NATIONAL ENERGY TECHNOLOGY LABORATORY

Presentation to

WESTCARB Annual Meeting

Oct 20, 2010

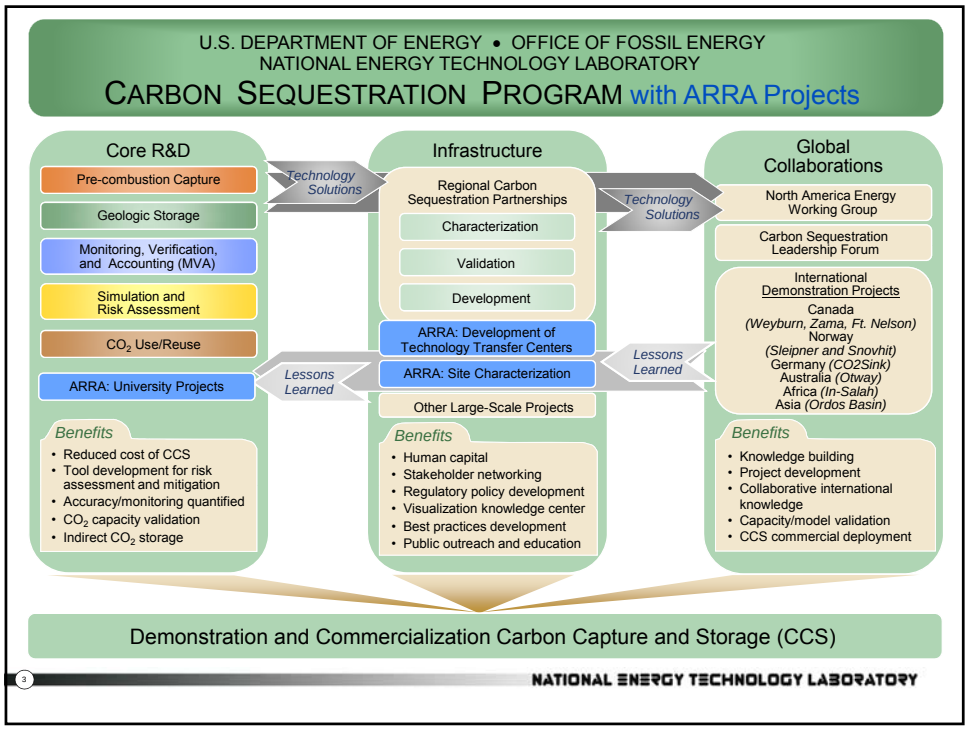
Sacramento, CA

Best Practices for CCS

John Litynski, PE
Sequestration Technology Manager
Sequestration Division Director (*Acting*)

Presentation Overview

- DOE's Program Summary (*where do BPM's fit*)
- Transferring lessons learned from the field
- Purpose of DOE's BPM
- DOE's Best Practice manuals update
- Other DOE Programmatic Documents


U.S. DEPARTMENT OF ENERGY • OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
CARBON SEQUESTRATION PROGRAM with ARRA Projects
Core R&D
Pre-combustion Capture
Geologic Storage
Monitoring, Verification, and Accounting (MVA)
Simulation and Risk Assessment
CO_2 Use/Reuse
ARRA: University Projects
Technology Solutions
Lessons Learned
Infrastructure
Regional Carbon Sequestration Partnerships
Characterization
Validation
Development
ARRA: Development of Technology Transfer Centers
ARRA: Site Characterization
Other Large-Scale Projects
Technology Solutions
Lessons Learned
Global Collaborations
North America Energy Working Group
Carbon Sequestration Leadership Forum
International Demonstration Projects
Canada (Weyburn, Zama, Ft. Nelson)
Norway (Sleipner and Snovhit)
Germany (CO2Sink)
Australia (Otway)
Africa (In-Salah)
Asia (Ordos Basin)
Benefits
• Reduced cost of CCS
• Tool development for risk assessment and mitigation
• Accuracy/monitoring quantified
• CO_2 capacity validation
• Indirect CO_2 storage
Benefits
• Human capital
• Stakeholder networking
• Regulatory policy development
• Visualization knowledge center
• Best practices development
• Public outreach and education
Benefits
• Knowledge building
• Project development
• Collaborative international knowledge
• Capacity/model validation
• CCS commercial deployment
Demonstration and Commercialization Carbon Capture and Storage (CCS)
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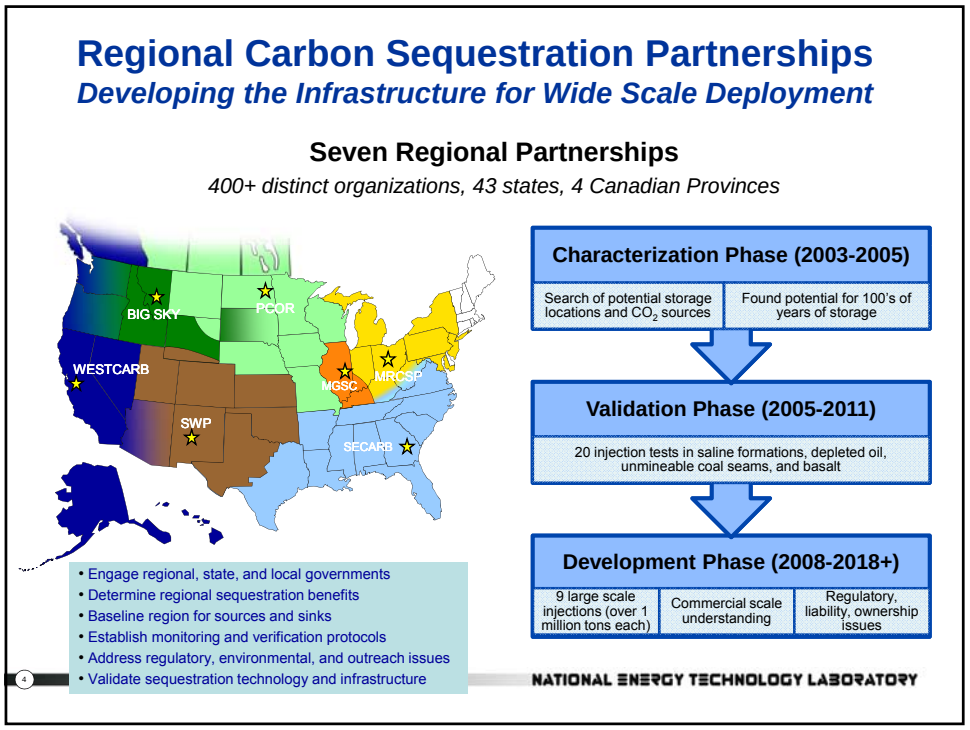
Regional Carbon Sequestration Partnerships
Developing the Infrastructure for Wide Scale Deployment
Seven Regional Partnerships
400+ distinct organizations, 43 states, 4 Canadian Provinces
BIG SKY
PCOR
WESTCARB
MGSC
MRCSP
SWP
SECARB
• Engage regional, state, and local governments
• Determine regional 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 (2005-2011)
20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt
Development Phase (2008-2018+)
9 large scale injections (over 1 million tons each)
Commercial scale understanding
Regulatory, liability, ownership issues
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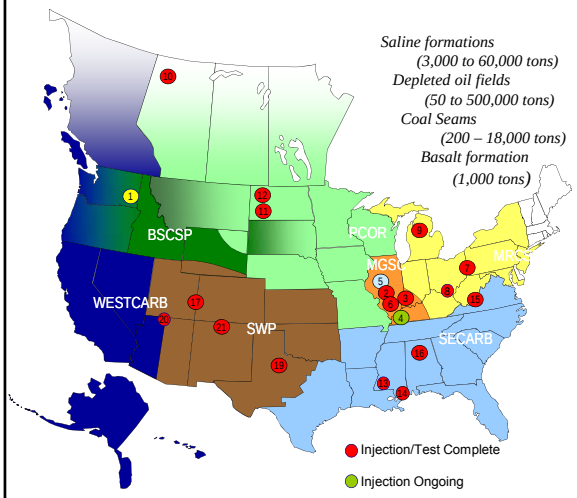
Transferring Lessons Learned from the Field

Small-Scale Geologic Field Tests



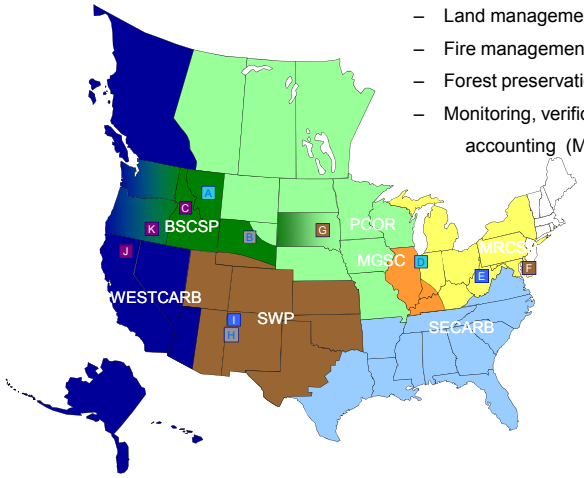
Completed 17 Injections

Over 1.35 M Tons injected

RCSP	Formation Type	Geologic Province
Big Sky	Saline 1	Columbia Basin
MGSC	Oil-bearing 2 3 4 Saline 5 Coal seam 6	Illinois Basin
MRCSP	Saline 7 8 9	Cincinnati Arch, Michigan Basin, Appalachian Basin
PCOR	Oil-bearing 10 11 Coal seam 12	Keg River, Duperow, Williston Basin
SECARB	Oil-bearing 13 Saline 14 Coal seam 15 16	Gulf Coast, Mississippi Salt Basin, Central Appalachian, Black Warrior Basin
SWP	Oil-bearing 17 18 Coal seam 19	Paradox Basin, Aneth Field, Permian Basin, San Juan Basin
WESTCARB	Saline 20	Colorado Plateau

Terrestrial Sequestration Field Tests

- Tree-plantings
- No-till farming
- Wetlands restoration
- Land management: grasslands, grazing lands
- Fire management
- Forest preservation
- Monitoring, verification, and accounting (MVA) technologies

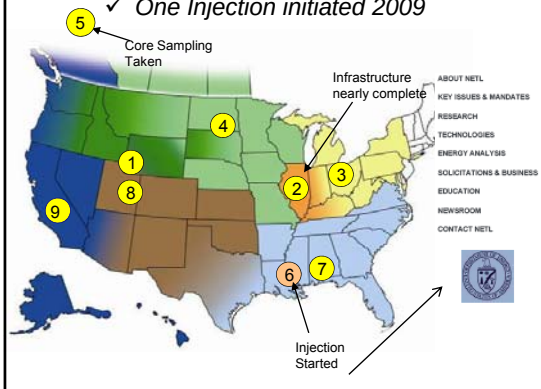


Terrestrial Project Categorization
- Agricultural soils
- Soil Reclamation
- Afforestation
- Accounting/Aggregation
- Wetlands Reclamation

RCSP Phase III: Development Phase

Major Milestone - Large-Volume Geologic Field Tests

- ✓ *Nine large-volume tests*
- ✓ *One Injection initiated 2009*




Publications
News Release

Release Date: November 5, 2009

DOE-Sponsored Mississippi Project Hits 1-Million-Ton Milestone for Injected CO_2

Project Helping Further CCS Technology and Meeting G-8 Goals for Deployment

Washington, D.C. —A large-scale carbon dioxide (CO_2) storage project in Mississippi has become the fifth worldwide to reach the important milestone of more than 1 million tons injected. As a result, it is helping to both further carbon capture and storage (CCS) as a mitigation strategy for global climate change and move forward G-8 recommendations for launching 20 projects of this type internationally by 2010.

The project, sponsored by the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE), is located at the Cranfield site in Southwestern Mississippi. It is led by the Southeast Regional Carbon Sequestration Partnership (SECARB), one of seven members of the Regional Carbon Sequestration Partnerships Program (RCSP) managed by the Office of Fossil Energy's National Energy Technology Laboratory (NETL).

MORE INFO
- Learn more about DOE's Regional Carbon Sequestration Partnership Program
- Link to SECARB web site

CCS is a group of technologies for capturing and compressing the CO_2 emitted by power plants or industrial sites, transporting it, and injecting it into suitable permanent storage sites, such as deep underground formations. It has been increasingly recognized by scientists and nations worldwide as an effective way to both reduce CO_2 emissions from existing sources and help avoid future emissions, making it part of a portfolio response to meet atmospheric CO_2 reduction goals. Additionally, the G-8 – of which the United States is a part – has endorsed demonstrating CCS by getting at least 20 industrial-scale projects underway, with the goal of broad deployment of the technology by 2020.

- Injection ongoing
- Injection Scheduled 2011-2015

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

Over 1,000,000 Tons injected at SECARB site

DOE's Best Practice manuals update

Best Practice Manuals
Communicating Lessons Learned

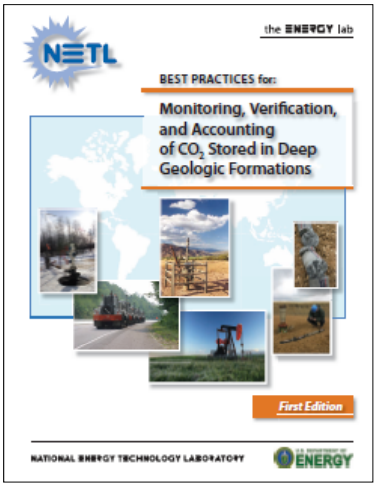
Best Practices Manual	Version 1 (Phase II)	Version 2 (Phase III)	Final Guidelines (Post Injection)
Monitoring, Verification and Accounting	2009	2017	2020
Public Outreach and Education	2009	2016	2020
Site Characterization	2010	2016	2020
**Simulation and Risk Assessment	2010	2017	2020
**Well Construction,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

Best Practice Manuals (BPMs) are Important Program Outputs

- **BPMs demonstrate to the public, regulators and policymakers that geologic storage is a safe effective GHG control technology**
- **BPMs provide technical guidance on key components of a storage project**
- **BPMs build upon knowledge and experience gained from the RCSP efforts and industry**
- **BPMs provide Information to potential developers of commercial CCS projects**

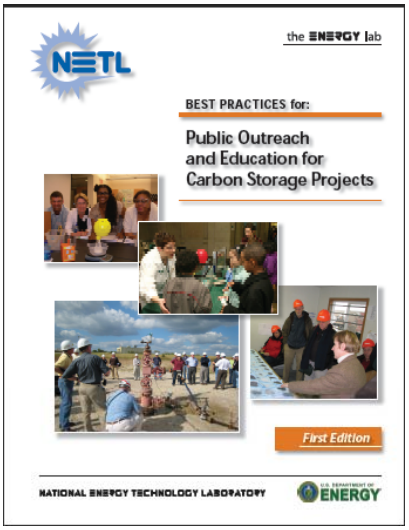
Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations (Jan 2009)

- **Based on DOE Supported and leveraged monitoring activities**
  - **RCSP Program**
  - **Core R&D**
  - **International Projects**
  - **Industrial applications**
- **Regulatory requirements and associated monitoring needs**
- **35 Technologies divided into:**
  - Primary
  - Secondary
  - Additional



Public Outreach is Key for Project Success (Jan 2010)

- **Focused on project developers**
- **Based on practical RCSP experience**
- **Do your homework**
  - Integrate outreach with project management
  - Establish an outreach team
  - Identify stakeholders
  - Conduct and apply social characterization
- **Develop plans and materials**
  - Develop plan tailored to community
  - Develop key messages
  - Tailor materials to audience
- **Implement, Assess and Refine**



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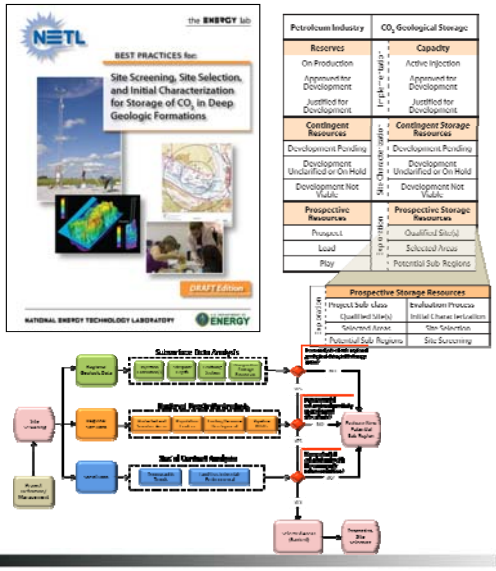
Site Screening, Site Selection, and Initial Characterization (June 2010)



- **Integrating Exploration Phase evaluation processes into one consistent (industry standard) framework, terminology and guidelines for communicating "project" related storage estimates**
- **Framework integrates processes and lessons learned from RCSP field projects into the Classification**
- **Provide stakeholders and greater sequestration community process and guidelines for site evaluation**

***Adapted from SPE_WPC_AAPG_SPEE*

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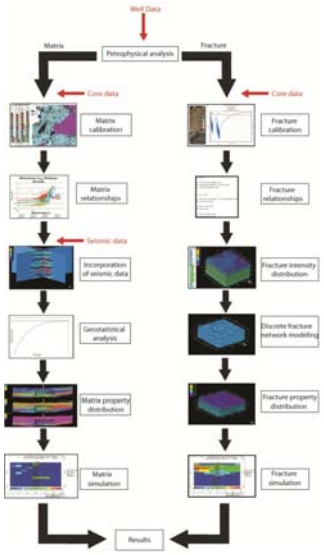
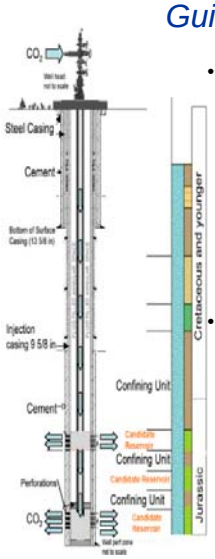
Risk Assessment and Simulation (Dec 2010)

- **Fundamentals of risk assessment**
  - CCS risks
  - Tools and approaches
- **Simulation of subsurface processes**
  - Hydrologic, geomechanical, thermal, geochemical and biological
- **RCSP experience in application of risk assessment and simulation**
  - Case histories
- **Inform MVA Plans, validate performance, quantify risks for project management and liability**



Well Construction and Operations (Dec 2010)

Guidance for Potential Project Developers



- **Project Planning Activities**
  - **Financial Planning**
  - **Continue Public Outreach**
  - **Project Review**
  - **Access Issues**
  - **Project Design**
  - **Project Plans**
  - **Permit Requirements**
  - **Siting and Permits**
- **Site Preparation**
  - **Site Security**
  - **Site Access**
  - **Facility Layout**
  - **Well Locations**
  - **Well Pad Preparation**
  - **Piping**
- **Drilling and Completion Operations**
  - **Well Drilling**
  - **Well Construction**
  - **Well Development/Stimulation**
  - **Evaluation and Testing**
  - **Pre-Injection Baseline Monitoring**
- **Injection Operations**
  - **Review of Drilling Results**
  - **Justification for Additional Wells**
  - **Equipment**
  - **Injection Process**
  - **Mitigation Activities**
  - **Produced Water**
- **Post Injection Operations**
  - **Long Term MVA**
  - **Plugging and Abandonment**
  - **Site Closure**

Best Practices for: Terrestrial Sequestration of Carbon Dioxide (Dec 2010)

Terrestrial Sequestration is the storage of CO2 in soils and plants

Research focused on improving management practices resulting in an increase in the amount of CO2 that can be stored in soils and plants

Best Practice Manual

Purpose:

To provide information for those considering terrestrial sequestration projects and those considering regulations/legislation governing carbon emissions caps

Topics covered include:

- **Land types and management methods that can maximize carbon storage in vegetation and soil.**
- **Analytical techniques necessary MVA for terrestrially stored carbon**
- **Status of GHG trading and the institutions involved**
- **Case studies of the RCSPs terrestrial field trials**

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Geologic Reservoir Classes for CO_2 Storage

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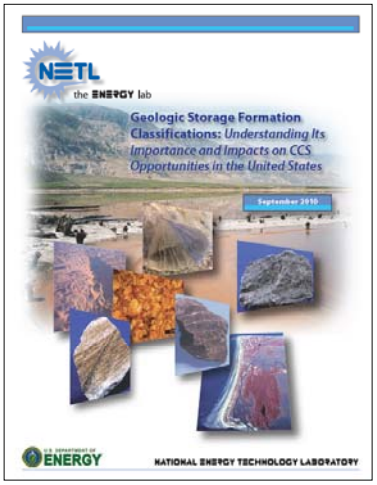
Depositional Environment Affects CO_2 Behavior in Reservoirs

- ***Architectural*** **framework created during deposition affects the behavior of CO_2 in a reservoir**
  - **Flow**
  - **Chemical reactions**
  - **Pressure**
  - **Injectivity**
  - **Containment**
  - **Efficiency**
- **CO_2 Storage Classification System focuses future R&D field test efforts**



Reservoir Depositional Classification Schematic

Rock Classification (Lithology)	Geoscience Institute for Oil and Gas Recovery Research Classification in 1991			DOE's Oil Reservoir Classification from 1990's	Sequestration Formation Classification 2010	
					Storage	Seals
Sedimentary	Clastic Reservoirs	Delta	Delta/Fluvial-Dominated	Class I Reservoirs	Deltaic	
			Delta/Wave-Dominated			
			Delta/Tide-Dominated			
			Delta/Undifferentiated		Coal/Shale	**Shales** *(fine terrigenous materials—clays,as well as from carbonates)* Deposited in Lacustrine, Fluvial, Alluvial, Near Shore & Open Ocean Marine Environments
		Fluvial	Fluvial/Braided Stream	Class 5 Reservoirs	Fluvial	
			Fluvial/Meandering Stream			
			Fluvial/Undifferentiated			
		Alluvial Fan			Alluvial	
		Strandplain	Strandplain/Barrier Cores and Shorefaces	Class 4 Reservoirs	Strandplain	
			Strandplain/Back Barriers			
			Strandplain/Undifferentiated			
		Turbidites	Slope-Basin	Class 3 Reservoirs	Turbidite	
			Basin			
		Eolian — *Wind Blown: Clastics and/or Carbonates*			Eolian	
		Lacustrine — *Lake Deposited: Clastics, Carbonates, Evaporites*			Lacustrine	**Evaporites** *(from various Lithology Deposited in Arid Settings)*
		Shelf			Shelf	
	Carbonate Reservoirs (>50% Carbonate content but can contain Terrigenous materials — sand, feldspar, non-carbonate boulders and evaporites)	Peritidal	Dolomitization Massive Dissolution Other			
		Shallow Shelf/ Open	Dolomitization Massive Dissolution Other	Class 2 Reservoirs	Shallow Shelf	
		Shallow Shelf/ Restricted	Dolomitization Massive Dissolution Other			
		Reef	Dolomitization Massive Dissolution Other		Reef	
		Shelf Margin	Dolomitization Massive Dissolution Other			
		Slope-Basin	Other			
Igneous	Basalts				Basaltic Interflow Zones	
	Granitic					
Metamorphic						

Field Testing CO_2 Storage Classes

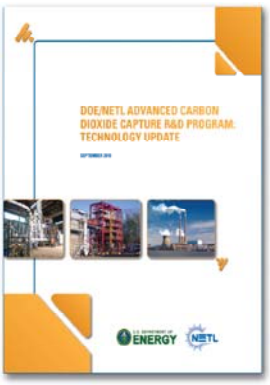
Matrix of Field Activities in Different Reservoir Classes

	High Potential Reservoirs					Medium Potential Reservoirs				Lower or Unknown Potential Reservoirs	
	Deltaic	Shelf Clastic	Shelf Carbonate	Strandplain	Reef	Fluvial Deltaic	Eolian	Fluvial & Alluvial	Turbidite	Coal	Basalt (LIP)
Large Scale Field Tests	–	1	–	–	1	3	–	1	–	–	–
Small Scale Field Tests	3	2	4	1	2	–	–	2	–	5	1
Site Characterization	1	–	8	6	–	3	3	2	2	–	1

Notes:
The number in the cell is the number of investigations per depositional environment.
Large Scale Field Tests – Injection of over 1,000,000 tons of CO_2
Small Scale Field Tests – Injection of less than 500,000 tons of CO_2
Site Characterization – Characterize the subsurface at a location with the potential to inject at least 30,000,000 tons of CO_2
Reservoir potentials were inferred from petroleum industry data and field data from the sequestration program.

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

- This comprehensive handbook provides an update on DOE/NETL R&D efforts on advanced CO_2 capture technologies for coal-based power systems.
- Prepared by the Existing Plants and Sequestration R&D Programs, the report tracks the progress of DOE/NETL pre-combustion, post-combustion, and oxy-combustion technologies for CO_2 capture.
- The handbook is available for download on the NETL website at these two locations:



http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

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

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

- Chapter 1: Introduction stressing the importance of developing cost-effective advanced CO_2 capture technologies.
- Chapter 2: Description of DOE/NETL's CO_2 capture R&D program.
- Chapter 3: Overview of the three basic configurations for CO_2 capture − pre-combustion, post-combustion, and oxy-combustion.
- Chapter 4: Provides some of the basic scientific principles and important operating parameters for the various CO_2 capture technologies.
- Chapters 5 through 10 report on the status of DOE/NETL's R&D efforts for pre-combustion capture; post-combustion capture; oxy-combustion; oxygen production; chemical looping; and advanced compression, respectively.
- Chapter 11: Review of DOE/NETL's CO_2 capture R&D collaborations.
- Appendix: Provides detailed information on the status and results of the current portfolio of DOE/NETL's CO_2 capture R&D projects.

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DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

Project Title:
CO_2 Capture from IGCC Gas Streams Using AC-ABC Process

Technology Area:	Technology Maturity:
Pre-Combustion Solvents	Pilot-scale using actual syngas

Primary Project Goal:

SRI International is developing, for integrated gasification combined cycle (IGCC)-based power plants, a carbon dioxide (CO_2) capture technology based on the use of a high-capacity and low-cost aqueous ammoniated solution containing ammonium carbonate (AC), which reacts with CO_2 to form ammonium bicarbonate (ABC).

Technical Goals:

- Test the technology on a bench-scale batch reactor to validate the concept.
- Determine the optimum operating conditions for a small pilot-scale reactor.
- Design and build a small pilot-scale reactor capable of continuous integrated operation.
- Perform pilot-scale tests to evaluate the process in a coal gasifier environment.
- Perform a technical and economic evaluation on the technology.

Technical Content:

The technology is based on the use of an aqueous ammoniated solution containing AC, which reacts with CO_2 to form ABC.

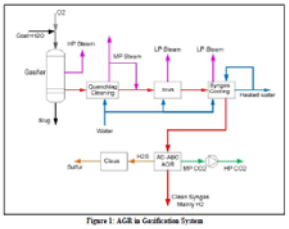

Figure 1: AGR in Gasification System

The concentrated ammoniated solution is used to capture CO_2 and hydrogen sulfide (H_2S) from synthesis gas (syngas) at high pressure. This technique reduces the size of the CO_2 stripper and operates at high pressure, reducing CO_2 compression needs. Both reduce electric power consumption. AC has high net

A technical and economic analysis will use Aspen modeling to generate the equipment sizing and heat and material flows, DOE cost models, and a base case, 750-MW nominal IGCC plant without CO_2 capture to compare the AC-ABC process with a similar-size plant using CO_2 capture with a Selexol subsystem.

Table 1: Solvent Parameters

	Parameter	Current R&D Value	Target R&D Value
Solvent Properties	Type of solvent	Aqueous ammoniated solution	Aqueous ammoniated solution
	Molecular weight	Nominal 18	Nominal 18
	Boiling point (°C)	Varies with pressure, 100°C at 1 atm	Varies with pressure, 100°C at 1 atm
	Heat of reaction (kJ/mole CO_2)	82 to 85 (depending on the NH_3/CO_2 ratio	≈82 to 85
	CO_2 loading/working capacity*, wt.%	10	20
	Solvent concentration, to stripper (mol/liter)	8 M NH$_3$	8 M NH$_3$
	Heat capacity of solution (kJ/K/kg)	3.5	3.5
	Viscosity, cP	1	1
Operating Conditions	Absorption temperature, °C	25	25 to 40
	Absorption pressure, atm	20	50
	CO_2 capture efficiency, %	>90	>90
	Regeneration method	Heating with steam	Heating with steam
	Regeneration temperature, °C	N/A	150
	Regeneration pressure, atm	N/A	50
Heat Integration	Required regeneration steam temperature, °C	120	170
Miscellaneous	Solvent make-up rate, kg/kgCO_2	N/A	N/A
Product Quality	CO_2 purity, %	>99%	98.1
	N_2 concentration, %	N/A	1.9
	Other contaminants, %	N/A	0.01
Process Performance	Electricity requirement, kWh/kgCO_2	N/A	195
	Heat requirement, kWh/kgCO_2	N/A	650.6
	Total energy (electricity equivalent), kWh/kgCO_2	N/A	681.3

*Working capacity is the loading difference CO_2 rich solution before and after it is regenerated.

Equations Describing Chemical Reaction:

$NH_4OH+CO_2 \rightarrow NH_4HCO_3$

$(NH_4)_2CO_3+CO_2+H_2O \rightarrow 2NH_4HCO_3$

$NH_4NH_2CO_2+CO_2+2H_2O \rightarrow 2NH_4HCO_3$

$NH_4HCO_3 \rightarrow NH_4HCO_3$ (precipitate)

Solvent Reaction Kinetics:

The absorption of CO_2 by the ammoniated solution is proportional (1st order) to the CO_2 partial pressure. Preliminary experiments confirm this behavior. The kinetics of CO_2 absorption is expected to be rapid at the elevated pressures and high CO_2 concentrations expected in the IGCC gas stream downstream of the water gas shift (WGS) reactors.

Solvent Heating/Cooling Method:

During regeneration, the liquid is heated by steam using a reboiler. In the absorber, the liquid is cooled using a heat exchanger and a coolant from a direct contact cooler.

Solvent Contaminant Resistance:

The solvent is expected to be resistant to several contaminants nominally present in an IGCC gas stream. Hydrogen sulfide reacts with the solvent, but it can be removed during the regeneration. The ammonia

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FY 2011 Programmatic Documents

- **Carbon Sequestration Atlas of the United States and Canada**
- **DOE CCS Roadmap**
- **Carbon Sequestration R&D Program Plan**
- ***Carbon Sequestration Project Portfolio updates***
  - *50+ new projects*

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

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For More Information About the NETL Sequestration Program

- **NETL website:**
  - **www.netl.doe.gov**

Reference Shelf

- **Annual Regional Carbon Sequestration Partnerships Meetings**

- **Office of Fossil Energy website:**
  - **www.fe.doe.gov**

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