Carbon Sequestration in Kansas
Update on DOE funded projects

– a) characterization of CO$_2$ sequestration capacity
  southern Kansas (FE0002056)

b) small scale field test at Wellington Field, Sumner County
  (FE0006821)

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Outline

• Locations of studies, schedule

• Accomplishments
  – Capacity for CO₂ sequestration in Arbuckle saline formation in southern Kansas
  – Source-sink network for CO₂ sequestration
  – Calibration sites for CO₂-EOR and Arbuckle saline formation
    • Wellington Field, Sumner County, 2ⁿᵈ year
    • New seismic and basement test @ Cutter Field, Stevens County, July-Oct. 2012

• Small scale field test at Wellington Field
  – Assessment of CO₂ injection zone, caprocks, and isolation from USDW
  – CO₂ plume management through simulation and MVA

• Summary
Regional Arbuckle Saline Aquifer & EOR-CO2 Mississippian chert reservoir
Wellington Field (DE-FE0002056) Funded Jan. 2010-August 2013

Small Scale Field Test @Wellington (DE-FE0006821) (BEREXCO) Funded Oct 1, 2011-2015

Western Annex CO2 Industry Consortium (Chester-Morrow oil fields & Arbuckle)

Abengoa Bioenergy (Colwich ethanol) Regional Assessment of deep saline Arbuckle aquifer

Cutter Field Basement test July-October 2012

Sunflower Electric Holcomb Station Power plant

Horizontal Test in Arbuckle -- Bemis-Shutts Field, Ellis Co. DE-FE0004566 (Vess-Murfin Drilling) 2010-2013

Westar Jeffrey Energy Center

Funded Jan. 2010- August 2013

50 miles

http://www.kgs.ku.edu/PRS/petro/ogSheetMap.html
3D Seismic and Basement Test
Cutter Field, Stevens County

July-October 2012

• Repeat work done at Wellington Field serving as western calibration site

• Integrate Cutter Field into regional geologic framework
  – Well based mapping, gravity, magnetics, and remote sensing
  – 120 mi² of regional three dimensional seismic imaging
KGS Cutter #1 well on Mississippian structural plateau on local structural high

Gerlach and Bittersweet team, 2012
Initial CO₂ Storage Capacity Estimate
(reported April 2011 for NATCARB) Deep Arbuckle Saline Formation

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

\[ G_{CO₂} = A_t \ h_g \ \phi_{tot} \ \rho \ E_{saline} \]

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

Gerlach and Bittersweet team, 2012

NATCARB, accessed 8-12
Source-Sink Network for CO$_2$ Sequestration

- **Infrastructure for capture and use of anthropogenic CO$_2$ in Kansas**
  - **1$^{st}$ Step** – Capture from Kansas ethanol plants and use in CO$_2$-EOR
  - **2$^{nd}$ Step** – Capture from other Kansas point sources and connect pipelines to other regional supplies; use for CO$_2$-EOR and saline formation sequestration
Ethanol Plants and Selected Oil Fields for CO$_2$-EOR

- Hall-Gurney Field (LKC)
- Stewart Field (Atoka)
- Pleasant Prairie Field (Miss Chester)
- Eubank Field (Chester)
- Shuck Field (Chester)
- Cutter Field (Morrow)
- Wellington Field: Miss
- Spivey-Grabs-Basil Field: Miss
- Geneoseo-Edwards Field (Arb)
- Chase-Silica Field (Arb)

Gravity-stable CO$_2$-EOR
Miscible

SW industry CO$_2$ EOR partnership Chester/Morrow fields

KGS in collaboration with Midwest Governor’s Association & Clinton Foundation Climate Initiative
Ethanol CO$_2$ pipeline concept – Step 1

Total annual CO$_2$ emissions (ethanol + fertilizer): 2.2 million metric tons/year (113 MMscf/day)

KGS in collaboration with Midwest Governor’s Association & Clinton Foundation Climate Initiative
Calibration Site for CO$_2$-EOR and Arbuckle Saline Formation

1. Wellington Field, Sumner County
   1. 12 mi$^2$ of multicomponent seismic
   2. Two wells drilled to basement
      1. 1600 ft of core and comprehensive wireline logs of caprocks and injection zones
      2. Porosity, permeability, pore type, fractures
      3. Geochemistry
      4. Rock mechanics
      5. Formation imaging
      6. DST and step rate/interference test to sample fluids, characterize flow units for phi-k assessment, continuity
2. Establish and characterize baffles, barriers, flow units

3. Construct integrated geomodel for simulation
   1. Interpolate key rock properties from 3D seismic
      1. Map properties of hydrostratigraphic units & caprocks
      2. Map fractures and faults extending well and test data

4. Coupled geomechanical-fluid flow simulation of CO$_2$
   1. Parameterization – core, log, test, geochemical data
   2. Predict plume dimensions through time
   3. Predict pressures, stress, and interaction with caprock
   4. Predict fate of CO2 plume and closure
   5. Define AOR and placement of MVA equipment
Plans

Small Scale Field Test at Wellington Field

1. Class II permit for CO$_2$-EOR pilot and Class VI permit for CO$_2$ saline test (submit application to EPA in September 2012)

2. Establish CO$_2$-EOR injection and install MVA in the Mississippian oil reservoir
   - Drill injection well and monitoring well and install MVA
   - Inject 30,000 metric tons (mid 2013)
   - Test model, and account and verify CO$_2$ to meet 99% sequestration.
   - Effectiveness, economics, and scaling facilities

3. Inject 40,000 metric tons CO$_2$ into Arbuckle saline formation with permit and DOE funding (~2014)

4. Test & refine model, verify and account for CO$_2$ injected to ensure 99% CO$_2$ storage permanence in the injection zone
Boreholes penetrating Mississippian oil reservoir in Wellington Field

- Location of Mississippian boreholes to be monitored during and after CO$_2$ injection into the Arbuckle via KGS #1-28

- Location of Mississippian injection borehole and 5-spot pattern of producing boreholes
Groundwater Wells

- No major municipal supply within 3 miles of 1-28 (proposed Arbuckle CO2 injector)
Stratigraphic Column New Basement Test
Berexco Wellington KGS #1-32
Completed at Wellington Field
February 2011
Conventional 4.5 inch core from base Pennsylvanian shales to basement (3550-5178 interval, 1628 gross ft, 1528 net feet)

- Top core = 3550 ft
- Pennsylvanian shales – caprock
- Tight lower Mississippian argillaceous siltstone (caprock)
- Chattanooga-Simpson Group caprock
- Arbuckle Group
- Baffles/barriers
- Proposed injection zone
- Mississippian dolomite (EOR)
- Multiple intervals of thick shale and interbedded Pennsylvanian and Permian carbonate strata
- Permian Evaporites (behind casing)
- 500 ft
- Land Surface
- 5200 ft
- 3600 ft
- 4200 ft
- 5158 ft - granite
- 200 ft
- 3600 ft
- 600 ft

http://www.kgs.ku.edu/stratigraphic/PROFILE/
CO₂ injection zones in Arbuckle saline formation and Mississippian oil reservoir, and associated caprocks -- Well profile in 2-way travel time of KGS #1-28 illustrating synthetic seismogram and seismic impedance (velocity x density) and well log suite used to derive these seismic properties.

- Top Mississippian
- Top Arbuckle
- Gasconade Dol.
- Cherryvale Sh.
- Giada Fm.
- Baffle/barrier
- Tight, dense
- High impedance
- CO₂ Injection zone
- Precambrian granite – bottom of core

[http://www.kgs.ku.edu/software/SS/](http://www.kgs.ku.edu/software/SS/)
Upper Primary Caprock Interval
(core slabs from KGS #1-32)

Lower Mississippian PIERSON LIMESTONE (~120 ft thick) : Dark, organic, argillaceous siltstone

3927-3939: olive gray, argillaceous dolomitic siltstone; 50% silt; wispy shale laminations; indistinct bedding; faint discontinuous laminations; gradational contact

3939-3975.6: medium dark gray; very argillaceous dolomitic siltstone; faintly laminated irregular; 30% silt; 3972-3973 cm-sized irregular calcareous nodules/coarse calcite; faint lenticular bedding alternating olive gray and medium dark gray

3975.6-3993: very dark greenish gray; shale; tight; dolomitic; around 20% silt; scattered black shale laminae; uniform; scattered pyrite; 3983 starts increasing silt; gradational contact
Arbitrary Seismic Profile in time – showing impedance (velocity x density)

- Top Mississippian
- Top Arbuckle
- Top Precambrian
- Top Oread
- Thick Lansing Group Shales
- Top Kansas City Ls.
- Lower Pierson

Baffle or potential barrier to vertical flow (high impedance)
Low impedance injection interval
Permeability Profile of Arbuckle in #1-32
with concentrations of redox reactive ions; ferrous iron, sulfate, methane, and nitrate
\((\text{Fe}^{2+}, \text{SO}_4^{2-}, \text{CH}_4, \text{NO}_3^-)\) in KGS #1-32 & #1-28

TEAs vs. Permeability and Depth

Redox reactive ions reflect changes in biogeochemistry occurring between upper and lower Arbuckle attributed to lack of hydraulic communication between the Upper and Lower Arbuckle

Scheffer, 2012
Lower Arbuckle injection interval
-Waters distinct from upper Arbuckle and Miss
-Lower intervals are also geochemically homogeneous

Scheffer, 2012
Fracture Characterization in Arbuckle

*Spectral acoustic log & core description*

Stacked baffles and barriers to vertical flow

*Top Arbuckle*

*Precambrian*

*Spectral Sonic*  
Visual

% Anisotropy  
5% Anisotropy cutoff  
Fractures  
Horizontal vugs  
No core recovery

Proposed Arbuckle injection zone

Scheffer, 2012
Rock Fabrics in “baffle” interval of middle Arbuckle -- Thin section photomicrographs

Barker et al. (2012)
Layered injection zone

- Probable communication between layers along boundaries and fractures
- Geochemical data suggests homogeneous hydrostratigraphic unit

Doveton, 2012
Core from Lower Arbuckle Injection Interval

5089-92 ft

5080-83

5053-56

4995-97.7 ft
4923.7 ft
Large dolomite crystals filling pore space in finely crystalline dolomite

4955.85 ft
Chalcedony filling pore surrounded by microporous silica

Rock Fabrics in proposed injection zone, lower Arbuckle

-- Thin section photomicrographs and SEM micrographs from KGS #1-32

Barker et al. (2012)

Dolomite-chert contact could be a potential reaction site with preferential dissolution of dolomite and formation of fractures along reaction fronts.
Porosity inversion on intermediate PSDM in (Petrel™) Geocellular model

Top Miss. Porosity (pay)

Pierson (apparent porosity, ~clay content)

Top Arbuckle surface

Lower Arbuckle injection zone

KGS #1-32

KGS #1-28

J. Rush, 2012

#1-32 w/GR log (right) & porosity (left)
Shales = more red
Porosity Inversion & Structure

Depth-Migrated 3D Seismic at Wellington Field

North direction into the right side of image

J. Rush, 2012
Provisional Coupled Geomechanical-Flow Model of 40,000 tons CO$_2$ injection into lower Arbuckle

Model Properties

• 3D Homogeneous Grid (*yet to included updated geomodel*)
• Pressure and CO$_2$ Solubility Considerations
• Dual porosity – matrix porosity and fractures
• This particular model **has yet to include:**
  - Potential faults or compartments within the reservoir (to be obtained from latest processing of 3D seismic)
  - Additional sealing units, overlying Mississippian formation
Coupled geomechanical-fluid flow modeling of CO₂ injection into lower Arbuckle

Porosity 2017-12-01  J layer: 25

File: co2 water solu
User: eugene
Date: 7/27/2012
Scale: 1:9408
Z/X: 4.00:1
Axis Units: m

Cap-Rock
Top Arbuckle
Por = 0.15  Frac. Por = 0.20
Tight Arbuckle
Por = 0.05  Frac. Por = 0.10
Injection zone
Por = 0.08  Frac. Por = 0.15

4780 ft Model Top
5200 ft Model Bottom

Holubnyak, 2012
9 mo. Injection Scenario – High Permeability Case – 40 kt CO₂

Matrix Flow

9 months of injection

Lower Arbuckle

Lower & mid Arbuckle

40 years

Entire Arbuckle

100 yrs. 11-21-2112

Holubnyak, 2012

300 yrs 1-1-2312
3D View of CO₂ Spatial Distribution – High Permeability Case – 40 kt CO₂

Note the significant amount of CO₂ trapped due to solubility and residual trapping effects in Lower Arbuckle zone

Holubnyak, 2012
9 Months Injection Scenario – High Permeability Case – 40 kt CO₂
Pressure Distribution (kpa) Over 3 Years

Holubnyak, 2012
Pressure Response Comparison for 3 Cases—40 Mt CO₂
Pressure, Cumulative Gas, and Gas Rate Plot

Mid. Arbuckle acting as a Sealing Unit
Max pressure ~ 800 kPa (116 psi)

9 months of injection, 40 kt CO2

Holubnyak, 2012
Summary of Penultimate Simulation Model for Class VI Application

- Even if Mid-Arbuckle zone is considered as a permeable medium, significant amount of the CO$_2$ is predicted to be trapped in or near the injection zone (Low Arbuckle) due to:
  - Decreased velocity of CO$_2$ travel through less permeable medium
  - Residual and solubility trapping of the CO$_2$ in the mid-Arbuckle zone

- The increase in formation pressure due to CO$_2$ injection is insignificant and caprock/shales will not experience dangerous stress levels.
Presentation Summary

- Locations of studies, schedule
- Accomplishments
  - Capacity for CO\textsubscript{2} sequestration in Arbuckle saline formation in southern Kansas & CO\textsubscript{2}-EOR in Mississippian
  - Source-sink network scenario for initiating CO\textsubscript{2} sequestration
  - Calibration sites for CO\textsubscript{2}-EOR and Arbuckle saline formation
    - Wellington Field, Sumner County
    - New seismic and basement test @ Cutter Field, Stevens County, July-Oct. 2012
- Small scale field test at Wellington Field
  - Assessment of CO\textsubscript{2} injection zone, caprocks, and isolation from USDW
  - CO\textsubscript{2} plume management through simulation and MVA
  - File application for Class VI geosequestration injection permit in September 2012
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