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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Mastering the Subsurface through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting  
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Project Team

DOE-NETL Contract #FE0006821

Project established November 2011

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CO₂ supplier

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InSAR-cGPS, active and passive seismic, geochemistry
Presentation Outline

1. Project Overview
   - Oil field in rural area operating since 1929
   - 55 wells, 21 million barrels produced, 46,000 barrels annually
   - Effective waterflood, ready for CO2-EOR
   - **Phase I** – Completed June 21, 2016 → 20,000 tonnes CO2 injected into Mississippian dolomite for EOR

2. Benefits to the Program

3. Technical Status
   - **Phase II** – 26,000 tonnes CO2 into Arbuckle saline aquifer, pending Class VI permit (2017)
Project Objectives

- Test Monitoring, Verification, and Accounting (MVA) technologies - partially addressed
  - National Labs tools:
    - U-Tube
    - Continuous Active-Source Seismic Monitoring (CASSM)
  - Other methods:
    - Surface and reservoir water analysis
    - 18- seismometer array for passive seismic
    - cGPS and InSAR
    - 2D and 3D Seismic
- CO$_2$ storage trough EOR and saline aquifer
- Commercialization plan
- Technology transfer
- US EPA UIC Class VI permit application
Benefits to the Program

DOE Program Goals

**Goal 1**: Develop & validate technologies to ensure 99% storage permanence,

**Goal 2**: Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness

**Goal 3**: Support industry’s ability to predict CO₂ storage capacity in geologic formations to within ±30%

**Goal 4**: Develop best practices for commercial-scale CCS

This Study

- Sub-basinal characterizations
- Ideal testing site for screening tools (i.e., NRAP)
- Reservoir & simulation models for geological storage
- Field test to verify characterization, modeling, and MVA
Benefits to the Program

• Demonstrate that 99 percent permanence of injected CO₂
  → 20,000 metric tons tonnes injected into KGS #2-32 into Late Mississippian siliceous dolomite reservoir between January 9 and June 21, 2016 → CO₂ plume and EOR response as forecast by model (Class II UIC permit)
  → 20,000 metric ton injection into underlying Lower Ordovician Arbuckle Group dolomitic saline aquifer (Pending Class VI UIC permit)

• Demonstrate reliable and cost effective MVA (monitoring, verification, and accounting) tools and techniques

• Develop best practices for effective and safe CO₂-EOR and CO₂ saline storage

![Diagram of Wellington Field well surface locations and Mississippian underpressure Injection zone]
Technical Status

Task 15. Evaluate Potential to Move Oil and Optimize for Carbon Storage

• Begin CO₂ injection into KGS #2-32 on January 9, 2016
• Completed injection on June 21, 2016
• 1,101 truckloads, 21,784 US tons, 19,803 metric tons, average of 120 tonnes per day, approximately 374,000 MCF of CO₂
• Total expenditures for purchasing CO₂ were $1,964,000. Our overall price for CO₂ was $90.16 per US ton from Linde Group
• Behaving as forecasted by gemodel/simulation

Monitoring technologies during Class II injection
1) Surface water analysis  
2) 18-seismometer array for passive seismic  
3) cGPS and InSAR  
4) Weekly analysis of 17 wells surrounding injector  
5) Repeat 2D seismic survey (July 2016)  
6) Post-CO₂ injection well performance around Class II well  
7) Arbuckle pressure monitoring since April 2016
Targeted area → High CO$_2$-EOR potential

- Petrel map of permeability distribution in the Mississippian dolomite
- CO$_2$ injection well is red vertical line
- Lower permeability noted east and south of the injection well, Berexco Wellington KGS #2-32
- Residual oil saturation in cored injection well averages 23%

J. Rush
Wellington Field small scale CO₂-EOR
Jason Bruns above (Caanon Well Services) and Dana Wreath upper right (VP Berexco, LLC) with KGS staff

- 30% oil cut
- Compared to ~1-2% field average

SCADA System installed on wells
Web Applications Built to Display and Analyze Data “in Real-Time” by the Team During Monitoring →
time lapse maps, cross plots, analytical tools, csv download

South-central Kansas CO₂ Project
CO₂ Sequestration
Summary Pages and Web Apps

Select the bubble button below to display respective module.
CO₂ Injection Begins 1-09-16

Pause in CO₂ Injection

CO₂ Injection Ends

4,000+ BO

CO₂ Production 2-29-16

Oil Recovery Starts 2-26-16

~18% of CO₂ injected has been produced

CO₂ Injected and Recovered & Oil Produced Through 7/31/16

Jan-16 Mar-16 Apr-16 Jun-16 Aug-16 Oct-16 Dec-16 Feb-17 Apr-17

CO₂ Purchased Daily (MCF)
CO₂ Produced Daily (MCF)
Cumulative CO₂ Produced (MCF)
Incremental Oil Daily (bbls)
Cumulative Incremental Oil (bbls)
Cum. Ratio Produced/Purchased CO₂
Efficiency, injected CO₂ (MCF)/ oil produced (STB)

CO₂ Injected and Recovered & Oil Produced Through 7/31/16
Time Lapse Alkalinity

During and Post CO₂ Injection

Dashboard

Run/Pause/Step Control

6/23/2016
End of CO₂ injection

High Alkalinity CO₂

Supercritical CO₂

Small fault

7/19/2016
Re-processed 3D seismic analysis: discrete fracture network vs. field CO₂ MVA data

T₅ = June 17, 2016

- KGS 2-32 Injection well
- Significant CO₂ production
- Detection of CO₂
- No detection of CO₂

CO₂ production

Discrete fracture network map

G. Tsoflias & B. Graham
Faults cut Mississippian, Arbuckle, and basement

Wellington-Anson Bates Fields, Sumner Co.
• Milestone 3. Pre-injection MVA baseline recording

- 18 seismometer array since Fall 2014
- cGPS and inSAR for processing since August 2014
- Five shallow monitoring wells around KGS #1-28 and domestic wells in vicinity
- Weekly baseline geochemistry and production data from 17 wells during CO₂-EOR
- Static bottom hole pressure in lower Arbuckle from KGS #1-28 since April 2016

![Map and Diagram](image)
Earthquake Catalog

No earthquake has been detected within Wellington field in association with the CO$_2$ injection in KGS #2-32

- 1905 total earthquakes: April 2015 - December 2016
- $M_c \sim 1.2$
- Smallest earthquake $M_w 0.4$
Induced Seismicity Southwest of Wellington Field

Total salt water injected by well (●), BOE produced by oil lease (●) and earthquakes (■) in 2014, Harper and Sumner Counties, Kansas

- Wellington Field Arbuckle Injection 26,000 tonnes = 142,000 bbls of fluid over 7 mo. or ~650 bbls per day
- Composite BW/BOE = 16:1 (6 % oil cut)

- Salt Water Disposal (Class II) in Harper and Sumner counties in 2014
  - 128,254,699 bbls
  - Equivalent to ~23 MM tonnes CO₂
- Oklahoma salt water disposal in 2014
  - >4,000,000,000 bbls
  - >20 billion tonnes CO₂

Milan 4.8 M Nov. ‘14

Min 1.9
Max 4.8
Mean 2.8
127 earthquakes in 2014
Kansas Regional Pressure Increase

- On 4-25-16, BHP in lower Arbuckle was +31.4 psig higher than what was recorded on 8/23/11.
- Since April, 2016 the pressure has risen to +32.9 psi → 1.5 psi (0.0147 psi/day or 0.44 psi/mo).
- Increase in pressure forecast by simulation of 2-county brine disposal
- **Regulators express concerns about storage capacity**

Pressure Increase of ~0.5 psi/month

Simulation model: $\Delta$ pressure (psi)

- Pressure increase without changes to injection rate
Accomplishments of the Wellington Project during BP2

ACTIVITIES CARRIED OUT TO DATE BY THE KANSAS TEAM

• Successful CO₂ injection in the Mississippian carried out by Berexco, LLC, Wichita, KS
• Injection done in a highly controlled and monitored environment
• Linde Group, a leader in CO₂ capture and supply, an excellent partner for the project, provided steady supply of CO₂
• Assisting in defining safe disposal and economic potential for Kansas reservoirs
• Rapid-response detection & mitigation procedures being tested are as part of a comprehensive operation & risk management plan
• Advanced monitoring technologies
• Wellington Field is proving to be a viable field laboratory
Synergistic Activities

- Collaboration with Susan Carroll, PI, LLNL

- Task addition \(\rightarrow\) **Experimental calibration of NMR well logs to determine pore connectivity in the injection zone at the Wellington CO\(_2\) storage demonstration site, Kansas**

- Site twining at ENOS and UK MEMOIR projects

- Data rich site with considerable data sharing with all data publically available
  - Carbonate and caprock cores, modern wireline logs, tests \(\rightarrow\) KU, KSU et students and faculty; industry consortium
  - Water and oil samples
  - Multicomponent 3D \(\rightarrow\) new processing techniques \(\rightarrow\) KU, KSU, BEG
  - Earthquake catalog being built from operating IRIS/KGS 18-seismometer array
  - Monitoring and risk analysis from operational plan for safe and effective injection and adaptation by EPA for this project
  - Test NRAP tools

- Extensive Web (Java) application tools and development, petrophysical application focus, data archiving
  - Need more users and explore incorporation into NATCARB
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