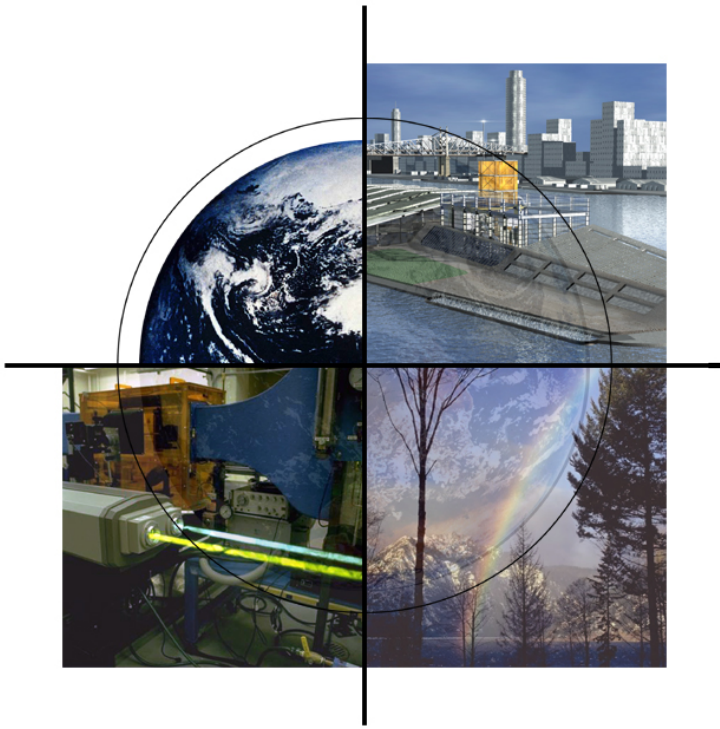
DOE's Carbon Capture and Sequestration R&D Program



Power-Gen International

Greenhouse Gas Regulation: The Future is Now – Panel Discussion

December 11-13, 2007
New Orleans, LA

Timothy E. Fout
Timothy.Fout@netl.doe.gov
National Energy Technology Laboratory

Technological Carbon Management Options

Pathways for Reducing GHGs - CO_2

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?

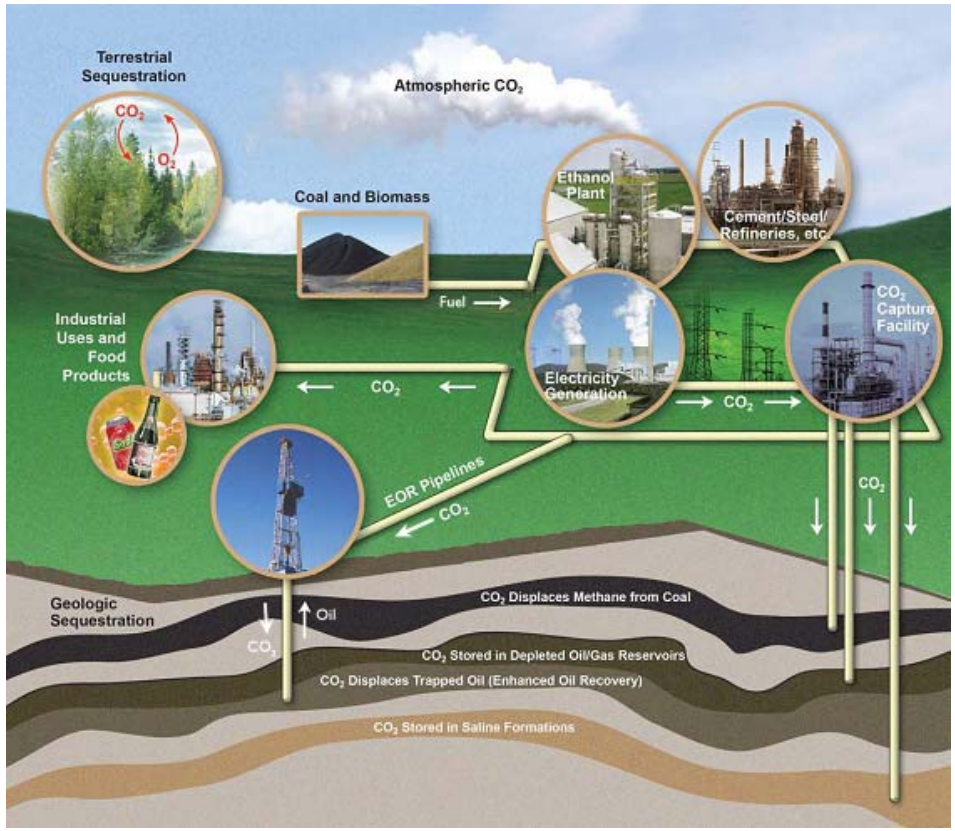
Capture and storage of CO_2 and other Greenhouse Gases that would otherwise be emitted to the atmosphere

Capture can occur:

- at the point of emission
- when absorbed from air

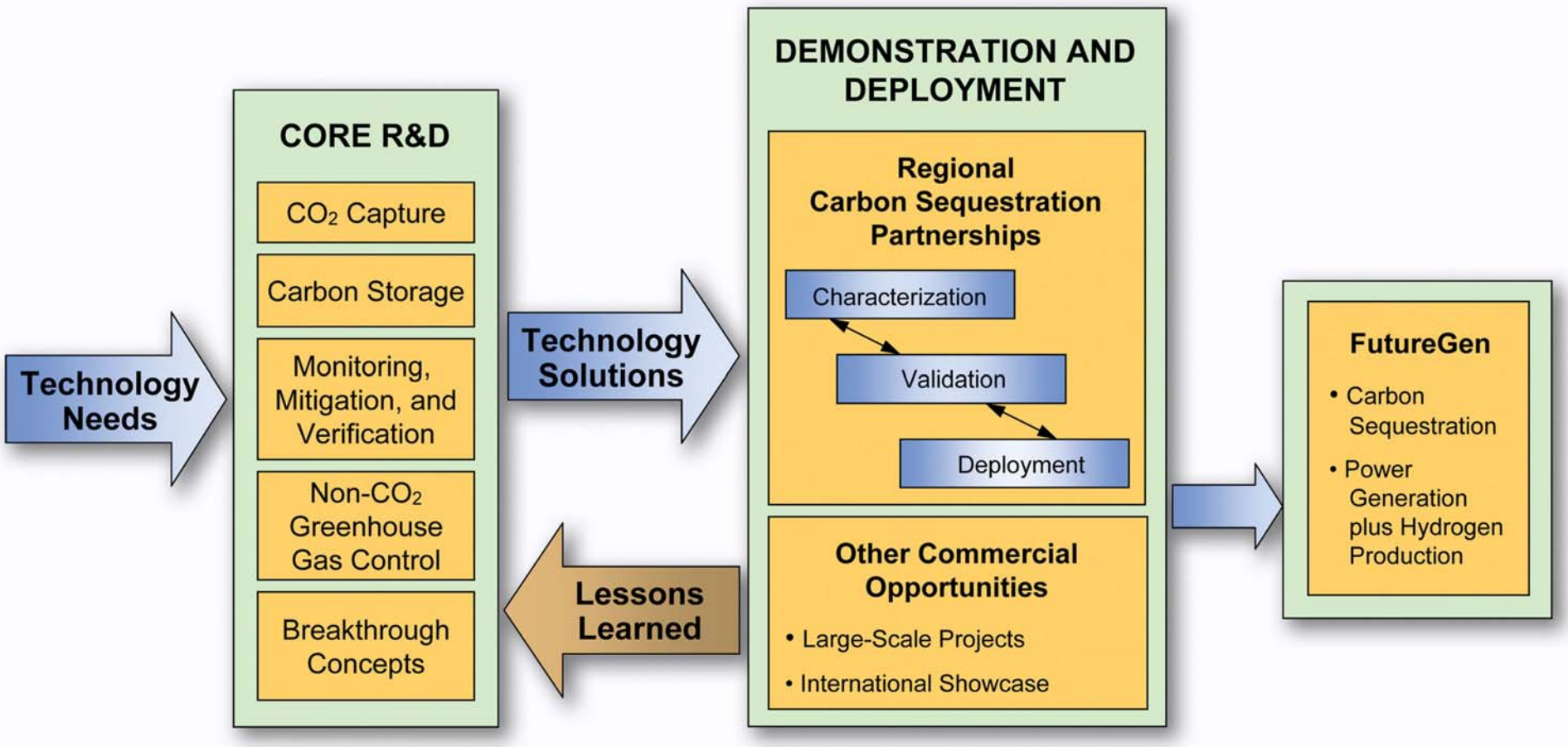
Storage locations include:

- 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

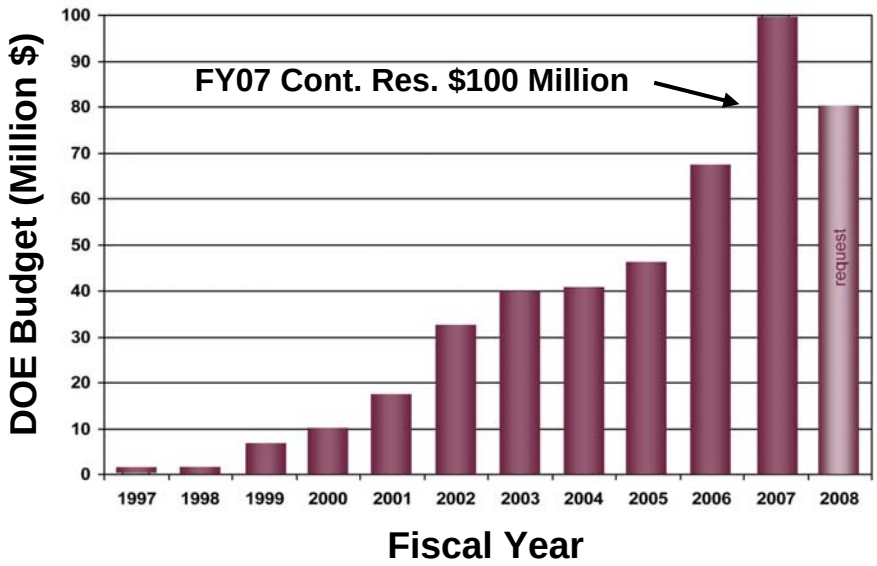


Carbon Sequestration Program Goals

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

  - 90% CO_2 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

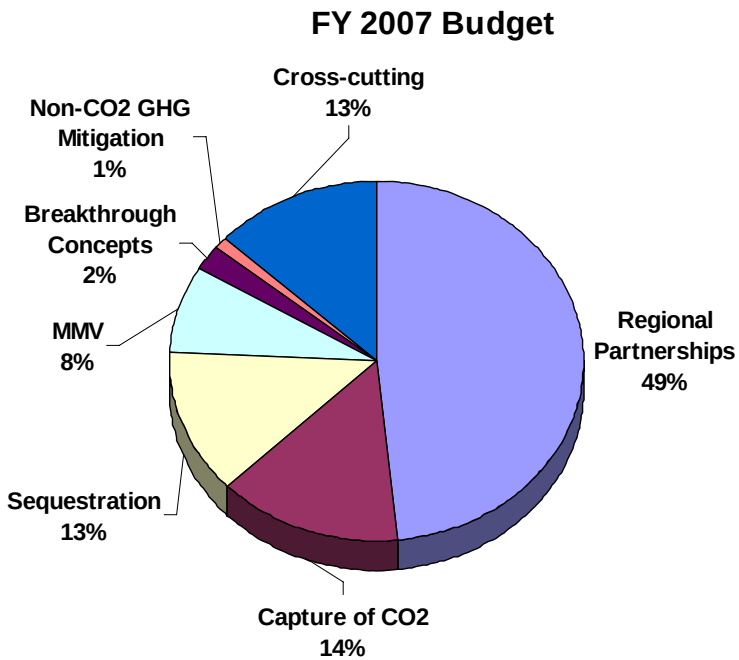


Strong industry support

~ 39% cost share on projects

Federal Investment to Date

~ $360 Million



Diverse research portfolio

~ 70 Active R&D Projects

Separation & Capture of CO_2 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_2 pressure due to flash regeneration
- Cooling / refrigeration of syngas to accommodate low operating temperatures; reheating prior to combustion
- H_2 losses, particularly in membranes
- Sulfur-tolerant materials / membranes

Post-combustion
(Flue Gas)

- Low-pressure flue gas dilute in CO_2
- Steam requirement for thermal regeneration (amines)
- High compression costs and large loads due to CO_2 produced at low pressure
- Flue gas contaminants

Oxygen Combustion
(OxyFuel)

- Cost of O_2 production and materials
- Cooled CO_2 recycled to control combustion temperatures

Carbon Capture Research Pathways
Chemical Solvents

Process Description

- Reversible chemical reaction(s) between CO_2 and aqueous absorbent solution
- Mature technology (MEA) at smaller scale

Potential Technology Solutions

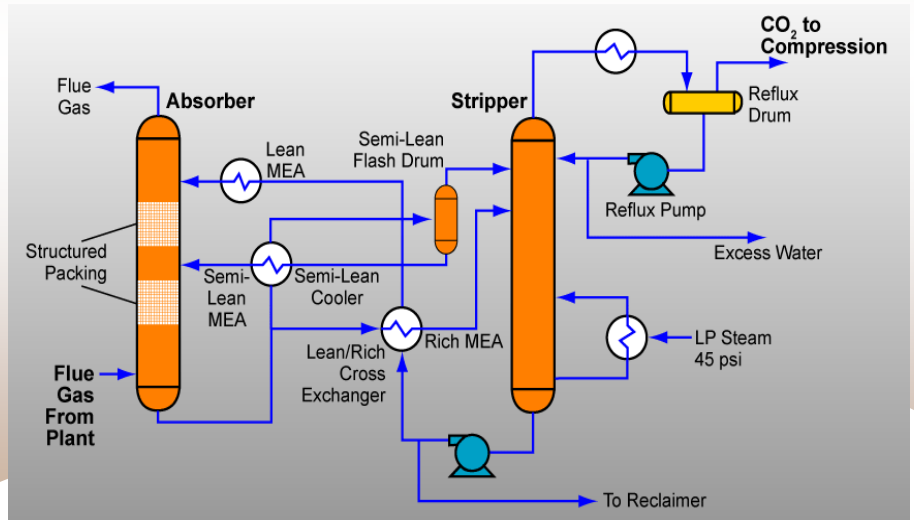
- Improved solvents (carbonates, hindered amines, ammonia, etc.)
- Blended and promoted solvents

Research Focus

- Identify lower cost alternatives to MEA
  - ✓ Low solvent cost
  - ✓ High CO_2 loading capacity
  - ✓ Non-corrosive
  - ✓ No solvent degradation
  - ✓ Low regeneration energy

Primary Research Partners

Alstom, NETL/ORD, Powerspan Corp.



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_2 partial pressure (IGCC systems)
- Mature technology (Selexol™ & Rectisol®) at smaller scale

Research Focus

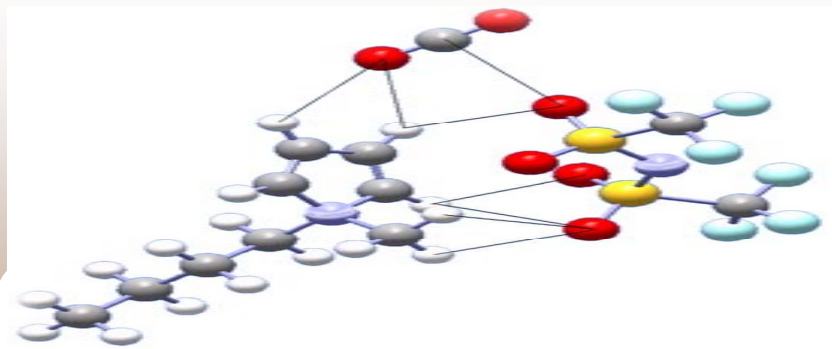
- Ionic Liquids (ILs)
  - ✓ High thermal stability
  - ✓ Low volatility
  - ✓ High CO_2 solubility
  - ✓ Separation media for H_2 and CO_2
  - ✓ High unit cost

Primary Research Partners

NETL/ORD, University of Notre Dame

R&D Progress

Over 19x increase in CO_2 solubility for physical ILs and 40x increase in CO_2 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_2 sorbents
  - ✓ Durable
  - ✓ High selectivity
  - ✓ Multiple regeneration cycles
  - ✓ High CO_2 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_2 on solid adsorbents by weak surface forces
- Adsorption capacity increases with CO_2 partial pressure
- Regeneration via TSA or PSA

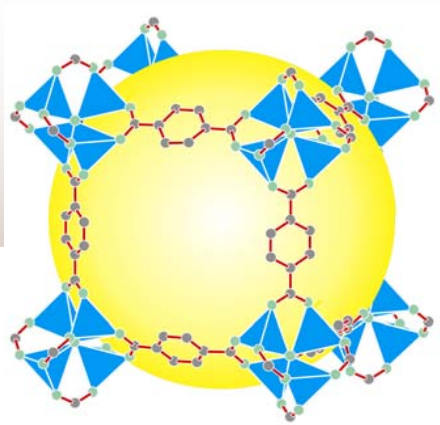
Research Focus

- 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_2
- Selectivity and permeability are key
- Most effective with high CO_2 partial pressure (IGCC systems)

Research Focus

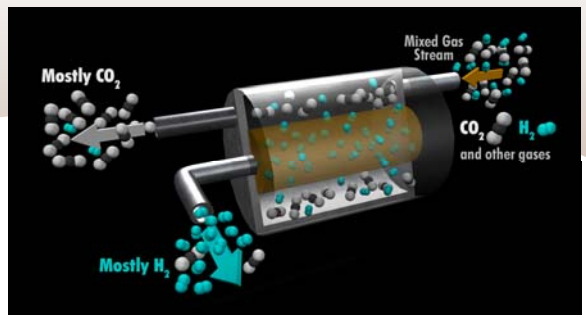
- More efficient CO_2 membranes
  - ✓ Durable
  - ✓ Improved selectivity
  - ✓ Thermal and physical stability
  - ✓ Sulfur tolerance

Primary Research Partners

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

Potential Technology Solutions

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



Carbon Capture Research Pathways
Advanced Oxycombustion Technologies

Process Description

- Combustion in pure O_2 to produce flue gas that is comprised of H_2O and CO_2
- CO_2 separation via H_2O condensation

Research Focus

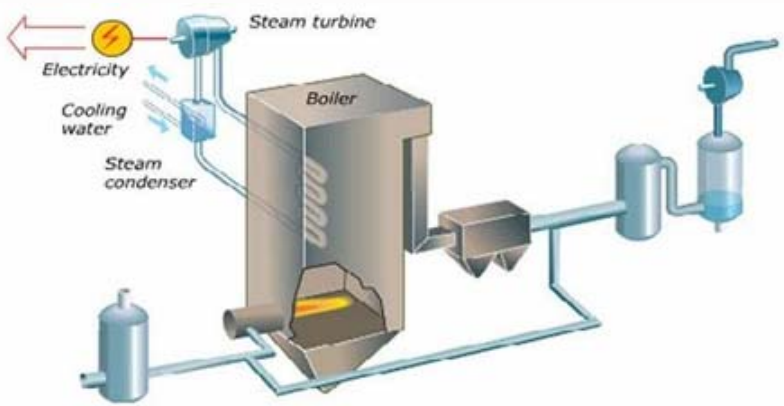
- Reduce O_2 production costs
- Improved oxyfuel boilers
  - ✓ Compact design
  - ✓ Advanced materials and burners
- Retrofit options
- Reduce flue gas recycle
- Co-sequestration

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

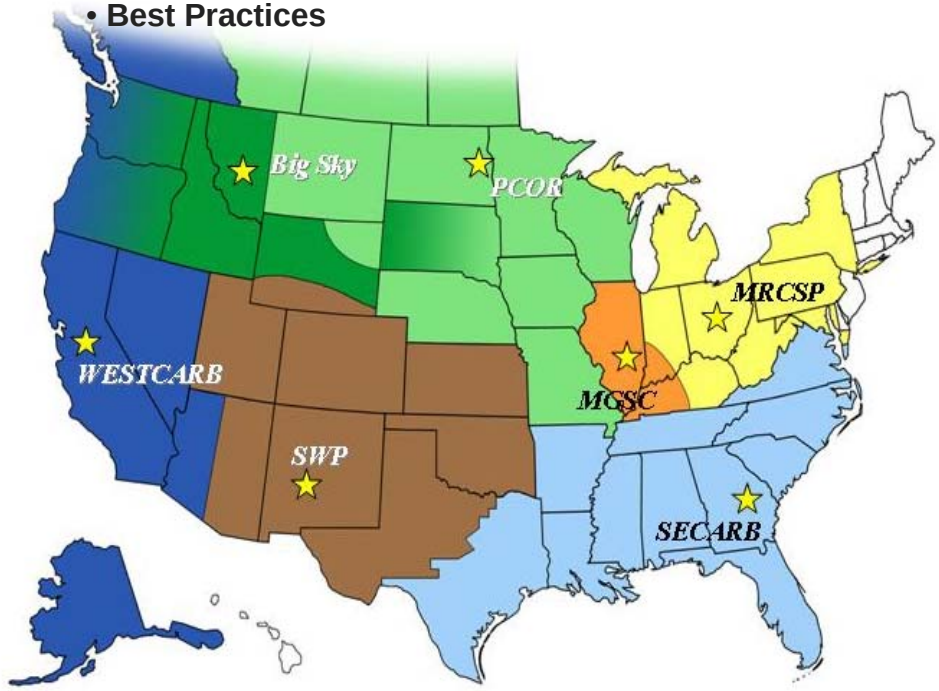
- **10 years (2007-2016)**
- **Up to 7 large volume injection tests**

Addressing:

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

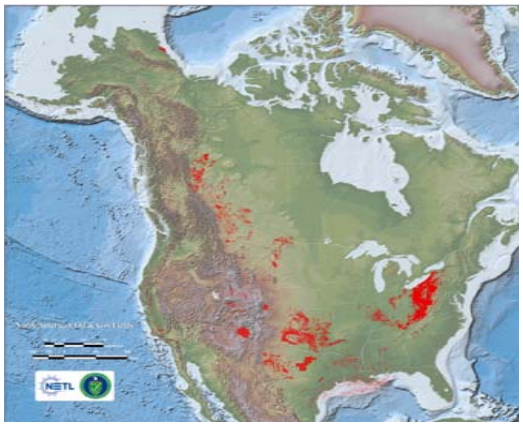
Representing:

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

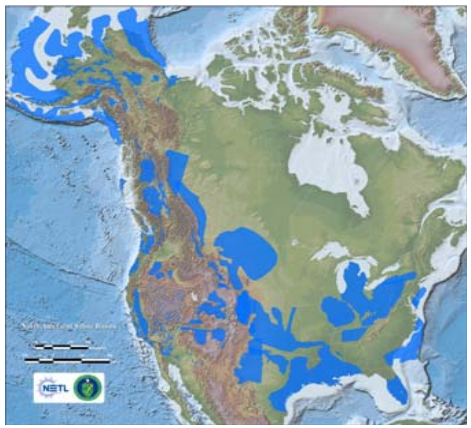


First Ever National Sequestration Atlas

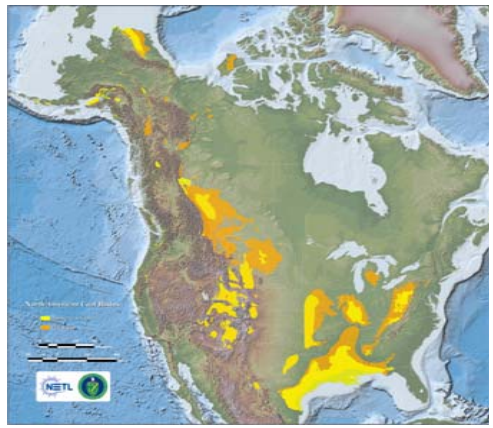
U.S. Emissions ~ 6 GT CO_2/yr all sources



Oil and Gas Fields



Saline Formations



Unmineable Coal Seams

North American CO_2 Storage Potential (Giga Tons)

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

Visit Office of Fossil Energy & NETL Websites

http://fossil.energy.gov/

http://www.netl.doe.gov