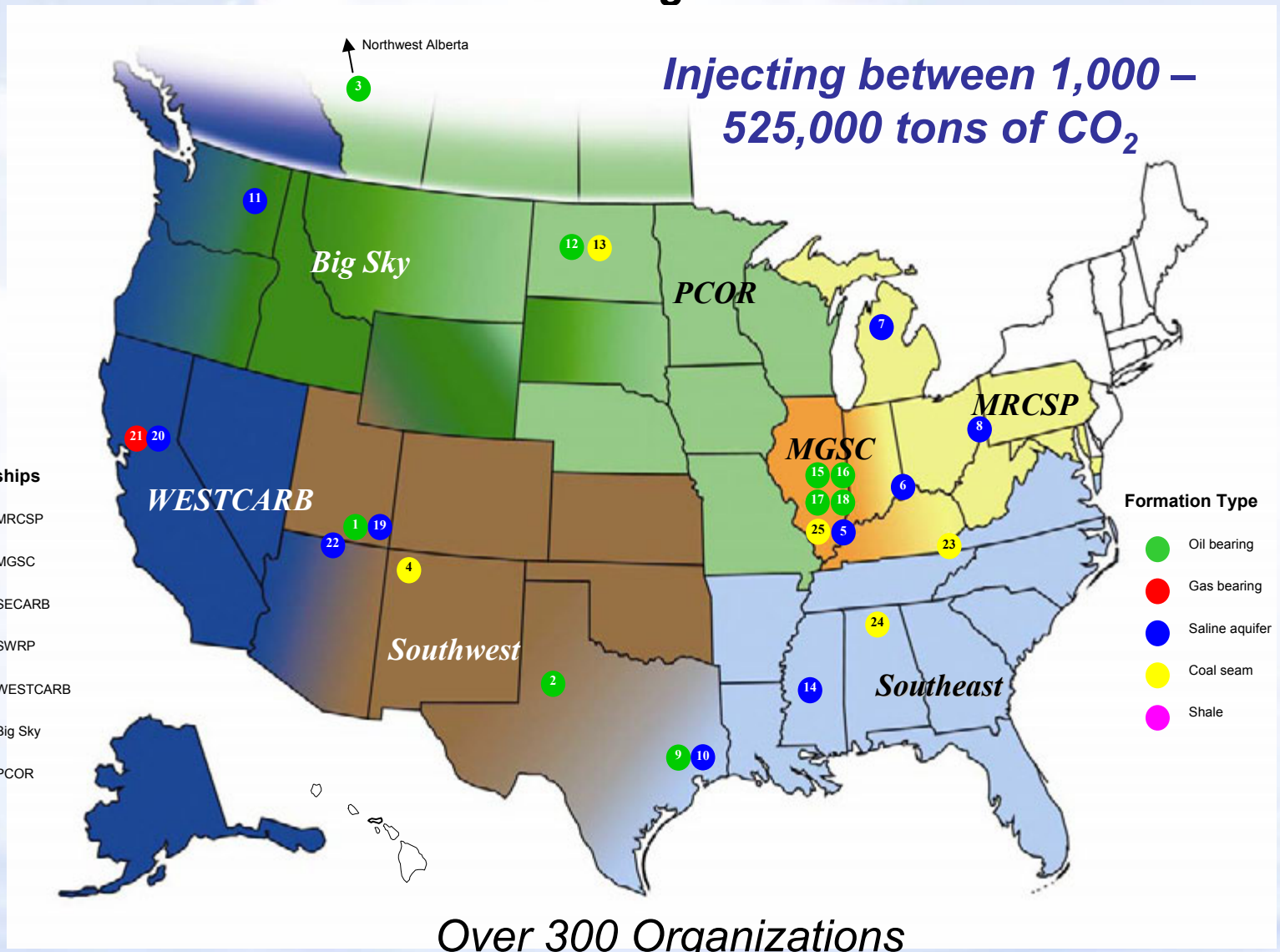
Phase I Highlights/Accomplishments

- **Identified Thousands of Years of Storage Capacity during Characterization Phase**
  - ➔ Coal Seams and Shales- ~ 18 GT
  - ➔ Oil and Gas Reservoirs - ~27 GT
  - ➔ Saline Formations - >5,000 GT
- **Identified Value Added Products in Potential Sinks**
  - ➔ Oil – 16 billion barrels of oil during sequestration in favorable fields
  - ➔ Coal Seams – 126 TCF CBM during sequestration in unmineable coal seams
- **Created a Carbon Sequestration Atlas for the U.S.**
  - ➔ NATCARB and Regional Atlases Available Online
  - ➔ www.natcarb.org



Regional Carbon Sequestration Partnerships

Phase II Geologic Field Tests



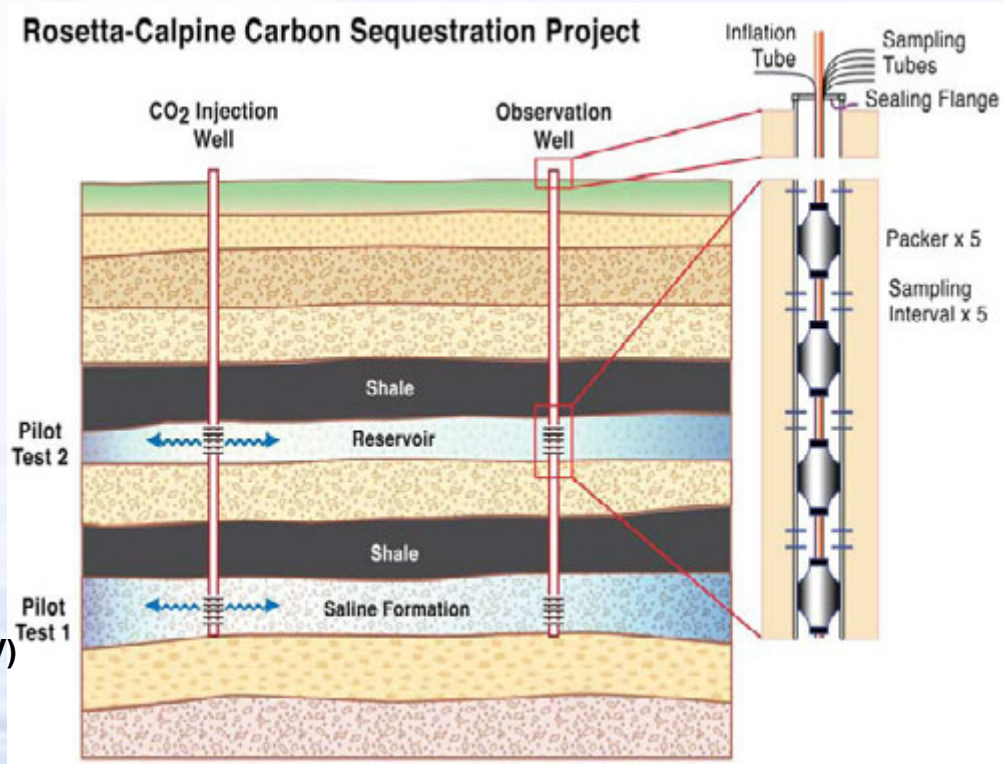
Over 300 Organizations

In Addition to Geologic - 10 Terrestrial Test

Example Phase II Project
WESTCARB

Rossetta-Calpine, Sacramento Valley, CA:

- ➔ Stacked sequestration EOR/Saline Aquifer test
- ➔ 2,000 tons CO_2 in a saline formation (end of 2006)
- ➔ 2,000 tons CO_2 in enhanced gas recovery scenario (end of 2007)
- ➔ 1.8 Gt CO_2 storage capacity in depleted gas fields in Sacramento Valley (128 fields)
- ➔ Estimated 140-840 Gt CO_2 storage capacity in saline formations in California, based on ten largest basins



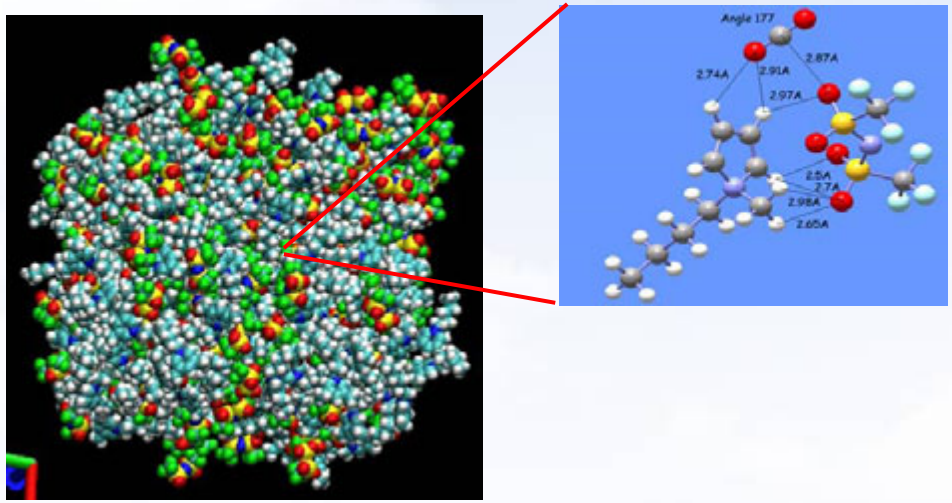
Regional Partnerships Addressing Key Issues

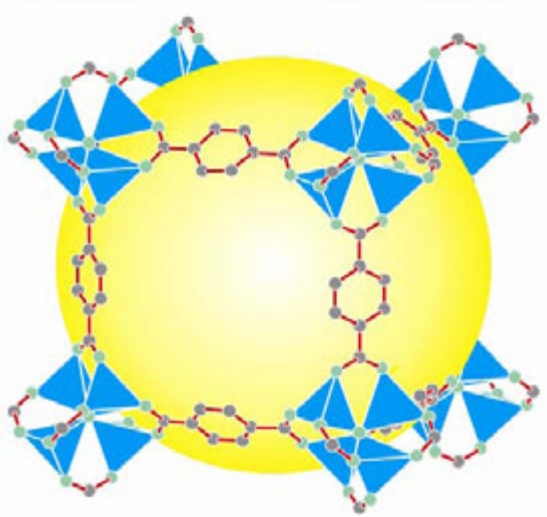
- Geologic Capacity estimates
- Site selection criteria
- Reservoir modeling and validation
- Monitoring, Mitigation, and Verification (MMV)
- Operational considerations
- Economics of sequestration

Core R&D - Separation and Capture
Advanced Capture Technologies

Ionic Liquids[(1)]

- Been discovered that CO2 is *highly soluble* in some ionic liquids
- Non-volatile liquid and high thermal stability
- Ability to capture SO2 with one solvent





Metal Organic Frameworks[(2)]

- Highly porous materials
- Thermally stable
- High loading capacities
- Low manufacturing costs

Participants: UOP LLC[(1)] and University of Notre Dame[(2)]

Funding Opportunity Announcement in CO_2 Capture
DE-PS26-06NT42829

- 'Novel Technology and Commercially Focused Approaches to CO2 Capture and Separation for Existing and Future Carbon Based Electric Generation Power Plants'
- Released: 4/19/2006
- Closes: 6/16/2006 at 8:00 PM Eastern Time
- Three (3) Areas of Interest
  - ➔ Breakthrough Approaches to Carbon Dioxide and Separation
    - Novel and innovative methods (Post- and Oxy-combustion)
  - ➔ Continued Development of Direct CO_2 Capture and Separation Technologies
    - Technologies continuing the development of post-, pre-, and oxy-combustion based CO2 capture
  - ➔ Field-Testing of CO2 Capture and Separation Technologies
    - Conduct field-testing of oxygen-based combustion and post combustion CO2 capture technologies
- $39 Million DOE over 3-yrs, Cost-Sharing required of 20% of project costs
- http://www.netl.doe.gov/business/solicitations/index.html#42829

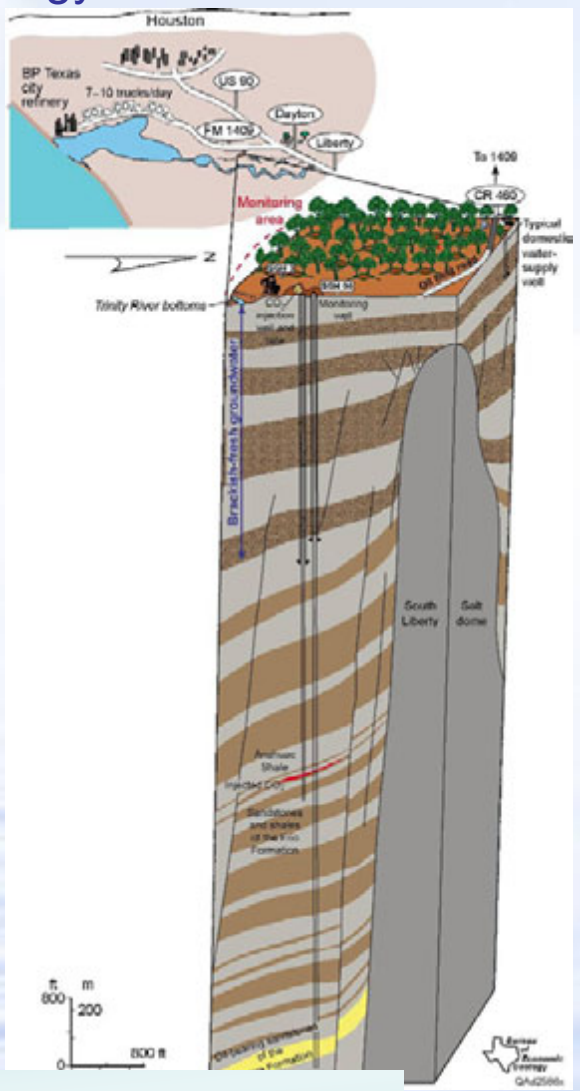
Sequestration Core R&D
Frio Brine Reservoir Pilot Test

Univ. of Texas Bureau of Economic Geology

- Investigated injectivity, safety, capacity and permanence of CO_2 for Gulf Coast saline reservoir

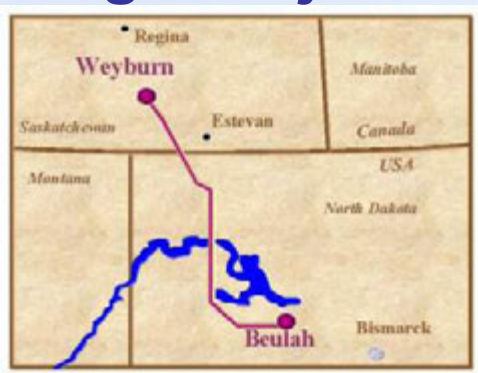
- Phase I (Oct 2004 injection):
  - demonstrated 1600 tons CO_2 injection at 5100 ft in a brine reservoir without adverse health, safety, or environmental effects;
  - determined the distribution of injected CO_2 using diverse monitoring technologies;
  - demonstrated validity of models; and
  - developed expertise necessary for success of large-scale CO_2 injection

- Phase II will follow these successes and inject ~700 tons CO_2 into unperturbed lower Frio sandstone unit using existing injection and observations wells; based on experience, study will:
  - develop effective monitoring strategy with geophysics, geochemistry, logging, and reservoir properties
  - refine reservoir modeling
  - develop best practices

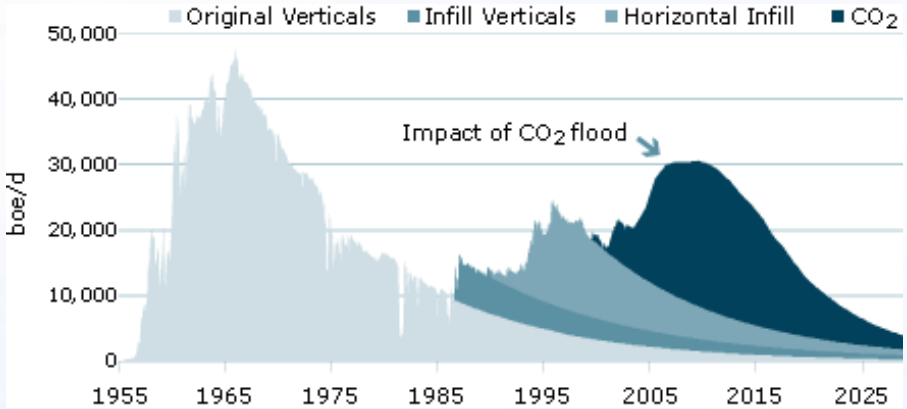


Participants: Texas BEG, BP, Schlumberger, Texas American Resources, Praxair, Core Labs, Sandia Technologies, LBNL, LLNL,ORNL, NETL

MMV Core R&D
IEA GHG Weyburn CO_2 Monitoring and Storage Project



- Weyburn field EOR flood operations inject CO_2 into carbonate oil reservoir at 5000 ft depth; integrated with CO_2 storage study
- CO_2 (with H2S) is piped 204 miles from Dakota Gasification Plant
- Results for CO_2 reduction:
  - 5000 tons/day of CO_2 stored in ground
  - more than 5 million tons already injected
  - storage potential of 30 million tons of CO_2
- Results for oil increase:
  - additional 10,000 barrels/day
  - oil production potential of additional 130 million barrels



- Phase II:
  - expand to the Midale Unit operated by Apache Canada Ltd. who will implement a field-wide CO_2 EOR project in 2005
  - expand studies of characterization, monitoring and verification, reservoir performance, modeling, environmental impacts, and risk assessment
  - develop a “Best Practices Manual” for geological storage, monitoring, and verification

Additional Information

http://www.netl.doe.gov/technologies/carbon_seq/index.html