SMALL SCALE FIELD TEST
DEMONSTRATING CO$_2$ SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO$_2$-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS
DE-FE0006821

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The University of Kansas
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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS
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Presentation Outline

- Benefit to the Program
- Project Overview
- Technical Status
- Accomplishments to Date
- Summary
Project Team

DOE-NETL Contract #FE0006821

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Benefit to the Program

• **Program goals being addressed** –
  – Demonstrate that 99 percent of injected CO$_2$ remains in the injection zone
  – Conduct small field test to support characterization, site operations, monitoring, and closure practices for [Class VI geosequestration Permit](#), Region 7 EPA, Kansas City

• **Project benefits of this small scale field test:**
  – Advance the science and practice of carbon sequestration in the Midcontinent
  – Evaluate reliable, cost effective MVA tailored to the geologic setting
  – Optimize methods for remediation and risk management
  – Provide technical information to local petroleum industry for implementation of CCUS
  – Enable additional projects and facilitate discussions on regulations and policy
Project Overview: Goals and Objectives

1. Negotiate cost of CO2 with new source and commence field activities in Fall 2013.
2. Begin injection of 30,000 metric tons of CO2 into Mississippian oil reservoir mid year 2014 using 5-spot pattern to demonstrate optimization for carbon sequestration.
3. Obtain Class VI permit by late 2014.
4. *Pending approval of Class VI injection application* -- Inject under supercritical conditions up to 40,000 metric tons of CO2 into the underlying Arbuckle saline aquifer.
5. Demonstrate state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques
6. Integrate MVA data and analysis with reservoir modeling studies to demonstrate and insure 99% CO2 storage permanence.
Technical Status

- **Replacing CO$_2$ source** – Colwich ethanol plant near Wellington remains closed.
- **Negotiations continuing** with 2 compressed CO$_2$ sources to maximize CO$_2$ for project, delivering at least 40,000 tonnes.
- **Begin field activities** as soon as CO$_2$ source is secured with Mississippian CO$_2$-EOR injection beginning in mid 2014.
- **File Class VI permit** for Arbuckle saline injection with EPA by in Fall 2013.
- **Saline injection** potentially begin by July 2015 immediately following test in the Mississippian oil reservoir.
Pending Class VI permit and DOE funding -- Inject up to 40,000 tonnes of CO₂ with tracers into lower Arbuckle saline aquifer and seismically image and sample in situ CO₂ plume to validate geomodel and simulations - U-Tube, CASSM and cross hole seismic with DTS & acoustic fiber optics (long string fiber pending)

Inject 30,000 tonnes of CO₂ into Mississippian oil reservoir to demonstrate CO₂-EOR and 99% assurance of storage with MVA

• Test for CO₂ and analyze fluid samples from Mississippian wells (if positive, run 2D seismic)
  (Underpressured oil reservoir should trap any vertically migrating CO₂)

• Monitor for tracers, CO₂, aqueous geochemistry in shallow freshwater wells

• Monitor ~600 ft deep well below shallow evaporite cap rock

• InSAR, CGPS surface deformation/IRIS seismometers

• Measure soil gas flux

CO₂-EOR, saline injection, Class VI, MVA - Wellington Field

J. Rush, KGS
No natural connection between USDW and underlying Paleozoic strata

Potentiometric surface of Arbuckle ~500 ft below USDW

Maximum injection pressure = 125 psi within 1st month of injection

Pressure front 1800 ft radius from injector

Pressure well below parting or fracture pressure of caprock

Regional study has established that Arbuckle is an open system.

Maximum Injection Pressure = 325 ft

Regional Arbuckle an open hydrogeologic system, not vertically connected
Technical Status
Class VI Geosequestration Injection Permit

• **Submittal of Class VI application:**
  – Late Fall 2013

• **Static and coupled dynamic modeling of saline aquifer** for up to 40 kton CO$_2$ injection

• **Injection zone** –
  – Highly permeable 150+ ft thick lower Lower Ordovician Arbuckle (Gasconade Dolomite, 100s of md to >1 D)
  – Multiple flow units decreasing thickness of buoyant supercritical CO$_2$ plume

• **Baffle and trapping of CO$_2$ plume (final model)** –
  – Multilayer plume under a ~400 ft thick shaly, low perm middle Arbuckle (lower Jefferson City-Cotter & Roubidoux formations)
  – Low pressure (<325 psi) and multi-layer plume (1800 ft radius) within lower Arbuckle (Gasconade) presents very low risk for caprock

• **Primary caprock interval** – ~230 ft gross thickness including Lower Mississippian argillaceous, organic dolosiltstone (Pierson/St. Joe Limestone), Chattanooga Shale and shales in the Simpson Group

• **USDW and interaction with subsurface brines** –
  – Marginal surface aquifer, its potentiometric surface ~500 ft above that of saline aquifer
  – Multiple secondary caprock/seals – 1000’s feet of shale, and 200 ft shallow evaporites
Permeability profile of Arbuckle in cored well - #1-32

with concentrations of redox reactive ions ($\text{Fe}^{2+}$, $\text{SO}_4^{2-}$, $\text{CH}_4$, $\text{NO}_3^-$) from KGS #1-32 & #1-28

Redox reactive ions reflect changes in biogeochemistry (microbial) occurring between upper and lower Arbuckle, in turn attributed to lack of hydraulic communication.

Scheffer, 2012
Lower and upper Arbuckle are not in hydraulic communication.

Oxygen & Hydrogen isotopes of brines from DST and perf & swabbing.

- Waters distinct from upper Arbuckle and Miss.
- Lower intervals are also geochemically homogeneous.

Scheffer, 2012
Ideal Input for Static and Dynamic Modeling with Characterization Being Accomplished Under Concurrently Funded DE-FE0002056
Aquifer Characterization
Arbuckle Saline Aquifer

- Dominantly cherty dolomite

- **Permeable** - Upper 70 m: very porous medium pelleted dolomitic pack-stones and grain-stones

- **Baffle** - Middle 110 m: tight, dense, micritic dolomite

- **Permeable** - Lower 110 m: thin dolomitic strataform breccias created by dissolution of evaporites, packstones and grainstones with discontinuous solution enhanced fractures
Aquifer Characterization

Mid Arbuckle baffle = tight rock

Lower Arbuckle Injection interval = include abundant micropores (microporous chert)
Primary Confining Zone Continuous in the Wellington Area
(Lower Mississippian Pierson fm.+Chattanooga Sh+Simpson Group)
West-East Seismic Impedance PSTM

Impedance = $\varphi \Delta t$

KGS #1-32  KGS #1-28

Top Kansas City Ls.  Top Mississippian

Mississippian Pierson/St. Joe Ls. Member, uppermost part of confining zone

D. Hedke, Hedke-Saenger
Boreholes penetrating the Arbuckle saline aquifer in Wellington Field

Berexco, LLC has:
- Purchased pore space
- Insured activity
- #1-28 well completion in compliance with EPA specs
- Disposal fee of CO2 as part of cost share

- Proposed monitoring borehole (#2-28) within 600 ft of the existing #1-28 CO2 injector into Arbuckle

- Yellow dot – modeled maximum size of CO2 plume, ~1400 ft radius

- Orange circle – extent of pressure field, 2500 radius, 325 psi max (0.485 psi/ft)
**Kmax**
Ranges from 0.01 to 425 md (whole core)

**Porosity** – predominately between 1-10%

Fractures (1-5, highest; 0, none)
Vugs (small to large, 1-5)

Shale = 1
Mudstone = 2
Packstone = 3
Grainstone = 4
Incipient breccia = 5
Breccia = 6
Sandstone = 7
Microbialite = 8

Minimum k reported as <0.01 md, but accuracy of measurement down to 0.005 md (Weatherford)

Core/Log Petrophysical Modeling

KGS #1-32 whole core analysis compared to core derived lithofacies  \( N = 480 \)
Flow units in the lower Arbuckle injection zone

Utilize whole core analysis, NMR, spectral sonic, and resistivity logs

Doveton and Fazelalavi, 2012
Improved permeability estimation in Wellington KGS #1-32 and correlation to Wellington KGS #1-28

- micro, meso, and mega groups defined
- core FZI and irreducible water saturation (from MRIL log)
- permeability computed from FZI value (Fazelalavi method)

Black points = core measured permeability
Correlations Between Kv and Kh from Whole Core Analysis & 5 Petrofacies Groups Derived from Techlog

Group 1
There are 15 whole core samples in this group; both vertical and horizontal permeability are less 0.01 mD.

M. Fazelalavi, KGS
**K_v Calibration and Correlation Using Techlog Derived Petrofacies in Mid Arbuckle**

M. Fazelalavi, KGS
Whole Core C/A - Log Integration
Arbuckle Saline Aquifer – Petrel™

Core well #1-32
3500 ft apart

Core well #1-28

Mud-dominated
Grain-dominated
Touching vugs

Stratigraphic cross section
KGS #1-32 to KGS #1-28

J. Rush, KGS
Rock Fabric From Core and Logs correlated to Seismic Depth Volume Using Petrel™

(W-E profile between KGS #1-32 and #1-28)

Mud-dominated
Grain-dominated
Touching vugs

J. Rush, KGS
3500 ft
Upscaled Horizontal Permeability in CMG Dynamic Model

Permeability I (md) 2014-01-01  J layer: 66

Top of Arbuckle

Perforation Zone, 150 ft

Minimum k limited by C/A measurement & log correlations = 0.05 md

Yevhen Holubnyak, KGS
Upscaled Vertical Permeability in CMG Dynamic Model
Permeability K (md) 2014-01-01 J layer: 66

Top of Arbuckle
#1-28
Perforation Zone, 150 ft

Minimum k limited by C/A measurement & log correlations = 0.05 md

Yevhen Holubnyak, KGS
Bottom Hole Pressure, 325 psi max. (0.485 psi/ft)
120 tonne/day, 40,000 tonne total CO₂

Yevhen Holubnyak, KGS
Vertical Delta Pressure Distribution

3 Months

6 Months

9 Months

1 year

Arbuckle only

Perforation Zone

~2500 ft diameter

psi

File: base case
User: eugene
Date: 7/25/201
Scale: 1:26639
Z/X: 12.00:1
Axis Units: ft

File: base case
User: eugene
Date: 7/25/201
Scale: 1:26639
Z/X: 12.00:1
Axis Units: ft

Yevhen Holubnyak, KGS
Lateral Delta Pressure Distribution

3 Months

6 Months

9 Months

1 year

~2500 ft radius

Yevhen Holubnyak, KGS
CO$_2$ Plume Vertical Extent in the Arbuckle

1 year

10 years

60 years

120 years

Perforation Zone

~2000 ft Max. diameter
Free Phase CO$_2$ Extends Out Along Flow Units of Injection Zone

40,000 tonnes confined to Arbuckle injection interval 1 year after injection

- Maximum diameter <2000 ft; layered aquifer in 150 ft injection interval
- Utilize seismic, whole core, and Techlog$^{\text{tm}}$ for Petrel$^{\text{tm}}$ static model
- CMG compositional dynamic model

Yevhen Holubnyak, KGS
Accomplishments to Date

- Multiple static and dynamic models of injection zone and caprock
- Class VI Injection Permit – completing internal review
- Latest modeling results for Class VI application
  - Transmissibility of the Arbuckle saline aquifer – new $k_v,h$, injection below conservative fracture gradient
  - Capacity of Arbuckle – adequate continuity and thickness
  - Fate of the CO$_2$ -- solution, dissolution, and capillary entrapment
  - Caprock integrity – fully cored and analyzed, phi-k, clay, continuity, mechanical properties
- Kansas Class VI application directed to facilitate the review process and enable discussions with EPA on appropriate financial assurance and an early closure of this small scale test.
Summary

Key Findings
- Suitable injection zones, caprock, and isolation from USDW
  - Arbuckle highly stratified three distinct hydrostratigraphic units
  - Even if mid-Arbuckle zone is considered as a permeable medium, significant amount of the CO₂ is predicted to be trapped in or near the injection zone due to decreased velocity of CO₂ travel through less permeable medium -- residual and solubility trapping
  - Pressure increase (325 psi) is insignificant and caprock/shales will not experience dangerous stress levels.

Lessons Learned
- Water geochemistry and biogeochemistry have proved extremely useful in evaluating interaction of hydrostratigraphic units
- Establishing magnitude and distribution of permeability in complex carbonate aquifer system requires multiple independent means to assess.

Future Plans
- Submit application for Class VI injection permit late 2013
- Begin field work for Class II EOR activities after negotiations with new source of CO₂ are completed
- Inject CO₂ into Mississippian oil reservoir first (mid 2014), followed by saline aquifer (mid 2015)
- Incorporate continuous and surface fiber optic acoustic recording (recently funded proposal, FOA 798 – Rob Trautz, PI, EPRI)
Appendix
**Kansas Geological Survey**

- **Name**: Lynn Watney  
  **Project Job Title**: Project Leader, Joint Principal Investigator  
  **Primary Responsibility**: Geology, information synthesis, point of contact

- **Name**: Saibal Bhattacharya  
  **Project Job Title**: Joint Principal Investigator  
  **Primary Responsibility**: Reservoir engineer, dynamic modeling, synthesis

- **Name**: Jason Rush  
  **Project Job Title**: Joint Principal Investigator  
  **Primary Responsibility**: Geology, static modeling, data integration, synthesis

- **Name**: John Doveton  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Log petrophysics, geostatistics

- **Name**: Dave Newell  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Fluid geochemistry

- **Name**: Rick Miller  
  **Project Job Title**: Geophysicist  
  **Primary Responsibility**: 2D seismic acquire & interpretation

- **Name**: TBN  
  **Project Job Title**: Geology Technician  
  **Primary Responsibility**: LiDAR support, water well drilling/completion

- **Name**: TBN  
  **Project Job Title**: Engineering Technician  
  **Primary Responsibility**: Assemble and analyze data, report writing

**KU Department of Geology**

- **Name**: Michael Taylor  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Structural Geology, analysis of InSAR and LiDAR

- **Name**: TBN  
  **Project Job Title**: Graduate Research Assistant  
  **Primary Responsibility**: Structural Geology, analysis of InSAR and LiDAR

**Kansas State University**

- **Name**: Saugata Datta  
  **Project Job Title**: Principal Investigator  
  **Primary Responsibility**: Aqueous geochemistry

- **Name**: TBN  
  **Project Job Title**: Graduate Research Assistant  
  **Primary Responsibility**: Aqueous and gas geochemistry

- **Name**: TBN  
  **Project Job Title**: 3- Undergraduate Research Assistants  
  **Primary Responsibility**: Aqueous and gas geochemistry

**Lawrence Berkeley National Laboratory**

- **Name**: Tom Daley  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Geophysicist, analysis of crosshole and CASSM data

- **Name**: Jennifer Lewicki  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Hydrogeology, analysis of soil gas measurements

- **Name**: Barry Freifeld  
  **Project Job Title**: Co-Principal Investigator  
  **Primary Responsibility**: Mechanical Engineer, analysis of U-Tube sampler

**Sandia Technologies, Houston**

- **Name**: Dan Collins  
  **Project Job Title**: Geologist  
  **Primary Responsibility**: Manage CASSM and U-Tube operation

- **Name**: David Freeman  
  **Project Job Title**: Field Engineer  
  **Primary Responsibility**: Manage field install of CASSM and U-Tube

**Berexco, LLC**

- **Name**: Dana Wreath  
  **Project Job Title**: VP Berexco  
  **Primary Responsibility**: Engineering, Manager of Wellington Field

- **Name**: Randy Kouedele  
  **Project Job Title**: Reservoir engineer  
  **Primary Responsibility**: Engineering

- **Name**: Staff of Wellington Field  
  **Project Job Title**:  
  **Primary Responsibility**: field operations

- **Name**: Beredco Drilling team  
  **Project Job Title**:  
  **Primary Responsibility**: Mississippian and Arbuckle drilling operations
Abbreviated Gantt Chart – SMALL SCALE FIELD TEST at Wellington Field, Sumner County, Kansas

Task 1. Project Management and Reporting

Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
- Confirm source of CO2
- Obtain EPA approval of Class VI Application

Task 3. Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
- Class II Application

Task 4. Drill Monitoring Borehole for CO2 Sequestration in Arbuckle Saline Aquifer

Task 5. Drill CO2 Injection Borehole at the Center of Mississippian CO2-EOR Pattern

Task 6. Reenter, deepen, & Complete Existing Plugged Arbuckle Borehole (Peasel 1)

Task 7. Revise Site Characterization Models and Simulations for CO2 Sequestration and submit a revised Site Characterization, Modeling, and Monitoring Plan to DOE:

Task 8. Inventory Well and Borehole Completions within Area of Influence of Small Scale CO2 Sequestration Project

Task 9. Establish MVA Infrastructure - Around CO2 Injector for CO2 Sequestration

Task 10. Pre-injection MVA - Establish Background (Baseline) Readings

Task 11. Design and Construct CO2 Compression & Loading Facility at CO2 Source

Task 12. Build infrastructure for CO2 Pressureization at Mississippian Injection Borehole for CO2 Sequestration

Task 13. Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation

Task 14. Fit Arbuckle Observation Well (#2-28) for MVA Tool Installation

Task 15. Begin Injection at Arbuckle Injector

Task 16. MVA During Injection - Mississippian and Arbuckle CO2 Sequestration

Task 17. Risk Management Related to CO2 Sequestration in Arbuckle Saline Aquifer

Task 18. Compare Simulation Results with MVA and Submit Update of Site Characterization, Modeling, and Monitoring Plan

Task 19. Post injection MVA - CO2 sequestration site limited to 1.5 years

Task 20. Evaluate CO2 Sequestration Potential in Arbuckle Saline Aquifer at Wellington

Task 21. Evaluate regional CO2 Sequestration Potential in Arbuckle Saline Aquifer in Kansas

Task 22. Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector

Task 23. Equipment Dismantlement and Install

Task 24. CO2 Transported to Mississippian Injector

Task 25. Monitor Performance of CO2-EOR Pilot

Task 26. Compare Pilot EOR Performance with Model Results

Task 27. Evaluate CO2 Sequestration Potential of CO2-EOR Pilot

Task 28. Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Task 29. Closure of CO2 Sequestration Project in Arbuckle Saline Aquifer at Wellington field

Task 30. Develop a Best Practice Manual:

Project ends 9/30/16
Bibliography

List peer reviewed publications generated from project per the format of the examples below

- **Journal, multiple authors:**
• **Publication:**
  – Watney, W.L., 2013, January 31st, AAPG Mississippian Forum, Oklahoma City, OK, Mississippian Carbonate and Chert Reservoirs in Kansas: Integrating Log, Core, and Seismic Information -- Lynn Watney (based primarily on Wellington Field) – discussion of caprock and Arbuckle as a disposal zone for brine and CO2
  – Watney, W.L., 2013, February 18-19, Applied Geoscience Conference, Houston, TX, Mississippian Exploration: Stratigraphy, Petrology, and Reservoir Properties -- Lynn Watney (based on new data from Wellington Field, considerations for CCUS, and regional mapping) – include caprock and disposal of brine and CO2
  – Watney, W.L., 2013, Analysis of the Late Devonian to Early Carboniferous (Fransnian-Tornaisian) Woodford (Chattanooga) Shale, presentation to AAPG Forum Woodford, Oklahoma City, April 11. This is an important caprock in Kansas and Oklahoma.
  – Watney, W.L., 2013, Petrophysical Analyses and Integrated Approaches, April 16-19, AAPG Short Course, Austin, TX. Centerpiece of the course material comes from the DOE-CO2 project.
Bibliography

Publications:
• DOE Site visit and project review, June 3-5, 2013, Regional CO2 Storage, Wellington and Cutter field calibration sites, SW Kansas CO2-EOR Initiative, and Small Scale CO2 Test Injection at Wellington, Wichita, KS.
• Lyle, S., Buchanan, R., Watney, L., Rush, J., Raney J., and Brian Dressel, DOE Project Manager, 2013, Presentation to the KGS Annual Kansas Field Conference participants including Kansas legislators and state officials, morning of Tuesday, June 4th, Meet bus at site of Wellington KGS #1-32. Brought core and posters in addition to describing DOE-CO2 project and answering questions pertaining economics, safety, and policy.
• Papers at Midcontinent Section meeting AAPG,
• Seismic attribute analysis of the Mississippian chert at the Wellington field -- Aryrat Sirazhiev
• Core transect across Shuck Pool: A Chesterian incised valley fill succession in Seward County, KS -- John Youle
• Online Development of New Kansas Type Logs -- Paul Gerlach
• In Situ Validation of PSDM Seismic Volumetric Curvature as a Tool for Paleokarst Heterogeneity Studies: Results from an Extended-Reach Lateral at Bemis-Shutts -- Jason Rush
• Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas - Eugene Holubnyak
• Dynamic Modeling of CO2 Geological Storage in the Arbuckle Saline Aquifer at Wellington Field -- Eugene Holubnyak
• CO2 Enhanced oil recovery and CO2 sequestration potential of the Mississippian Chester -- Martin Dubois
• Systematic and episodic structural deformation in southern Kansas and implications for CCUS -- Lynn Watney
• Evaluating CO2 Utilization and Storage in Kansas -- Lynn Watney
• Core workshop -- Wellington KGS #1-32, Sumner County, and Cutter KGS #1, Stevens County, Kansas -- Lynn Watney