Evaluating Carbon Storage in Morrowan and Mississippian oil fields and Underlying Lower Ordovician Arbuckle Saline Aquifer in Southern Kansas

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ABSTRACT

Kansas currently has no large scale source of CO2 available to support an active CCUS industry, yet oil fields in Kansas offer substantial reserves potentially recoverable by CO2-EOR (~ 2 billion bbls). Oil fields in southern Kansas also overlie a deep (>1200 m), thick (150 to 300 m) Arbuckle saline aquifer that could greatly increase CO2 storage capacity in these fields. Operation of overlying fields could also serve to monitor, verify, and account (MVA) for CO2 that is injected and aid in achieving cost-effective management of commercial scale CO2 storage (10's millions of metric tons) in the saline aquifer while reducing uncertainty.

A multi-disciplinary investigation funded by DOE and cost share from industry partners is evaluating the CO2 storage capacity in five oil fields and establishing regional storage capacity of the deep saline Arbuckle aquifer. Regional 3D seismic, digital well logs, potential fields, and remote sensing data are being used to build geomodels and conduct simulations at additional sites potentially best suited for commercial scale CO2 storage. Together field and site studies will serve to calibrate the regional model.

Co2 will be injected on a small scale in a Mississippian reservoir and the underlying Arbuckle saline aquifer in one of these fields, Wellington Field, Sumner County, Kansas. Drilling, coring, and seismic acquisition in Wellington and more recently at Cutter Field in Stevens County, Kansas has added new information about the complex hydrostratigraphic units that comprise the Arbuckle and characteristics of the overlying caprock. Geomodeling and reservoir simulations of Morrow and Chester sandstone reservoirs in southwestern Kansas, and the Osage-Meramec dolomitic chert reservoir at Wellington Field are focused on evaluating the efficacy of CO2-EOR. This extended knowledge is being applied to gain a Class VI permit to inject CO2 into the Arbuckle at Wellington Field. The information obtained and methodologies applied in the CO2-EOR projects will assist industry in implementing optimal carbon management. Combining the oil field and underlying saline aquifer will help to minimize uncertainty and risk aided by the knowledge gained from field development and the fact that the accumulation of oil attest to the integrity of overlying sealing strata.

Background To Project DE-FE0002056

The project funded by U.S. Department of Energy and cost share partners is focused evaluating the potential for CO2-EOR in Mississippian and lower Pennsylvanian sandstone and chert reservoirs and CO2 storage potential in the thick Arbuckle Group saline aquifer that underlies these reservoirs in southern Kansas.

The study is a collaborative, 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.

The project has three areas of focus: 1) collection of seismic and drilling data at Wellington and Cutter oil fields and modeling CO2-EOR and sequestration of CO2, 2) characterization of CO2 storage potential in 25,000 square mile/ 33-county area of southern Kansas, and 3) perform static and dynamic modeling for CO2-EOR of Shuck, Eubank North, and Pleasant Prairie South fields in southwestern Kansas using existing well, production, and seismic data contributed by industry partners.

The primary DOE program goals are to develop data and methodologies to use that data tailored to Kansas that will support industries' ability 1) to accurately estimate CO2 storage capacity in the reservoirs studied and 2) convey metrics to define economics and information to assess risk in deploying CO2 projects in Kansas.

Acknowlegements -- The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0002056 and DE-FE0006821. W.L. Watney and Jason Rush, Joint PIs. Project is managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.

PROJECT DE-FE0002056

MODELING CO2 SEQUESTRATION IN SALINE AQUIFER AND DEPLETED OIL RESERVOIR TO EVALUATE REGIONAL CO2 SEQUESTRATION POTENTIAL OF OZARK PLATEAU AQUIFER SYSTEM, SOUTH-CENTRAL KANSAS

KSCO2

Benefits of this program to DOE and stakeholders interested in CO2 utilization in Kansas

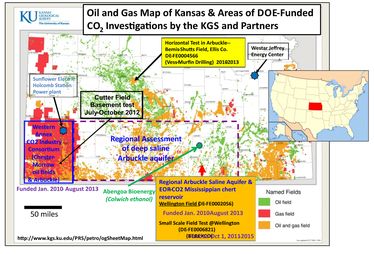
1) **identify CO2 storage capacity to aid in sizing resources that are needed for industrial sources of CO2;**

2) **provide efficient, proactive public access to the data and results derived from the study using latest information technology, e.g., *project's interactive map and Java web applications*;**

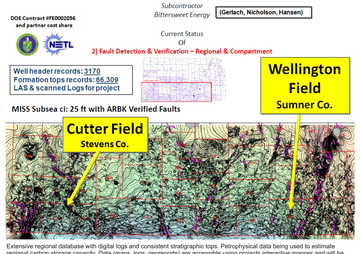
3) **utilize new comprehensive data collected from the project at Wellington (*Sumner County*) and Cutter fields (*Steven's County*) to refine fundamental understanding of the interaction of CO2 with the rocks, brine, and oil;**
   a. Characterize and quantify properties in ~500-1000 ft thick Lower Ordovician Arbuckle saline aquifer

4) **systematic structural and stratigraphic analysis in Kansas:**
   a. identify and digitize key wells to develop consistent stratigraphic nomenclature and classification and digital lithologic control for the subsurface,
   b. refine stratigraphic correlations and resulting maps,
   c. incorporate donated regional 3D seismic information, reprocess state-wide gravity-magnetics maps, and conduct remote sensing to identify structures, verify faults and flexure, and conduct risk analysis.

5) **evaluate commercial scale CCUS feasibility and assess risks at five oil fields and 8 regional sites.**



Structure Contour Map -- Top Mississippian with regional faults



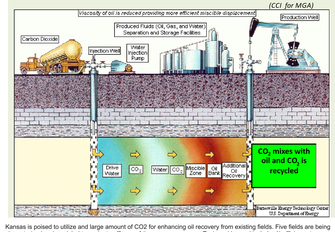
Extensive regional database with digital logs and consistent stratigraphic tops. Petrophysical data being used to estimate regional carbon storage capacity. Data (maps, logs, georeports) are accessible using projects interactive mapper and will be also accessible through NATCARB ATLAS.

Relevance of Carbon Capture Utilization and Storage in Kansas

- Coal-fired power plants to produce for years in Kansas
  - Need to address problem of CO_2 emissions
- DOE efforts to develop carboncapture, utilization, and storage (CCU$) infrastructure
  - Kansas participating in that effort
- Initiatives of the *Midwestern Governors Association*
- CO_2-EOR– proven & reliable technology (utilization)
  - Potential applications in many depleted KS fields
- Deep saline aquifers – have potential to sequester/dispose of large volumes of CO_2
  - Arbuckle saline aquifer in KS
    - Is deep and thick - suitable for supercritical CO_2 injection
    - Underlies a large area in south-central KS
- Kansas centrally located to major CO_2 emitting states and cities
- CO_2 sequestration has the potential of becoming a major industry in KS
  - CO3-EOR
  - Government incentives
  - Value of CO_2 as commodity
  - Infrastructure
  - Maturation of technology and regulations

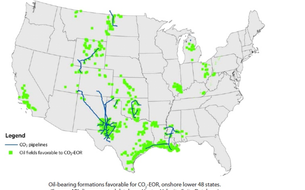
KSCO2

2 billion barrels of recovered oil demands
670 – 1,050 MMT net CO2

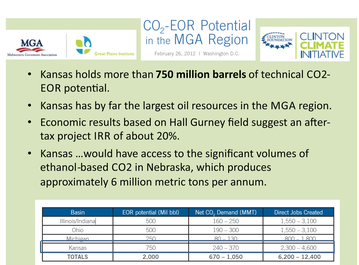


Kansas is poised to utilize and large amount of CO2 for enhancing oil recovery from existing fields. Five fields are being characterized and modeled to evaluate efficacy of the recovery process. Topics addressed include: 1) efficiency to sequester the CO2, 2) best practices tailored to Kansas to monitor and verifying the CO2, 3) managing the CO2 plume and risks.

Current Pipeline Infrastructure

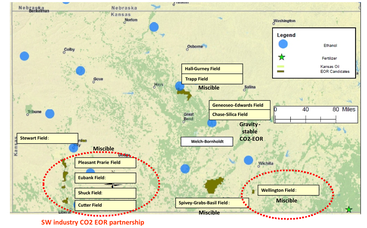


Oil-bearing formations favorable for CO_2 EOR, onshore lower 48 states.
(Source: IHS disaggregated database, Ventex Velocity Suite Database)



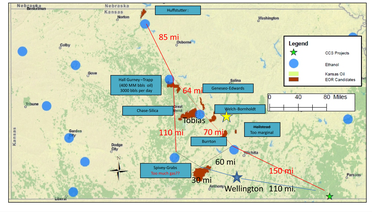
Study conduced for the *Midwest Governor's Association* indicated that Kansas is on the top of the states in this region in terms of utilizing the Co2 for enhanced oil recovery and that industrial sources of Co2 are available in the region. Study was conducted by the Clinton Climate Initiative.

Ethanol Plants and Selected Oil Fields for CO2-EOR



SW industry CO2 EOR partnership
Chester/Morrow fields

CO2 Pipeline Scenario: *Select CO2-EOR Candidates*



Major accomplishments and project completion

1) Provide interactive maps and documentation to access information on the distribution and rock properties of the Lower Ordovician Arbuckle Group in southern Kansas covering approximately 33 counties in 25,000 mi2 area. Success measured in >3000 wells scanned, >2000 wells digitized wells correlated. Prepare final estimate of CO2 storage capacity for the deep saline aquifer within ±30 percent)

2) Develop static and dynamic models of carbon dioxide injection within the Arbuckle Group saline aquifer and the overlying Mississippian siliceous dolomite oil reservoir at Wellington Field (Sumner County, Kansas) based on drilling two 5200 ft deep basement tests, 1620 ft of coring, logging, and extensive testing and analysis. Acquired, processed, and interpreted 12 mi2 of multicomponent 3D seismic.

3) Evaluate CO2 sequestration potential in Arbuckle Group saline aquifer and CO2-EOR in four fields in southwestern Kansas (*Calibration site for storage and evaluate suitability of site for CO2 injection*).

4) Drill, core, test 7500' basement test at Cutter Field, Stevens County, KS; acquire 10 mi2 of multicomponent 3D seismic.

5) Simulate CO2-EOR @ four fields – Cutter, South Pleasant Prairie, Eubanks North, and Shuck fields

Partners
FE0002056

Southwest Kansas CO_2-EOR Initiative
Industry Partners (modeling 4 Chester/Morrowan oil fields to make CO2 ready)

Dawson-Markwell Exploration Co.

Industrial and Electrical Power Sources of CO_2

DOE-NETL Contract – Small Scale Injection #FE0006821

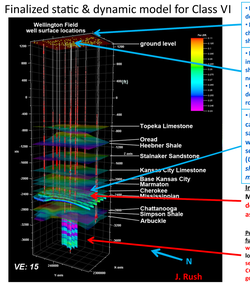
KANSAS STATE UNIVERSITY
Department of Geology

Project Objectives -- DE-FE0006821 Small Scale Injection

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons (680,000 MCF) of CO2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (*monitoring, verification, and accounting*) tools and techniques to monitor and visualize the injected CO2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO2 plume dispersal and estimate tonnage of CO2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure.

Additionally, approximately 30,000 metric tons (510,000 MCF) of CO2 will be injected into the overlying Mississippian to evaluate miscible CO2-EOR potential. The CO2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Finalized static & dynamic model for Class VI



- InSAR/LiDAR CGPS surface deformation/IRIS seismometers
- Measure soil gas flux and chemistry through series of shallow probes.
- Monitor for tracers, CO_2, inorganics and organics in 12 shallow freshwater wells (in two nests of 6 wells)
- Monitor two deeper wells ~600 ft deep below shallow evaporite cap rock
- Measure for tracers and CO_2 casing head gas and fluid samples from Mississippian wells (if positive, run 2D seismic) (*Underpressured oil reservoir should trap any vertically migrating CO2*)

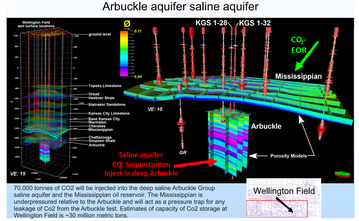
Inject 30,000 tonnes of CO_2 into Mississippian oil reservoir to demonstrate CO2-EOR and 99% assurance of storage with MVA

Pending Class VI permit and DOE funding -- Inject 40,000 tonnes of CO_2 with SF6 and krypton tracers into lower Arbuckle saline aquifer and seismically image and sample in situ CO_2 plume development to verify geomodel and simulations

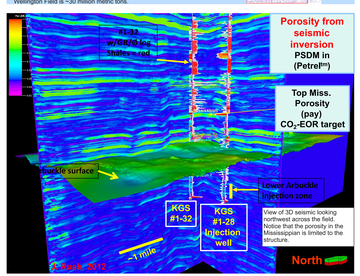
3D Petrel geomodel depicting the key stratigraphic intervals at Wellington Field. Porosity is illustrated for the Mississippian oil reservoir and the Arbuckle with brighter blues as higher porosity. Proposed injection zone in the Arbuckle is the lower Gasconade Dolomite to Gunter Sandstone interval. The log columns are scaled in gamma ray, the more red the more clay content.

The extensive monitoring methods are listed along the right side of the figure to verify and account for the location of the CO2 plume. Monitoring methods are also being evaluated to determine best and most cost efficient technologies for Kansas.

Mississippian siliceous dolomite reservoir & Arbuckle aquifer saline aquifer

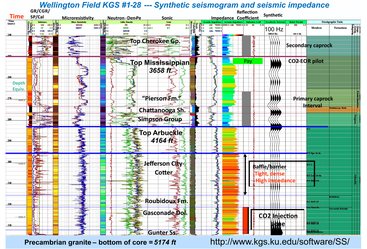


70,000 tonnes of CO2 will be injected into the deep saline Arbuckle Group saline aquifer and the Mississippian oil reservoir. The Mississippian is underpressured relative to the Arbuckle and will act as a pressure trap for any leakage of Co2 from the Arbuckle test. Estimates of capacity of Co2 storage at Wellington Field is ~30 million metric tons.



CO_2 injection zones in Arbuckle and Mississippian

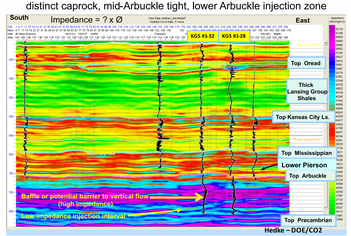
Wellington Field KGS #1-28 -- Synthetic seismogram and seismic impedance



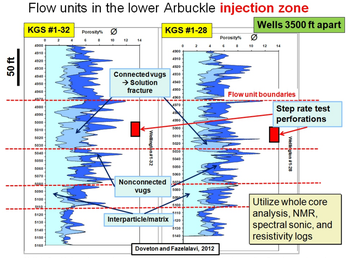
The Mississippian pay zone is clearly see as a low impedance interval (blue color). Similarly, the injection zone in the Arbuckle is (green to yellow).

Arbitrary seismic impedance profile

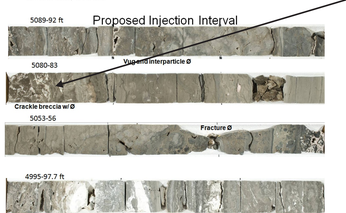
distinct caprock, mid-Arbuckle tight, lower Arbuckle injection zone



Flow units in the lower Arbuckle **injection zone**



Multiple **Crackle breccia** zones in upper peritidal cycles – possibly dissolved evaporites. Breccia pores have also been enhanced through dissolution on the Lower Arbuckle – *Gasconde Dolomite interval*, which serves are the injection zone. Figure above shows pore types from well log response in the injection interval sets, which compares closely to the core.

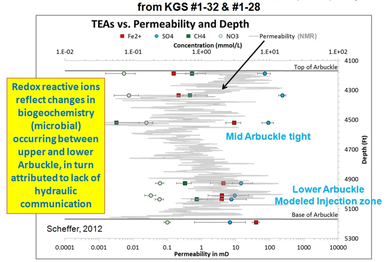


DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

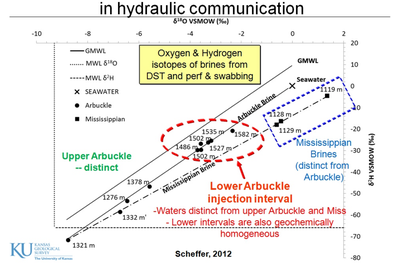
Permeability profile of Arbuckle in cored well - #1-32

with concentrations of redox reactive ions (Fe^{2+}, SO_4^{2-}, CH_4, NO_3^-) from KGS #1-32 & #1-28



Permeability profile from Coate's permeability algorithm of the nuclear magnetic resonance log showing three basic divisions of the 1000 ft thick Arbuckle Group. Brines sampled from DST and perf and swab testing show contrasting chemical, isotopic, and microbial composition supporting premise that the Arbuckle is comprised of three distinct and hydraulically isolated hydrostratigraphic units.

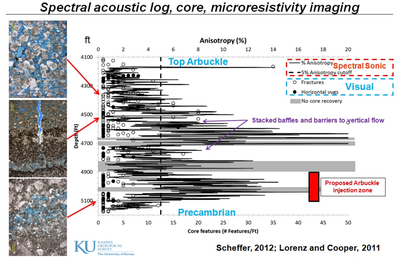
Lower and upper Arbuckle are not in hydraulic communication



This is the clearest indication to date that the lowest hydrostratigraphic unit (proposed injection zone) in the Arbuckle Group is hydraulically isolated from the upper units and from the Mississippian. This attests to the effectiveness of the middle "baffle" unit and overly caprock.

Zonal fracturing in Arbuckle

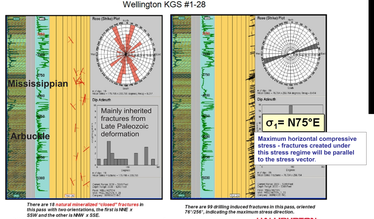
Spectral acoustic log, core, microresistivity imaging



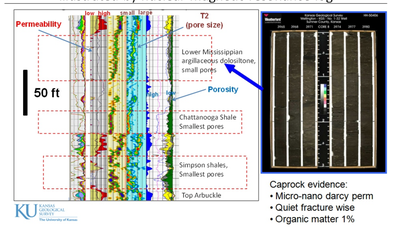
Many of the fractures in the Arbuckle are zonal, and specific to beds and their mechanical/textural properties that they exhibit. The zonal fracture units are meter-scale, part of the peritidal dolomite/siliceous bedsets that comprise the Arbuckle. The highest permeability corresponds to grain-supported clean carbonate and, in particular, the crackle breccia zones that are believed to represent dissolved evaporites.

Fracture Statistics: 5249'-3030'

Wellington KGS #1-28

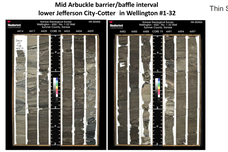


230 ft gross thickness interval of primary caprock in KGS #1-28 (injection well) – illustrated by nuclear magnetic resonance log

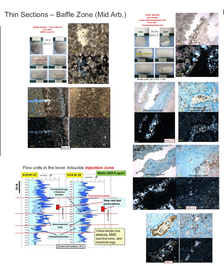


Caprock evidence:
- Micro-nano darcy perm
- Quiet fracture wise
- Organic matter 1%

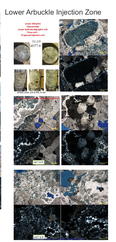
Mid Arbuckle barrier/baffle interval
lower Jefferson City-Cotter in Wellington #1-32



Thin Sections – Baffle Zone (Mid Arb.)

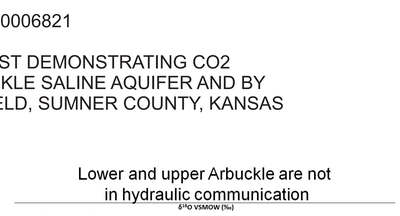


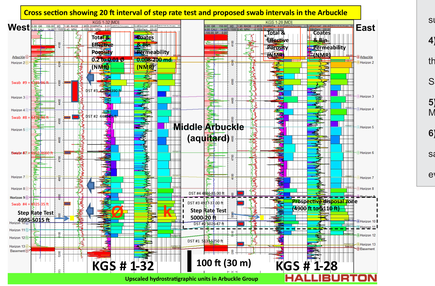
Lower Arbuckle Injection Zone



Flow units in the lower Arbuckle injection zone

Pairs of photomicrographs
Plane light and crossed nichols

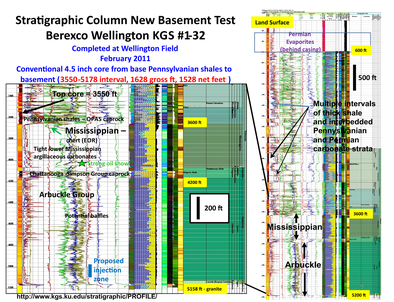




Stratigraphic Column New Basement Test Berexco Wellington KGS #1-32

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)



- Freshwater Aquifers
- Groundwater Recharge
- Potentiometric Surface
- Lateral Seepage Velocity
- Water Use
- Major Water Users
- Withdrawal Rates

Demonstrating the protection of the USDW (U.S. Drinking Water) is critical to a successful Class VI Geosequestration

Draft Underground Injection Control (UIC) Program Class VI Well Site Characterization Guidance for Owners and Operators
http://water.epa.gov/type/groundwater/uic/class6/upload/GS_Site_Char_Guidance_DRAFT_FINAL_031611.pdf

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Class VI Geosequestration Injection Permit

1) **Submittal of Class VI application to EPA in June 2013**

2) **Static and coupled dynamic modeling of saline aquifer for 40 kton CO2 injection (supported by DE-FE0002056)**

3) **Injection zone –**
   a. Highly permeable lower Arbuckle (100s of md to >1 D, ~300 ft thick)
   b. Multiple flow units to decrease thickness of single phase buoyant supercritical CO2 plume

4) **Baffle and trapping of CO2 plume –**
   a. Plume likely accumulate under low pressure only below and within ~400 ft thick middle Arbuckle (lower Jeff-City Cotter & Roubidoux)
   b. Pressure and plume behavior within lower Arbuckle (Gasconade to Gunter Ss.) – very low risk for caprock and movement into nearest deep wells

5) **Primary caprock interval** – ~230 ft gross thickness including Lower Mississippian argillaceous siltstone, Chattanooga and Simpson shales

6) **USDW and interaction with subsurface brines –**
   a. Marginal surface aquifer, its potentiometric surface ~500 ft above that of saline aquifer
   b. Multiple secondary caprock/seals – 1000's feet of shale, and 200 ft shallow evaporites

Suitability of site to inject C02 into the Arbuckle saline aquifer

1) **Suitable injection zone, caprock, and isolation from USDW**
   a. Arbuckle highly stratified three distinct and at least locally isolated hydrostratigraphic units
   b. Even if mid-Arbuckle zone is considered as a permeable medium, significant amount of the CO2 is predicted to be trapped in or near the injection zone due to decreased velocity of CO2 travel through less permeable medium – *residual and solubility trapping*
   c. Modeled pressure increase (226 psi) is insignificant and caprock/shales will not experience dangerous stress levels. Modeled pressure under caprock is slightly greater than 5 psi. Pore pressure will dissipate to near pre-injection pressure.
   d. Arbuckle fluid level is 600 ft below the USDW and pressure of injection would not force brine from Arbuckle into the USDW.
   e. No wells or transmissive faults are present to permit escape of free phase Co2.

2) **Geomechanical analysis and low pressure of CO2 injection into the Arbuckle continue to find that it will be virtually impossible to encounter stress related failure along existing fracture and fault planes due to CO2 injection.**

3) **Simulation results indicate that area of review is within 1000 ft of the injection well, Wellington KGS #1-28**
   a. free phase will penetrate slightly into middle of Arbuckle containing barriers
   b. baffles in middle Arbuckle will obstruct vertical flow and smaller pores to trap the free phase CO2
   c. CO2 plume will contract soon after (3-6 months) cease injection

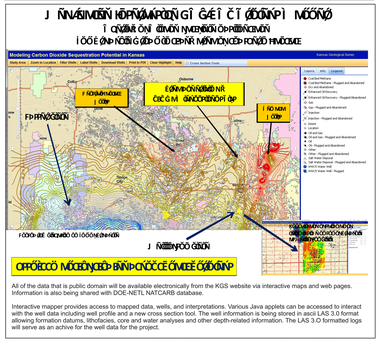
4) **Underpressurization of the upper Mississippian is throughout the area around Wellington Field**
   a. supports the hydraulic isolation of the upper Mississippian from units above and below including the Arbuckle injection zone
   b. underpressurization supports no transmissive faults in the immediate area
   c. natural or induced differential pressures insufficient to mobilize ancient faults
   d. adds addition assurance that the Mississippian is a pressure trap for any CO2 that might leak from the underlying Arbuckle.
   e. Results are consistent with stable isotope data that indicates the Mississippian and Arbuckle hydrostratigraphic units are isolated.

5) **The primary and secondary caprock are most adequate for this small scale test injection based on a combination of geomechanical measurements and modeling, capillary entry pressure, and continuity of the combined caprocks based on seismic imaging.**

Wellington, Cutter, Pleasant Prairie South, Eubank North, and Shuck fields

Each field -- static and dynamic models being completed to evaluate CO2-EOR in Morrow and Chester sandstone oil reservoirs, and Warsaw/Osage Mississippian dolomitic chert oil reservoir

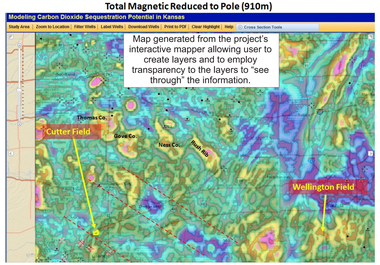
Extensive new data acquired in Wellington and Cutter fields
- over 20 square miles of multicomponent 3D seismic
- 3 basement (Proterozoic igneous rock) tests drilled, totaling over 18,000 ft
- Cored over 2600 ft of section from lower Pennsylvanian to Proterozoic basement
  - Exhaustively logged
  - Extensive being tested



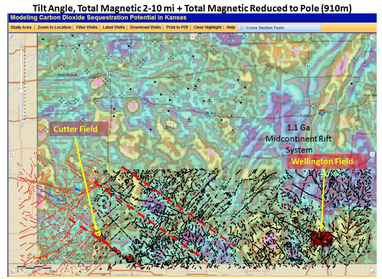
All of the data that is public domain will be available electronically from the KGS website via interactive maps and web pages. Information is also being shared with DOE-NETL NATCARB database.

Interactive mapper provides access to mapped data, wells, and interpretations. Various Java applets can be accessed to interact with the well data including well profile and a new cross section tool. The well information is being stored in ascii LAS 3.0 format allowing formation datums, lithofacies, core and water analyses and other depth-related information. The LAS 3.0 formatted logs will serve as an achive for the well data for the project.

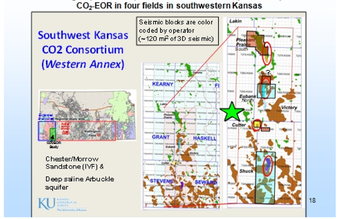
Reprocessed Kansas Magnetics -- Tilt Angle, Total Magnetic 2-10 mi + Total Magnetic Reduced to Pole (910m)



Tilt Angle, Total Magnetic 2-10 mi + Total Magnetic Reduced to Pole (910m)



Evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer and CO_2-EOR in four fields in southwestern Kansas

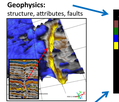


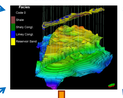
Southwest Kansas CO_2-EOR Initiative

Integrated Multi-Discipline Project for CO_2-EOR Evaluation

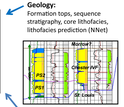
Static Model

Geophysics: structure, attributes, faults

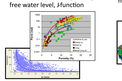




Geology: Formation tops, sequence stratigraphy, core lithofacies, lithofacies prediction (NNet)

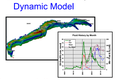


Petrophysics: Core K-Phi, corrected porosity, free water level, J-function

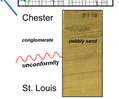


Engineering: PVT and fluid analysis, recurrent histories, dynamic modeling

Dynamic Model



Chester



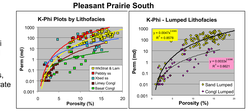
St. Louis

Dubois, 2012 — 10

Example from modeling of Pleasant Prairie South

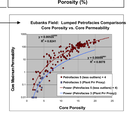
Pore throats, permeability, Sw are dependent on lithofacies

Pleasant Prairie
- Five core lithofacies have somewhat distinctive K-Phi trends (left), but are not all distinguishable on logs
- Lumped into two lithofacies, Sandstone and Conglomerate (right)



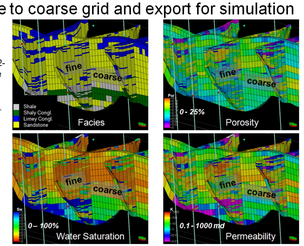
Pore throats, hence permeability and capillary pressure (and Sw) are a function of lithofacies. Thus it is important to distinguish lithofacies in the characterization and modeling process

Eubank
- Lumped lithofacies in Eubank have very similar K-Phi relationships as Pleasant Prairie
- Eubank sandstone has very slightly lower permeability for a given porosity



Upscale to coarse grid and export for simulation

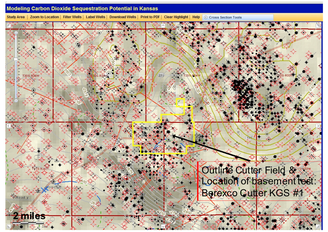
Fine-grid static model 2-ft *h* cells were upscaled to 10-ft *h* cells for simulation.



Example of geomodel from Chester incised valley fill at Eubank Field.

Cutter Field drill site, SW Kansas

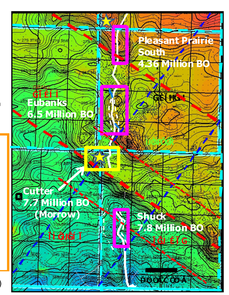
Top Mississippian (contours), surface lineaments (red lines), Lower Permian top Ft. Riley Ls. dip gradient (gray shading)



Mission Accomplished

Berexco Cutter KGS #1 was drilled in August-September 2013. Multicomponent seismic was acquired and has been processed. Data obtained is public information. Upper Morrow oil reservoir is being characterized for CO2-EOR upcoming static and dynamic modeling to accompany analogous study of the Chester sandstone reservoirs in Pleasant Prairie South, Eubanks North, and Shuck Fields.

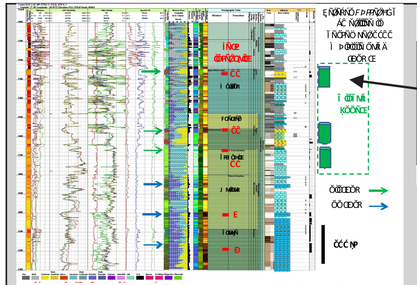
Chester valley incision and fill predated post-Mississippian – pre-Middle Pennsylvanian Ouachita related structural events
- However, traps in valley fill sand pools were sprung by Ouachita events.
- No channel deflection around features.
- Ubiquitous fractures in Chester IVF cores.
- Antecedent paleogeomorphology controlling valley location is discussed in context of more subtle structural deformation



- **Subsea structure on top of Mississippian Meramec** (Ste. Gen. in most of the area). 25' C.I. (smoothed)
- Chester incised valley axis shown as white line.
- DOE investigated Chester valley fill fields located within pink rectangles.
- **Horst blocks** at Cutter, Victory-Eubank and Pleasant Prairie are faulted on south and west flanks
- **Horst blocks** on north sides of regional NW-trending lineaments

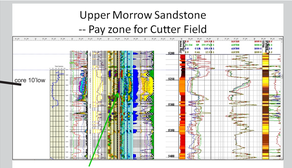
Youle (DOE-CO2)

Structure in southwest Kansas near the Anadarko Basin is rather complex with notable fault systems. Both Mississippian and Pennsylvanian oil and gas fields in the area are clearly controlled by these some of these faults that provided conduits for hydrocarbon migration and traps for accumulation. The new Cutter KGS #1 well that was drilled into the basement encountered oil shows through the lower Paleozoic and upcoming testing will determine the nature of the brines and the oil shows. The knowledge provided by this new data regarding the hydrocarbon system (conduits for fluid migration, timing of migration, reservoirs and seals) is providing a basis for understanding the storage of carbon dioxide in this region.



Upper half of cored interval in KGS Cutter #1, 1042 ft of core cut in the interval from lower Atokan to near base of the Lower Ordovician Gunter Sandstone. 15 ft above Proterozoic granite. Well was cased and casing will be perforated and fluids swabbed in intervals shown beginning ~June 10, 2013

Upper Morrow Sandstone -- Pay zone for Cutter Field

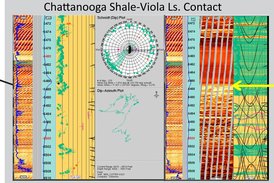


Nuclear magnetic resonance log illustrating the main producing zone at Cutter Field, the upper Morrow Sandstone. The NMR log profile is compared with resistivity log on the right.

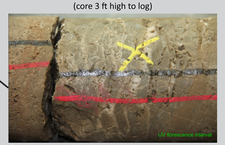
New well being analyzed as western anchor to the regional characterization study – basement test with 1042 ft of core from Middle Pennsylvanian to Precambrian containing oil shows into Lower Paleozoic

API: 15-189-22781 KID: 1044138961
Lease: Cutter KGS Well 1
Original operator: Berexco, LLC
Current operator: BEREXCO LLC
Field: Cutter
Location: T31S R35W, Sec. 1 S2 S2 S2 NE

Chattanooga Shale-Viola Ls. Contact

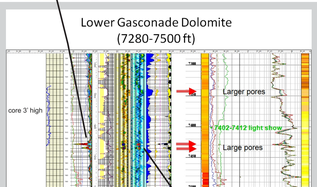


Lower Jefferson City-Cotter Fm, 6932 ft (core 3 ft high to log)

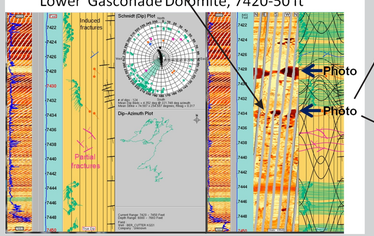


Conglomeratic zone at the top of a peritidal cycle, similar to successions observed in Wellington Field.

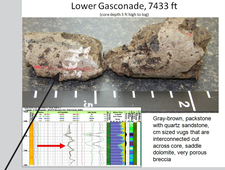
Lower Gasconade Dolomite (7280-7500 ft)



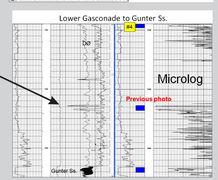
Lower Gasconade Dolomite, 7420-50 ft



Lower Gasconade, 7433 ft



Lower Gasconade to Gunter Ss.

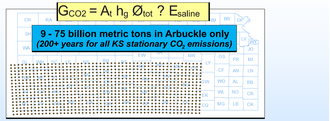


Initial CO_2 storage capacity

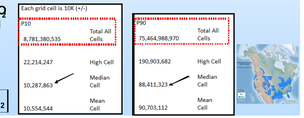
(reported April 2011 to NATCARB) Arbuckle Saline Formation

$G_{CO2} = A_t\ h_g\ \emptyset_{tot}\ ?\ E_{saline}$

9 - 75 billion metric tons in Arbuckle only *(200+ years for all KS stationary CO_2 emissions)*

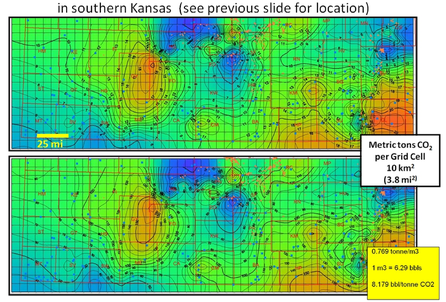


Metric tons CQ per Grid Cell 10 km² (3.8 mi²)



Gerlach and Bittersweet team, 2012

P10 (top) and P90 (bottom)
Storage Volume CO_2 (million metric tons) in deep slaine aquifer in southern Kansas (see previous slide for location)



Summary

Advances in Carbon Capture and Geologic Storage of CO2

· Kansas has added new information about the complex hydrostratigraphic units that comprise the Arbuckle and characteristics of the overlying caprock.

· Geomodeling and reservoir simulations of Morrow and Chester sandstone reservoirs in southwestern Kansas, and the Osage-Meramec dolomitic chert reservoir at Wellington Field are focused on evaluating the efficacy of CO2-EOR.

· This extended knowledge is being applied to gain a Class VI permit to inject CO2 into the Arbuckle at Wellington Field.
· The information obtained and methodologies applied in the CO2-EOR projects will assist industry in implementing optimal carbon management.

· Combining the oil field and underlying saline aquifer will help to minimize uncertainty and risk aided by the knowledge gained from field development and the fact that the accumulation of oil attest to the integrity of overlying sealing strata.