Modeling CO$_2$ Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO$_2$ Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas

Project Number (DE-FE0002056)

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Jennifer Raney (Asst. Project Manager)

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Lawrence, KS 66047

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS
August 12-14, 2014
Presentation Outline

1. Benefits to the Program
2. Project Overview
3. Technical Status
4. Accomplishments to Date
5. Summary
1. Benefit to the Program

• Goal—
  – Predict geologic CO$_2$ storage capacity within ±30%
  – Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.

• Project benefits --
  – Refine CO$_2$ storage capacity of the Arbuckle saline aquifer with regional simulation through the use of large-scale simulation (currently 9-75 billion tonnes, 200 yrs. KS emissions)
  – Quantify CO$_2$ storage at Wellington, Cutter, Pleasant Prairie South, Eubank, and Shuck fields through compositional reservoir simulation addressing storage efficiency and optimized use of CO$_2$ for EOR
  – Utilize extensive digital (LAS) log database, 3D seismic, gravity-magnetics, and remote sensing to evaluate site suitability, risk, and storage efficiency, regionally, and 10 simulated sites with most favorable conditions for commercial scale (>30 MM tonnes) storage
  – Allow user to query and analyze information via Interactive Project Mapper, NATCARB, and suite of Java applications
Project Overview: Goals and Objectives

- Static and dynamic modeling of the Lower Ordovician Arbuckle Group in 25,000 mi\(^2\) area (*Predict CO\(_2\) storage within \(\pm 30\) percent and develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness*)
  - **Success** –
    a) Mapped the aquifer’s hydrostratigraphic units/flow units and confining strata;
    b) Simulated commercial scale CO\(_2\) injection at 10 sites;
    c) Estimating regional storage capacity through composition simulation using flow units and their key properties (\(\Phi, kv, kh, Pc\)) using neural net realizations founded on core, test, and petrophysical data from Wellington and Cutter field calibration coreholes.

- Model CO\(_2\) storage at Wellington & Cutter flds and three additional fields in southwestern Kansas
  - **Success** –
    a) Drilled 3 basement tests, 2@ 5200 ft TD at Wellington Fld & 1@7700 ft (Cutter Fld)
    b) Cored 2552 ft of Arbuckle and caprock in Wellington and Cutter fields
    c) Collected 22 mi\(^2\) of multicomponent 3D seismic
    d) Built static (Petrel) and dynamic models (CMG) with CO\(_2\) storage and EOR outcomes
Static and dynamic modeling of the Lower Ordovician Arbuckle Group in 25,000 mi² area

Predict CO₂ storage within ±30 percent

Information accessed via projects interactive mapper

Wellington Field
Sumner Co.

Cutter Field
Stevens Co.
MegaModel (simulation) and 10 regional sites for commercial-scale simulation

**CO₂ Storage Capacity of the Arbuckle in Southern Kansas (25,000 mi²)**

- 10 local modeling sites (yellow boxes) including Cutter and Wellington fields
- Simulation of entire 25,000 mi² based on estimation of rock properties
- *Predict CO₂ storage within ±30 percent*
MegaModel grid showing local refinement

Elevation (ft) from lowest cell

50x vertical Exaggeration

Williams, Gerlach, Fazelalavi, Doveton, KS CO₂
Illustration of local grid refinement, site 4b, SE Kansas
Neural network (NN) prediction of Arbuckle permeability from logs
Comparison of permeability predictions in validation well (#1-28) by neural network with different numbers of nodes in the hidden layer

core-log calibrated

\[ k = 1014 \left[ \frac{a}{S_\text{wir} \phi_e} + b \right]^2 \frac{\phi_e^3}{(1 - \phi_e)^2} \]

predicted

Neural network

Doveton & Fazelalavi, KGS, CO2
Flow units & computed \( Kh \) & \( Kv \) in Arbuckle Group for Digital Type Wells (●)

- Correlation of flow units
- Between Cutter and Wellington Fields (350 km)
Lower Flow Unit For Regional Modeling in Arbuckle Group 25,000 mi² in southern Kansas

Stucture - sea level datum, 100 ft C.I.

50 miles

Cutter KGS #1

Wellington KGS #1

Gerlach, CO₂

Low Kv1 – Gasconade & Gunter Sandstone

Thickness, 10 ft C.I.
Structural cross section showing regional Arbuckle flow units, southern Kansas

Index map, Kansas

Permeability, md
Java Applets (freeware)  
-- assist in geoengineering analysis of reservoirs  
Predict geologic CO₂ storage capacity within ±30%

http://www.kgs.ku.edu/Gemini/Tools/Tools.html
CO$_2$ and oil & gas mapper
Cumulative oil fields with Upper Pennsylvanian oil production

Northwest Kansas

Hall-Gurney

View lease production via bubble map
Cumulative Oil Lease Production
Hall-Gurney Field, 2012

Decline curve
1 MM bbl lease

Early 2000’s
KU-Murfin
CO2-EOR
test site

http://www.kgs.ku.edu/software/production/

http://www.kgs.ku.edu/PRS/Ozark/GBubbleMap/GBubbleMap.html
Mississippian Reservoir and Caprock in Wellington #1-32

Mississippian Reservoir

Wellington Field

at residual saturation

Log analysis applet

Depth-constrained cluster analysis using GR, Pe, Dphi, Nphi

Cluster Analysis - Group Means

Number of Charts = 10  
R-squared = 0.772

(Resistivity vs. Porosity)

Depth-constrained cluster analysis using GR, Pe, Dphi, Nphi

Oil show and indicated pay in Group 9

Group 2

Group 6 (wet)

Group 9

Group 10

Mississippi Reservoir Wellington Field at residual saturation
Southwest Kansas CO$_2$-EOR Initiative

Evaluate CO$_2$ sequestration potential in Arbuckle Group saline aquifer and CO$_2$-EOR in four fields in southwestern Kansas – Anadarko, Berexco, Cimarex, Glori, Elm III, Merit

Southwest Kansas CO2 Consortium (Western Annex)
Oil production unevenly distributed in valleys shown by well and OOIP in North Eubank unit

Dubois, Youle, and Williams, in prep.
Reservoir heterogeneity-- stratigraphically complex

-- Four Parasequences in North Eubank unit

Sandstone = yellow; Sandy shale = brown; Gray = shale
Length of section ~ 5 miles

Dubois, Youle, and Williams, in prep.
1. By 2011 water injection exceeded production by approximately one million barrels per year.
2. The reservoir system was significantly under-pressured, having an original BHP of 1572 psig.
3. A normal BHP would be 2350 psi (5500 ft deep x 0.43 psi/ft).
4. Rock fracture pressure is likely to be approximately 3500 psi if the fracture gradient is 0.65 psi/ft.
5. Fractures and conduits were not open until reservoir pressure exceeded approximately 2500 psi.

--- sinkholes possibly responsible for loss of injected water → Will limit CO₂ injection pressures

Reservoir simulations done with four suspected leak points

Dubois, Youle, and Williams, in prep.
Porosity Model (log/3D seismic) of the Siliceous Dolomite Reservoir Upper Mississippian, Wellington Field

Progradation of the Mississippian on West Side of Wellington Structure
-- Looking SW

Rush, KGS
Wellington Field looking NW

Fault juxtaposes reservoir and non reservoir facies

J. Rush, KGS
CO2 plume from simulation of small scale field test injection (26,300 tonnes)
Petrography, Berexco Wellington KGS #1-32
Thin sections from the Mississippian oil reservoir
-- dolomite, silica, minor amounts of anhydrite, organic matter, pyrite
Upper Mississippian Reservoir Quality

Permeability vs Porosity for different Rock Types in Well 1-32

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<thead>
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<tr>
<td>8</td>
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<td>13</td>
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<td>14</td>
<td>5.61</td>
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Schlumberger Techlog Wellbore Software Platform

M. Fazelalavi, KGS
Accomplishments to Date

- KGS Milestone 1.2: Acquire/analyze seismic, geologic and engineering data - Wellington field -- COMPLETED
- KGS Milestone 1.3: Develop initial geomodel for Wellington field -- COMPLETED
- KGS Milestone 1.4: Locate and initiate drilling of Well #1 at Wellington field -- COMPLETED
- KGS Milestone 2.1: Complete Well #1 at Wellington - DST, core, log, case, perforate, test zones -- COMPLETED
- KGS Milestone 2.2: Complete Well #2 at Wellington - Drill, DST, log, case, perforate, test zones -- COMPLETED
- KGS Milestone 2.3: Update Wellington geomodels - Arbuckle & Mississippian -- COMPLETED
- KGS Milestone 2.4: Evaluate CO₂ Sequestration Potential of Arbuckle Group Saline Aquifer - Wellington field -- COMPLETED
- KGS Milestone 3.1: CO₂ sequestration & EOR potential - Wellington field – 98%
- KGS Milestone 3.2: Characterize leakage pathways - Risk assessment area -- COMPLETED
- KGS Milestone 3.3: Risk assessment related to CO₂-EOR and CO₂-sequestration -- COMPLETED
- KGS Milestone 3.4: Regional CO₂ Sequestration Potential - 33 Counties – 99%
Summary

• **Key findings**

  1. Initial estimates of CO₂ P10 & P90 storage in the Arbuckle aquifer are being refined using dynamic modeling at 10 regional sites and single MegaModel spanning southern Kansas.

  2. Use of a reservoir approach to assessing regional storage should improve the estimation of geologic CO₂ storage capacity to within ±30%.

  3. Coring, extensive fluid sampling, well testing, and multicomponent 3D seismic provide a rich basis in Wellington and Cutter fields to serve as calibration sites for the regional models.

  4. Field studies serve as potential template for commercial deployment of CCS in Kansas with an oil field overlying a thick saline aquifer on a structure suited for staged carbon storage that can be accomplished by the local petroleum industry.

  5. Calibration was accomplished with multiple, independent methods that addressed the reservoirs at all scales.

  6. Approaches used by petroleum industry permitted extending key reservoir properties → vertical and horizontal permeability → rational flow units → closely conforming with regional stratigraphic correlations.

• **Future Plans**
  – Complete the final report.
Appendix

– These slides will not be discussed during the presentation, **but are mandatory**
## ORGANIZATIONAL STRUCTURE

**Modeling CO₂ Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO₂ Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas**

### Principal Investigators

- Jason Rush -- Joint PI
- W. Lynn Watney - Joint PI

### Kansas Geological Survey

<table>
<thead>
<tr>
<th>Co-Principal Investigators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerry D. Newell -- stratigraphy, geochemistry</td>
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<tr>
<td>Jason Rush -- Petrel geomodeling and data integration</td>
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<tr>
<td>Richard Miller -- geophysics</td>
</tr>
<tr>
<td>John Doveton -- log petrophysics and core-log modeling</td>
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<tr>
<td>Jianghai Xia -- gravity-magnetics modeling &amp; interpretation</td>
</tr>
<tr>
<td>Marios Sophocleous -- geochemistry</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Key Personnel</th>
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<tbody>
<tr>
<td>John Victorine -- Java web app development</td>
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<tr>
<td>David Laffin -- manage core &amp; curation</td>
</tr>
<tr>
<td>Mike Killion -- modify ESRI map service for project</td>
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<tr>
<td>Jennifer Raney -- asst. project manager</td>
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<tr>
<td>Debra Stewart, Dan Suchy -- data management</td>
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<tr>
<td>Yevehn 'Eugene' Holubnyak, Petroleum Engineer</td>
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<tr>
<td>Fatemeh &quot;Mina&quot; FazelAlavi, Engineering Research Assistant</td>
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### KU Department of Geology

<table>
<thead>
<tr>
<th>Co-Principal Investigators</th>
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<tbody>
<tr>
<td>Evan Franseen -- sedimentology, stratigraphy</td>
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<tr>
<td>Robert Goldstein -- diagenesis, fluid inclusion</td>
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<tr>
<td>David Fowle -- reactive pathways, microbial catalysis</td>
</tr>
<tr>
<td>Jennifer Roberts -- reactive pathways, microbial catalysis</td>
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<tr>
<td>George Tsoflias -- geophysics</td>
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<th>Grad Research Assistants</th>
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<tr>
<td>Aimee Scheffer (graduated) -- biogeology &amp; geochemistry</td>
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<tr>
<td>Breanna Huff -- biogeology</td>
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<tr>
<td>Christa Jackson -- biogeology and geochemistry</td>
</tr>
<tr>
<td>Ayrat Sirazhiev (graduated) -- geophysics</td>
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<tr>
<td>Yousuf Fadelalkarem -- geophysics</td>
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<tr>
<td>Brad King -- diagenesis</td>
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</tbody>
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### Key Personnel

- Larry Nicholson -- regional data acquisition, 2 yrs.
- Dana Wreath - manager, reservoir and production engineer
- Anna Smith -- regional data acquisition, 2 yrs.
- Randy Koudele - reservoir engineer
- Bill Lamb - reservoir engineer

### Berexco, Beredco Drilling -- Wichita, KS

- Wellington Field access; drilling, coring, completion and testing; modeling and simulation

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<td>Dana Wreath - manager, reservoir and production engineer</td>
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<td>Randy Koudele - reservoir engineer</td>
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<td>Bill Lamb - reservoir engineer</td>
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### Bittersweet Energy, Inc., Wichita, KS

- Tom Hansen, Principal, Wichita, Geological Supervision - regional data, Arbuckle hydrogeology
- Paul Gerlach -- regional data acquisition, 2 yrs.
- Larry Nicholson -- regional data acquisition, 2 yrs.
- Anna Smith -- regional data acquisition, 2 yrs.
- Ken Cooper, Petrotek Engineering, Littleton, CO - engineer, well injection, hydrogeology
- John Lorenz, Scott Cooper, FractureStudies, Edgewood, NM - core fracture study

### Kansas State University

**Seismic and Geochemical Services**

<table>
<thead>
<tr>
<th>Co-Principal Investigators</th>
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<tbody>
<tr>
<td>Saugata Dutta -- reactive pathways and reaction constants</td>
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<tr>
<td>Abdelmoneam Raef -- seismic analysis and modeling</td>
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<tr>
<td>Robin Barker (graduated)</td>
</tr>
<tr>
<td>Derek Ohl - seismic analysis and modeling</td>
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<tr>
<td>Randi Isham -- seismic</td>
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<tr>
<td>Brent Campbell - aqueous geochemistry</td>
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### Services

- LOGDIGI, LLC, Katy, TX - wireline log digitizing
- David G. Koger, Dallas, TX - remote sensing data and analysis
- Weatherford Laboratories, Houston, TX - core analyses
- CMG - Simulation Services, Calgary, Alberta – greenhouse gas simulation and software
- Halliburton, Liberal, KS - wireline logging services
- Hedke-Saenger Geoscience, LTD, Wichita, KS - geophysical acquisition, interpretation & design
- Susan E. Nissen, McLouth, KS - Geophysical Consultant, volumetric curvature
- Lockhart Geophysical, Denver, CO - acquis & interpret 2D shear wave, gravity & mag
- Fairfield Industries, Inc., Denver, CO - 2D, 3D multicomponent seismic processing
- Paragon Geophysical Services, Wichita, KS - 3D seismic acquisition
- Echo Geophysical, Denver, CO - 3D seismic processing
- Converging Point - QC seismic acquisition
- Noble Energy, Houston, TX - Denver, CO - collaborating co., fields adjoining Wellington

### Southwest Kansas CO2 EOR Initiative - Chester Morrow

- Martin Dubois, IHR, LLC -- team lead, geomodeling
- John Youle, Sunflower Energy -- core and depositional models
- Ray Sorenson, consultant -- data acquisition and advising
- Eugene Williams, Williams Engineering -- reservoir modeling

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**DOE project -- DE-FE002056**
Gantt Chart
Bibliography

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

- **Journal, one author:**

- **Journal, multiple authors:**

- **Publication:**