Evaluate CO₂ Sequestration Potential of Arbuckle Group Saline Aquifer and CO₂-EOR in select Mississippian and Chester-Morrow fields in southern Kansas

Total Budget = $12.6 million
DOE Funding = $9.9 million

W. Lynn Watney and Saibal Bhattacharya
GSAC Meeting, KGS
Dec 2, 2010
Study Goal
Evaluate CO₂ Sequestration Potential in KS
- Deep Saline Arbuckle Aquifer in southern KS
- Select depleted mature oil fields (Mississippian & Chester/Morrow)
Start Date - Dec 2009
No CO₂ will be injected in this 3-year project

Overview - DOE-funded Project - Watney
Subsurface fate of injected CO₂ - Saibal
Update Geomodeling Studies – Watney
Update Reservoir Simulation Studies – Saibal
Upcoming Schedule - Saibal

http://www.kgs.ku.edu/PRS/Ozark/index.html
Subjects Outside the Purview of this Project

- CO₂ capture from point sources
- CO₂ transmission – from source to injection sites
- Who owns the pore space?
- CO₂ injection regulations
- Leakage monitoring
- Liability

**Newly funded DOE Project at KGS** – “Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage compartments in the Arbuckle saline aquifer: Reducing uncertainty in CO₂ storage and permanence”

*PIs: Jason Rush & Saibal Bhattacharya*

*Industry Partners: Murfin Drilling Co. and Vess Oil Corporation*

*Total Budget = $1.9 million, DOE Funding = $1.5 million*
Southwest Regional Partnership on Carbon Sequestration

Carbon Sequestration Initiative

On November 21, 2002 Spencer Abraham, former Secretary of Energy, announced to the National Coal Council in Washington, DC a global climate change initiative involving “joint government-industry partnerships working together to find sensible, low cost solutions” for reducing GHG emissions.

These partnerships . . . each made up of private industry, universities, and state and local governments will become the centerpiece of our sequestration program. They will help us determine the technologies, regulations, and infrastructure that are best suited for specific regions of the country.

As a result, seven regional partnerships were formed:
- Big Sky Regional Carbon Sequestration Partnership
- Plains CO₂ Reduction Partnership
- Midwest Geological Sequestration Consortium
- Midwest Regional Carbon Sequestration Partnership
- Southeast Regional Carbon Sequestration Partnership
- Southwest Regional Partnership on Carbon Sequestration
- West Coast Regional Carbon Sequestration Partnership

NATCARB (National Carbon Sequestration Database and GIS) is hosted at KGS and funded NETL
Relevance of CO₂ Sequestration in KS

- Coal-fired power plants to produce for years in Kansas
- DOE efforts to develop carbon capture and storage (CCS) infrastructure
- Initiatives of the *Midwestern Governors Association*
- CO₂-EOR – proven technology for EOR - select depleted oilfields
- Deep saline aquifers – potential to sequester large volumes of CO₂
  - Arbuckle deep saline aquifer underlies large areas in southern KS
- KS centrally located to major CO₂ emitting states and cities
- CO₂ sequestration - potential to become a major industry in KS
  - Government incentives
  - Value of CO₂ as commodity
  - Infrastructure
  - Maturation of technology and regulations
The document contains a map of the Central Kansas Uplift, Sedgwick Basin, and Hugoton Embayment. It highlights various locations such as the Westar Jeffrey Energy Center, Sunflower Electric Holcomb Station Power plant, Wheatland Electric Injection well (new), and the Western Annex. It also mentions Wellington Field (Sumner County) and nearby counties, with contours representing the thickness of the Arbuckle Group. Additional note: Core, injectivity, and aquifer modeling data are available from the OXY-Chembrine injection facility and the Arbuckle Saline Aquifer & EOR CO2 Mississippian Chert/Dolomite reservoir in Wellington Field.
Project Extension Study Area
Western Annex

Western Annex Area
Project Objectives

■ Build Geomodels
  - Field Scale
    - Wellington field (Sumner County)
    - Chester/Morrow fields (Western Annex)
  - Regional Scale – Integrated Model
    - Arbuckle saline aquifer - 17+ counties (south-central KS)
    - Arbuckle Saline Aquifer - Western Annex

■ Simulate CO₂ sequestration potential – Arbuckle Saline Aquifer
  - 17+ county area & Western Annex
    - Identify and model potential sequestration sites
    - Estimate sequestration capacity of Arbuckle saline aquifer in KS

■ Simulate sequestration potential – CO₂-EOR in depleted fields
  - Wellington field (Sumner County)
  - Several Chester/Morrow fields – Western Annex

■ Risk analysis related to CO₂ sequestration

■ Technology transfer
Existing CO₂ Pipeline Infrastructure
Vicinity of Western Annex

Infrastructure is gradually building:
Oklahoma CO₂ Infrastructure

From: Chaparral Energy presentation at JP Morgan conference (March 2010)
Industry Partners – Western Annex
SW Kansas CO₂ Sequestration Consortium

Industrial and Electrical Power Sources of CO₂
# Project Team Members

## Principal Investigators

**Saibal Bhattacharya -- Lead Engineer**

**W. Lynn Watney - Lead Geologist**

## UNIVERUS OF KANSAS

<table>
<thead>
<tr>
<th>Kansas Geological Survey</th>
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<tbody>
<tr>
<td><strong>Co-Principal Investigators</strong></td>
</tr>
<tr>
<td>Kerry D. Newell, Co-PI -- strucure and diagenesis</td>
</tr>
<tr>
<td>Jason Rush, Co-PI -- Petrel geomodeling and data integration</td>
</tr>
<tr>
<td>Richard Miller, Co-PI -- seismic interpretation, shearwave analysis</td>
</tr>
<tr>
<td>John Doveton, Co-PI -- log petrophysics and core-log modeling</td>
</tr>
<tr>
<td>Jianghui Xia, Co-PI -- gravity-magnetics modeling &amp; interpretation</td>
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<tr>
<td>Marios Sophocleous, Co-PI -- aquifer modeling &amp; well testing</td>
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<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 Laflen -- manage core &amp; curation</td>
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<tr>
<td>Mike Killion -- modify ESRI map service for project</td>
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<tr>
<td>Kurt Look, Glen Gagnon, manage and integrate data</td>
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<tr>
<td>Deb Stewart, Dan Suchy, LeaAnn Davidon, Patrick Totaro, Matt Kuntzsch, Matt Kuntzsch, Jennifer DiDonato</td>
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<tr>
<td>Dana Heljeson - website</td>
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<td>Valerie Moreau - accounting and reporting</td>
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<tr>
<th>KU Department of Geology</th>
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<tbody>
<tr>
<td>Evan Franseen, Co-PI -- stratigraphy and diagenesis of OPAS</td>
</tr>
<tr>
<td>Robert Goldstein, Co-PI -- diagenesis, fluid inclusion</td>
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<tr>
<td>Bradley King, GRI, diagenesis</td>
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<tr>
<td>David Fowle, Co-PI -- reactive pathways, microbial catalysis</td>
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<tr>
<td>Jennifer Roberts, Co-PI -- reactive pathways, microbial catalysis</td>
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<tr>
<td>Geology Technician (TBD) - fluid/rock handling</td>
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<tr>
<td>Aimee Scheffer - Microbial studies</td>
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<td>Breanna Huff - Microbial studies</td>
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<tr>
<th>Services</th>
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<tbody>
<tr>
<td>LOGDIGI, LLC, Katy, TX - wireline log digitizing</td>
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<tr>
<td>KOGER, Dallas, TX - remote sensing data and analysis</td>
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## SUBCONTRACTS

<table>
<thead>
<tr>
<th>Kansas State University - Seismic and Geochemical Services</th>
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<tbody>
<tr>
<td>PI- Saugata Datta -- reactive pathways and reaction constants</td>
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<tr>
<td>PI- Abdelmoneam Raef -- seismic analysis and modeling</td>
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<tr>
<td>GRA - Robinson Barker - aqueous geochemistry</td>
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<td>GRA 2 - seismic analysis and modeling</td>
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<tr>
<th>Bittersweet Energy, Inc., Wichita, KS</th>
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<tbody>
<tr>
<td>Tom Hansen, Principal, Wichita, Geological Supervision - regional data, hydrogeology of Arbuckle</td>
</tr>
<tr>
<td>Paul Gerlach -- regional data acquisition</td>
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<tr>
<td>Larry Nicholson -- regional data acquisition</td>
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<tr>
<td>Anna Smith -- regional data acquisition</td>
</tr>
<tr>
<td>Ken Cooper, Petrotek Engineering, Littleton, CO- engineer, well injection, hydrogeology</td>
</tr>
<tr>
<td>John Lorenz, FractureStudies, Edgewood, NM -- structural analysis</td>
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<tr>
<th>CMG - Simulation Services, Calgary, Alberta</th>
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<tr>
<td>simulation software and Greenhouse Gas Simulation Consultancy</td>
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<tr>
<th>Weatherford Laboratories, Houston, TX</th>
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<td>core analyses</td>
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<tr>
<th>Berexco, Beredco Drilling -- Wichita, KS</th>
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<tr>
<td>access to Wellington Field; drilling, coring, completion and testing; modeling and simulation</td>
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<tr>
<td>Key Berexco staff</td>
</tr>
<tr>
<td>Dana Wreath - manager, reservoir and production engineer</td>
</tr>
<tr>
<td>Randy Koudele - reservoir engineer</td>
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<tr>
<td>Bill Lamb - reservoir engineer</td>
</tr>
<tr>
<td>Halliburton, Liberal, KS -- wireline logging services</td>
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<tr>
<td>Hedke-Saenger Geoscience, LTD., Wichita, KS - geophysical interpretation</td>
</tr>
<tr>
<td>Susan E. Nissen, McLouth, KS -- Geophysical Consultant - volumetric curvature</td>
</tr>
<tr>
<td>Russ Opfer, Lockhart Geophysical, Denver, CO -- gravity &amp; mag</td>
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<tr>
<td>Bruce Karr, Fairfield Industries, Inc., Denver, CO -- 2D, 3D processing</td>
</tr>
<tr>
<td>Paragon Geophysical Services, Wichita, KS -- 3D seismic acquisition</td>
</tr>
<tr>
<td>Echo Geophysical, Denver, CO -- 3D p-wave seismic processing</td>
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<td>Converging Point - QC seismic acquisition</td>
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<tr>
<th>Project Enhancement - Western Annex</th>
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<tr>
<td>Enhanced Oil Recovery - Chester/Morrow Fields</td>
</tr>
<tr>
<td>Martin Dubois -- geologist, project manager</td>
</tr>
<tr>
<td>John Youle -- geologist, geomodel development</td>
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<tr>
<td>Ray Sorenson -- geologist, geomodle development</td>
</tr>
<tr>
<td>Paul Gerlach -- geologist, geomodel development</td>
</tr>
<tr>
<td>petroleum engineer (TBN) -- reservoir simulation</td>
</tr>
<tr>
<td>Dennis Hedke, Susan Nissen - seismic interpretation</td>
</tr>
<tr>
<td>Paragon - seismic acquisition</td>
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</table>
Technical Outreach
Presentations to date

- Jan 2010 - Kansas House Energy and Utilities Committee, Topeka
- Feb. 2010 - DOE National Energy Technology Lab (NETL), Pittsburg, PA
- Apr 2010 - Southwest Kansas Royalty Owners Association, Hugoton
- Apr 2010 - Kansas Independent Oil and Gas Association, Great Bend
- May 2010 - Kansas Water Authority, Wichita
- May 2010 - EPA Region 7 UIC Meeting, Kansas City
- Aug 2010 - Kansas Next Step Oil and Gas Seminar, Hays
- Sep 2010 - Kansas Department of Health and Environment, Geology Fall Seminar, Wichita
- Oct 2010 – DOE-NETL Annual Review Meeting, Pittsburgh
- Nov 2010 - Kansas Geophysical Symposium
- Nov 2010 - Briefing to Kansas Corporation Commission officials on drilling at Wellington Field
- Nov 2010 – GSA Annual Meeting, Denver
- May 2011 – Abstract accepted for AAPG 2011 Annual Meeting, Houston
Industry participation in infrastructure development possible if CO₂-EOR is viable

Global annual CO₂ emissions ≈ 8 × 10⁹ tons

Earth Policy Institute

>400 yrs
Current Global emissions

<table>
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<tr>
<th>Formation Type</th>
<th>10⁹ Metric Tons</th>
<th>%</th>
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<tbody>
<tr>
<td>Saline Aquifers</td>
<td>3,297 – 12,618</td>
<td>91.8 – 97.5</td>
</tr>
<tr>
<td>Unmineable Coal Seams</td>
<td>157 – 178</td>
<td>4.4 – 1.4</td>
</tr>
<tr>
<td>Mature Oil &amp; Gas Reservoirs</td>
<td>138</td>
<td>3.8 – 1.1</td>
</tr>
<tr>
<td>Total Capacity</td>
<td>3,592 – 12,934</td>
<td>100.0</td>
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Dec 1, 2010
DOE Update:
500 to 5700 yrs of storage capacity

CO₂ Sequestration Projects Worldwide
Deep Saline Aquifers

- Acid-gas injection (Canada)
- Sleipner (Norway)
- In Salah (Algeria)
- Snøhvit (Norway)
- Gorgon (Australia)
- Mongstad (Norway)
- E.ON (UK)
- ZeroGen (Australia)
- RWE IGCC (Germany)
- Vattenfall (Germany)

- Nagaoka (Japan)
- Frio (USA)
- Ketzin (Germany)
- Otway I & II (Australia)
- RCSP - Phase II (USA)
- RCSP - Phase III (USA)
- HARP, WASP, ASAP, Quest, Aquistore (Canada)
Effectiveness of Injecting Supercritical CO$_2$
**In situ fate & entrapment of CO$_2$**

Injected CO$_2$ entrapped in 4 different ways
- some dissolves in brine
- some gets locked as residual gas (saturation)
- some trapped as minerals
- Remaining CO$_2$ – resides as free phase
  - Sub- or super-critical as per *in situ* conditions
    (depth/pressure and temperature)

### CO$_2$ Entrapment Audit:

1. **Residual gas**
   - Start 45% to End 65%
2. **Solution**
   - Start 18% to End 28%
3. **Minerals**
   - Start negligible to End 5%
4. **Free Phase**
   - Start 37% to End 2%

Ozah, 2005 – *In situ CO$_2$* distribution after 50 years of injection
Dissolution of CO₂ in Brine

Convection Cycle increases entrapment
CO₂ Entrapment as Residual Gas

Residual Trapping

Residual saturation dependent on lithofacies properties – relative permeability and hysteresis endpoints

www.ieagreen.org.uk
CO₂ Entrapment as Minerals

Very slow process.

Important effects –
1) Precipitation leading to injectivity changes.
2) Dissolution and creation of cavities -- Adversely affect integrity of the caprock.

CaCO₃ (Calcite) precipitation occurs at all scales

www.ieagreen.org.uk
Frio Pilot Injection (Texas) - Free Phase Supercritical CO\textsubscript{2} Plume

Current tools (geologic modeling, reservoir simulation, wireline logging, 3D seismic) are capable of tracking subsurface CO\textsubscript{2} migration.

Hovorka et al., 2006, 4-20-06 NETL Fact Sheet & Daley et al., 2007

Leading edge of plume attenuates -- due to solution and entrapment as CO\textsubscript{2} contacts more pore space and brine.

Time Lapse Pulsed Neutron log

CO\textsubscript{2} plume
Ozark Plateau Aquifer System
Arbuckle Saline Aquifer with Primary, Secondary, and Tertiary Caprocks

Net Halite (salt) Isopach (thickness), CI 100’

Total Permian evaporite thickness ranges from 400 to 2000’ in south-central KS. These evaporites serve as ideal cap rocks being located between shallow freshwater aquifers and hydrocarbon bearing strata and deeper Arbuckle saline aquifer.
Site selection for CO₂ sequestration CRITICAL, because all wells drilled in the area have to be accounted for and properly completed before onset of CO₂ injection.

Cross Section Showing Hutchinson Salt Member in Relation to other Geologic Strata

- **Yaggy Gas Storage**
- **Hutchinson**

**Casing Leak**

- 650 psi
- 7 miles

**Lateral movement of gas plume resulted in pressure attenuation (650 psi to 130 psi)**

**Watney et al. (2003)**
Wells Digitizing Inventory
Regional Mapping & Log Analysis

- Pre-Cambrian Wells = 292
- Arbuckle Wells = 14,105
- Type Wells (>200’ into Arbuckle) = 1,417
- Super Type Wells (>400’ into Arbuckle, 1980 or later) = 91

LAS Files (300+ wells)
Regional Study – Tasks Completed and In Progress
Arbuckle Mapping and Areas of Interest

Structure top of Arbuckle Group, regional study area

Isopach Arbuckle Group

Initial Arbuckle modeling site southern Sedgwick County

Wellington Field

50 mi
Regional Study – Tasks Completed and In Progress
Interactive Web-based Project Mapper and Well Data Analysis Tools

Overlay map, configuration top Arbuckle with cross section index

http://maps.kgs.ku.edu/co2/?pass=project

Zoomed in View
• Cross section
• Type well filter

West-East Stratigraphic (left) & Structural (right) Cross Sections
Log-derived lithology and porosity
Mississippian to Precambrian interval
Arbuckle exposure at base of Missouri River, north-central Missouri – Elevation 450 ft & ~200 mi northeast
Assume hydrostatic gradient = 0.435 psi/ft

Permian Hugoton Gas Field
Western Kansas
Original SIP = 435 psi

Sorenson (2005)

Map of the difference between estimated hydraulic head at base of Arbuckle test interval and measured shut-in pressure
Wellington Field Study – Tasks Completed and In Progress
3D seismic P-Wave Processing, Initial Interpretations, & Borehole Site Selection

Mississippian Time Structure

Mississippian Amplitude

Test Borehole Location #28-1

Test Borehole Location #32-1
Wellington Field Study – Tasks Completed and In Progress
3D Seismic P-Wave Processing, Initial Interpretations, & Borehole Site Selection

Arbuckle Time

Most Negative Curvature

Mississippian (blue)-Arbuckle (red) Curvature Overlay

Test Borehole Location #28-1
Move location of #32-1 to east

Courtesy of Susan Nissen / Geotexture
Wellington Field Study – Tasks Completed and In Progress
Geomodel Construction - Porosity Fence Diagram
Mississippian Oil Reservoir

Porosity

0.275

Petrel Model using N-D porosity logs
-- Jason Rush

Test Borehole ~ Location #28-1
Test Borehole ~ Location #32-1

North
Initial Simulation Studies – Tasks Completed and In Progress

Arbuckle flow unit (hydrostratigraphic unit) characterization
Depth-constrained cluster analysis of petrophysical logs
Java-based WELL PROFILE

Precambrian Basement

Arbuckle Structure

Oxy-Chem #10

Interval of interest for CO₂ injection

100 ft.

Jefferson City-Cotter & Roubidoux aquifer (JCC-Rou 1)

JCC 3 - Shaly aquitard

JCC 2 - aquifer

Shaly-aquitard JCC 1

JCC 4 - aquifer

Roubidoux

Rwa - Salinity gradient

Top of Arbuckle

Computed curves

Depth-constrained cluster analysis of petrophysical logs

Arbuckle  Structure

Precambrian

Initial Simulation Studies – Tasks Completed and In Progress

Arbuckle flow unit (hydrostratigraphic unit) characterization
Depth-constrained cluster analysis of petrophysical logs
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Arbuckle Structure

Oxy-Chem #10

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JCC 3 - Shaly aquitard

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Shaly-aquitard JCC 1

JCC 4 - aquifer

Roubidoux

Rwa - Salinity gradient

Top of Arbuckle

Computed curves
Initial Simulation Studies – Tasks Completed and In Progress
9 Township Model – centered around Oxy-Chem #10

Grids: 330’ by 330’
Injection pressure < fracture pressure (3000 psi)
Injection from 2010 to 2060. Run till 2200.

Capacity & Injectivity
Initial Simulation Studies – Tasks Completed and In Progress
2D Model around Oxy-Chem #10 – 20 Layer Model Inputs

Approximately 300 core analysis archived from Arbuckle reservoirs – Byrnes et al 2003

Approximately 300 core analysis archived from Arbuckle reservoirs – Byrnes et al 2003

Salinity vs. Depth

\[ y = 6032.8e^{0.0007x} \]
\[ R^2 = 0.6491 \]
Upcoming Schedule

- Sites selected and permitted for test bore holes #1 & 2
- Industry partner (BEREXCO) completed land/lease legal work
- Rig to move to location for drilling test bore hole #1 on December 20th
- Rig reserved for 3 months
  - Will drill test bore hole #2 after completion of #1 – back to back, finish early February 2011
  - 1600 ft of core
  - Case well and test Arbuckle – pressure & water chemistry
- 2D shear wave survey shot after drilling test bore hole #1
  - Complete converted wave interpretation of multi-component 3D seismic survey
  - Model fractures & faults and refine geomodels of Mississippian oil reservoir and Arbuckle aquifer
- Core Analysis – mid-2011
- Geochemistry – mid-2011
- Revise Geomodel & Simulation – later half of 2011
- Western Annex – Parallel study starting from Feb 2011
- Project End Date – Dec 2012
- Planning to respond to anticipated new DOE solicitation for Small-scale pilot CO₂ injection in early 2011
  - < 500,000 tons of CO₂