Carbon Sequestration: Siting Opportunities In Western States

Workshop on Gasification Technologies

March 14, 2007

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Premise: Rising CO₂ and Temperatures

Six warmest years of global record all after 1990.
One Approach: CO₂ Sequestration

From the November 1st, 2002 issue of Science: Hoffert et al., “Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet”

<table>
<thead>
<tr>
<th>Fossil fuel</th>
<th>Energy content [TW-yr]</th>
<th>Carbon content [GTC]</th>
<th>(E&lt;sub&gt;fuel&lt;/sub&gt;/C) [TW-yr/GtC]</th>
<th>(E/C) [TW-yr/GtC]</th>
<th>Sequestration rate [GtC/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>1200</td>
<td>570</td>
<td>2.1</td>
<td>1.9 - 1.6</td>
<td>5 - 6</td>
</tr>
<tr>
<td>Oil</td>
<td>1200</td>
<td>750</td>
<td>1.6</td>
<td>1.4 - 1.2</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Coal</td>
<td>4800</td>
<td>3690</td>
<td>1.3</td>
<td>1.2 - 1.0</td>
<td>9 - 10</td>
</tr>
</tbody>
</table>
Ongoing Tests: DOE’s Regional Partnerships

Field Test Type
- Oil bearing
- Gas bearing
- Saline aquifer
- Coal seam
- Terrestrial

Partnerships
- MRCSP
- MGSC
- SECARB
- SWRP
- WESTCARB
- BigSky
- PCOR
The Southwest Carbon Sequestration Partnership

In all partner states:
• major universities
• geologic survey
• other state agencies

as well as
• Western Governors Association
• five major utilities
• seven energy companies
• three federal agencies
• the Navajo Nation
• many other critical partners
Southwest CO$_2$ Sources

- electrical power plants
- cement & other plants
- urban centers
- non-point sources

Total regional point source emissions
~10$^8$ t/yr.
Key Aspect for Site Selection:
Identify Best Sink for the Source

For example, in the Southwest project, our first tasks were:
• Characterized region’s sources and sinks
• Identified best options by tying sources to sinks
• Outcome: In Southwest, “first opportunities” lie along existing CO₂ pipelines
Site Selection Concept: “String of Pearls”

Ongoing pilot demonstrations will test short-term strategy: *sequester along pipelines*
Sites Selected for Testing

Four of over 100 geologic options were selected as the most promising opportunities for evaluation:

1) combined enhanced oil recovery with sequestration and

2) Deep brine reservoir sequestration testing, Paradox Basin, Utah

June, 2007
150,000 tons/year
Four of over 100 geologic options were selected as the most promising opportunities for evaluation:

(3) combined enhanced coalbed methane production and sequestration testing, San Juan Basin, NM

September, 2007
75,000 tons/year
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(4) combined enhanced oil recovery and sequestration testing, Permian Basin, TX

Renewed focus: Monitoring of CO₂ operations at SACROC

March, 2008
300,000 tons/year
What is a good approach for selecting a site for commercial-scale geologic sequestration?
Sequestration Site Selection Depends on some important practical issues:

- site ownership
- details of liability for site
- details of regulatory requirements associated with site
- capability for long-term monitoring at the site
Sequestration Site Selection Depends on some critical technical issues:

• proximity to high-capacity reservoirs
• proximity to existing pipelines
• proximity to transmission lines or railroads
• elevation (IGCC)
• low-risk geology, e.g., deep, thick seals, no faults, etc.
Probably the first and most important criterion is:

• proximity to high-capacity storage reservoirs
Minimum Coalbed Capacities:
Arizona 24,000 tons
Colorado 500 Mtons
Kansas 2.1 Mtons
New Mexico 75 Mtons
Oklahoma 1.8 Mtons
Utah 30 Mtons
Wyoming 194 Mtons
Total Oil/Gas Field Capacities:
Arizona 7 Mtons
Colorado 1.7 Gtons
Kansas 377 Mtons
New Mexico 8 Gtons
Oklahoma 10 Gtons
Utah 1.4 Gtons
Maximum Deep Saline Field Capacities:
Arizona 92 Mtons
Colorado 3.8 Gtons
Kansas 10.6 Gtons
New Mexico 10 Gtons
Oklahoma 9 Mtons
Texas 48 Gtons
Utah 508 Mtons
Wyoming 507 Mtons
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One site on the short list for deployment of a major-scale demonstration of geologic sequestration (1 million ton per year injection):

Uinta Basin, Utah
Data Needs: Map of Area

Oil/Gas + Observed Overpressure Suggest Good Seals
Data Needs: Strat and Cross-Section

UDR = Uinta and Duchesne River Formations
UM = Upper Marker of Green River Formation
MM = Middle Marker of Green River Formation
TCM = Carbonate Marker of Green River Fm.
FS = Flagstaff Member, Green River Formation
NH = North Horn Formation (Cretaceous)
Data Needs: Pressure Data

Questions:

(1) Will significant overpressure be induced by injection?

(2) Can the overpressure be controlled?

(3) If overpressure is propagated far distances, will significant strain (or fault activation) be possible at those distances?

Observed Overpressure:

- Altamont
- Red Wash
- Sunnyside
Data Needs: Experimental Benchscale Rock Hydrologic and Mechanical Data
Quick Summary of Mechanical Results
Mean Tensile Strength: 10.6 MPa
Mean Comp. Strength: 132 MPa
Mean Young’s Modulus: 45,000 GPa
Mean Poisson’s Ratio: 0.19
Mean Bulk Modulus: 77,000 GPa
Data Needs: Permeability and Porosity

Trend for single fracture

Initial Trend

- Samples with insignificant clay
- Samples with clay content > 5%
- Data of Pitman et al., 1982
# Data Needs: Elastic Parameters

<table>
<thead>
<tr>
<th></th>
<th>All Samples</th>
<th>UB Samples</th>
<th>North of DFZ</th>
<th>In DFZ</th>
<th>South of DFZ</th>
<th>Amoco Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young’s Modulus (GPa)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>43</td>
<td>14</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.7 x10^4</td>
<td>2.8 x10^4</td>
<td>3.2 x10^4</td>
<td>2.8 x10^4</td>
<td>3.6 x10^4</td>
<td>1.7 x10^4</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.9 x10^4</td>
<td>6.1 x10^4</td>
<td>5.4 x10^4</td>
<td>6.1 x10^4</td>
<td>3.6 x10^4</td>
<td>6.9 x10^4</td>
</tr>
<tr>
<td>Mean</td>
<td>4.5 x10^4</td>
<td>4.7 x10^4</td>
<td>4.5 x10^4</td>
<td>4.9 x10^4</td>
<td>4.1 x10^4</td>
<td>4.5 x10^4</td>
</tr>
<tr>
<td>Median</td>
<td>4.7 x10^4</td>
<td>4.9 x10^4</td>
<td>5.0 x10^4</td>
<td>5.1 x10^4</td>
<td>4.1 x10^4</td>
<td>4.5 x10^4</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.4 x10^4</td>
<td>1.0 x10^4</td>
<td>1.2 x10^4</td>
<td>1.1 x10^4</td>
<td>8.1 x10^3</td>
<td>1.5 x10^4</td>
</tr>
</tbody>
</table>

| **Poisson’s Ratio (no units)** |             |            |              |        |              |               |
| N                   | 17          | 14         | 3            | 9      | 2            | 3             |
| Minimum             | 0.10        | 0.14       | 0.14         | 0.14   | 0.21         | 0.10          |
| Maximum             | 0.26        | 0.26       | 0.24         | 0.26   | 0.26         | 0.17          |
| Mean                | 0.19        | 0.20       | 0.18         | 0.20   | 0.23         | 0.13          |
| Median              | 0.19        | 0.20       | 0.15         | 0.19   | 0.23         | 0.12          |
| Standard Deviation  | 0.05        | 0.04       | 0.05         | 0.04   | 0.04         | 0.04          |

| **Bulk Modulus (GPa)** |             |            |              |        |              |               |
| N                   | 17          | 14         | 3            | 9      | 2            | 3             |
| Minimum             | 4.0 x10^4   | 4.0 x10^4  | 4.0 x10^4    | 4.2 x10^4 | 7.3 x10^4   | 5.1 x10^4     |
| Maximum             | 1.3 x10^5   | 1.3 x10^5  | 9.5 x10^4    | 1.3 x10^5 | 7.9 x10^4   | 8.9 x10^4     |
| Mean                | 7.7 x10^4   | 7.9 x10^4  | 6.8 x10^4    | 8.4 x10^4 | 7.6 x10^4   | 6.5 x10^4     |
| Median              | 7.3 x10^4   | 7.3 x10^4  | 6.8 x10^4    | 7.3 x10^4 | 7.6 x10^4   | 5.5 x10^4     |
| Standard Deviation  | 2.3 x10^4   | 2.4 x10^4  | 2.7 x10^4    | 2.5 x10^4 | 4.6 x10^3   | 2.1 x10^4     |

**Mean Values**

- **Young’s Modulus**: 45,000 GPa
- **Poisson’s Ratio**: 0.19
- **Bulk Modulus**: 77,000 GPa
Data Needs: Compressive Strength

- **Method:** Uniaxial compression

- **“Typical” Values:**
  - 60-270 MPa

- **Average:** 132 MPa
  - Amoco: 124 MPa
  - UB: 149 MPa
    - NORTH: 136 MPa
    - in DFZ: 160 MPa
    - SOUTH: 120 MPa
Data Needs: Tensile Strength

- **Method:**
  - Brazil Tests

- **“Typical” Values:**
  - 4-14 MPa

- **Average:**
  - 10.6 MPa (UB only)
    - NORTH: 11.9 MPa
    - in DFZ: 10.3 MPa
    - SOUTH: 8.8 MPa

- **TRENDS?**
• 40 CO₂ injection wells penetrating Green River Fm below Mahogany Shale
• no production wells
• dissolved phase shown here (follows separate phase, for most part)
• overpressures develop in lower permeability marginal lacustrine facies
• overpressures terminate at higher permeability open lacustrine facies
• CO₂ migrates more freely in higher permeability open lacustrine facies
Migration Distance and Rate are Controlled by: Absolute & Relative Permeability, Capillarity

Results specific to this Uinta Basin Simulation (e.g., its structural geometry, topographically driven flow, etc.)
Outcome of this example site-selection study:

- The Uinta basin holds many potential sites for large-scale injection and storage
- Many reservoirs in the basin have high capacity for CO2, as well as low-risk, thick top-seals
- Reservoir characterization and modeling suggests that these reservoirs are robust for sequestration
- The basin has many coal resources
- The basin has nearby pipelines for taking CO2 to market (if appropriate)
- The basin has many transmission lines (rights-of-way issue)
General Summary

Sequestration site selection depends on both practical and technical issues, including:

• site ownership
• details of liability for site
• regulatory requirements associated with site
• capability for long-term monitoring at the site
• proximity to high-capacity storage reservoirs
• proximity to existing pipelines
• proximity to transmission lines or railroads (e.g., for right-of-way)
• low-risk geology, e.g., deep, thick seals, no faults, etc.