NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE's Sequestration Program

Sean Plasynski, PhD

Sequestration Technology Manager

U.S. DEPARTMENT OF ENERGY

Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

Sequester Carbon

- Capture & Store
- Enhance Natural Sinks

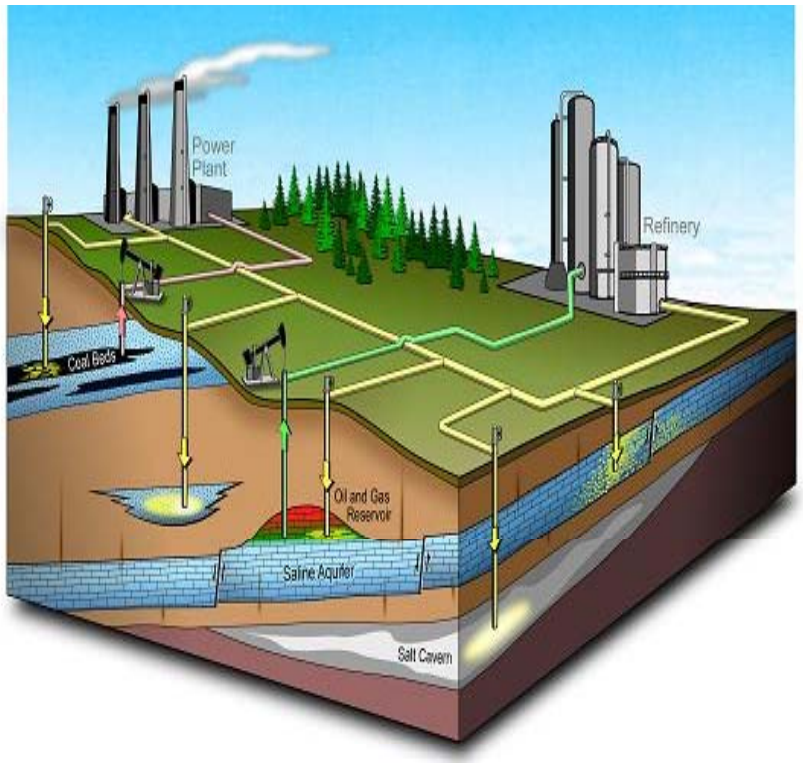
All options needed to:

- Affordably meet energy demand
- Address environmental objectives

Carbon Sequestration Program Goals

Develop Technology Options That...

- **Deliver technologies & best practices that provide Carbon Capture and <u>Safe</u> Storage (CCSS) with:**
  - 90% CO_2 capture at source
  - 99% storage permanence
  - < 10% increase in COE
    - Pre-combustion capture (IGCC)
  - < 30% increase in COE
    - Post-combustion capture
    - Oxy-combustion



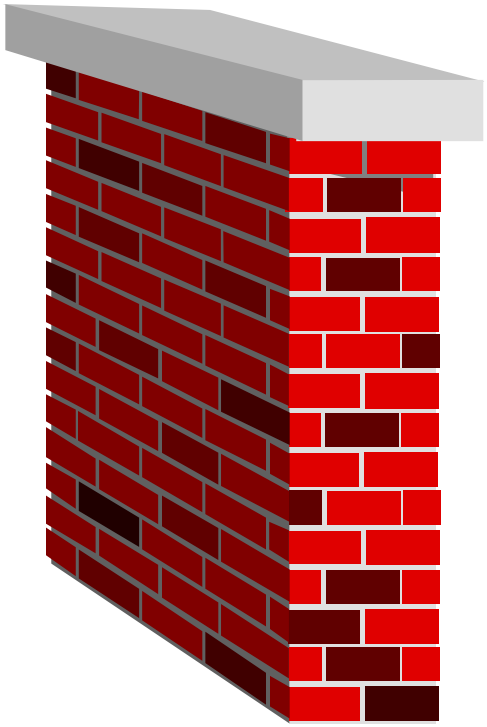
Key Challenges to Carbon Capture and Storage

Technical Issues

- **Capture Technology**
  - Existing Plants
  - New Plants (PC)
  - IGCC
- **Cost of CCS**
- **Sufficient Storage Capacity**
- **Permanence**
- **Best Practices**
  - Storage Site Characterization
  - Monitoring/Verification
  - Modeling

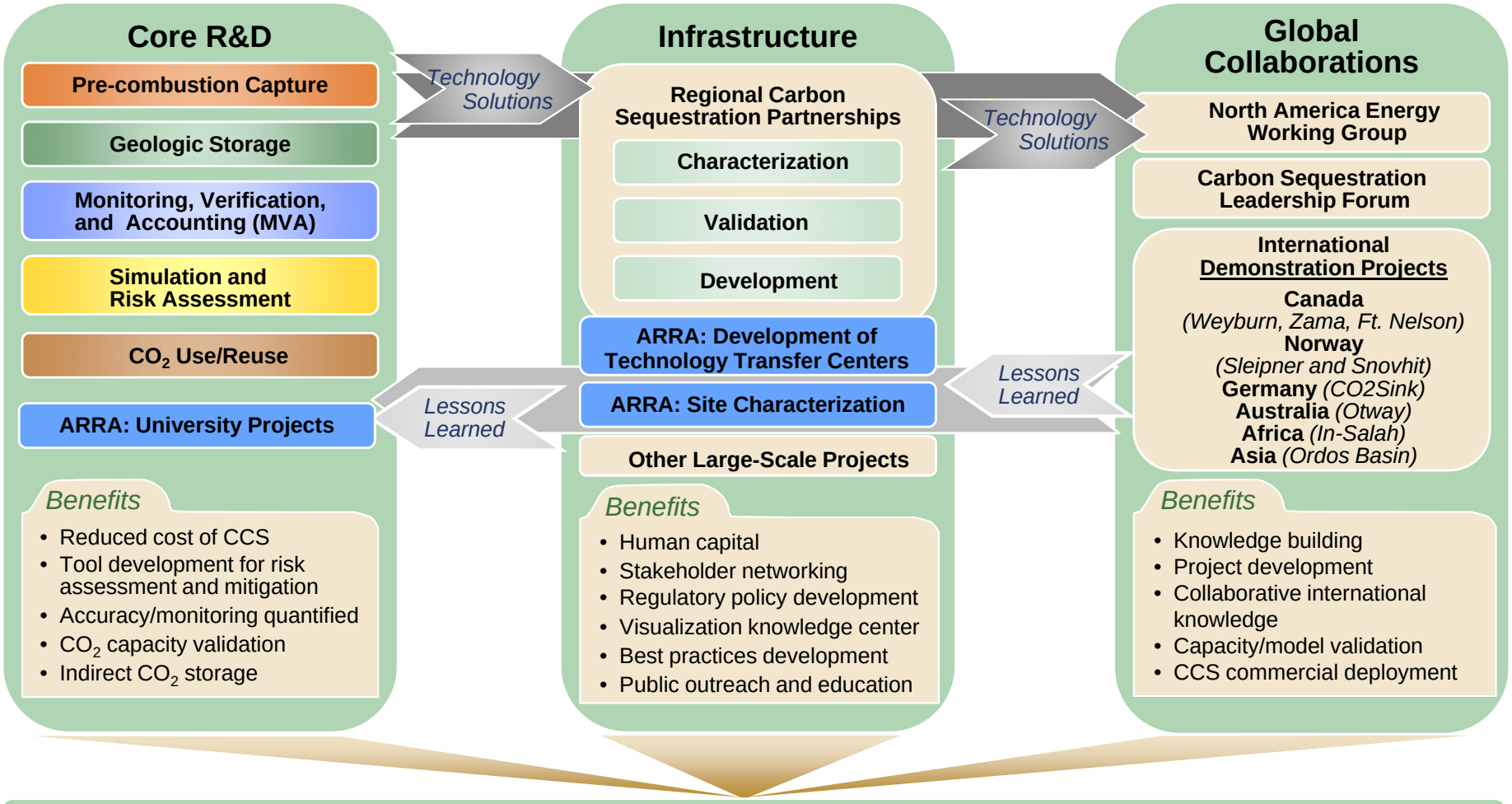
Legal/Social Issues

- **Regulatory Framework**
  - Permitting
  - Treatment of CO_2
- **Legal Framework**
  - Liability
  - Ownership
    - pore space
    - CO_2
- **Infrastructure**
- **Human Capital**
- **Public Acceptance (NIMBY → NUMBY)**



U.S. DEPARTMENT OF ENERGY • OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

CARBON SEQUESTRATION PROGRAM with ARRA Projects



Demonstration and Commercialization Carbon Capture and Storage (CCS)

Infrastructure

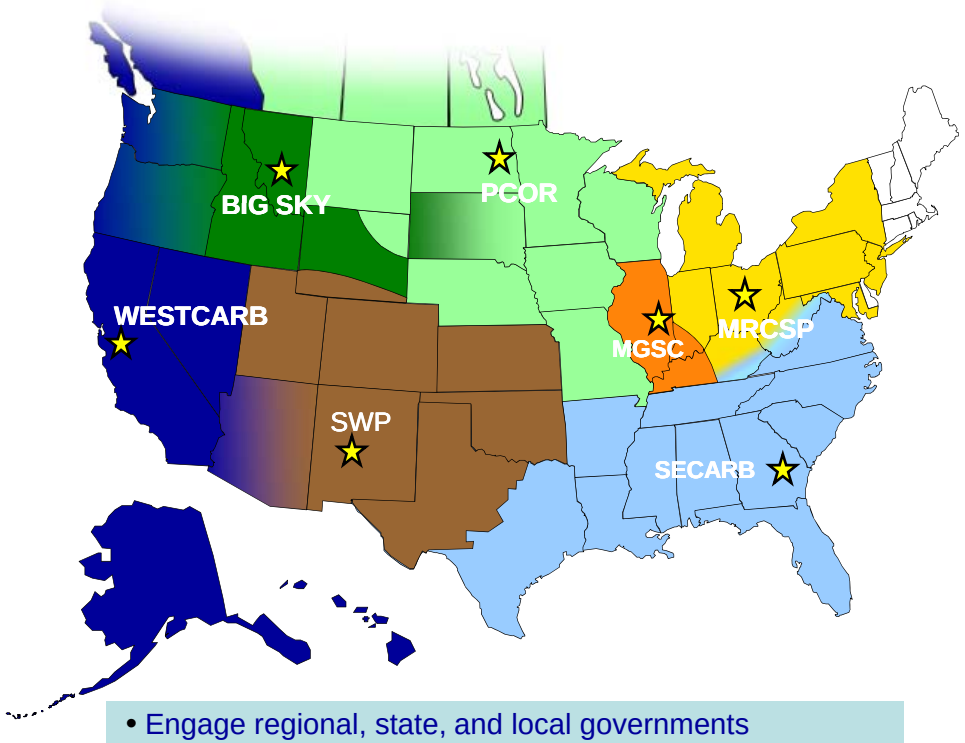
Regional Partnerships

Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment

Seven Regional Partnerships

400+ distinct organizations, 43 states, 4 Canadian Provinces



- Engage regional, state, and local governments
- Determine regional sequestration benefits
- Baseline region for sources and sinks
- Establish monitoring and verification protocols
- Address regulatory, environmental, and outreach issues
- Validate sequestration technology and infrastructure

Characterization Phase (2003-2005)

Search of potential storage locations and CO_2 sources	Found potential for 100's of years of storage

Validation Phase (2005-2010)

20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt

Development Phase (2008-2017+)

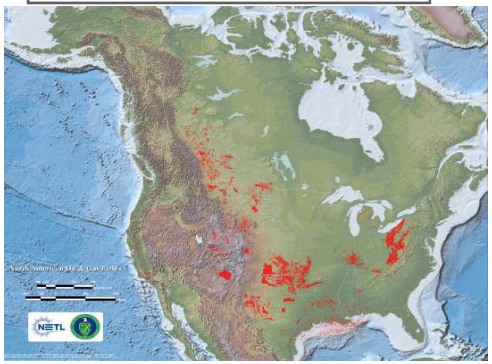
9 large scale injections (over 1 million tons each)	Commercial scale understanding	Regulatory, liability, ownership issues

National Atlas Highlights

Hundreds of Years of Storage Potential

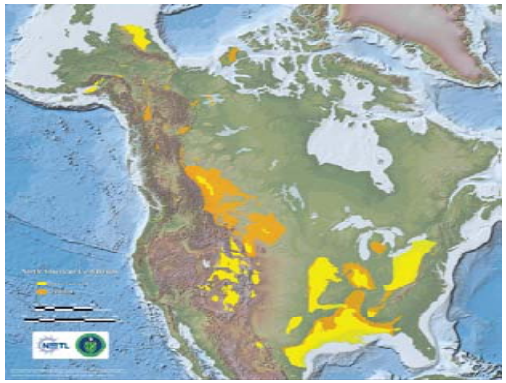
U.S. Emissions ~ 6 GT CO_2/yr all sources

2008 Conservative Resource Assessment



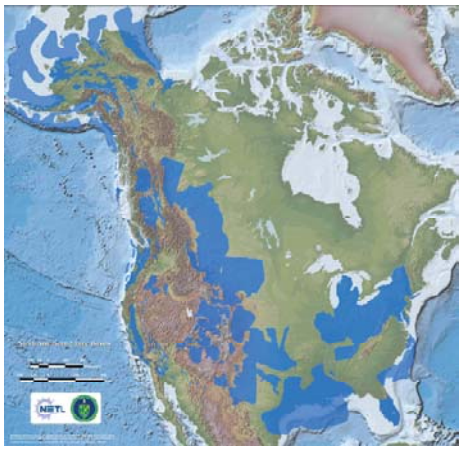
Oil and Gas Fields

*138 GT CO_2 Storage Resource**



Unmineable Coal Seams

*157-178 GT CO_2 Storage Resource**



Saline Formations

*3,300–12,600 GT CO_2 Storage Resource**

Carbon Sequestration Atlas of the United States and Canada (Atlas III)

Release date: November 2010

Featuring updates:

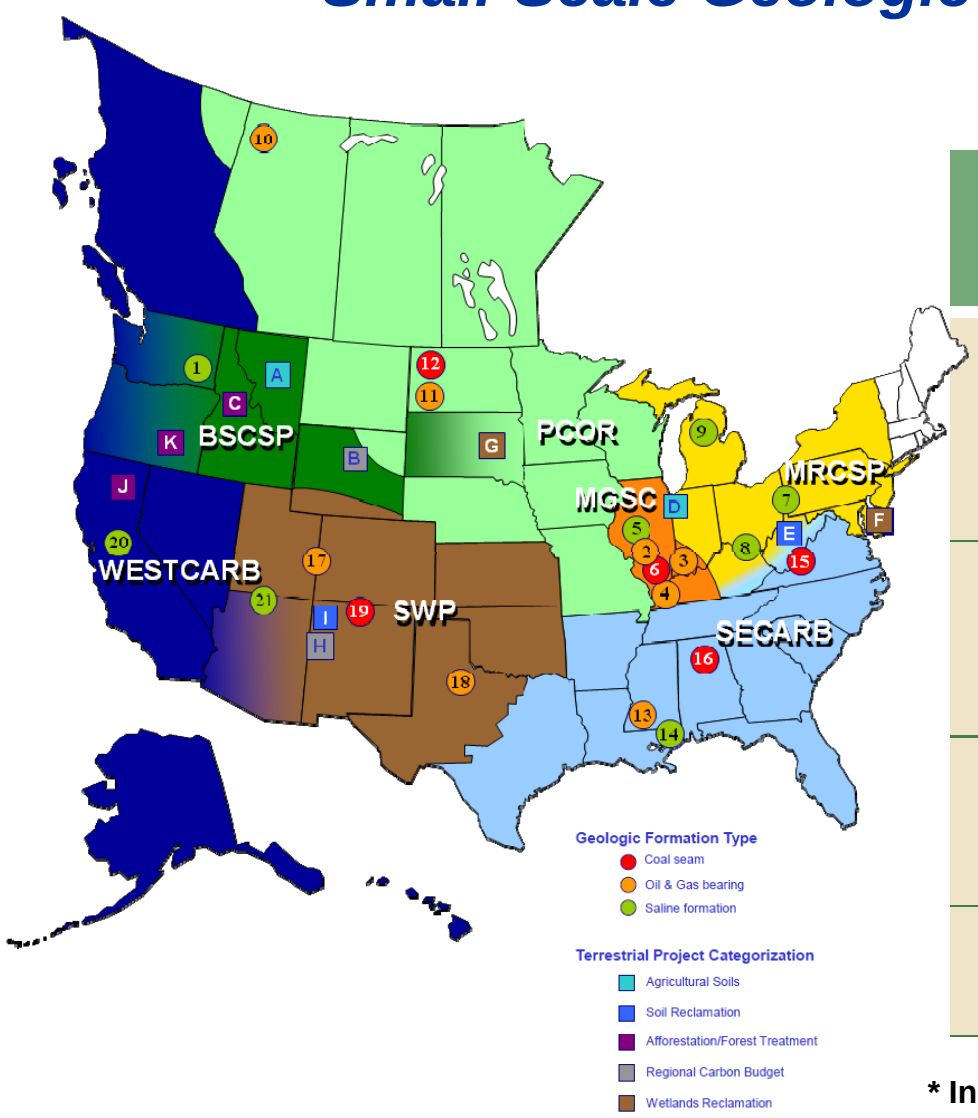
- **DOE's Carbon Sequestration Program**
- **DOE's International Collaborations**
- **DOE's National Risk Assessment Program**
- **Regional Carbon Sequestration Partnership Activities**
- **Refined CO2 source estimates and CO2 storage potential across the RCSP regions**
- **Worldwide CCS projects, CCS regulatory issues,**
- **NATCARB's improved databases and GIS system**

**2008 Carbon Sequestration Atlas of the United States and Canada.*

Available for download at http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf

RCSP Phase II: Validation Phase

Small-Scale Geologic and Terrestrial Tests



Injection Reservoirs (Total)	RCSPS	Deposition Environments Tested	Range CO_2 (metric tons)
Saline Formations (7)*	MGSC* MRCSP SECARB WESTCARB	Shallow Shelf-Restricted Strandplain Braided Fluvial Near Shore Marine Delta Marine	0-60,000
Enhanced Oil Recovery-EOR (8)	MGSC PCOR SECARB SWP	Fluvial Marine Shelf Pinnacle Reef Shallow Shelf Open	50-630,000
Coalbed Methane-ECBM (5)	MGSC PCOR SECARB SWP	Coal	90-16,700
Basalt (1)	Big Sky	Basalt	1,000

*** Includes Phase II Saline Test that evolved into Phase III Test**

Midwest Geological Sequestration Consortium (MGSC) Enhanced Coalbed Methane Test

Purpose: Determine CO_2 injection and storage capability and ECBM recovery potential of Illinois Basin Coal Seams

- Pennsylvania Carbondale Formation
- Drilling depth 900-1,000 feet (in 7-foot thick Springfield Coal)
- Test site was located at Tanquary field in Wabash County, Illinois
- CO_2 micro pilot to assess coal swelling and permeability reduction was done

Injection Well with Monitoring Equipment at MGSC ECBM Test Site

Accomplishment Highlights:

- Pre-injection site MVA began in February 2007
- Four total wells (three monitoring and one injection) drilled and completed by May 2008
- Injection began in fall of 2008 and a total of 100 tons (91 metric tons) of $CO_2$was injected.

Methane gas production was noted at the face and butt cleat monitoring wells, and CO_2 was observed at all monitoring wells.

Midwest Regional Carbon Sequestration Partnership (MRCSP) Michigan Basin Saline Test

Photo taken of drilling work at Charlton Field in Ostego County, Michigan

- Saline Formation – Bass Islands Dolomite
- Site well characterized due to oil and gas exploration in area (many available well logs)
- Injection Depth 3,400-3,500 feet
- Total injection of ~60,000 metric tons (Two-stage injection)

This picture shows the well actively engaged in injection at Michigan Basin Test Site

Accomplishments Highlights:

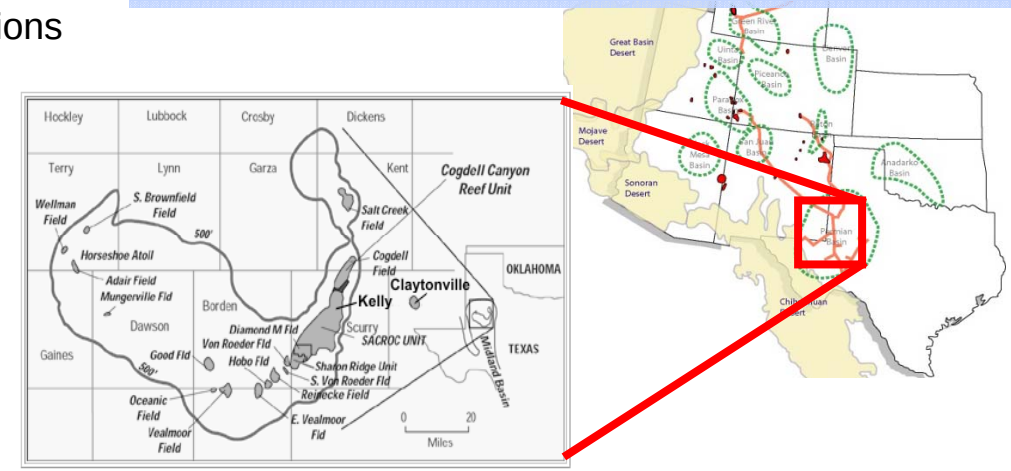
- Initial injection of approximately 11,000 tons (10,000 metric tons) of CO_2 was completed in March 2008.
- Completed post-injection monitoring, including a combination of cross-well seismic, hydraulic monitoring, PFT tracers, microseismic array, and wireline logging.
- An additional 55,000 tons (50,000 metric tons) of CO_2 injected July 2009.
- Outreach efforts have included informational materials, public meetings with regular follow-ups to local stakeholders and ongoing briefings to key officials and community opinion leaders.

Southwest Regional Carbon Sequestration Partnership (SWP) – Permian Basin, Texas

This test includes a post-audit modeling analysis of injected CO_2 for EOR over the last 30 years at the SACROC Unit in addition to intense MVA analyses of ongoing CO_2 injection.

- Target Formations: Cisco and Canyon Formations within the Horseshoe Atoll Play and Pennsylvanian Reef/Bank Play
- Depths of flooded zone 6,300-7,100feet
- Injecting ~86,000 tons CO_2 in new area of SACROC utilized for project
- CO_2 source: McElmo Dome

SWP Validation Phase Field Test – SACROC Oil Field Unit

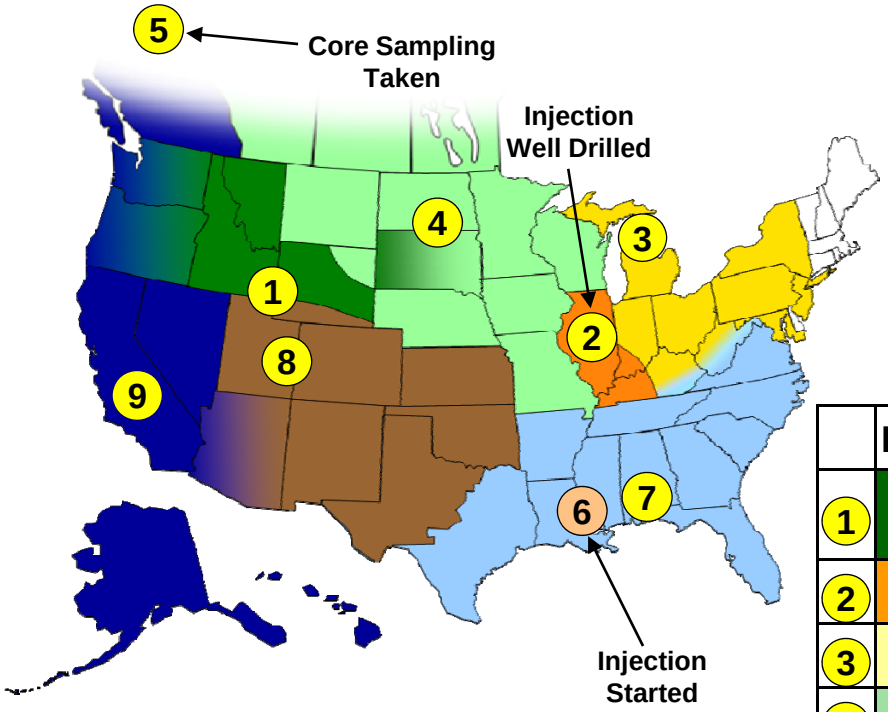


Accomplishment Highlights:

- Baseline surface fluxes measured.
- Baseline reservoir groundwater (brine) compositions assessed.
- 3-D reservoir model grids assembled.
- 3-D reservoir simulations successfully run, using models that are fully parameterized with multiphase flow of oil, CO2, brine, and reactive chemistry.
- Surface and subsurface geologic maps and cross-sections refined through new mapping techniques.
- 3-D reflection seismic survey completed.
- 2-D vertical seismic profile (VSP) completed.
- CO2 injection started in first two wells in September 2008 and second two well injection in November 2008.

RCSP Phase III: Development Phase

Large-Scale Geologic Tests



Injection Ongoing

Injection Scheduled 2011/2015

Note: Some locations presented on map may differ from final injection location

✓ *Nine large-volume tests*

✓ *Injections scheduled 2011/2015*

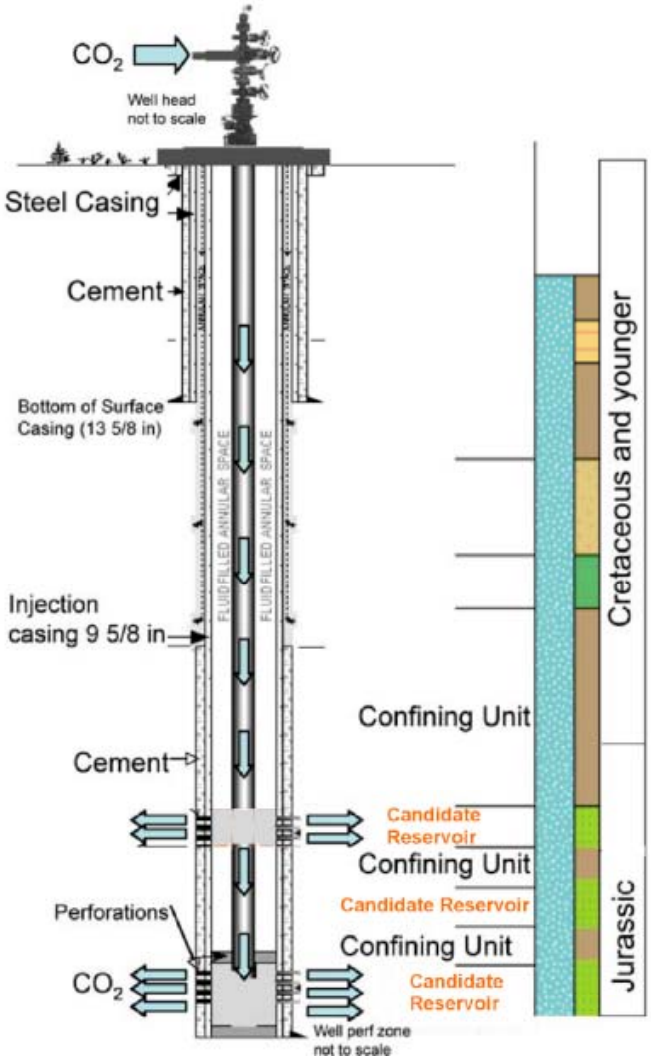
	Partnership	Geologic Province	Type
1	Big Sky	Triassic Nugget Sandstone / Moxa Arch	Saline
2	MGSC	Deep Mt. Simon Sandstone	Saline
3	MRCSP	St. Peter Sandstone	Saline
4	PCOR	Williston Basin Carbonates	Oil Bearing
5		Devonian Age Carbonate Rock	Saline
6	SECARB	Lower Tuscaloosa Formation	Saline
7		Paluxy Formation	
8	SWP	Regional Jurassic & Older Formations	Saline
9	WESTCARB	Central Valley	Saline

RCSP Development Phase

Strive to Attain the Following Goals

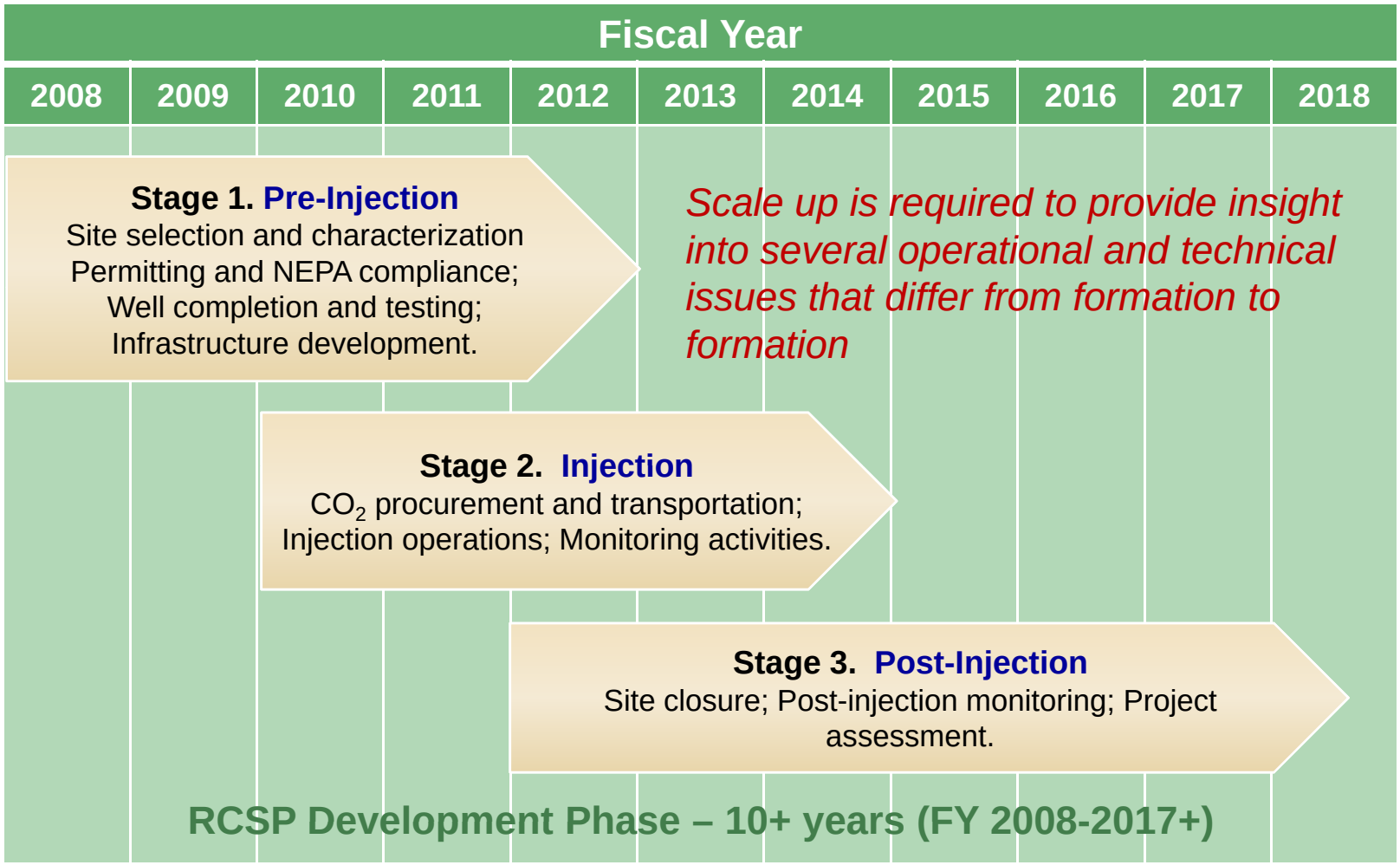
- **Validate Geologic Storage**
  - Injectivity and Capacity
  - Storage Permanence
- **Develop Monitoring Methodologies**
  - Areal Extent of Plume and Leakage Pathways Mitigation
- **Develop from Experience**
  - Risk Assessment Strategies
  - Best Practices for Industry
- **Support Regulatory Development**

- **Engage in Public Outreach and Education**



RCSP Development Phase

Scaling Up Towards Commercialization



Midwest Geological Sequestration Consortium

Large-Scale Project Site – Illinois Basin

Target Formation

- Mt. Simon Sandstone, Illinois Basin
- Injection well: 7,230 ft deep

CO_2 Source

- ADM's Ethanol Production Facility

CO_2 Injection Amount

- 1 million metric tons over 3 years (2011)

Current Status

- Completed drilling injection well with micro-seismic sensors and geophone well
- Completed 4 square mile 3D seismic survey
- Groundwater monitoring wells completed
- Construction of compression/dehydration facility and pipeline is near completion
- Working on environmental baseline
- Awaiting approval of UIC permit modification to begin drilling verification well

Midwest Regional CS Partnership

Large-Scale Project Site – Michigan Basin

Target Formation

- St. Peter Sandstone (Primary)
- Bass Islands Dolomite (Secondary)

CO_2 Source

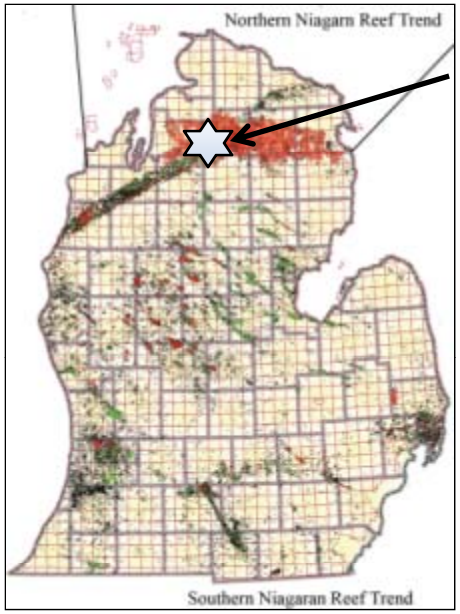
- DCP-Midstream Gas Processing Facility

CO_2 Injection Amount

- 1 million metric tons over 4 years (2011)

Current Status

- Received DOE approval for modification plan based on Michigan as new primary site
- Completing preliminary geologic assessment of Otsego County area
- Completed “Communications Plan” and met with various stakeholders including government and regulatory agencies



Otsego County, MI

Plains CO_2 Reduction Partnership

Large-Scale Project Site – Ft. Nelson

Target Formation

- Elk Point Group/Sulphur Point Formation

CO_2 Source

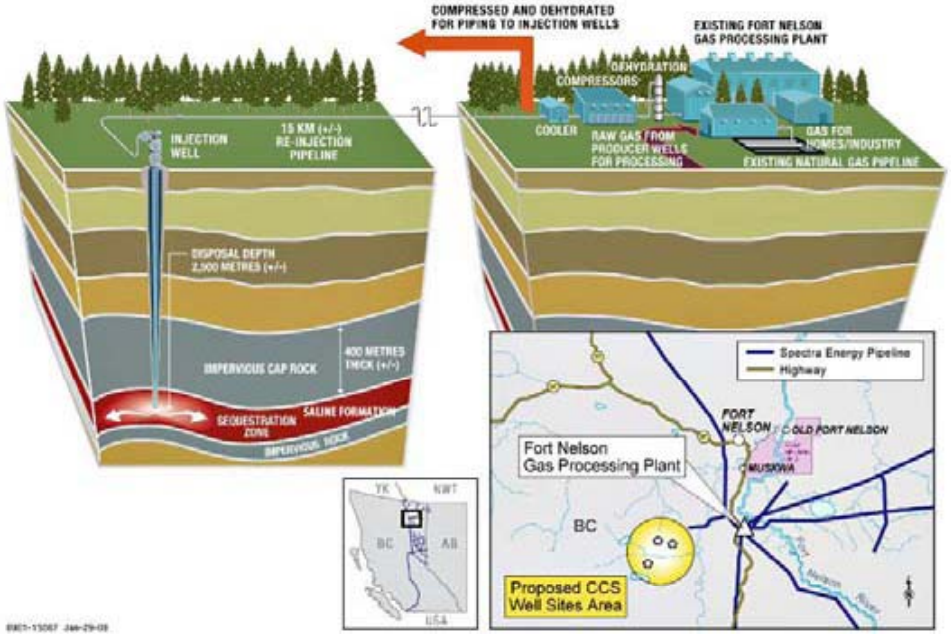
- Spectra Energy's Fort Nelson Natural Gas Processing Plant

CO_2 Injection Amount

- As much as 2.2 million tons/year
- Injection anticipated summer 2012

Current Status

- Drilling of exploration well completed
- Conducted "side-track" to acquire additional reservoir data
- Developing integrated Risk Management Plan (RMP), Modeling and MVA Program



Plains CO_2 Reduction Partnership

Large-Scale Project Site – Bell Creek

Target Formation

- Colorado Group/Muddy Sandstone Formation

CO_2 Source

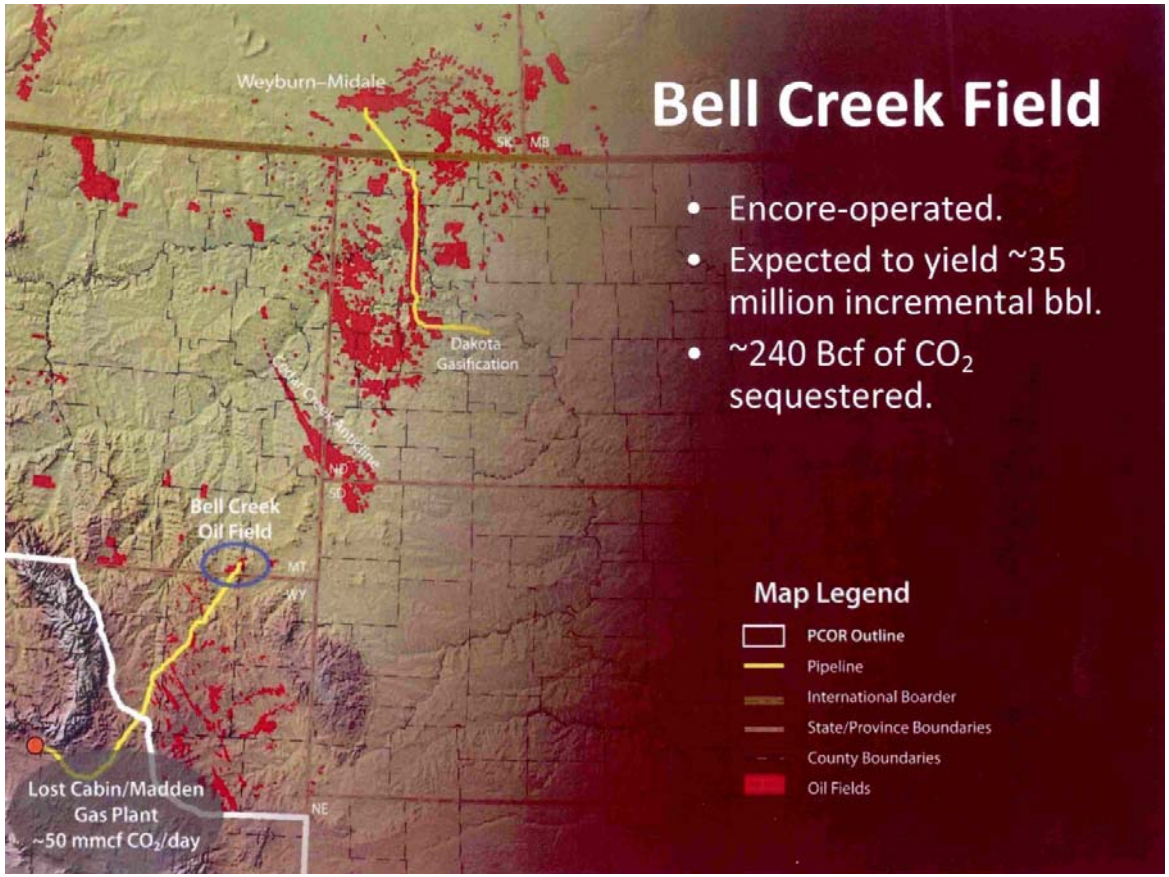
- Lost Cabin/Madden Gas Plant operated by Conoco Phillips

CO_2 Injection Amount

- As much as 1 million tons/year
- Injection anticipated summer 2013

Current Status

- Under negotiation with commercial partner (Denbury Resources Inc.)



Southeast Regional CS Partnership

Large-Scale Project Site – Saline "Early Test"

Target Formation

- Massive Sandstone Lower Tuscaloosa

CO_2 Source

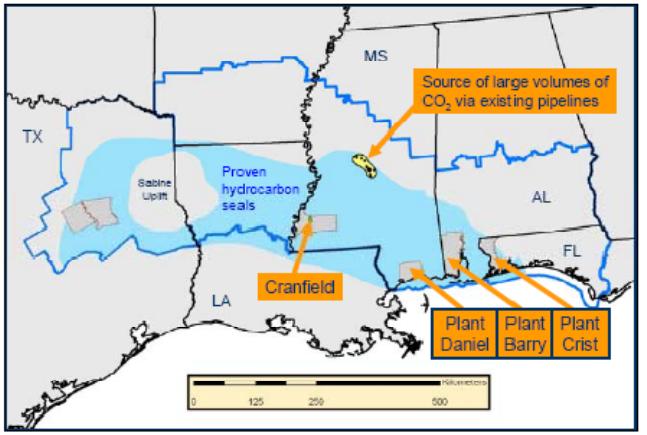
- Jackson Dome (natural source) delivered via Denbury Resources' Sonat CO_2 pipeline

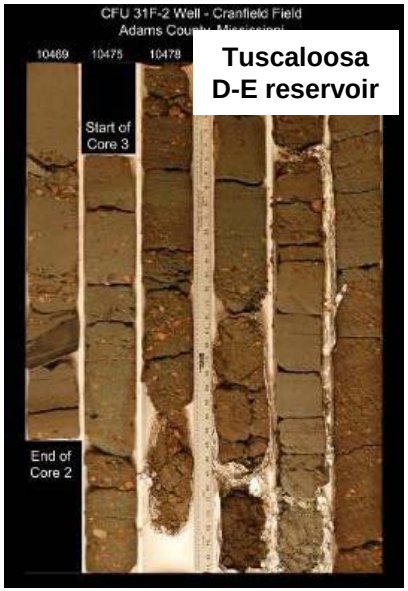
CO_2 Injection Amount (Current)

- > 2.0 million metric tons (combined P2 and P3)

Current Status

- Injection began on 04/01/2009
- Injection rate is ~ 432 metric tons/day
- Monitoring wells(F2 and F3) are between 220-370 feet from injection well
- Electrical Resistivity Tomography (ERT) receivers were installed in the two monitoring wells





Southeast Regional CS Partnership

Large-Scale Project Site – Anthropogenic Test

Target Formation

- Paluxy Formation, Citronelle Field

CO_2 Source

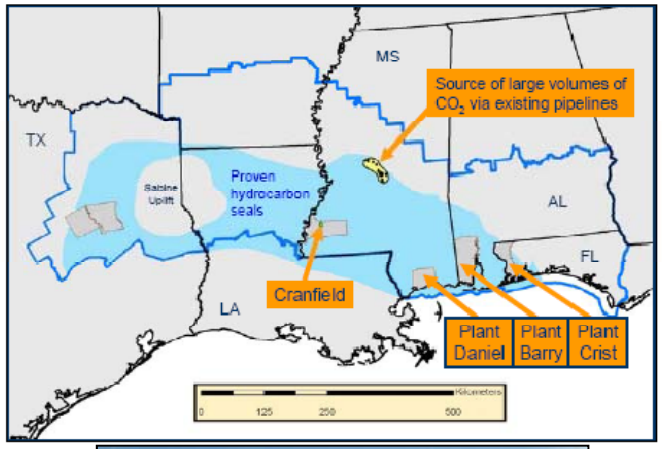
- Southern Company's Plant Barry Power Station

CO_2 Injection Amount

- ~ 300,000 metric tons over 3 years (2011)

Current Status

- Capture Unit Groundbreaking at Southern Company's Plant Barry Coal-fired Power Plant (April 14th)
- Commenced Baseline Characterization
- Environmental Information Volumes (EIV) completed and in process of Environmental Assessment (EA)



RCSP Large-Scale Alternative Project Sites

Big Sky, Southwest and WESTCARB Partnerships

Target Formation

- Saline Formations

CO_2 Sources

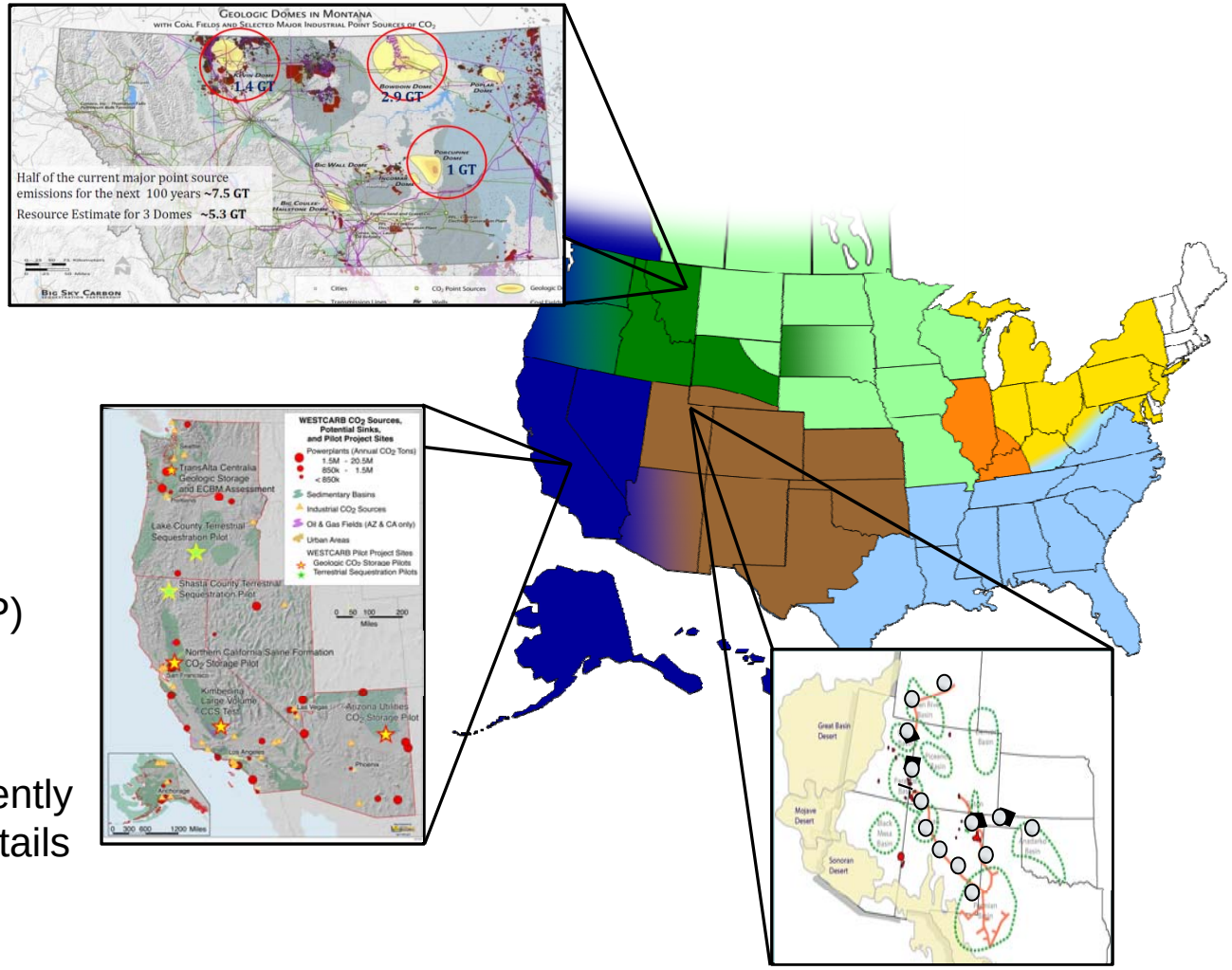
- Natural CO_2 Sources
- Petroleum Refinery
- Coal Power Plant

CO_2 Injection Amount

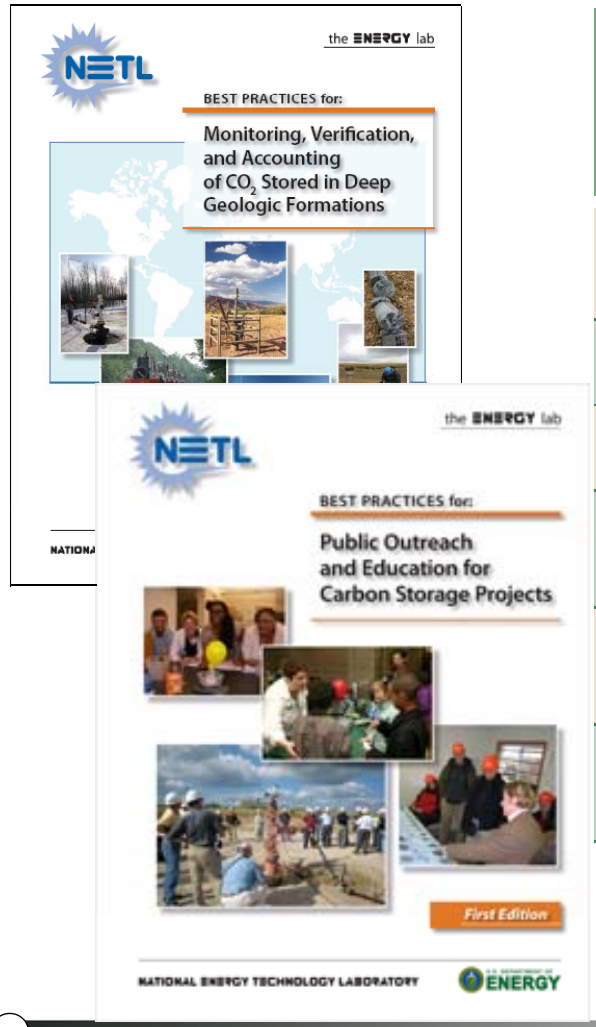
- ~ 1,000,000 metric tons over 3-4 years (each RCSP)

Current Status

- Initial project sites are currently being re-negotiated and details will be forthcoming once modifications are complete



CCS Best Practice Manuals Appearing
Critical Requirement For Significant Wide Scale Deployment -Capturing Lessons Learned



Best Practices Manual	Version 1 (Phase II)	Version 2 (Phase III)	Final Guidelines (Post Injection)
Monitoring, Verification and Accounting	2009	2017	2020
Public Outreach and Education	2009	2016	2020
Site Characterization	2010	2016	2020
**Simulation and Risk Assessment	2010	2017	2020
**Well Construction, Operations and Completion	2010	2017	2020
Terrestrial	2010	**2016 – Post MVA Phase III**	

***Regulatory Issues will be addressed within various Manuals*

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

Large Geological Storage Projects Underway

Each Stores > 1 Million Tonnes CO_2/yr

Sleipner Project- Norway

- CO_2 removed from natural gas produced on production platform in North Sea
- Injection into saline reservoir under sea
- Started 1996

Weyburn – Saskatchewan

- EOR project with 50 wells
- Uses CO_2 from coal gasification plant
- Started 2000

In Salah Gas Plant - Algeria

- Injection into saline formation downdip of gas reservoir
- Started 2004

Photos from Staoil Website

Lines of Evidence Suggesting Geological Storage Will Be Secure

- **Natural CO_2 reservoirs**
- **Oil and gas reservoirs**
- **Natural gas storage**
- **70 CO_2 EOR projects in U.S.**
- **50 acid gas injection sites in North America**
- **Numerical simulation of geological systems**
- **Current Large-Scale CO_2 storage projects**

"At least 99%+ retention is likely for well selected and managed storage sites"

Bullets Based on Rubin, CMU; Quote from IPCC Special Report on Carbon Capture & Storage

Visit Our Websites

Office of Fossil Energy

www.fe.doe.gov

NETL

www.netl.doe.gov