Central Appalachian Basin Unconventional Reservoir Small Scale CO₂ Injection Tests

Coalbed Methane and Shale

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Motivation for Test

- **Carbon Capture, Utilization and Storage (CCUS)**
  - Utilization is key to make the business case make sense for carbon capture

- **Previous funded Tests**
  - Russell County, VA – 1,000 ton test
  - Central Appalachian Geologic Characterization
  - Black Warrior Basin, Alabama

- **Regional need for CO2 Sink in Appalachia focused on Utilization**

- **Coal and Shale**
  - Adsorption of CO2 on the organic surface – safe and secure
  - CO2 can displace unrecovered methane and enhance recovery
  - Infrastructure in place
  - Low pressure
SECARB Phase II
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 CO₂ injection
- Stacked coal reservoir
- Evidence of preferential adsorption: elevated N₂ and CH₄
- Enhanced CH₄ recovery at two offset wells, no CO₂ breakthrough
- EUR of test well has increased by 85 percent
65% of CO2 Retained in Russell County Test
SECARB Phase II – Black Warrior Basin Test

Total Well Production for Permit 12450-C

- Gas (Mcf)
- Oil (bbls)
- Gas Sales (Mcf)
- Water (bbls)
Current 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)\(^1,2,3,4,5\)
- Marshall Miller & Associates\(^2,3\)
- 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; Praxair; Trimeric

Collaborators
- Schlumberger
- Global Geophysical Services
- Oak Ridge National Laboratory
- University of Nottingham / British Geological Survey, University of Tennessee, University of Virginia,
- Southern Illinois University, Oklahoma State University

1 Project management
2 Operations
3 Research
4 Risk management
5 Outreach
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 (~24 months)
- **Current status:** site closed
Shale CO₂ Injection Test in Morgan County, Tennessee
Operations Overview
Shale CO\textsubscript{2} Injection Test in Morgan County, Tennessee

Operations Overview
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)
Shale CO₂ 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
50% of CO2 Retained in Morgan County Test
CBM Injection Test Sites
Russell and Buchanan Counties, VA
CO₂ INJECTION TEST IN BUCHANAN CO., VA

- 13,000-ton CO₂ injection
- 15-20 thin, stacked coal seams
- Phase I: 10,601 tons
- Phase II: 2,662 tons
- Flowback: 210 tons
CBM CO₂ Injection Test in Buchanan County, VA

- Oakwood coalbed methane field
- Stacked coal reservoir, 15-20 seams
- Tight shale and sandstone confining units
- Over 13,000 tons CO₂ injected in two distinct Phases injection over 17 months in three legacy wells
- CO₂ storage + Enhanced gas recovery
- US EPA Class II UIC Permit
- Current status: Post-injection monitoring.
CBM CO$_2$ 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
Production history for Buchanan County CO$_2$-ECBM test injection wells

Higher production for DD7 $\rightarrow$ enhanced permeability on anticline

Wells shut in for test
CBM CO₂ Injection Test in Buchanan County, Virginia
Reservoir Modeling

CO₂ Injection simulations used to define Area of Review (AOR) for monitoring program

18-layer reservoir model
CBM CO₂ 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 CO$_2$ Injection Test in Buchanan County, Virginia
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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
Continuous, Real-time Monitoring

Monitoring and Characterization Wells

Surface and Downhole Pressure and Temperature Gauges
*(Higher CO2 content in shallow coals and higher ethane content in deeper coals)
Surface Deformation Measurement
Time-lapse GPS Data

- Direct sensing/ground reference
- Stations within and outside AOR
- Survey assembly:
  - 4-ft borehole, 6-in diameter
  - Steel rod secured with cement and rebar
  - CHC X90-OPUS receivers
- Data collection:
  - variable occupation time (hours); accuracy tradeoff
  - Accuracy: mm-scale
Project Timeline
Two Injection Phases

Currently in Post-injection Monitoring
CO₂ INJECTION OPERATIONS

- Injection operations at DD-7
- Coriolis flow meters
- SCADA
  - Continuous monitoring
  - Real-time controls
  - Relay data from monitoring wells
CO₂ INJECTION TEST RESULTS

- Max injection pressure at DD-7A during Phase I and II
- Injection pressure fell and leveled at 100psi during both phases
CO₂ INJECTION TEST RESULTS

- Injectivity decreases in all wells for Phase I and II
  - Levels out before zero

[Graphs showing CO₂ injection test results and injection & flowback temperatures for Phase I and II wells DD7, DD7A, and DD8.]
Start of Injection Phase I: July 2015
End of Injection Phase I: April 2016

CO2 Injection Diagram: Phase I

- Pressure, psia
- Temperature, °F

- Solid
- Liquid
- Vapor

Melting Line
Saturation Line

DD7
DD7A
DD8
Microseismic monitoring

**Combined TFI for pre-injection survey**  
December 20, 2014-January 1, 2015

**Combined TFI for early injection survey**  
June 27-July 16, 2015

• Results for both surveys show generally higher acoustic activity on western margin
CO$_2$ INJECTION TEST RESULTS

- CO$_2$ breakthrough at DD-8A
- 12.9% during Phase I
- 4.65% during Phase II
CO₂ INJECTION TEST – TRACER RESULTS

• Breakthrough of PMCP in DD-7 water prior to injection
• Breakthrough of SF₆ in DD-8A Phase I injection
WATER INJECTION TEST TO DELINEATE CO₂ PLUME MIGRATION

*Not to scale
WATER INJECTION TEST TO DELINEATE CO₂ PLUME MIGRATION

- Coal thickness
- Flow rate
- Production per foot of coal
WATER INJECTION TEST TO DELINEATE CO$_2$ PLUME MIGRATION

- Coal thickness
- Flow rate
- Production per foot of coal
WATER INJECTION TEST TO DELINEATE CO₂ PLUME MIGRATION

- More CO₂ in shallow coals
  - Zone 6 = Seaboard

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<th>Ethane</th>
<th>CO₂</th>
<th>Methane</th>
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**Legend:**
- Propane
- Ethane
- CO₂
- Methane

**Graph:**
- **Z1:** 100% CO₂
- **Z2:** 70% CO₂, 30% Methane
- **Z3:** 50% CO₂, 50% Methane
- **Z4:** 30% CO₂, 70% Methane
- **Z5:** 20% CO₂, 80% Methane
- **Z6:** 10% CO₂, 90% Methane
INITIAL FLOWBACK RESULTS

- Flowback Commenced on 1/8/2018
- ~80 – 90% CO₂
- 500 tons of CO₂
- Flowrates are up 10-30%
- Significant Propane in the produced gas
Conclusions and Opportunities

• 4 Successful injections
  • SECARB Phase II Pilot Tests
  • 500 tons in Chattanooga Shale
  • Over 13,000 tons of CO2 into 3 CBM wells in Buchanan County, VA

• Local service providers utilized

• Favorable injectivity / high storage capacity

• Potential for demonstration-scale test

• Potential for commercialization = economic development
  • Enhanced gas recovery
  • CO2 based infrastructure
  • Continued support of tax base and jobs
  • Job creation
Commercialization Opportunities