U.S. Dept of State:

Foreign Service Officers' Coal and Power Training Course

Bruce M. Brown

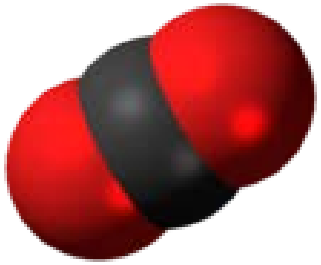
Infrastructure and Partnership Coordinator

July 19, 2013

Sources of CO_2

Natural Sources of CO_2

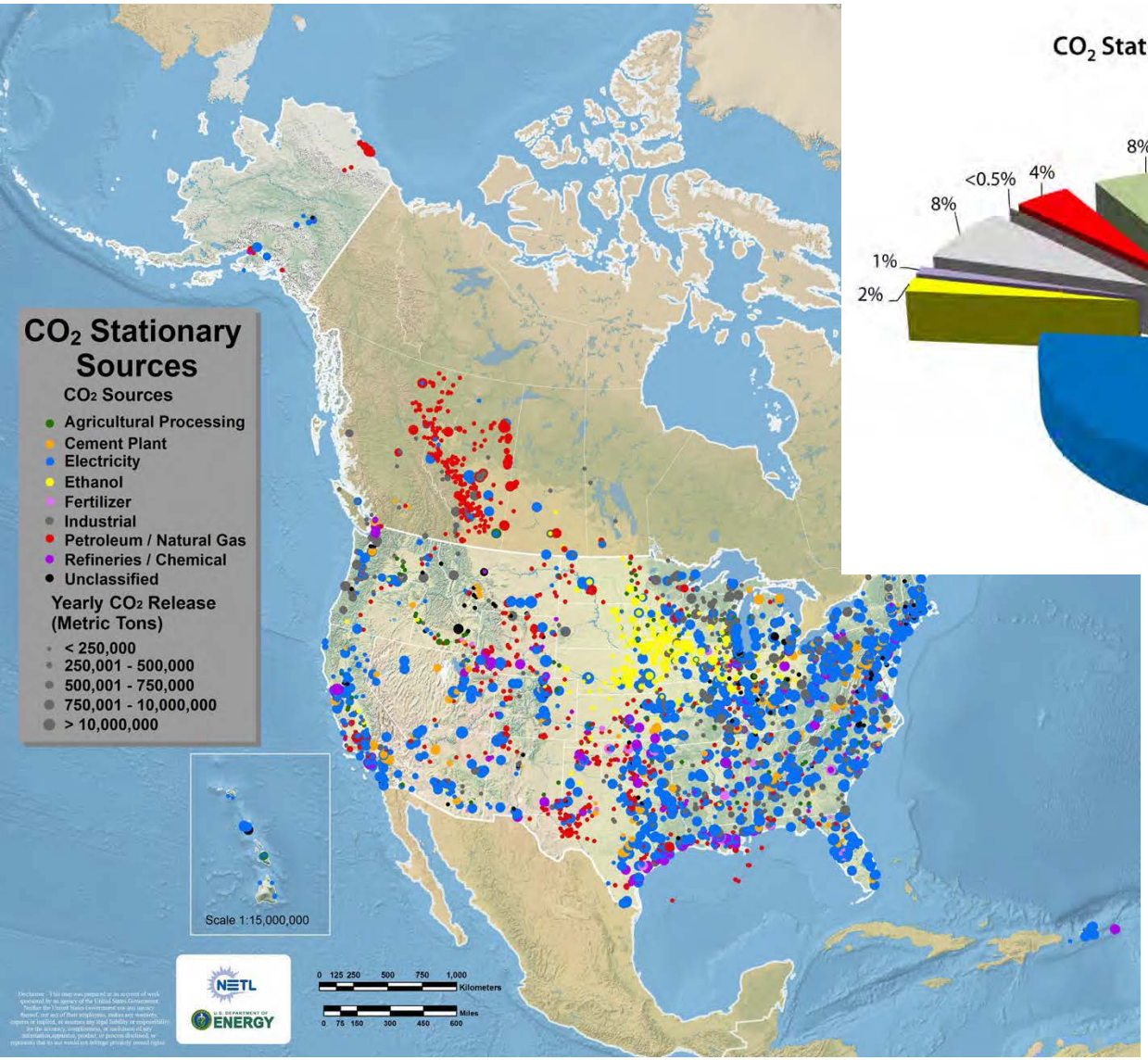
- Respiration from animals and plants,
- Volcanic eruptions,
- Forest and grass natural fires,
- Decomposition of biomass material (plants and trees), and
- Naturally occurring sources in geologic formations.

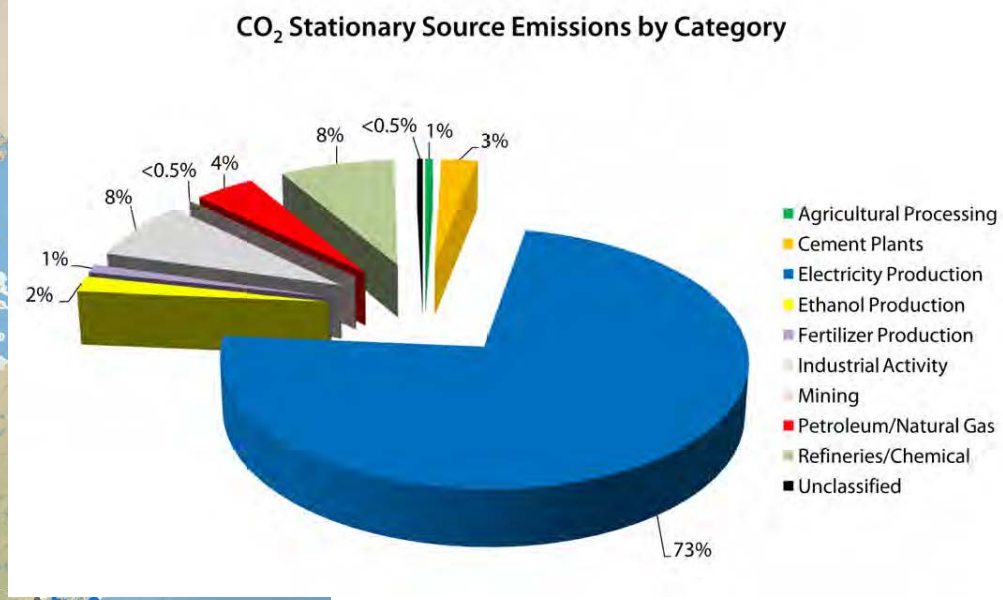


Anthropogenic (man made) Sources of CO_2

- Burning of fossil fuels (power generation),
- Cement production and other industrial processes,
- Deforestation,
- Agriculture, and
- Changes in natural land usage.

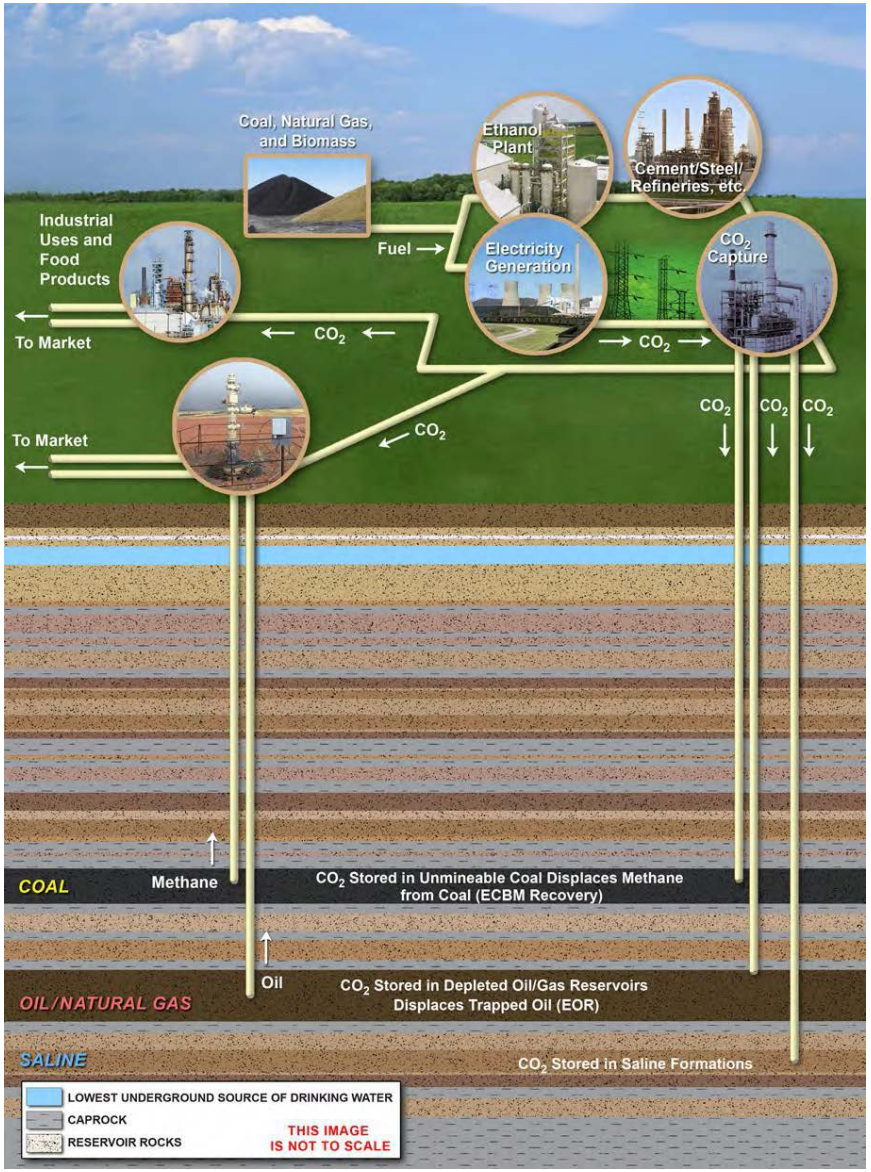
Stationary Sources of Anthropogenic CO_2



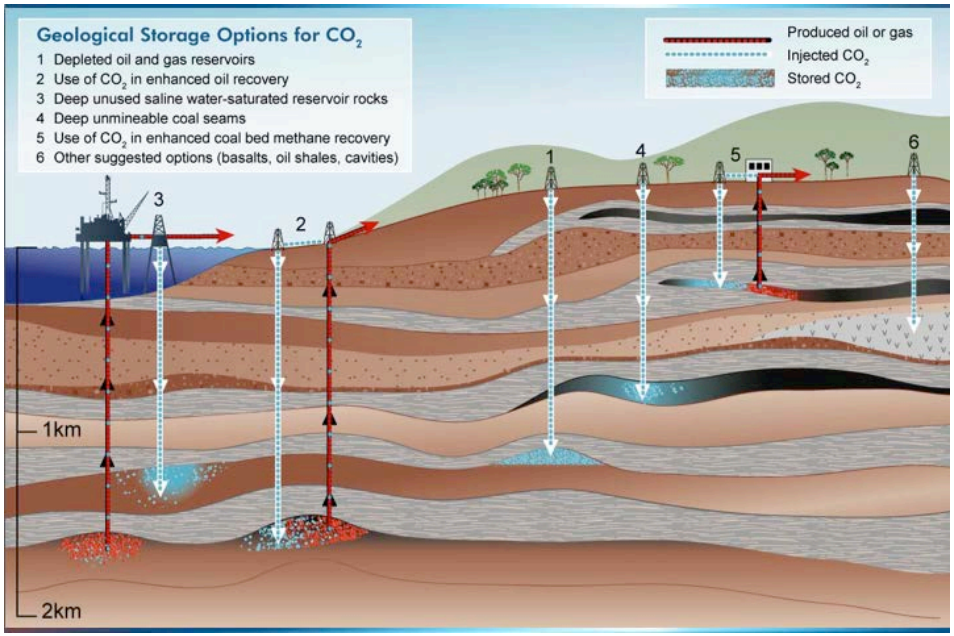


Most of the stationary anthropogenic CO_2 sources are for electricity production.

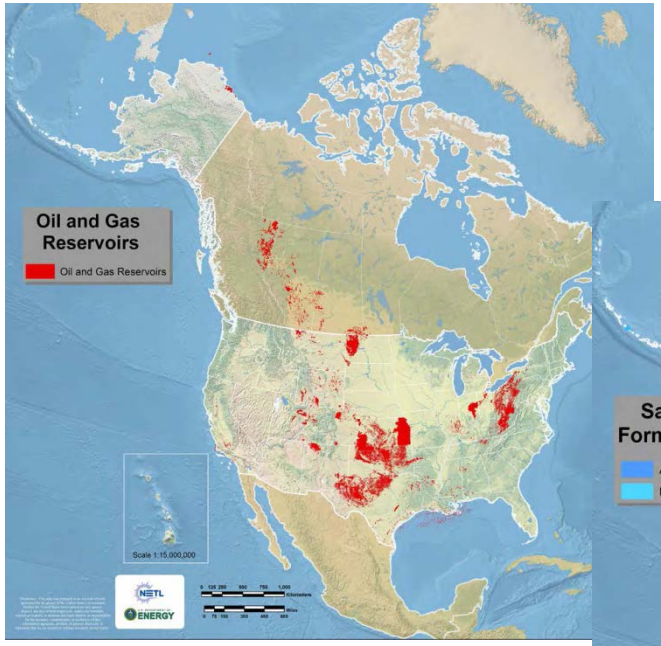
What should we do with CO_2?



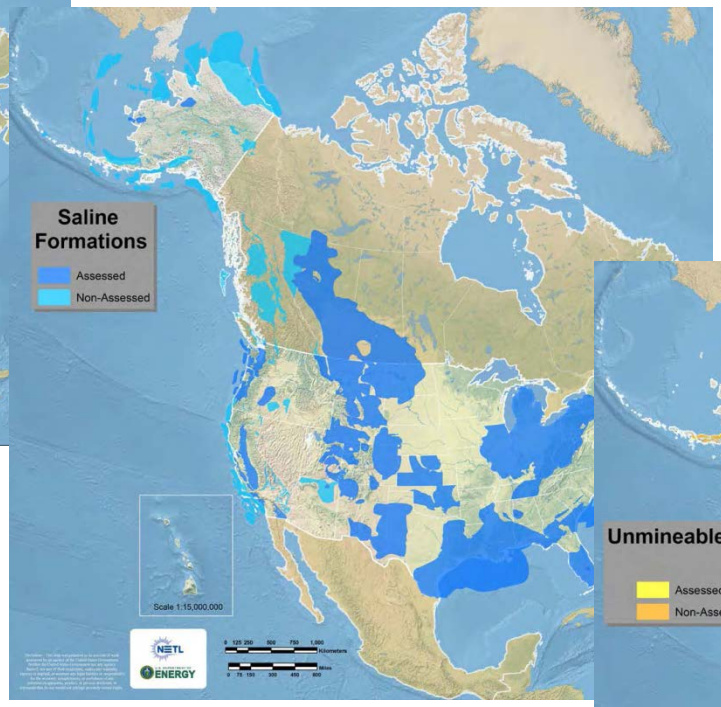
1. CO2 is captured,
2. Used for industrial purposes or food products.
3. Or, transported (generally through a pipeline) to an injection facility.
4. Used for enhanced oil and gas recovery or simply stored.



Where do we put the CO_2?

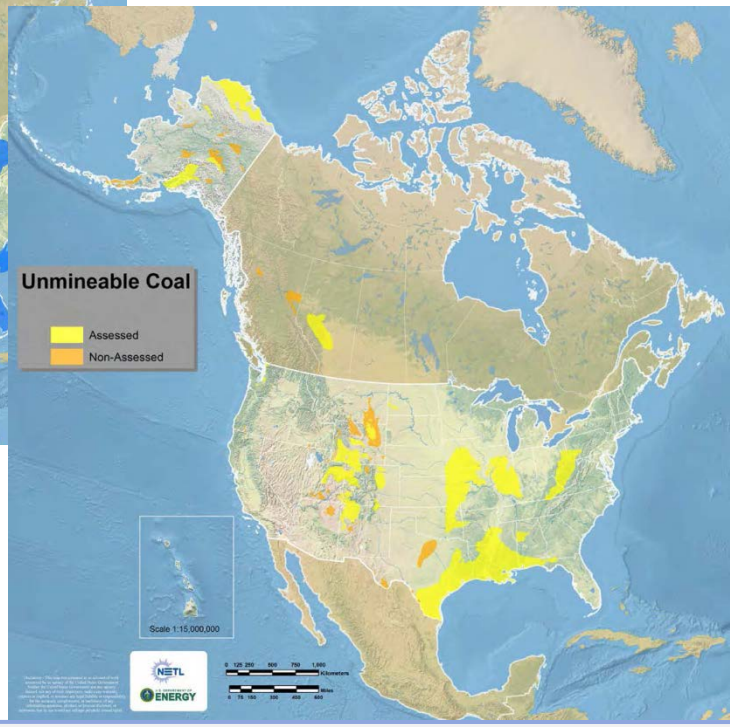


Oil and Gas Reservoirs



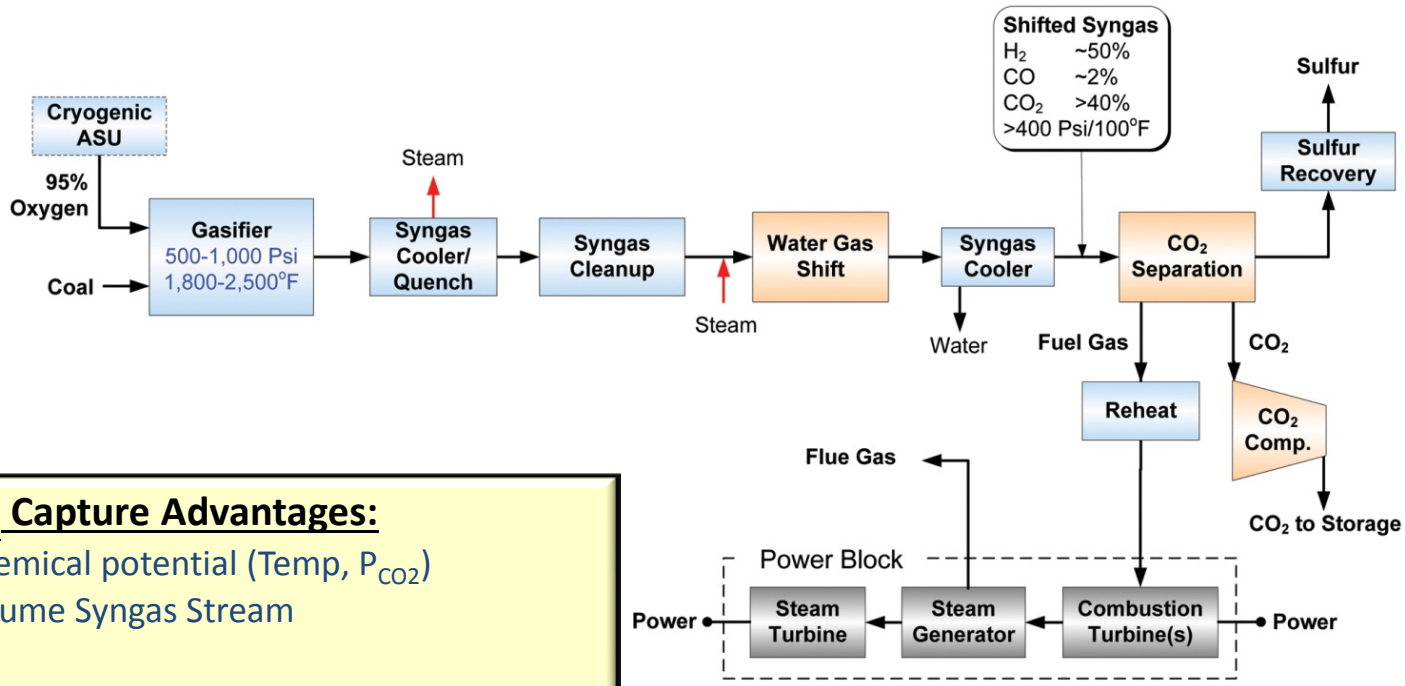
Saline Formations

Un-mineable Coal Seams



IGCC Power Plant System

Pre-combustion CO_2 Scrubbing



IGCC CO_2 Capture Advantages:

- High chemical potential (Temp, P_{CO2})
- Low Volume Syngas Stream

Selexol™ CO_2 Capture Advantages:

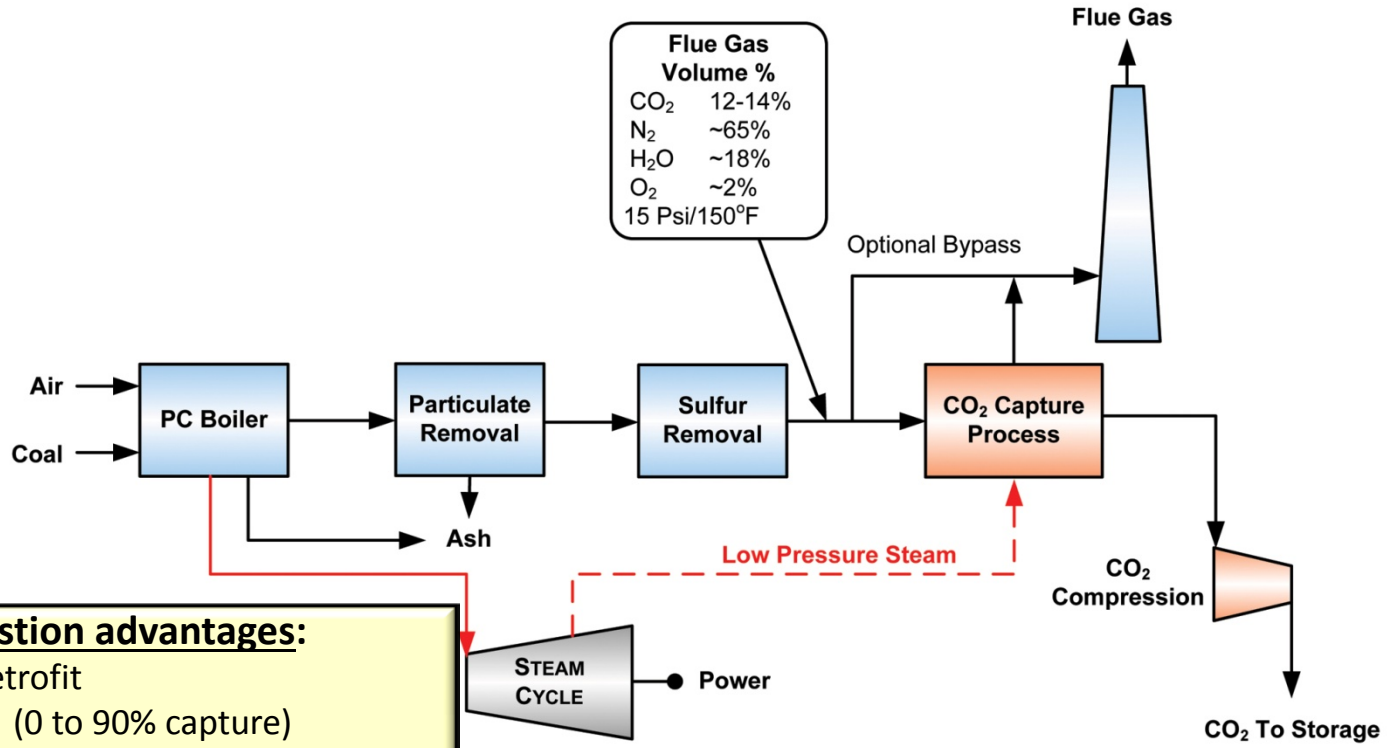
- 30+ years of commercial operation (55 worldwide plants)
- Physical Liquid Sorbent
- Highly selective for H_2S and CO_2
- CO_2 is produced at "some" pressure

Key Challenges:

- Complex, integrated power process
- Additional process (WGS) to get high capture rates
- Current technology (Selexol) requires cooling and reheating

Pulverized Coal Power Plant System

Post-combustion CO_2 Scrubbing



Post-combustion advantages:

- Back-end retrofit
- Slip-stream (0 to 90% capture)

Amine scrubbing Advantages:

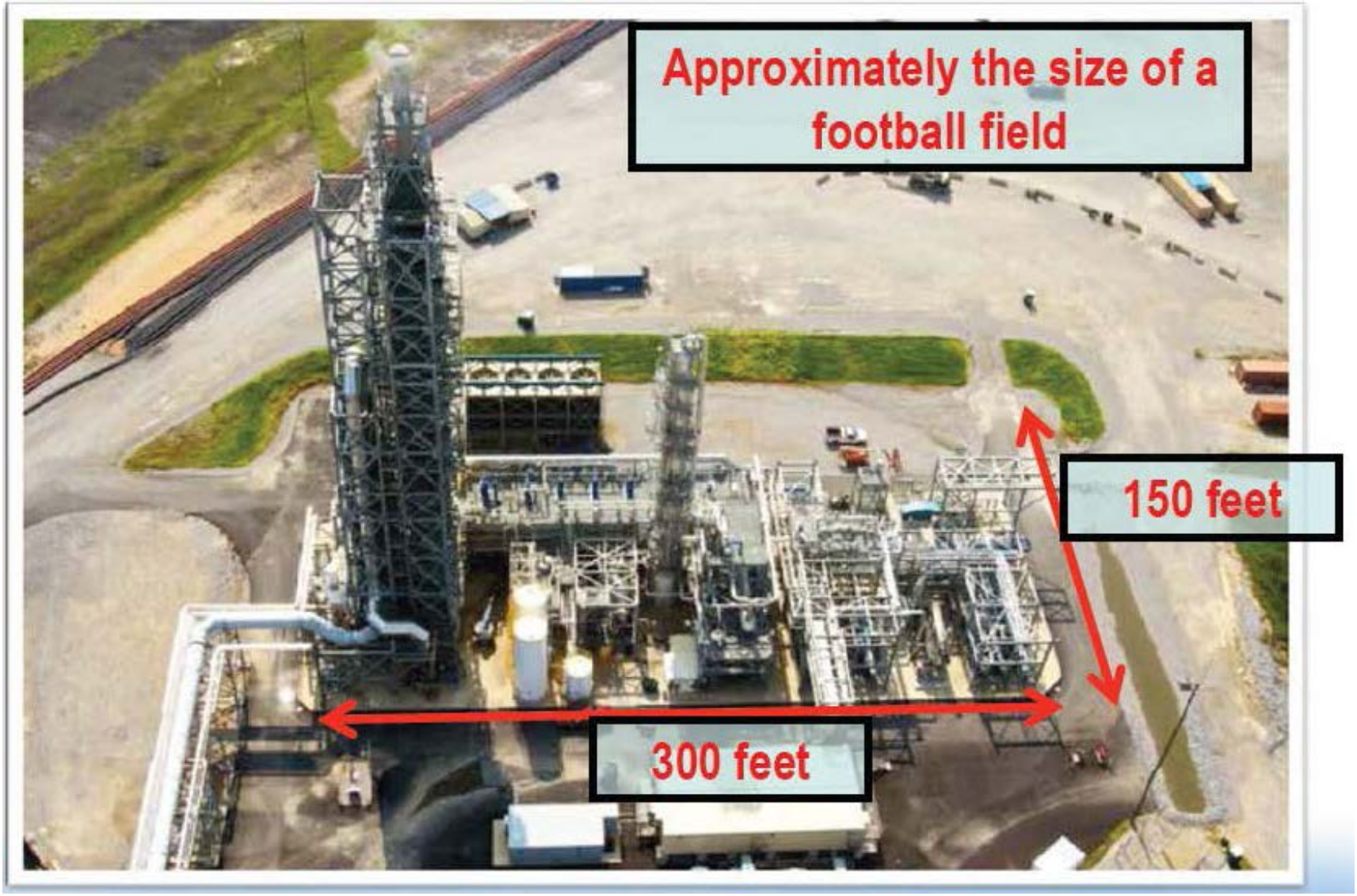
- Proven Technology (Petroleum refining, NG purification)
- Chemical solvent → High loadings at low CO_2 partial pressure
- Relatively cheap chemical ($2-3/lb)

Key Challenges:

- Dilute flue gas (12-15 volume %)
- 2-3 MM acfm for a 500-600 Mwe plant
- ~50% currently scrubbed for SOx/NOx
- Increased cooling requirements

Post Combustion Capture Plant

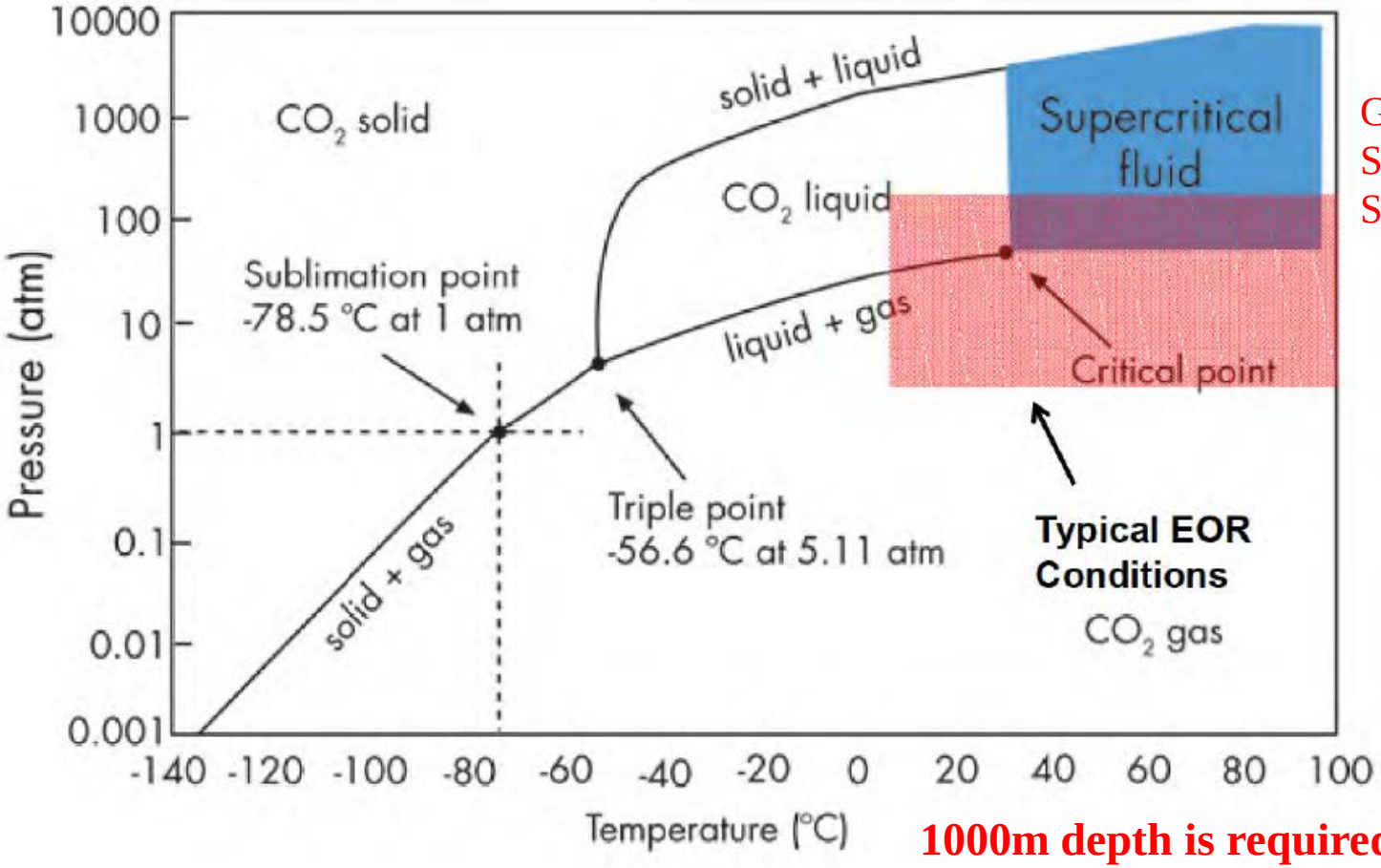
25 MWe slip stream, capturing ~550 metric tons per day



Deployment Barriers for CO_2 Capture On New and Existing Coal Plants Today

1. **Scale-up**
   - Current Post Combustion capture ~200 TPD
   - 550 MWe power plant produces 13,000 TPD
2. **Energy Penalty**
   - 20% to 30% less power output
3. **Cost**
   - Increase Cost of Electricity by 80%
   - Adds Capital Cost by $1,500 - $2,000/kW
4. **Regulatory framework**
   - Transport — pipeline network
   - Storage
5. **Economies of Scale**
   - Land, power, water use, transportation, process components, …

CO_2 Phase Diagram



Geological Sequestration - Subsurface Conditions

1000m depth is required for the weight of the rock to be high enough to keep the CO_2 supercritical

CO_2 as a Supercritical Fluid

Supercritical CO_2

- temperature in excess of 31.1 °C
- pressure in excess of 72.9 atm (about 1,057 psi).
- SupercriticalCO_2 is dense like a liquid but has viscosity like a gas.

The main advantage of storing CO_2 in the supercritical condition is that the required storage volume is substantially less than if the CO_2 were at standard (room) pressure conditions .

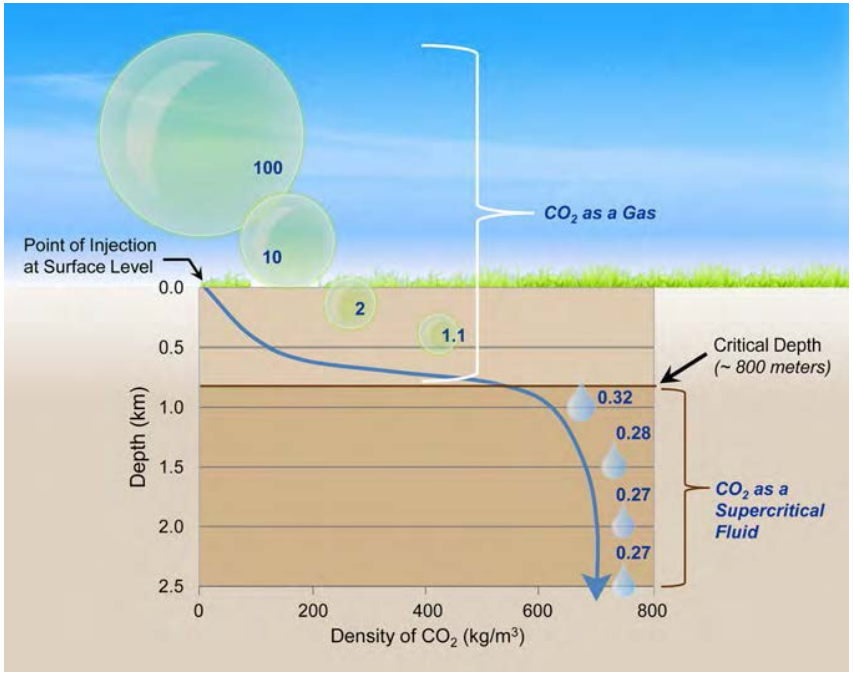


Illustration of pressure effects on CO_2 volume (based upon image from the Cooperative Research Centre for Greenhouse Gas Technologies [CO_2CRC]).

Temperature naturally increases with depth in the Earth's crust, as does the pressure of the fluids (brine, oil, or gas) in the rocks.

At depths below about 800 meters (about 2,600 feet), in most places on Earth, the natural temperature and fluid pressures are in excess of the critical point of CO_2.

This means that CO_2 injected at these temperatures and pressures will be in the supercritical condition.

Technologies for Monitoring and Accounting of CO_2

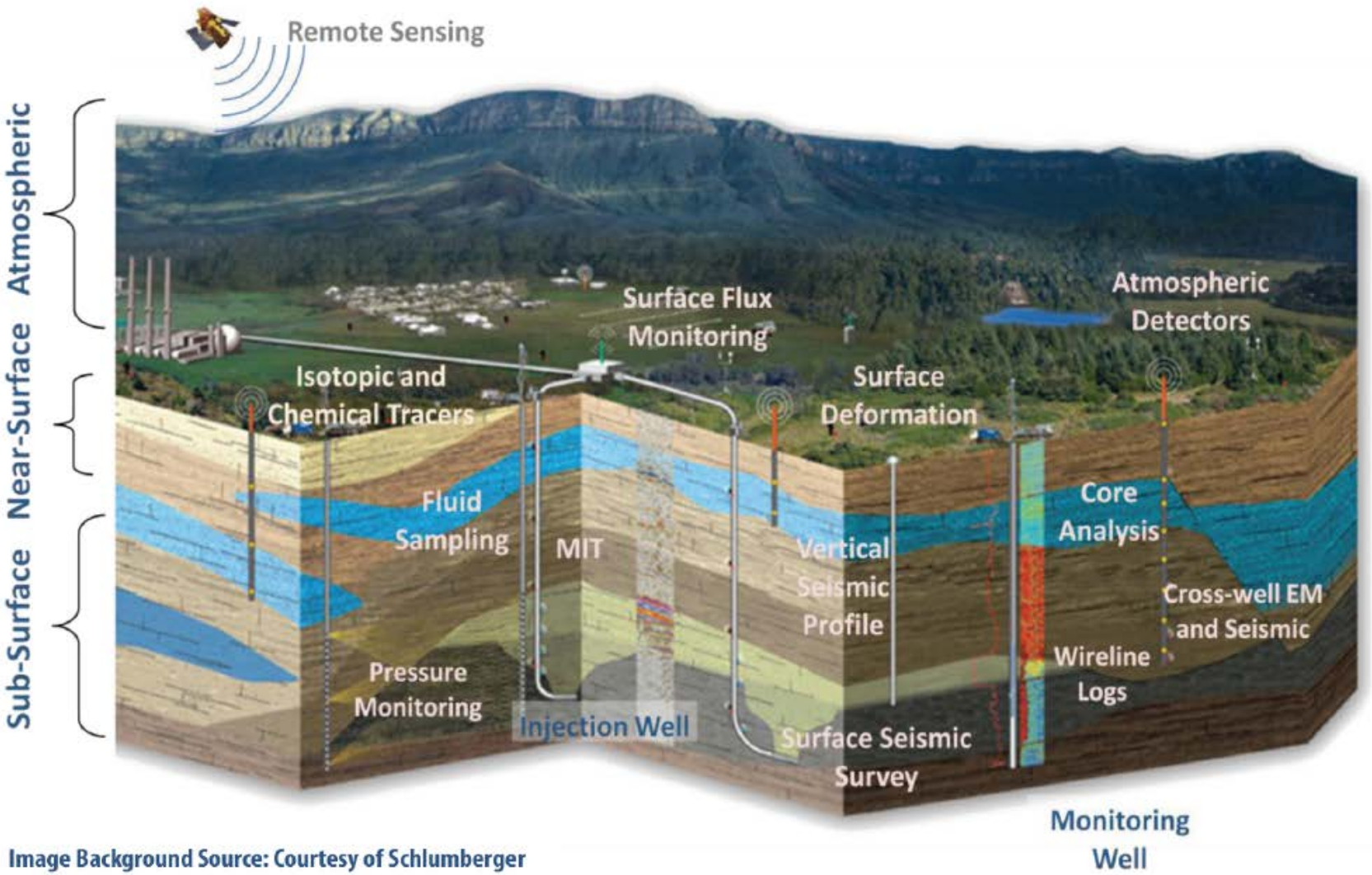


Image Background Source: Courtesy of Schlumberger

Carbon Storage Program

Mission and Program Drivers

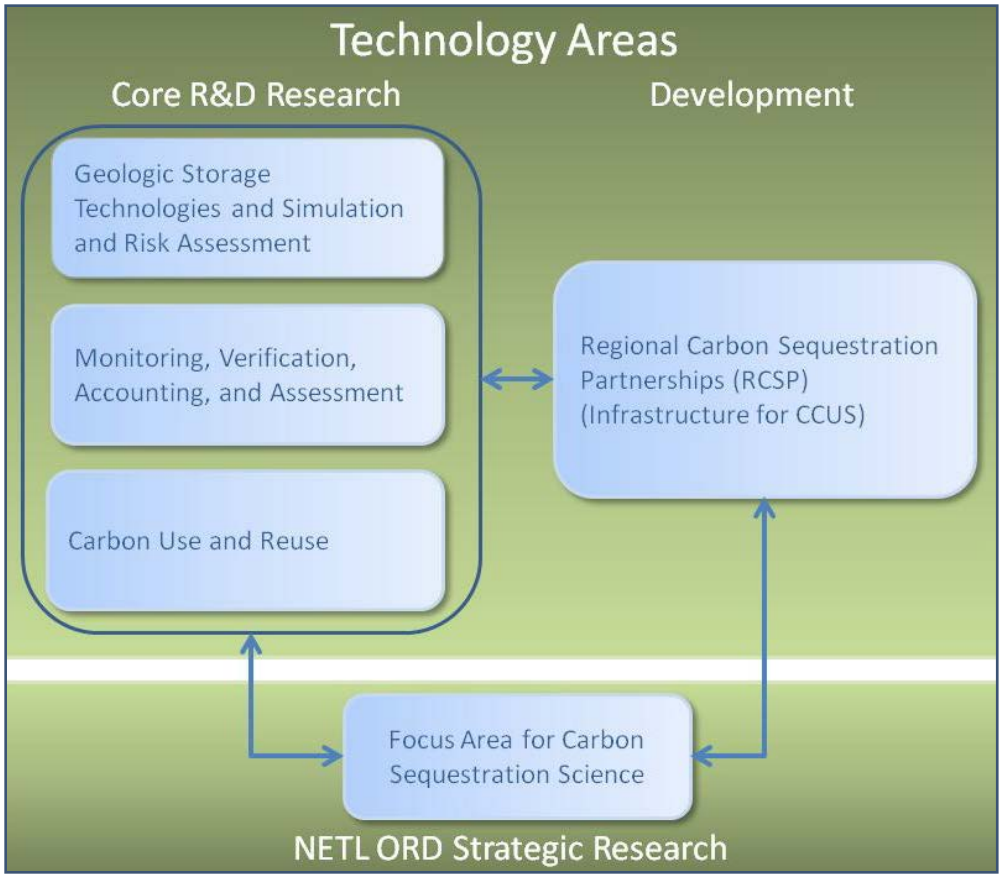
Developing effective and economically viable enabling technologies – then validating them in small- and large-scale (extensive monitoring) field projects to ensure safe and permanent storage of CO_2 from power and industrial source

- Industry and regulatory agencies will have the capability to monitor and account for safe and permanent storage of CO_2 throughout the U.S. *(New EPA Regulations)*
- Demonstrate that Carbon Storage is a viable technology solution that can be implemented on a large-scale and is safe for the environment *(Public Perception)*
- Development or integration of new or adapting existing technologies, such as seismic monitoring, to be cost-effective in order to reduce overall storage project costs *(Commercial Toolbox)*
- Ensure technologies are ready for wide-scale deployment of CCS allowing a diverse energy portfolio *(Fossil Fuels)*

Carbon Storage Program

Total Base Program Value is $1.06 B – over 100 Projects

Additional Total Awarded ARRA Projects $160 M – 60 projects



Program Goals

Account for 99% CO_2
Improve Storage Efficiency
Estimate Capacity +/- 30%
Best Practices Manuals

Benefits

Mitigate GHG Emissions
Credits for CO_2 Storage
Increased Oil/NG Recovery
Reduce Capital and O&M Costs
Reduce Environmental Footprint

Carbon Storage Program

Core R&D Key Technology Areas (TRL 2-5)

Geologic Storage Technology Area

(Storage Technologies and Simulation and Risk Assessment)

- **Wellbore** *construction and materials*
- **Mitigation** *technologies for wells and natural pathways*
- **Fluid flow, reservoir pressure, and water management**
- **Geochemical** *effects on formation, brine, and microbial communities*
- **Geomechanical** *impacts on reservoirs- seals and basin-scale coupled models; microseismic monitoring*
- **Risk Assessment** *databases and integration into operational design and monitoring*

MVAA Technology Area

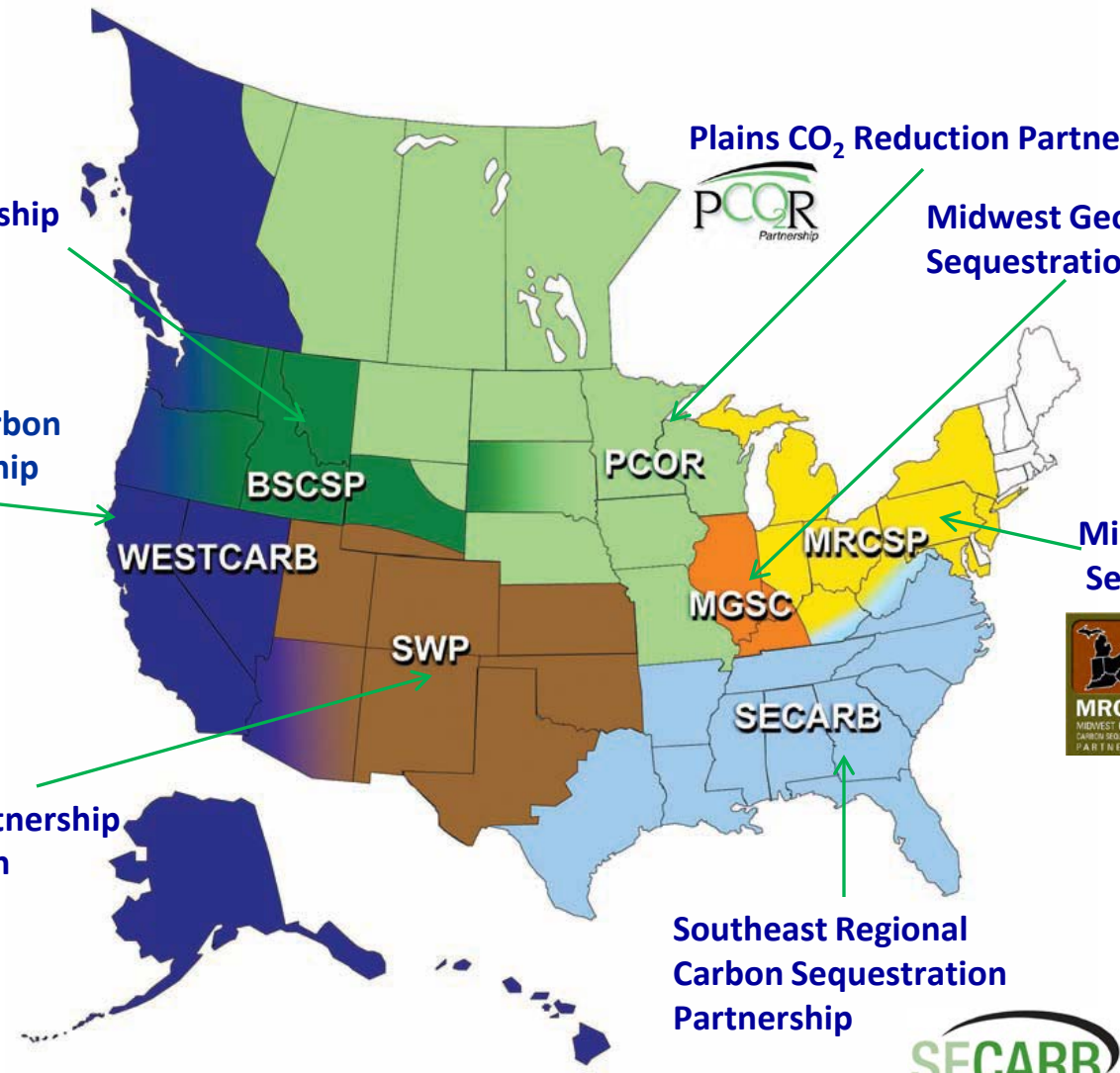
- **Atmospheric Monitoring** *and remote sensing technologies*
- **Near -Surface Monitoring** *of soils and vadose zone*
- **Subsurface Monitoring** *in and near injection zone*
- **Intelligent Monitoring Systems** *for field management*

CO_2 Use/Reuse Technology Area

- **Chemicals**
- **Polycarbonate plastics**
- **Minerals and cements (building products)**
- **EOR, EGR, and ECBM**

Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment



Big Sky Carbon Sequestration Partnership

Plains CO_2 Reduction Partnership

Midwest Geological Sequestration Consortium

West Coast Regional Carbon Sequestration Partnership

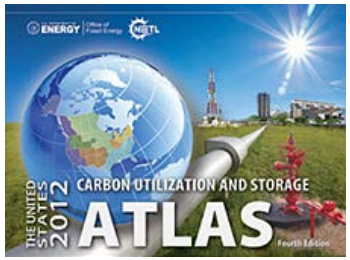
Midwest Regional Carbon Sequestration Partnership

Southwest Regional Partnership on Carbon Sequestration

Southeast Regional Carbon Sequestration Partnership

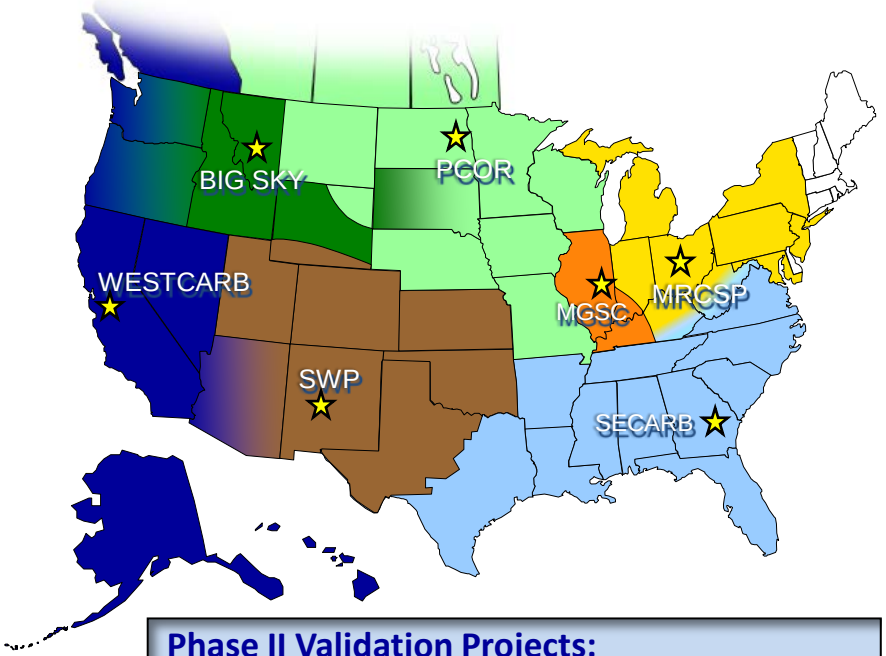
Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment



Seven Regional Partnerships

400+ distinct organizations, 43 states, 4 Canadian Provinces

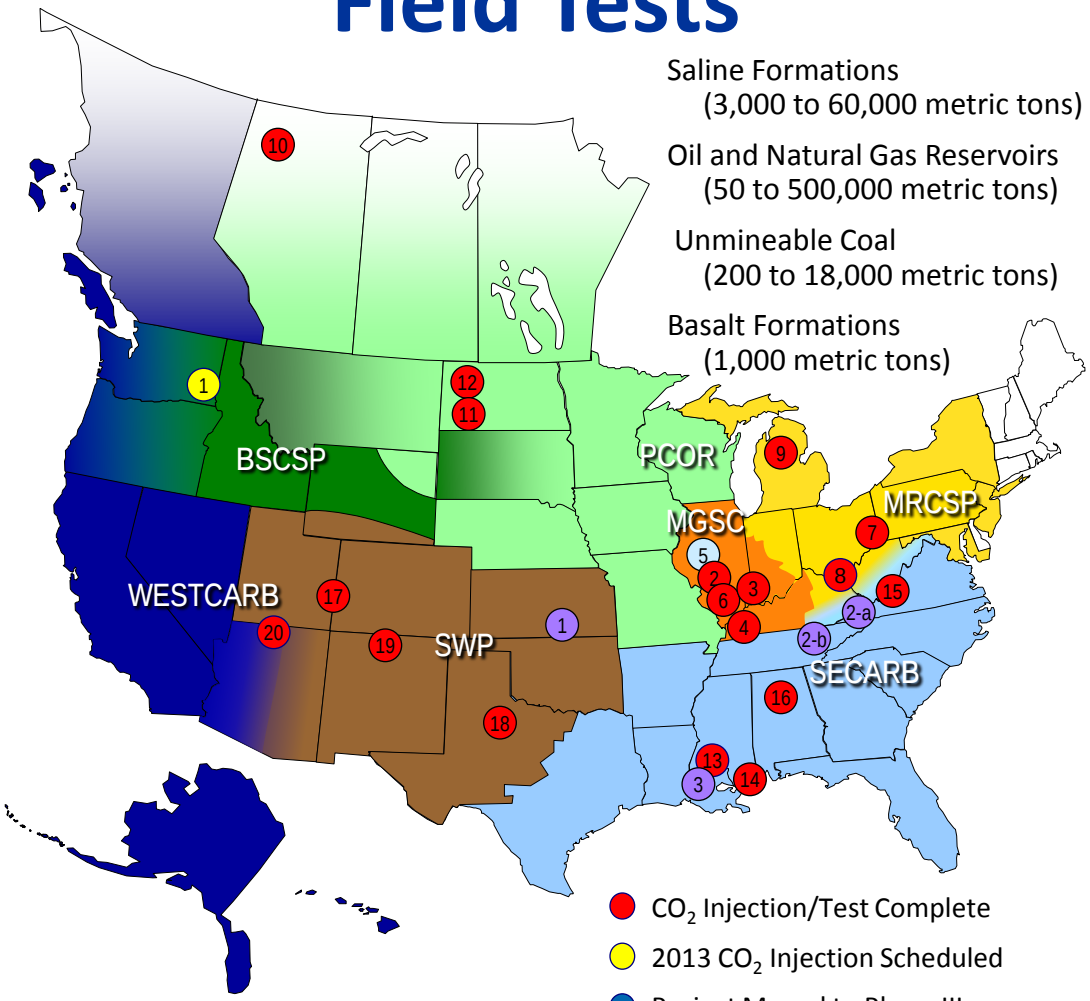


RCSP	Geologic Province	Injection Volume (metric tons MT)
BIG SKY	Kevin Dome-Duperow Formation	TBD
MGSC	Illinois Basin-Mt. Simon Sandstone	>532,000
MRCSP	Michigan Basin-Niagaran Reef	191,000
PCOR	Powder River Basin-Muddy Sandstone	June 2013
	Horn River Basin-Carbonates	TBD
SECARB	Gulf Coast - Tuscaloosa Formation	>3,400,000
	Gulf Coast – Paluxy Formation	>60,000
SWP	Anadarko Basin-Morrow Sandstone	Sept 2013
WESTCARB	Regional Characterization	

Phase II Validation Projects:

Completed 18 Field Project s injection ~1.2 MMT
Saline Formations (3,000 to 60,000 MT)
Oil and Gas Reservoirs (50 to 500,000 MT)
Unmineable Coal (200 to 18,000 MT)
Basalt Formation (1,000 MT)

Small-Scale Geologic Field Tests



Saline Formations
(3,000 to 60,000 metric tons)

Oil and Natural Gas Reservoirs
(50 to 500,000 metric tons)

Unmineable Coal
(200 to 18,000 metric tons)

Basalt Formations
(1,000 metric tons)

- CO_2 Injection/Test Complete
- 2013 CO_2 Injection Scheduled
- Project Moved to Phase III (Large-Scale Injection)
- Small-Scale CO_2 Injection Sites (added July 2011)

Completed 18 Injections

Over 1.2 MMT Injected

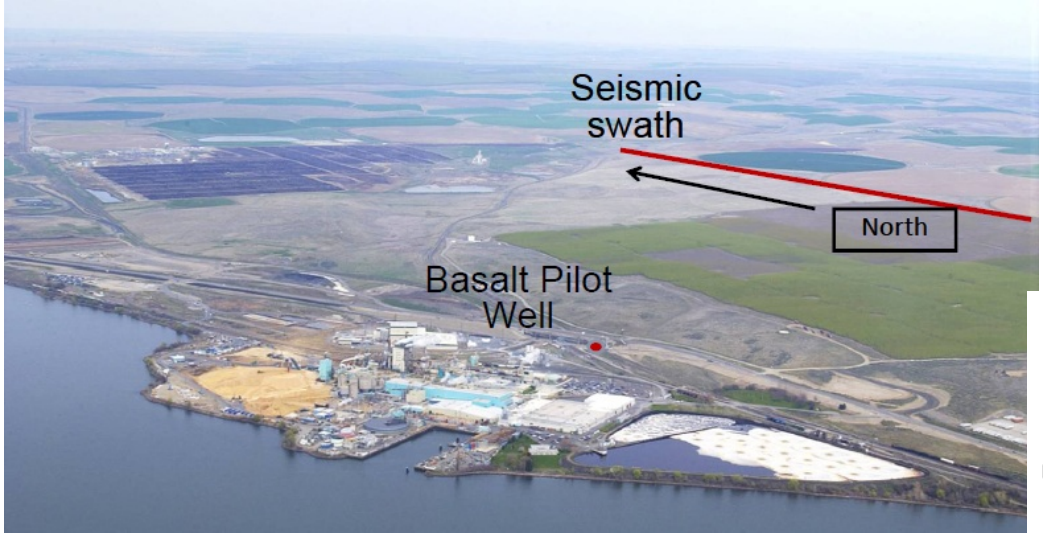
RCSP	Formation Type	Geologic Province
BIG SKY	SALINE 1	Columbia Basin
MGSC Midwest Geological Sequestration Consortium	OIL-BEARING 2 3 4 SALINE 5 COAL SEAM 6	Illinois Basin
MRCSP Midwest Regional Carbon Sequestration Partnership	SALINE 7 8 9	Cincinnati Arch, Michigan Basin, Appalachian Basin
PCOR The Plains CO_2 Reduction Partnership	OIL-BEARING 10 11 COAL SEAM 12	Keg River, Duperow, Williston Basin
SECARB Southeast Regional Carbon Sequestration Partnership	OIL-BEARING 13 SALINE 14 COAL SEAM 15 16	Gulf Coast, Mississippi Salt Basin, Central Appalachian, Black Warrior Basin
SWP Southwest Regional Partnership on Carbon Sequestration	OIL-BEARING 17 18 COAL SEAM 19	Paradox Basin, Aneth Field, Permian Basin, San Juan Basin
WESTCARB West Coast Regional Carbon Sequestration Partnership	SALINE 20	Colorado Plateau

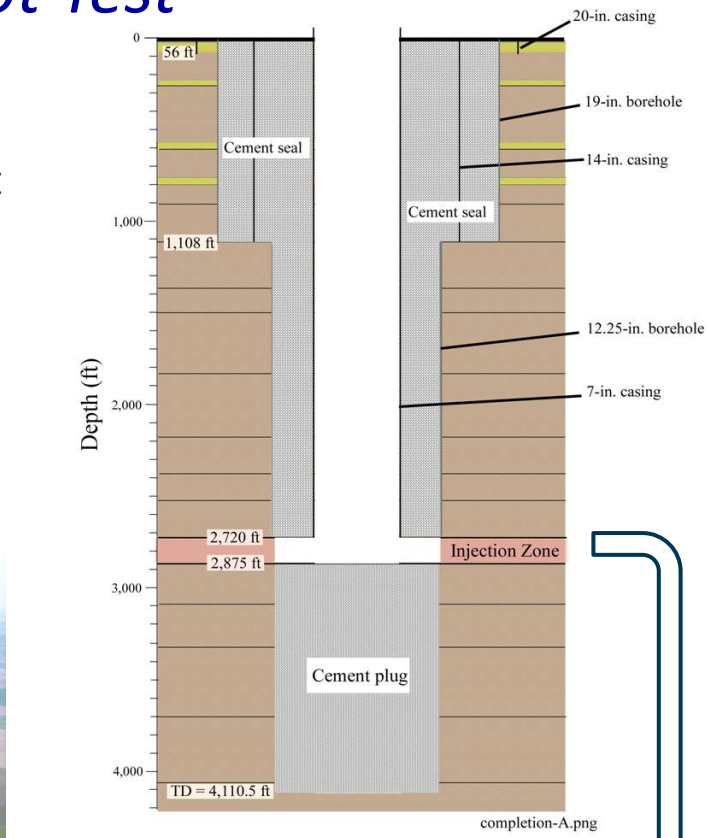
Other Small Scale Injections	Formation Type	Geologic Province
University of Kansas	OIL-BEARING & SALINE 1	Sedwick Basin
Virginia Tech	COAL SEAM 2-a ORGANIC SHALE 2-b	Appalachian Basin; Sourwood or Oakwood CBM fields
Blackhorse Energy, LLC	OIL-BEARING 3	Gulf Coast Basin; First Wilcox Sand

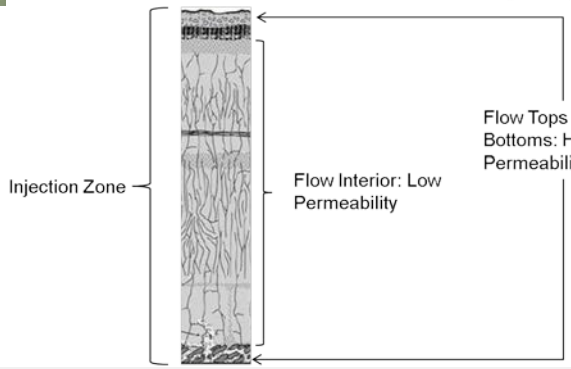
Big Sky Carbon Sequestration Partnership

Phase II – Basalt Pilot Test

- **Only basalt storage test in continental U.S.**
- **Advantages of Basalt for CO_2 storage**
  - Extensive Basalt Formations in Pacific Northwest
  - Layered storage above and below basalt flows
  - Significant potential for CO_2 mineralization
- **Host Site: Boise White Paper LLC - Wallula, WA**
- **CO_2 Injection Permit (WA Dept. of Ecology)**
  - 1000 metric tons max.
- **Target Injection Date: July 2013**

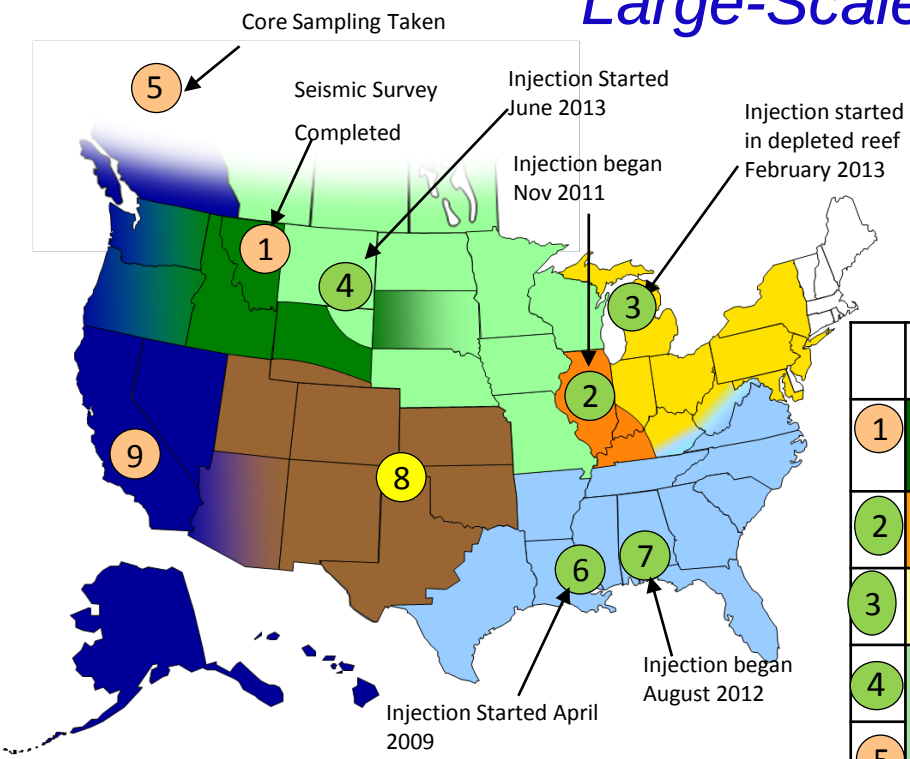






RCSP Phase III: Development Phase

Large-Scale Geologic Tests



- Injection Ongoing
- 2013 Injection Scheduled
- Injection Scheduled 2013-2015

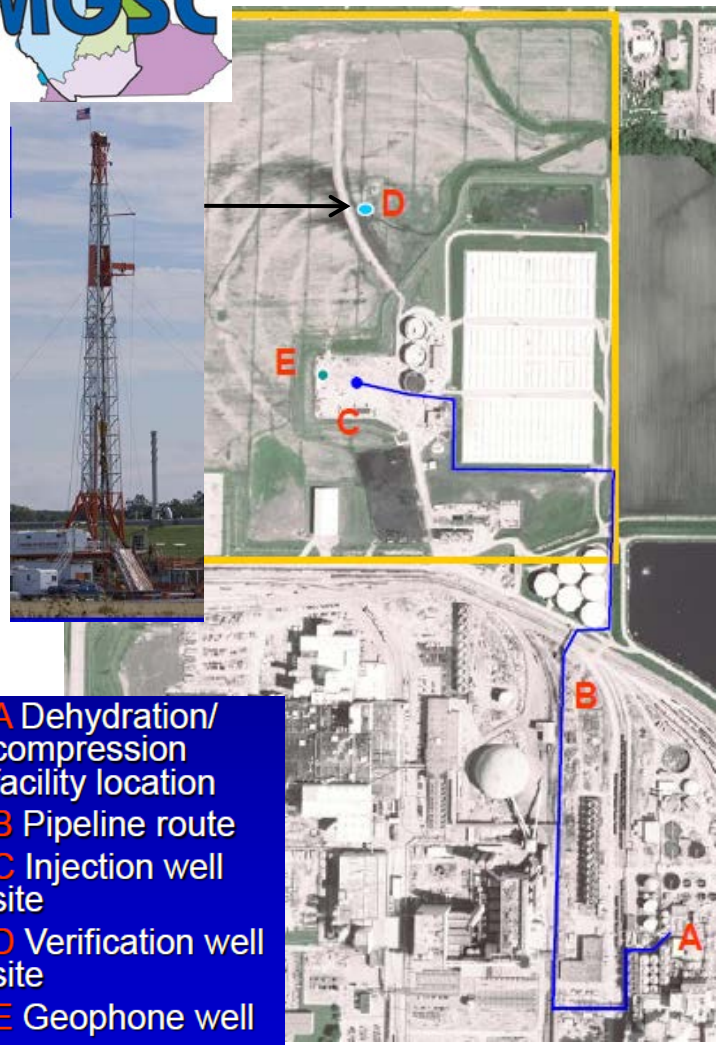
Note: Some locations presented on map may differ from final injection location

- ✓ *Large-volume tests*
- ✓ *Four Partnerships currently injecting CO_2*
- ✓ *Remaining injections scheduled 2013-2015*

	Partnership	Geologic Province	Target Injection Volume (tonnes)
1	Big Sky	Nugget Sandstone	1,000,000
2	MGSC	Illinois Basin- Mt. Simon Sandstone	1,000,000
3	MRCSP	Michigan Basin- Niagaran Reef	1,000,000
4	PCOR	Powder River Basin- Bell Creek Field	1,500,000
5		Horn River Basin- Carbonates	2,000,000
6	SECARB	Gulf Coast – Cranfield Field- Tuscaloosa Formation	3,400,000
7		Gulf Coast – Paluxy Formation	250,000
8	SWP	Regional CCUS Opportunity	1,000,000
9	WESTCARB	Regional Characterization	

Midwest Geological Sequestration Consortium

Illinois Basin Decatur Project

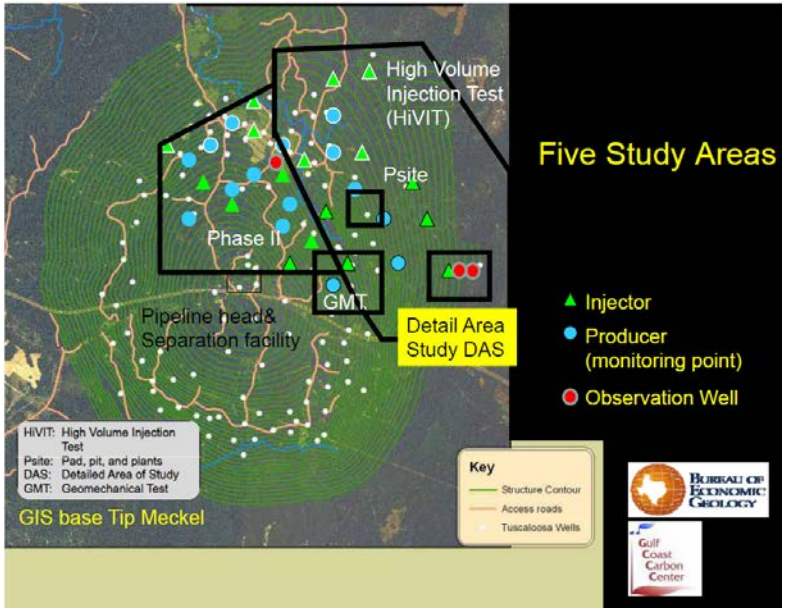


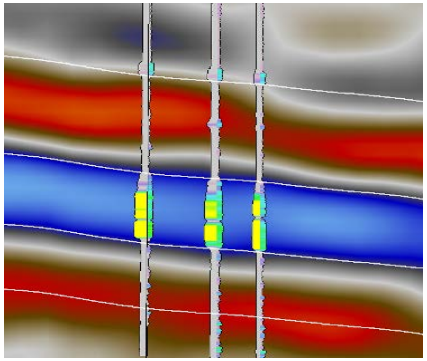
- **First large scale (1MMT) saline test on land**
- **1MMT from ethanol fermentation facility**
- **Dehydrated and compressed to 1500 PSI**
- **Injecting 1,000 MT per day since Nov 2011**
- **Over 532,000 MT injected to date**
- **Geology**
  - *Storage Formation: Mount Simon Sandstone*
  - *Seal: 500ft of Eau Claire Shale*
- **Designed to meet UIC Class VI requirements**

CO_2 Pipe to Injection Well

Compression Facility

Southeast Regional Carbon Sequestration Partnership *Cranfield Field Project*





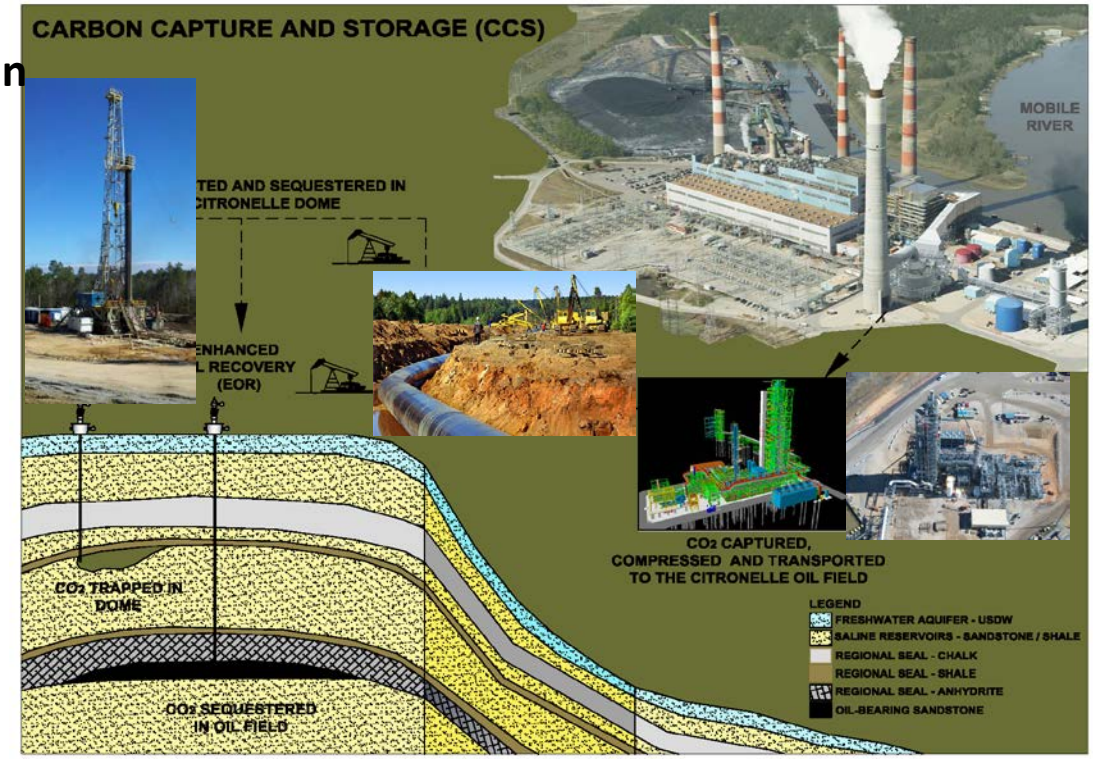
- **First large scale storage project**
- **In collaboration with Denbury Resources**
- **Injection rate was 432 MT/day, now <100 MT/day**
- **Over 3.4 MMT injected for storage**

- **Extensive MVA plan to account for stored CO_2 in the injection zone:**
  - *4-D geophysics (ERT, VSP)*
  - *Geochemical (U-tube technology)*
  - *Field pressure monitoring*
  - *Distributed temperature*
  - *Wireline logging*

Southeast Regional Carbon Sequestration Partnership

Citronelle-Plant Barry Field Project

- **Largest fully integrated capture (25MW) and saline storage project in the U.S.—MHI KS1 amine process**
- **Southern Company's Plant Barry Power Station**
- **UIC Class V permit with Class VI requirements**
- **Projected CO_2 Injection Amount ~ 250,000 MT over 2 years**
- **CO_2 injection started August 20, 2012. >60,000 MT injected to date**



Global Collaborations

Leveraging International Geologic Storage R&D Projects

International Demonstrations

– Sponsor multi-national R&D including Canadian Weyburn-Midale, Australian Otway, and Iceland CarbFix projects

Carbon Sequestration Leadership Forum

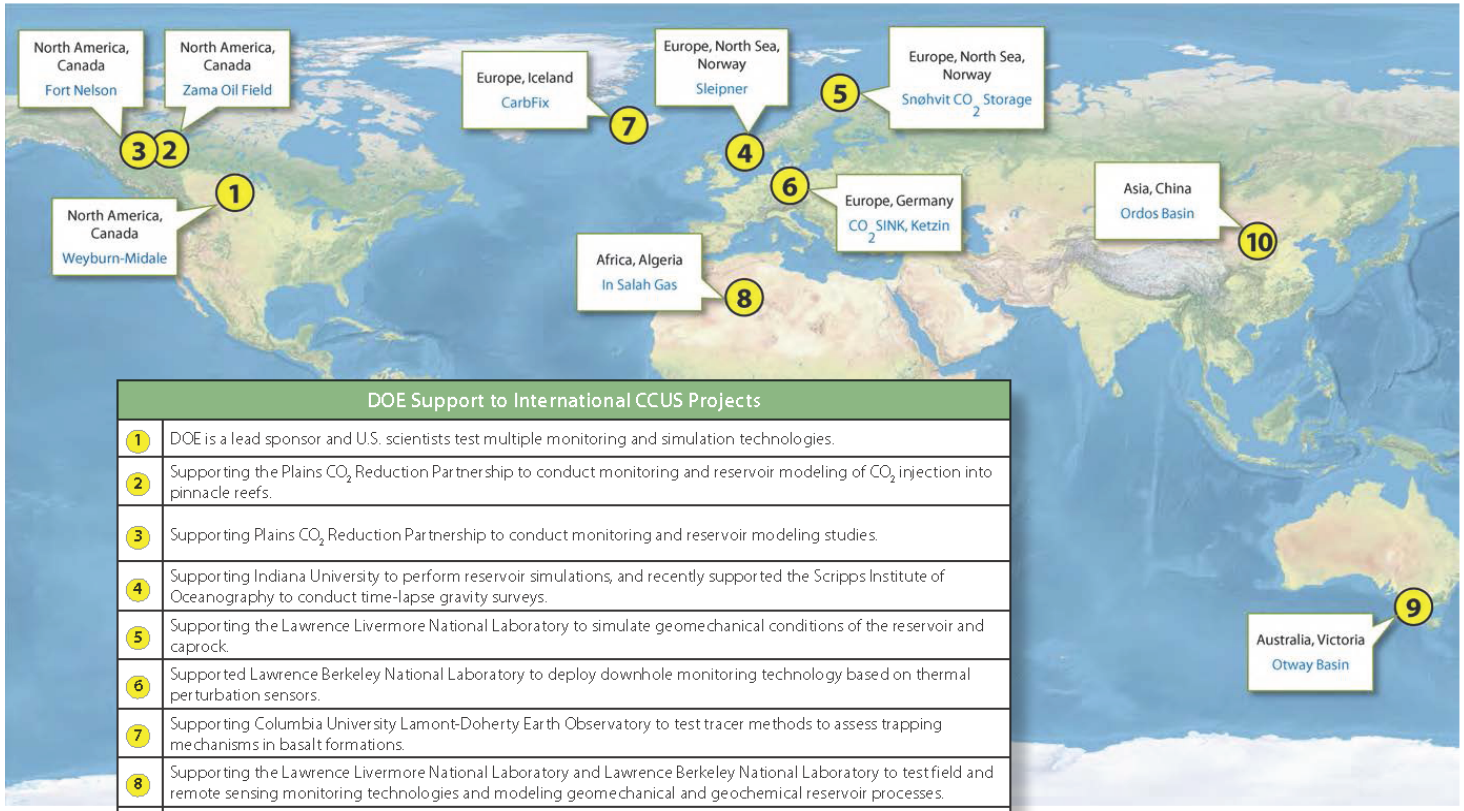
– International ministerial-level organization focused on improved CCS technologies

North American Carbon Atlas Partnership

– Joint initiative between U.S., Canada, and Mexico to map CO_2 sources and storage

Other International Activities

– Partnerships with IEA GHG R&D Programme, IEA, others

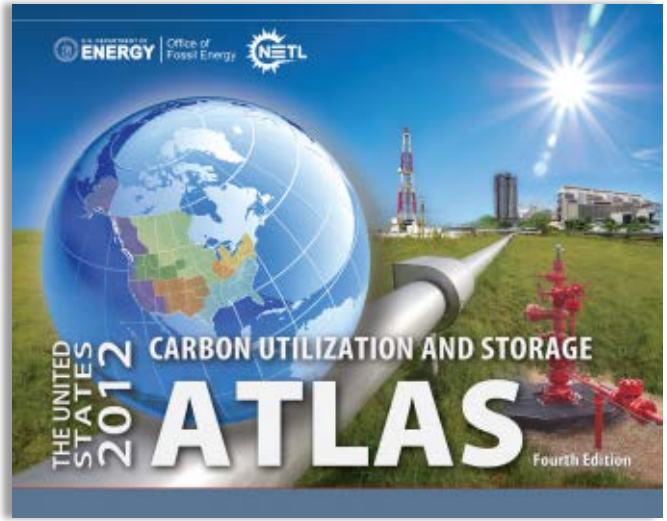


DOE Support to International CCUS Projects	
1	DOE is a lead sponsor and U.S. scientists test multiple monitoring and simulation technologies.
2	Supporting the Plains CO_2 Reduction Partnership to conduct monitoring and reservoir modeling of CO_2 injection into pinnacle reefs.
3	Supporting Plains CO_2 Reduction Partnership to conduct monitoring and reservoir modeling studies.
4	Supporting Indiana University to perform reservoir simulations, and recently supported the Scripps Institute of Oceanography to conduct time-lapse gravity surveys.
5	Supporting the Lawrence Livermore National Laboratory to simulate geomechanical conditions of the reservoir and caprock.
6	Supported Lawrence Berkeley National Laboratory to deploy downhole monitoring technology based on thermal perturbation sensors.
7	Supporting Columbia University Lamont-Doherty Earth Observatory to test tracer methods to assess trapping mechanisms in basalt formations.
8	Supporting the Lawrence Livermore National Laboratory and Lawrence Berkeley National Laboratory to test field and remote sensing monitoring technologies and modeling geomechanical and geochemical reservoir processes.
9	Supporting scientists at Lawrence Berkeley National Laboratory to test multiple monitoring technologies at depleted gas field and saline formations.
10	Supporting West Virginia University and Lawrence Livermore National Laboratory to assess capacity for storage, and simulating hydrogeologic and geochemical reservoir conditions.

Focus Area for Carbon Sequestration Science

U.S. 2012 Carbon Utilization and Storage Atlas (Atlas IV)

Released in December 2012



- **Updated CO_2 stationary source emission estimates and storage potential of various geologic storage types:**
  - *at least 2,400 billion metric tons total storage resource*
  - *3.3 billion metric tons annual CO_2 emissions*
- **Outlines DOE's Carbon Storage Program**
- **Showcases updated info about Regional Carbon Sequestration Partnership (RCSP) CO_2 storage activities**
- **New information from the ARRA Site Characterization projects**
- **Highlights CCS collaborations and worldwide CCS projects**

http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIV/Atlas-IV-2012.pdf

Carbon Storage Program

Key Technologies Successes

Core R&D Technology Area

- *Hasting EOR Field testing a state-of-the-art system to monitor CO_2 in the subsurface, using GPS and InSAR satellite imagery allowing monitoring of large areas (University of Miami)*
- *Successful test of a prototype fiber-optic seismic borehole system that can generate highly accurate 3D maps of subsurface and CO_2 to assure storage permanence. (Paulsson Inc.)*
- *Successful controlled test of a differential absorption light detection and ranging (DIAL) instrument to measure CO_2 concentration at the surface at ZERT, plans are underway to test at the BIGSKY large-scale field project in September 2013 (Montana State University)*

Regional Carbon Sequestration Partnerships (Infrastructure) Technology Area

- *MGSC-Illinois Basin, SECARB-Cranfield, Plant Barry and MRCSP-Michigan Basin Large-Scale Field Projects have injected over 4 million metric tons*
- *Shortly, PCOR-Bell Creek Large-Scale Field Project will begin reporting injection volumes along with monitoring activities in conjunction with active EOR sites*
- *SWP- Anadarko Basin and Big Sky– Kevin Dome Field Projects have completed major field activities in preparation for injection later in 2013/2014*