

# DOE's Carbon Capture and Sequestration R&D Program

## *Power-Gen International Greenhouse Gas Regulation: The Future is Now – Panel Discussion*

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# Technological Carbon Management Options

## *Pathways for Reducing GHGs - CO<sub>2</sub>*

### Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

### Improve Efficiency

- Demand Side
- Supply Side

### Sequester Carbon

- Enhance Natural Sinks
- Capture & Store

### All options needed to:

- Affordably meet energy demand
- Address environmental objectives



# What is Carbon Sequestration?

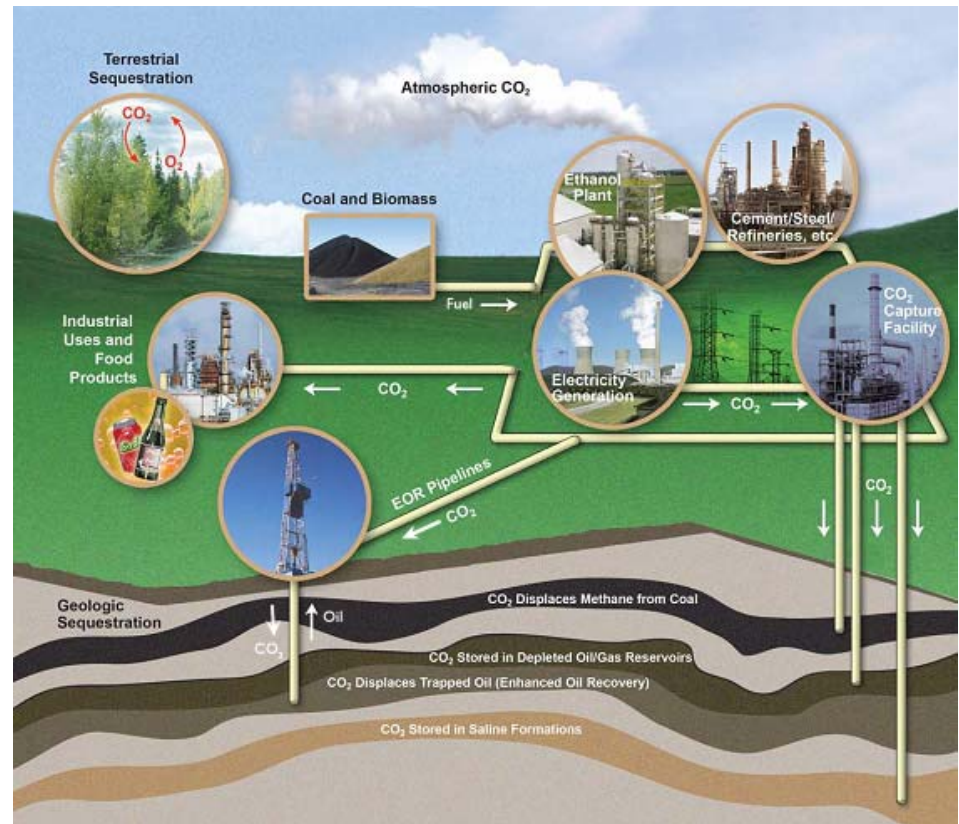
*Capture and storage of CO<sub>2</sub> and other Greenhouse Gases that would otherwise be emitted to the atmosphere*

## Capture can occur:

- at the point of emission
- when absorbed from air

## Storage locations include:

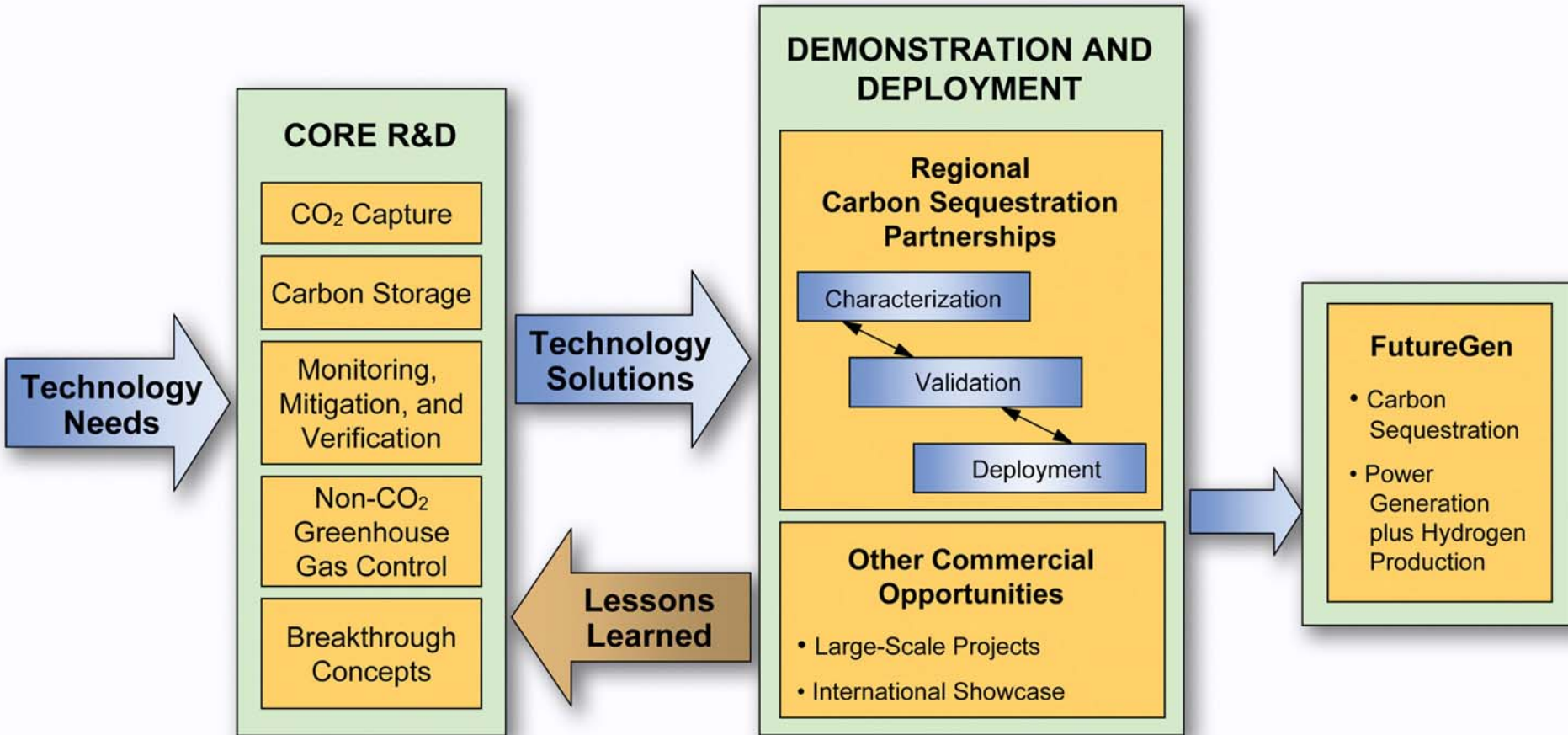
- underground reservoirs
- conversion to solid materials
- trees, grasses, soils, or algae



Source: Carbon Sequestration Technology Roadmap and Program Plan 2007



# DOE's Carbon Sequestration Program Structure



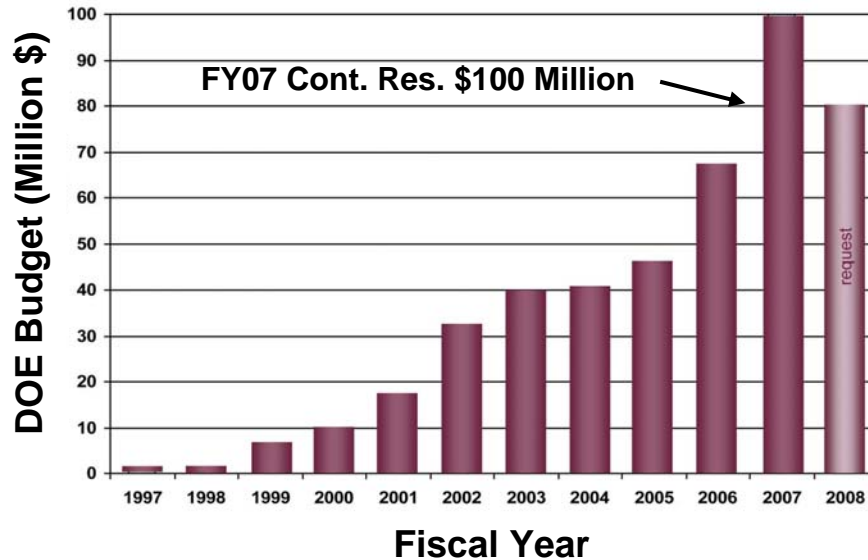
# Carbon Sequestration Program Goals

- **Deliver technologies & best practices that validate:**

- 90% CO<sub>2</sub> capture
- 99% storage permanence
- < 10% increase in COE (pre-combustion capture)
- < 20% increase in COE (post- and oxy-combustion)



# DOE's Carbon Sequestration Program Statistics

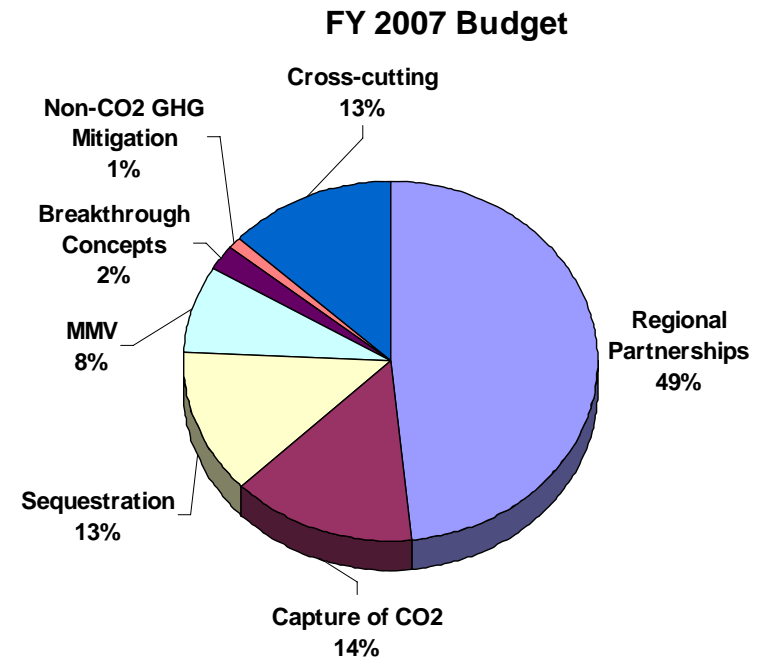


**Strong industry support**  
 ~ 39% cost share on projects

**Federal Investment to Date**  
 ~ \$360 Million

**Diverse research portfolio**

~ 70 Active R&D Projects



# Separation & Capture of CO<sub>2</sub> from Coal-Based Power Plants

## Issue

- Demonstrated technology is costly & energy-intensive

## Approaches

- Post-combustion
- Pre-combustion
- Oxycombustion
  - Chemical looping

## Research Pathways

- Chemical & Physical Solvents
- Chemical & Physical Sorbents
- Membranes
- Advanced Oxycombustion Technologies



# Carbon Capture RD&D Challenges

## Pre-combustion (Synthesis Gas)



- Loss of CO<sub>2</sub> pressure due to flash regeneration
- Cooling / refrigeration of syngas to accommodate low operating temperatures; reheating prior to combustion
- H<sub>2</sub> losses, particularly in membranes
- Sulfur-tolerant materials / membranes

## Post-combustion (Flue Gas)



- Low-pressure flue gas dilute in CO<sub>2</sub>
- Steam requirement for thermal regeneration (amines)
- High compression costs and large loads due to CO<sub>2</sub> produced at low pressure
- Flue gas contaminants

## Oxygen Combustion (OxyFuel)



- Cost of O<sub>2</sub> production and materials
- Cooled CO<sub>2</sub> recycled to control combustion temperatures



# Carbon Capture Research Pathways

## *Chemical Solvents*

### Process Description

- Reversible chemical reaction(s) between CO<sub>2</sub> and aqueous absorbent solution
- Mature technology (MEA) at smaller scale

### Research Focus

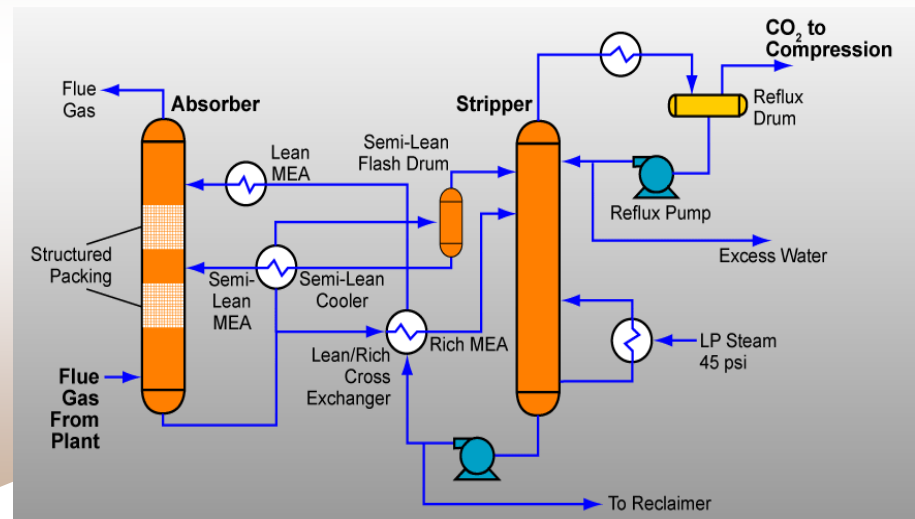
- ❖ Identify lower cost alternatives to MEA
  - ✓ Low solvent cost
  - ✓ High CO<sub>2</sub> loading capacity
  - ✓ Non-corrosive
  - ✓ No solvent degradation
  - ✓ Low regeneration energy

### Primary Research Partners

*Alstom, NETL/ORD, Powerspan Corp.*

### Potential Technology Solutions

- ❖ Improved solvents (carbonates, hindered amines, ammonia, etc.)
- ❖ Blended and promoted solvents



Source: DOE/NETL



# Carbon Capture Research Pathways

## *Physical Solvents*

### Process Description

- Bulk phenomenon where liquids absorb a gaseous species from a gas mixture
- Most effective with high CO<sub>2</sub> partial pressure (IGCC systems)
- Mature technology (Selexol™ & Rectisol®) at smaller scale

### Research Focus

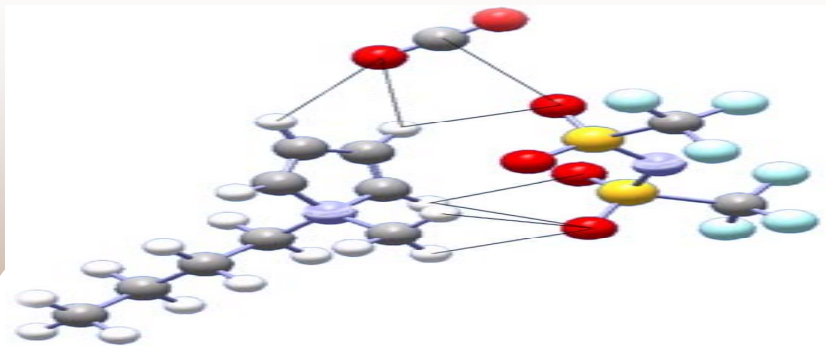
- ❖ Ionic Liquids (ILs)
  - ✓ High thermal stability
  - ✓ Low volatility
  - ✓ High CO<sub>2</sub> solubility
  - ✓ Separation media for H<sub>2</sub> and CO<sub>2</sub>
  - ✓ High unit cost

Primary Research Partners

*NETL/ORD, University of Notre Dame*

### R&D Progress

*Over 19x increase in CO<sub>2</sub> solubility for physical ILs and 40x increase in CO<sub>2</sub> solubility for ILs with chemical complexation when compared to ILs available at the beginning of the project*



# Carbon Capture Research Pathways

## *Chemical Sorbents*

### Process Description

- Chemical adsorption involves bonding with a solid sorbent
- Low moisture content reduces regeneration steam requirements

### Research Focus

- ❖ Solid regenerable CO<sub>2</sub> sorbents
  - ✓ Durable
  - ✓ High selectivity
  - ✓ Multiple regeneration cycles
  - ✓ High CO<sub>2</sub> adsorption capacity
  - ✓ Low cost

### Primary Research Partners

*NETL/ORD, Research Triangle Institute, University of Akron, UOP LLC*

### Potential Technology Solutions

- ❖ Sodium & potassium oxides
- ❖ Carbonates
- ❖ Amine-enriched sorbents (Zeolites)



# Carbon Capture Research Pathways

## *Physical Sorbents*

### Process Description

- Physical adsorption of CO<sub>2</sub> on solid adsorbents by weak surface forces
- Adsorption capacity increases with CO<sub>2</sub> partial pressure
- Regeneration via TSA or PSA

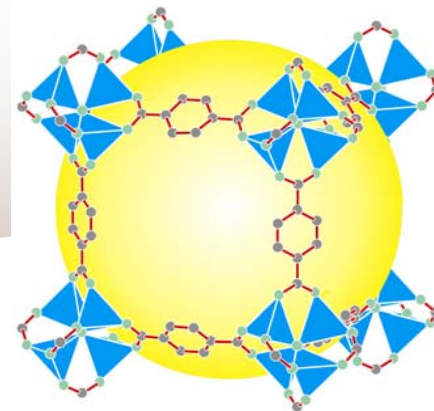
### Research Focus

- ❖ Metal organic frameworks (MOFs)
  - ✓ Hybrid organic/inorganic ordered structures w/ high porosity
  - ✓ High thermal stability
  - ✓ High adsorption capacity
  - ✓ High selectivity
  - ✓ Customized sorption properties
  - ✓ Good adsorption/desorption rates

Primary Research Partner  
UOP LLC

### Future Work

- ❖ Evaluate hydrothermal stability
- ❖ Synthesis, forming, and scale-up
- ❖ Process design and economics



# Carbon Capture Research Pathways

## *Membranes*

### Process Description

- Diffusion via a physical or chemical interaction between the membrane and CO<sub>2</sub>
- Selectivity and permeability are key
- Most effective with high CO<sub>2</sub> partial pressure (IGCC systems)

### Research Focus

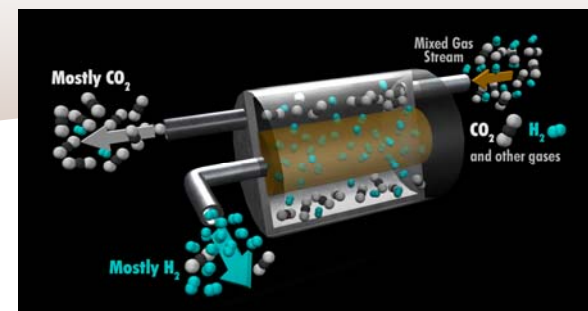
- ❖ More efficient CO<sub>2</sub> membranes
  - ✓ Durable
  - ✓ Improved selectivity
  - ✓ Thermal and physical stability
  - ✓ Sulfur tolerance

### Primary Research Partners

*Carbozyme, Membrane Technology & Research, NETL/ORD, SRI International, LANL & INEEL*

### Potential Technology Solutions

- ❖ Polymers (PBI)
- ❖ Metals (palladium)
- ❖ Facilitated transport
- ❖ Molecular sieves
- ❖ Gas absorption membranes
- ❖ Carbonic anhydrase enzyme
- ❖ Ionic liquids



# Carbon Capture Research Pathways

## *Advanced Oxycombustion Technologies*

### Process Description

- Combustion in pure O<sub>2</sub> to produce flue gas that is comprised of H<sub>2</sub>O and CO<sub>2</sub>
- CO<sub>2</sub> separation via H<sub>2</sub>O condensation

### Research Focus

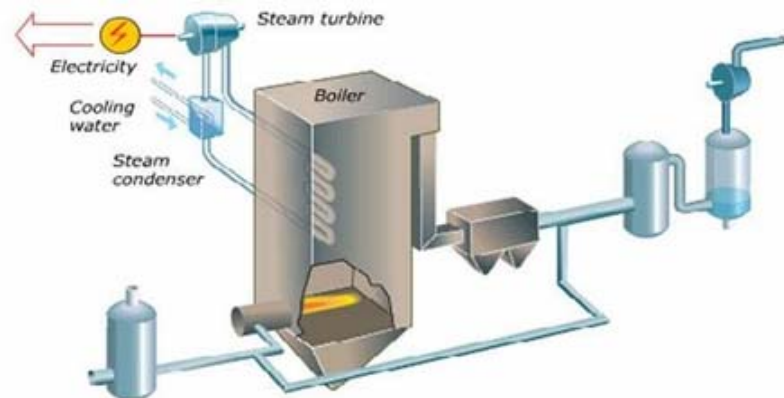
- ❖ Reduce O<sub>2</sub> production costs
- ❖ Improved oxyfuel boilers
  - ✓ Compact design
  - ✓ Advanced materials and burners
- ❖ Retrofit options
- ❖ Reduce flue gas recycle
- ❖ Co-sequestration

### Primary Research Partners

*B&W, BOC Group, Jupiter Oxygen, NETL/ORD, Praxair, SRI*

### Potential Technology Solutions

- ❖ Oxygen Transport Membranes (OTM)
- ❖ Ceramic Autothermal Recovery (CAR)
- ❖ Integrated Pollutant Removal
- ❖ Chemical Looping



# Regional Carbon Sequestration Partnerships

## Creating Infrastructure for Wide Scale Deployment

### Characterization Phase

- 24 months (2003-2005)

### Validation Phase

- 4 years (2005 - 2009)
- Field validation tests
  - 25 Geologic
  - 11 Terrestrial

### Deployment Phase

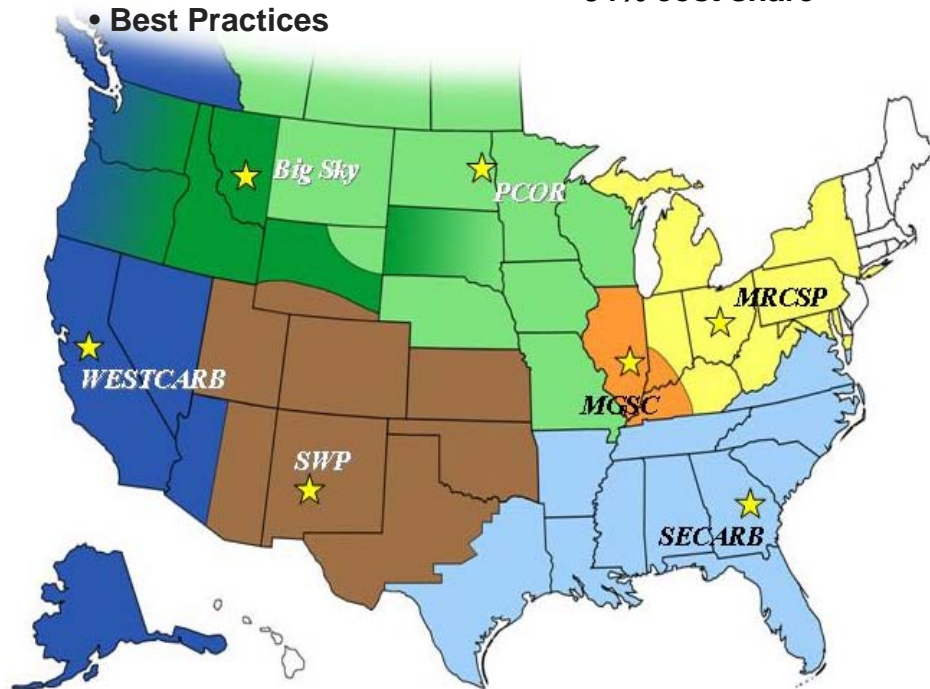
- 10 years (2007-2016)
- Up to 7 large volume injection tests

#### Addressing:

- Permitting
- Regulatory framework
- Public Acceptance
- Liability
- Best Practices

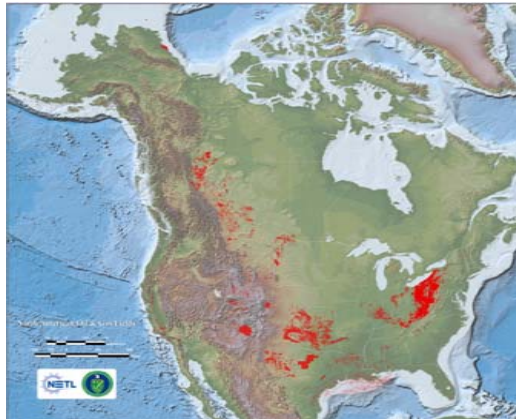
#### Representing:

- >350 Organizations
- 41 States
- 4 Canadian Provinces
- 3 Indian Nations
- 34% cost share

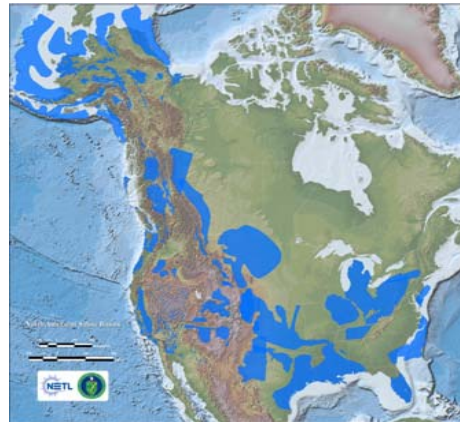


# First Ever National Sequestration Atlas

U.S. Emissions ~ 6 GT CO<sub>2</sub>/yr all sources

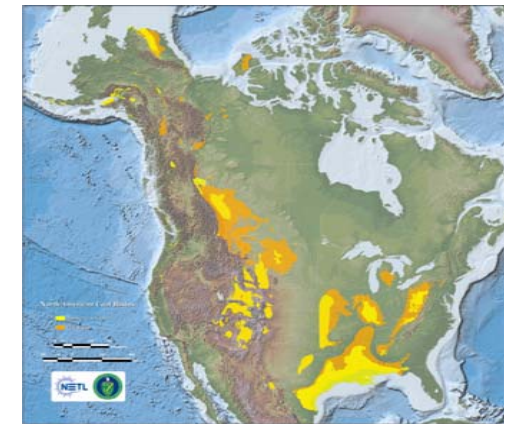


**Oil and Gas Fields**



**Saline Formations**

North American CO<sub>2</sub> Storage Potential  
(Giga Tons)



**Unmineable Coal Seams**

Sink Type	Low	High
Saline Formations	969	3,223
Unmineable Coal Seams	70	97
Oil and Gas Fields	82	83

**Hundreds of  
Years of  
Storage  
Potential**



Available for download at [http://www.netl.doe.gov/publications/carbon\\_seq/refshelf.html](http://www.netl.doe.gov/publications/carbon_seq/refshelf.html)



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- [2005 Annual Site Environmental Report](#)
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