Geological Sequestration of CO₂
A Brief Overview and Potential for Application for Oklahoma

Presented to Oklahoma Clean Lakes and Watersheds Association
Quartz Mountain Resort
April 1, 2009

Dominic DiGiulio, Ph.D.

Office of Research and Development
National Risk Management Research Laboratory,
Ground Water and Ecosystem Restoration Division, Ada, OK
Outline of Presentation

• Brief Overview of Geological Sequestration
• Potential for CO2-EOR in Oklahoma
• Research at R.S. Kerr Research Center, Ada, OK

Disclaimer:

This presentation does not necessarily reflect EPA policy.
Carbon Capture and Storage (CCS) and Geological Sequestration (GS)

From DOE, 2008
Stationary Sources of CO$_2$
CCS as Part of the Big Picture

- Coal: 800 gigawatt-sized plants with all the carbon captured and permanently sequestered
- Nuclear: 700 new gigawatt-sized plants (plus replacement plants)
- Concentrated solar thermal electric: 1,600 gigawatts peak power
- Solar photovoltaics: 3,000 gigawatts peak power
- Efficient buildings: savings totalling 5 million gigawatt-hours
- Efficient industry: savings totalling 5 million gigawatt-hours, including co-generation and heat recovery
- Wind power: 1 million large wind turbines (2 megawatts peak power)
- Vehicle efficiency: all cars 60 miles per US gallon
- Wind for vehicles: 2,000 gigawatts wind, with most cars plug-in hybrid electric vehicles or pure electric vehicles
- Cellulosic biofuels: using up to one-sixth of the world’s cropland
- Forestry: end all tropical deforestation

From Romm, 2008
Trapping Mechanisms
The buoyancy of supercritical CO₂ necessitates that the injection zone must be overlain by a primary confining system of sufficient regional thickness and lateral extent to contain the entire CO₂ plume and associated pressure front. This will initially be the primary mechanism of containment.

In stratigraphic trapping (left), CO₂ is trapped by an overlying layer of cap rock coupled with impermeable rock within a narrowing of the storage formation.

In structural trapping, CO₂ is trapped by a fold in the rock formations (middle) or by impermeable rock layers shifted along a sealing fault (right) to contain the CO₂.
Capillary Trapping

From Bryant, 2005
Dissolution/Ionic Trapping

\[ CO_2 (g) + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{2-} + 2H^+ \]
Dissolution of silicates releases carbonate forming cations (Na, Al, Fe, Mg, Ca) in formation and cap rock.
Primary Mechanisms of CO₂ Storage (not including adsorption to coal and shale)

From IPCC Special Report on Carbon dioxide Capture and Storage
Improved Design = Less Liability

From Benson, 2008
Storage Formations
Deep Saline Aquifers

Figure DOE, 2007
“Unmineable Coal Seams

Figure from DOE, 2007
Enhanced Coal Bed Methane (ECBM) Recovery

- Value added incentive.
- Access to “unmineable” coal deposits.
- Potential 1.5% storage capacity in U.S.

- Swelling - reduction of permeability.
- Brine disposal.
- Close to or part of USDWs
- Many coal seams too shallow for storage as supercritical fluid.
Potential Storage in Basalt

The release of Ca$^{2+}$ and Mg$^{2+}$ ions from silicate minerals in basalt could result in rapid precipitation of carbonate minerals.

From Goldberg et al. 2008

From DOE, 2007
Most of the storage capacity in Oklahoma associated with oil and gas reservoirs.

Figures and table from DOE, 2007
**Enhanced Oil Recovery (EOR)**

During miscible displacement, CO₂ lowers the viscosity and interfacial tension of oil. Deep “light” oil.

**Figures from Basin Oriented Strategies for CO₂ Enhanced Oil Recovery: Oklahoma, DOE, NETL, March 2005**
CO$_2$-EOR
Benefits of CO₂-EOR

- **Value Added Incentive.** Revenue for petroleum corporations from additional production of petroleum and carbon credits. Revenue for corporations or utilities selling CO₂ to meet cap and trade requirements.
- **Tax Revenue.** Substantial increase in tax revenue for States.
- **Trade Imbalance.** Reduce trade imbalance for imported petroleum with decreased reliance on countries hostile to U.S.
- **Infrastructure.** Some existing infrastructure already present. Widespread application will create additional infrastructure such as pipelines for eventual injection into saline aquifers.
- **Mineral Rights.** Mineral rights at petroleum reservoirs are already established.
- **Site Characterization.** Unlike saline aquifers, petroleum reservoirs are already well characterized.
- **Carbon Neutrality.** CO₂-EOR is 70% carbon neutral. Improve design to achieve 100% carbon neutrality (Corn-based ethanol only 10-15% carbon neutral and a net contributor to CO₂ emissions when coal used as a process fuel).

Taken from: Storing CO2 with Enhanced Oil Recovery, DOE/NELT-402/1312/02-07-08
Nationwide CO2-EOR application would add about 85 billion barrels of incremental domestic oil supply ~ (4X current proved reserves).

Figure from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08
As of 2006, there were 86 CO2-EOR project in the U.S.

Figure from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08
Conceptual Pipeline System Connecting Fossil-Fuel Based CO₂ Sources with Major Petroleum Reservoirs

CO₂ could be provided by H₂ plants in Ponca City (11 MMcfd), Ardmore (26 MMcfd), and Wynnewood (9 MMcfd).

Figure from Basin Oriented Strategies for CO₂ Enhanced Oil Recovery: Oklahoma, DOE, March 2005
History of Oklahoma Crude Oil Production, 1950-2002

Figure from Basin Oriented Strategies for CO₂ Enhanced Oil Recovery: Oklahoma, March 2005
Technical recovery at 63 large reservoirs (60.5% of state) is about 5.4 billion barrels.

Technical recovery in entire state is about 9 billion barrels from 45 billion barrels remaining. OOIP was 60 billion barrels.

Figure from Basin Oriented Strategies for CO2 Enhanced Oil Recovery: Oklahoma, March 2005
Federal Rule-Making

120 day comment period

Environmental Protection Agency

40 CFR Parts 144 and 146
Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO₂) Geologic Sequestration (GS) Wells; Proposed Rule
DOE Research
Phase II Field Validation
25 Geologic Tests

- Injections 750-525,000 Tons CO₂
- Validating geologic formation capacities and injectivity
- Testing formation seals

- MMV technologies
- Permitting requirements
- Public outreach

Partnerships
MROSP
MCOG
SECARMS
SRP
WESTCARMS
Big Sky
POOR

Formation Type
Oil bearing
Gas bearing
Salt formation
Coal seam

2003 2005 2007 2009 2011 2013 2015 2017

Characterization Phase - $15M
Characterize regions for carbon capture and storage opportunities

Validation Phase - $112M
Validate technologies through field testing in geologic and terrestrial sinks

Deployment Phase – up to $470M
Large volume deployment tests of sequestration technologies
Summary of Potential Monitoring Tools

From CO2STORE, 2007

<table>
<thead>
<tr>
<th>Seismic Imaging</th>
<th>Onshore only</th>
<th>Offshore only</th>
<th>Onshore &amp; Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D/4D surface seismic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time lapse 2D surface seismic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multicomponent seismic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acoustic imaging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boomer / Sparker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High resolution acoustic imaging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microseismic monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well based</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4D cross-hole seismic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4D VSP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sonar Bathymetry         |              |               |                    |
| Sidescan sonar           |              |               |                    |
| Multi beam echo sounding |              |               |                    |

| Gravimetry               |              |               |                    |
| Time lapse surface gravimetry |         |               |                    |
| Time lapse well gravimetry|              |               |                    |

| Electric / Electromagnetic |              |               |                    |
| Surface EM                 |              |               |                    |
| Seabottom EM               |              |               |                    |
| Cross-hole EM              |              |               |                    |
| Permanent borehole EM      |              |               |                    |
| Cross-hole ERT             |              |               |                    |
| ESP                        |              |               |                    |

| Geochemical Fluids        |              |               |                    |
| Downhole fluid chemistry  |              |               |                    |
| PH measurements           |              |               |                    |
| Tracers                   |              |               |                    |
| Marine                    |              |               |                    |
| Seawater chemistry        |              |               |                    |
| Bubble stream chemistry   |              |               |                    |

| Gasses Atmosphere         |              |               |                    |
| Short closed path (NDIRs & IR) |        |               |                    |
| Short open path (IR diode lasers) |    |               |                    |
| Long open path (IR diode lasers) |        |               |                    |
| Eddy covariance           |              |               |                    |

| Soil gas                  |              |               |                    |
| Gas flux                  |              |               |                    |
| Gas concentrations        |              |               |                    |

| Ecosystems                |              |               |                    |
| Ecosystems studies        |              |               |                    |

| Remote sensing            |              |               |                    |
| Airborne hyperspectral imaging |        |               |                    |
| Satellite interferometry   |              |               |                    |
| Airborne EM               |              |               |                    |

| Others                    |              |               |                    |
| Geophysical logs          |              |               |                    |
| Pressure / temperature    |              |               |                    |
| Tiltmeters                |              |               |                    |
Research at R.S. Kerr Research Center
Potential Leakage Pathways and Consequences

From Benson and Hepple (2005)
Use soil-gas, gas flux, and ground-water monitoring of C1-C4 hydrocarbons, CO₂, δ13C, Δ14C, H₂, He, H₂S, ²²²Rn, major ions, pH, and inorganics to evaluate the presence of existing migration pathways.
Evaluate Impacts to USDWs due to Carbon Dioxide Release from Geologic Sequestration Projects: Modeling and Experimental Studies (NRMRL-Ada)

- Conduct column and batch-scale studies from formation (USDW) samples collected from test sites.
- Examine and simulate element partitioning and associated kinetics between the solid and aqueous phase over a range of CO$_2$ partial pressures.
- Where appropriate, modify geochemical databases with the most current thermochemical data.
- Use results to prepare sampling strategies for a controlled CO$_2$ injection field study.
Use semi-analytical solutions to create a user-friendly, open-source software package to allow a rapid, inexpensive, first-order determination of the Area of Review

- Solutions will complement not replace need for numerical analysis.
- Can be used for designing monitoring strategies (e.g., pressure perturbation in overlying permeable formation).
- Computationally more efficient for evaluating leakage through abandoned wells

Figure from Birkholzer et al., 2008
Questions?

“How on earth do we turn it off?”