Geologic Carbon Storage in the Lower Ordovician Arbuckle Group Saline Aquifer in Kansas

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Confluence C (Westin Denver Downtown)
Overview

- Small scale field test at Wellington Field
- One of two calibration sites for southern Kansas CO$_2$ storage assessment (65,000 km$^2$)
- Plans remain to inject up to 40,000 tonnes (0.75 BCF) scCO$_2$ into Gasconade Dolomite of Arbuckle Group at Wellington Fld.
- 3D geocellular geomodel based on two basement tests and 434 m of core, wireline logs, 3D multi-component seismic volume and well testing
- Predict behavior of scCO$_2$ plume based on compositional simulator
- Monitor overlying Mississippian oil reservoir for leakage
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The study is a collaboration, multi-disciplinary effort between the KGS, Geology Departments at Kansas State University and The University of Kansas, BEREXCO, INC., Bittersweet Energy, Inc. Hedke-Saenger Geoscience, Ltd., Improved Hydrocarbon Recovery (IHR), Anadarko, Cimarex, Merit Energy, GloriOil, Dawson-Markwell Exploration, and Noble Energy.
Wellington Field
Site of Proposed Small Scale Field Test

Top Mississippian Structure, 10 ft C.I.

20 MM Barrel Mississippian Oil Field above Arbuckle Group
Initial CO₂ Storage Capacity Estimate

Deep Arbuckle Saline Formation

\[ G_{\text{CO}_2} = A_t h_g \, \varnothing_{\text{tot}} \, \rho \, E_{\text{saline}} \]

9-75 billion metric tons in Arbuckle only (200+ years for all KS stationary CO₂ emissions)

- **\( \varnothing_{\text{tot}} \) = total bulk volume of pore space available**
- **\( \rho \) = CO₂ density**
- **\( E_{\text{saline}} \) = fraction of the total pore volume that will be occupied by the injected CO₂**
- **\( E_{\text{saline}} \) ranges between 0.40 and 5.5 percent over the 10th to 90th percent probability range**

Metric tons CO₂ per Grid Cell
10 km² (3.8 mi²)

<table>
<thead>
<tr>
<th>Grid Cell</th>
<th>Total All Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>P10</td>
<td>8,781,380,535</td>
</tr>
<tr>
<td>P90</td>
<td>75,464,988,970</td>
</tr>
</tbody>
</table>

- 0.769 tonne/m³
- 1 m³ = 6.29 bbls
- 8.179 bbl/tonne CO₂

Gerlach and Bittersweet team, 2012
Thickmess (ft) (top) & Initial (P90) Estimate of CO\textsubscript{2} Storage (millions tonnes/10 km\textsuperscript{2} cell) (bottom) in Southern Kansas

Arbuckle Isopachous map

P90 CO\textsubscript{2} Storage Capacity
Million tonnes/10 km\textsuperscript{2} grid

65,000 km\textsuperscript{2}

0.769 tonne/m\textsuperscript{3}
1 m\textsuperscript{3} = 6.29 bbls
8.179 bbl/tonne CO\textsubscript{2}
Regional Study Area for CO\textsubscript{2} Storage Assessment
-- Deep Saline Arbuckle Aquifer Overlain by Thick Evaporites (Salt/Halite & Anhydrite)

Thickness of Permian evaporites ranges from 400 to 2000 ft (120-600 m) in southern Kansas

Regional study area of CO\textsubscript{2} project in southern Kansas: 230 mi x 85 mi
Pending Class VI permit and DOE funding -- Inject up to ~40,000 tonnes of CO₂

- U-Tube, CASSM and cross hole seismic
- DTS & acoustic fiber optics (long string fiber pending)

Inject 28,000 tonnes of CO₂ into Mississippian oil reservoir to demonstrate CO₂-EOR and 99% assurance of storage with MVA

- Tracers to detect injected CO₂
- Monitor ~600 ft deep well below shallow evaporite cap rock
- Test for CO₂ in Mississippian wells
  (*Underpressured oil reservoir should trap any vertically migrating CO₂*)

Pending Class VI permit and DOE funding -- Inject up to ~40,000 tonnes of CO₂

- InSAR & CGPS → surface deformation
- IRIS seismometers & 3C accelerometers

Red column ~ gamma ray API

J. Rush, KGS
Primary Confining Zone Continuous in the Wellington Area
(Mississippian argillaceous Cowley facies + Chattanooga Shale + Simpson Group)
West-East Seismic Impedance PSTM

Impedance = $\phi \Delta t$

Wells 1 km apart
KGS #1-32
KGS #1-28

Arbuckle injection interval
Barrier Middle Arbuckle (high impedance, continuous)
Top Kansas City Ls.
Top Mississippian
Top Arbuckle

Mississippian Cowley facies, uppermost part of confining zone

D. Hedke, Hedke-Saenger
Aquifer Characterization
Arbuckle Saline Aquifer

- Dominantly cherty dolomite

- **Permeable** - Upper 70 m: porous medium pelleted dolomitic packstones and grainstones

- **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
Plenty of Microporosity, Even in the Lower Arbuckle CO2 Injection Zone

Lower Arbuckle
(Gasconade)
Lower hydrostratigraphic unit
Flow unit –
Proposed Injection unit

whole core: phi 2.2% 89 md
Rock fabrics in aquitard of middle Arbuckle Group

--- Thin section photomicrographs

Anticipated reaction of CO₂ with –
1) argillaceous and sulfide/oxide material in the fracture pores,
2) reaction rims and microporosity in chert & dolomite and increased surface area along pore systems

4388.8 ft
Stylolite with clay in brecciated zone in fine-to-coarse crystalline peloidal dolomite

Barker et al. (2012)
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

**TEAs vs. Permeability and Depth**

Scheffer, 2012

Redox reactive ions reflect changes in biogeochemistry (microbial) occurring between upper and lower Arbuckle, in turn attributed to lack of hydraulic communication.
Lower and Upper Arbuckle Are Not in Hydraulic Communication

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

Scheffer, 2012

- Waters distinct from upper Arbuckle and Miss
- Lower intervals are also geochemically homogeneous
Variable Zonal Fracturing Through the Arbuckle

*Spectral (dipole) acoustic log and visual core description*

Scheffer, 2012; Lorenz and Cooper, 2011
Kmax
Ranges from 0.01 to 425 md (whole core)

Porosity – predominately between 1-10%

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)

KGS #1-32 whole core analysis compared to core derived lithofacies N = 480
Stratigraphic Cyclicity and Corresponding Lithofacies
Define Flow units Lower Arbuckle Injection Zone

KGS #1-32
Porosity% Ø

KGS #1-28
Porosity% Ø

Wells 1 km apart

50 ft

50 ft

Connected vugs → Solution fracture

Nonconnected vugs

Interparticle/matrix

Wellington #1-32

Wellington #1-28

Perforations for variable rate pump test

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

Stratal cycles
Upscaled Horizontal Permeability in CMG Dynamic Model

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

Top of Arbuckle

Perforation Zone, 150 ft

#1-28

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 CO$_2$

KGS 1-28 base case 4 aq t.irf
Wells within and below confining zone

- Plugged and Abandoned
- Active
- KGS 1-28 Injection Well
- KGS 1-32 Characterization Well
- KGS 2-28 Proposed Monitoring Well

Total CO₂ Plume Extent
(2 years since the start of injection)
Summary

Key Findings
- Suitable injection zones, caprock, and isolation from USDW
  - Arbuckle highly stratified three distinct hydrostratigraphic units
  - Significant amounts of the scCO$_2$ are predicted to be trapped in or near the injection zone due to decreased velocity of CO$_2$ travel through less permeable medium -- residual and solubility trapping
  - Pressure increase (325 psi) is insignificant

Lessons Learned
- Water geochemistry and biogeochemistry have proved extremely useful
- Multiple independent means required to assess permeability in complex carbonate aquifer system requires

Future Plans
- Submit application for Class VI injection permit in May 2014
- Begin field work for Class II EOR activities after negotiations with new source of CO$_2$ are completed
- Inject CO$_2$ into Mississippian oil reservoir first (Fall 2014), followed by saline aquifer (mid 2015)