Summary of Current Regional Carbon Sequestration Partnership Activities, USA

December 9, 2010
CCS Technical Workshop
Kyoto, Japan

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Gulf Coast Carbon Center
Bureau of Economic Geology
The University of Texas at Austin
Outline

• Department of Energy & National Energy Technology Laboratory – Regional Carbon Sequestration Partnership Program (RCSP)
• Integrated Systems – Source to Sink
• Role of Enhanced Oil Recovery
• Pressure
• Onshore vs. Offshore
Carbon Sequestration Program Goals

*Develop Technology Options That...*

- Deliver technologies & best practices that provide Carbon Capture and Storage (CCS) 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
Regional Carbon Sequestration Partnerships

Innovation for Characterization to Large Scale Injection

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 CO₂ sources

Found potential for 100’s of years of storage

Validation Phase (2005-2011)

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


9 large scale injections

Commercial scale understanding

Regulatory, liability, ownership issues
RCSP Phase II: Validation Phase
Small-Scale Geologic and Terrestrial Tests

<table>
<thead>
<tr>
<th>Injection Reservoirs (Total)</th>
<th>RCSPS</th>
<th>Deposition Environments Tested</th>
<th>Range CO₂ (metric tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline Formations (7)^</td>
<td>MGSC^ MRCSP SECARB WESTCARB</td>
<td>Shallow Shelf-Restricted Strandplain Braided Fluvial Near Shore Marine Delta Marine</td>
<td>0-60,000</td>
</tr>
<tr>
<td>Enhanced Oil Recovery-EOR (8)</td>
<td>MGSC PCOR SECARB SWP</td>
<td>Fluvial Marine Shelf Pinnacles Reef Shallow Shelf Open</td>
<td>50-630,000</td>
</tr>
<tr>
<td>Coalbed Methane-ECBM (5)</td>
<td>MGSC PCOR SECARB SWP</td>
<td>Coal</td>
<td>90-16,700</td>
</tr>
<tr>
<td>Basalt (1)</td>
<td>Big Sky</td>
<td>Basalt</td>
<td>1,000</td>
</tr>
</tbody>
</table>

* Includes Phase II Saline Test that evolved into Phase III Test
RCSP Phase III: Development Phase

Large-Scale Geologic Tests

✓ Nine large-volume tests
✓ Injections scheduled 2011/2015

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

Note: Some locations presented on map may differ from final injection location.
# CCS Best Practice Manuals

Critical Requirement For Significant Wide Scale Deployment

*Capturing Lessons Learned*

<table>
<thead>
<tr>
<th>Best Practice Manual</th>
<th>Version 1 (Phase II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring Verification and Accounting</td>
<td>2009</td>
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<td>Site Characterization</td>
<td>2010</td>
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<tr>
<td>Simulation and Risk Assessment</td>
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<tr>
<td>Well Construction and Closure</td>
<td>2010</td>
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<tr>
<td>Regulatory Compliance</td>
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<td>Public Education</td>
<td>2009</td>
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<tr>
<td>Terrestrial Sequestration Practices</td>
<td>2010</td>
</tr>
</tbody>
</table>
AEP @ Mountaineer, WV

American Electric Power
Post-combustion capture: chilled ammonia
Operational 2015
1.5 Mt/yr capture and storage
Illinois Basin-Decatur Test Site

Archer Daniels Midland (ADM)
Corn ethanol plant

- A Dehydration/compression facility location
- B Pipeline route
- C Injection well site
- D Verification well site
- E Geophone well

Quickbird Satellite Image: 9/16/2008
Southern Company, MS

CO₂ Capture Unit at Alabama Power’s Plant Barry

MHI advanced amine capture unit
• 25 MW post combustion slip stream
• Compress CO₂ to 2000 psi

12-mile CO2 pipeline constructed by Denbury Resources

CO₂ Injection at Denbury’s Citronelle Field 2011-2013

SECARB researchers will monitor injection and 3-years post injection
CO₂ use for Enhanced Oil Recovery (EOR) is Sequestration
West Texas EOR

~150 million metric tons CO₂ injected for EOR since 1972 by various oil companies

~75 million metric tons CO₂ recovered through 2010

SWP + BEG researchers have documented no impact to overlying potable groundwater.
The Role of EOR: Stacked Storage Concept

Near-term and long-term sources and sinks linked in a regional pipeline network

Enhanced oil and gas production to offset development cost and speed implementation

Very large volume storage in stacked brine formations beneath reservoir footprints
Cranfield, MS: SECARB Phase 3
Example of stacked storage concept

- Mississippi River
- Natchez, Mississippi

- 3,000 m depth
- Gas cap, oil ring, downdip water leg
- Shut in since 1965
- Strong water drive
- Returned to near initial pressure
Closely spaced injectors and observation wells in brine reservoir @ 3 km depth
High frequency fluid sampling via U-tube yields data on flow processes

Small diameter sampler with N₂ drive brings fluids quickly to surface with tracers intact
CO₂ dissolution into brine liberates dissolved CH₄

Breakthrough of CO₂
Additional flow paths – more methane extracted
Double injection rate

Originally brine methane saturated
No samples

CH₄, CO₂

BEG, LBNL, USGS, ORNL, UTDoG,
data compiled by Changbing Yang BEG
Cross Well Electrical Resistance Tomography: Flow dynamics at inter-well scale over months

Resistive plume = CO$_2$ in reservoir
Conductive plume = workover fluids?

Observation well F2 electrodes
Observation well F3 electrodes

Second Resistive plume out of section migration

50ft

Operation

-50.0
-25.0
0.000
25.0
50.0
Problem: Many wells-

- How Good is Cement?

Surface casing to protect USDWs

Remaining open annulus between rock and casing = Potential leakage path for CO₂ or displaced brine?

Add CO₂ for Tertiary production of hydrocarbon resource

Original development 1940’s-60’s

Pressure as Monitoring Tool: Cranfield, MS

Dedicated observation well

Injection wells
Surface & downhole data collected every minute and uploaded every 10 minutes to website.
Continuous 2-year data series

Maximum sustained pressure differential >1,200 psi
Suggests old wells have reasonable integrity.

Some aspects of data difficult to interpret, but likely relate to complicated well completion.
Pressure & Boundary Conditions
Influence Capacity

OPEN

CLOSED
Ron Surdam, Wyoming, USA

Injected CO₂ will raise pressure and displace large volumes of brine – where will it go?

Extraction wells may be viable, but costs of re-injecting brine may be high.

Potential to desalinate brine for economic use of water is being considered.

A CARBON CAPTURE AND STORAGE NETWORK FOR YORKSHIRE AND HUMBER

An introduction to understanding the transportation of CO₂ from Yorkshire and Humber emitters into offshore storage sites.
AUSTRALIA 2009 RELEASE OF OFFSHORE AREAS FOR GREENHOUSE GAS STORAGE ASSESSMENT
USA Offshore CCS Activities

Offshore Texas, Gulf of Mexico
T. Meckel & R. Trevino, TX BEG

~6,400 square miles
Extends 10.3 miles offshore
40% bays, estuaries, and passes
60% seaward of barrier islands
<20% currently leased

Significant offshore potential in northern Gulf of Mexico

NETL 2010 Atlas of Capacity

SCS Energy LLC

The proposed storage wells will be 70 miles from the New Jersey coast. The carbon dioxide will be pumped 1.5 miles under the sea floor.

Wilmington Graben, offshore LA
Mike Bruno, Terralog Tech.
Offshore Monitoring: RITE

Michimasa Magi: IEA Natural Releases Meeting, Maria Laach, Germany, Nov. 2010

2. Ocean Sequestration Project  2. Natural Analogue Study

Observation of Natural CO₂ Analogue Site

Dissolution Process of CO₂ Droplets

Hatoma Knoll & Yonaguni Knoll in Okinawa Trough (FY2002)
CO₂ Leakage & CO₂ Droplets & Gas Analysis
ROV Hyper Dolphin by JAMSTEC

Hatoma Knoll in Okinawa Trough (FY2004-2005)
CO₂ Leakage & CO₂ Droplets & pH distribution
ROV Hakuyo 2000

Wakamiko Caldera in Kagoshima Bay FY2007
CO₂ Leakage & pH distribution
R/V Hakuyo

(WAKOSHIMA Bay)

Behavior of Dissolved CO₂

NW Elhuku SM in Mariana Arc FY2006
pH Distribution by CREPI

(MARIANA ARC)

CO₂ Leakage Process

Wakamiko Caldera in Kagoshima Bay FY2008-2009
Sub-bottom Profiler & Side Scan Sooner

Wakamiko Caldera in Kagoshima Bay FY2007
pH Distribution
AUV REMUS by CRIEPI

Wakamiko Caldera in Kagoshima Bay and Other Site FY2010 - ?
Short multi-channel Profiler

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CO₂ is common in many geological settings.

Understanding the historic ability of basins to naturally buffer CO₂ will greatly reduce uncertainties about long-term fate of injected CO₂.
Global CO₂ Map

Each country is sized proportional to its annual CO2 emissions.

Thank you to Japanese hosts, especially Ziqiu Xue.
I look forward to working on this important international issue with Japanese researchers.