Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small-Scale CO2 Injection Test

Project Number: DE-FE0006827

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO2 Storage
August 21-23, 2012
Presentation Outline

- Project Objectives and Background
- Shale CO$_2$ Injection Test in Morgan County, Tennessee
- Coalbed Methane CO$_2$ Injection Test in Buchanan County, Virginia
- Conclusions
Project Overview: Goals and Objectives

✿ Objectives:
  - Inject up to 20,000 metric tons of CO2 into 3 vertical CBM wells over a one-year period in Central Appalachia
  - Perform a small (approximately 400-500 metric tons) Huff and Puff test in a horizontal shale gas well

✿ Goals
  - Test the storage potential of unmineable coal seams and shale reservoirs
  - Learn about adsorption and swelling behaviors (methane vs. CO2)
  - Test the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery

✿ Major tasks:
  - Phase I: site characterization, well coring, injection design
  - Phase II: site preparation, injection operations
  - Phase III: post-injection monitoring, data analysis, reservoir modeling
Research Partners

- Virginia Center for Coal and Energy Research (Virginia Tech) 1,2,3,4,5
- Cardno 2,3
- Gerald Hill, Ph.D. 1,4
- Southern States Energy Board 1,5
- Virginia Dept. of Mines, Minerals and Energy 3
- Geological Survey of Alabama 3
- Sandia Technologies 3
- Det Norske Veritas (DNV) 4
- Consol Energy (Research Group) 2,3

Industrial Partners

- Consol Energy (CNX Gas)
- Harrison-Wyatt, LLC
- Emory River, LLC
- Dominion Energy
- Alpha Natural Resources
- Flo-CO2

Collaborators

- Schlumberger
- Global Geophysical Services
- Oak Ridge National Laboratory
- University of Tennessee
- University of Virginia
- Southern Illinois University
- Oklahoma State University
## Project Schedule

### Phase I
**(10/1/11 – 3/31/13)**
- **Characterization**
  - Drill char. Well
  - Core sample analysis
  - Modeling
  - Baselines for monitoring
- **Injection design**
- **Monitoring design**
  - Well locations
  - Geophysical surveys
- **Go/no go 1:** permits, access (12 months)
- **Go/no go 2:** characterization (18 months)

### Phase II
***(4/1/13 – 9/30/15)***
- **Site preparation**
  - Conversion of production wells
  - Drill monitor wells
  - Install additional monitor stations
- **CO₂ injection period**
  - (3/18/14 - 3/31/14) - Shale
  - (7/02/15 - 6/30/16) - CBM
- **Monitoring**
  - Atmosphere
  - Surface
  - Reservoir

### Phase III
**12 months (TBD)**
- **Site closure**
  - Conversion of injection and monitor wells
  - Site restoration
- **Post-injection characterization**
  - Data analysis and interpretation
  - Post-injection monitoring
  - Reservoir modeling
  - Assessing enhanced recovery for commercialization

**Ongoing:** CO₂ Injections, Reservoir Modeling, Monitoring, Education/Outreach
Previous Experience in Huff and Puff Test in Russell County, Virginia (2009)

Production curve for huff-and-puff test well, Russell County, Virginia, 2009

- 1000-ton CO$_2$ injection
- Stacked coal reservoir
- Evidence of preferential adsorption: elevated N$_2$ and CH$_4$
- Enhanced CH$_4$ recovery at two offset wells, no CO$_2$ breakthrough
- 30% CO$_2$ in flowback over 5 years
- EUR of test well has increased by 48 percent
Shale CO₂ Injection Test (510 tons)
Morgan County, Tennessee

- Horizontal well in Chattanooga Shale formation, drilled in 2009
- Legacy producing gas well permitted under TDEC
- 510 tons for “huff and puff” injection test
- Injection period: March 18-31, 2014 (14 days)
- Shut-in period: March 31- July 29, 2014 (~4 months)
- Flowback period: July 29, 2014- present (~12 months)
- Current status: post-injection monitoring
Shale CO₂ Injection Test in Morgan County, Tennessee
Monitoring, Verification, and Accounting (MVA)

MVA Overview:

- Gas and water sampling
  - Commenced: 4/2013
  - Injection Well: HW-1003
  - 13 Offset Monitoring Wells
    - 3 Horizontal / 10 Vertical
    - 11 In-zone / 2 Out-of-zone

- Perfluorocarbon tracer study

- Surface water sampling

Monitor for:

- Injection Phase: % Composition, Tracer Arrival
- Soaking Phase: Pressure, % Composition
- Flowback Phase: Flowrate, % Composition, Tracers
Shale CO$_2$ Injection Test in Morgan County, Tennessee

Operations Overview
Shale CO₂ Injection Test in Morgan County, Tennessee
Operations Overview
Shale CO\(_2\) Injection Test in Morgan County, Tennessee

Injection Summary

- 510 tons CO\(_2\) injected
- Avg. Flow Rate: 40 tons/day
- Avg. Wellhead Temp: 50\(^\circ\) F
- Max Wellhead Pressure: ~500 psi (Gas Phase)
Shale CO₂ Injection Test in Morgan County, Tennessee
Monitoring, Verification, and Accounting (MVA)

Perfluorocarbon Tracers

- Sulfur Hexafluoride (SF₆)
  - 0.574 kg at 50-ton mark
  - Booster Pump and Air Compressor

- Perfluoromethylcyclopentane (PMCP)
  - 0.854 kg at 50-ton mark
  - Syringe Pump

- Perfluoromethylcyclohexane (PMCH)
  - 0.894 kg at 350-ton mark
  - Syringe Pump
Shale CO$_2$ Injection Test in Morgan County, Tennessee
Results to Date

**Injection period:**
- No increased concentration of CO$_2$ at offset wells *
- No detection of tracers at offset wells *

**Shut-in period:**
- Wellhead pressure leveled out at 260 psig for 3 months *
- No liquids downhole
- All gas phase in wellbore
Shale CO₂ Injection Test in Morgan County, Tennessee
Results to Date

Injection period:
- No increased concentration of CO₂ at offset wells *
- No detection of tracers at offset wells *

Shut-in period:
- Wellhead pressure leveled out at 260 psig for 3 months*
- No liquids downhole
- All gas phase

*Indications of closed system behavior
- Consistent with modeled predictions
- CO₂ confinement → storage option
Shale CO₂ Injection Test in Morgan County, Tennessee
Flowback Results

- EGR: An increase versus baseline production
- Correlated production of hydrocarbons and CO₂
- 34 percent of injected CO₂ produced to date (173 tons)
- Current CO₂ production rate of 0.22 tons/day
- $60 per ton of CO₂ Injected for EGR (including NGLs)
Shale CO$_2$ Injection Test in Morgan County, Tennessee
Results to Date

Production of heavy hydrocarbons elevated from baseline values:

- Role of pressure, viscosity and adsorption/desorption processes
- Enhanced recovery→ implications for other shale plays
CBM CO₂ Injection Test in Buchanan County, Virginia

- Oakwood coalbed methane field
- Stacked coal reservoir, 15-20 seams
- Tight shale and sandstone confining units
- 20,000-tonne CO₂ injection over one year in three legacy production wells
- CO₂ storage + Enhanced gas recovery (EGR)
- US EPA Class II UIC Permit
- Current status: Injection on-going.
CBM CO₂ Injection Test in Buchanan County, Virginia
Reservoir Modeling

Stratigraphic cross section through injection wells

Modeling Considerations:

- 15-20 coal seams in injection zone
- Average seam thickness of 1.0 feet
- Depth range: 900-2200 feet
- Variable lateral continuity
- Intermediate and overlying seals
- Dynamic reservoir properties (active production operations)
- Multi-phase flow
CBM CO$_2$ Injection Test in Buchanan County, Virginia
Reservoir Modeling

18-layer reservoir model

CO$_2$ Injection simulations used to define Area of Review (AOR) for monitoring program

DD7

DD7A

DD8
CBM CO$_2$ Injection Test in Buchanan County, Virginia
Monitoring, Verification, and Accounting (MVA)

Oakwood Field Demonstration Site

MVA Focus Area
- Injection wells
- CBM production wells
- MVA boundaries
- Roads
- Monitoring and characterization wells
- Microseismic array (28 stns)
- GPS array (20 monuments)
CBM CO₂ Injection Test in Buchanan County, Virginia
Monitoring, Verification, and Accounting (MVA)

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CBM CO₂ Injection Test in Buchanan County, Virginia
Monitoring, Verification, and Accounting (MVA)

MVA Approach

Borehole-scale technologies:
- Pressure/Temperature
- Gas/H₂O composition
- Tracers/Isotopes
- Formation logging

Technologies deployed over large areal extents:
- Microseismic/TFI
- Surface deformation measurement (GPS + InSAR)

- Combination of technologies will provide data sets with overlapping spatial and temporal scales.
  - Data will help distinguish signals from CO₂ operations vs. active CBM operations
  - Data sets will cross validate each other

- Selected technologies to address/overcome challenges of reservoir geometry and terrain
Injection Skid for 3 wells w/ Coriolis Flowmeters, Valves and Radio/Cell Communication
SCADA (supervisory control and data acquisition) system

- Real-time graphing
- Alarms and Valve control:
  - flowrate, injection pressure, casing pressure
  - 30 second communication via radio
Real-time Injection and Monitoring Data
1,470 metric tons injected to date (1,617 tons)

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<tr>
<th>Date</th>
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<th>DD7A (metric tons)</th>
<th>DD8 (metric tons)</th>
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DD7A – 589 metric tons
DD7 – 409 metric tons
DD8 – 470 metric tons
DD7 Injection Rate and WellHead Pressure

- DD7 Injection Pressure (psig)
- DD7 (metric tons / day)
Injection Well Liquid Level

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Accomplishments to Date

- Completed Geologic Characterization for CBM Test Site and Shale Test Site
- Site Selection of 3 CBM Wells in VA for Injection
- Site Selection of 1 Horizontal Shale Well in TN for Injection
- Access Agreements for CBM Test completed
- Access Agreements for Shale Test completed
- Conducted Risk Workshop and developed Risk Register
- Performed detailed reservoir modeling analysis and assessment for CBM and Shale Tests
- Developed Drilling, Monitoring and Injection Plans
- Initiated Public Outreach Plan
- Shale Test Injection Complete – Flowback Underway
- Coring/Drilling at CBM Test Site complete
- CBM Test Injection Underway
Synergistic Activities

- Reservoir Modeling
- Core Analysis
- Field Projects
- Tracer Studies
- Gas and Water Sampling
Summary

• Shale Test Injection successful
  – Flowback showed EGR and specifically NGLs

• CBM Test Injection underway
  – Multiple wells allow for varied injection rates and pressures as well as fall-off testing
  – No breakthrough at monitoring or offset wells
Appendix
Benefit to the Program

- Develop technologies that will support industries’ ability to predict CO2 storage capacity in geologic formations to within ±30 percent.
- Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.
- The research project is testing the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery.
- The technology, when successfully demonstrated, will provide guidance for commercialization applications of ECBM and EGR.
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<th>Funding</th>
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<td><strong>Task 1.0--Project Management and Planning</strong></td>
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<td><strong>Task 2.0--Site Selection and Access Agreements</strong></td>
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Bibliography


- Gilliland, E., Ripepi N., Schafrik, S., Schlosser, C., Amante, J., Louk, A.K., Diminick, E., Keim, S., Keles, C. and M. Karmis, Monitoring design and data management for a multi-well CO2 storage/enhanced coalbed methane test in a stacked coal reservoir, Buchanan County, Virginia, USA, Future Mining 2015, Sydney, Australia, November 4-6, 2015,


Bibliography


