Evaluation of Carbon Sequestration in Kansas -- Update on DOE-Funded Project

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Kansas Water Authority – Committee of the Whole
Wichita, May 14, 2010
Outline

- Why consider carbon sequestration in Kansas?
- What are key components in geologic carbon sequestration?
  - Deep saline aquifers and Enhanced Oil Recovery (EOR)
  - Supercritical CO₂ injection
  - Dynamic processes that sequester CO₂ (flow and storage)
    - Geomodel development -- Quantitative aquifer/reservoir (EOR) characterization
  - Simulation of CO₂ sequestration at target sites
    - Estimate capacities and fate of CO₂
  - Risk Analysis - best practices
    - Evaluating well status
- Status of 3-year DOE-funded project (startup – Dec. 8, 2009)
  - Data gathering – seismic, gravity-magnetics, well data
  - Geomodel development for 17+ county area
  - Geomodel development in Wellington Field in Sumner County

Creation of KWA (Legislative Act of 1981) – Duties include “Reviewing plans of any state or local agency related to the water resources of the state”
Relevance of CO₂ Sequestration in Kansas

- Coal-fired power plants to produce for years in Kansas
  - Need to address problem of CO₂ emissions

- DOE efforts to develop carbon capture and storage (CCS) infrastructure
  - Kansas participating in that effort

- Initiatives of the *Midwestern Governors Association*

- CO₂-EOR – proven & reliable technology
  - Potential applications in many depleted KS fields

- Deep saline aquifers – have potential to sequester large volumes of CO₂
  - Arbuckle saline aquifer in KS
    - Is deep and thick - suitable for *supercritical* CO₂ injection
    - Underlies a large area in south-central KS

- Kansas centrally located to major CO₂ emitting states and cities

- CO₂ sequestration has the potential of becoming a major industry in KS
  - Government incentives
  - Value of CO₂ as commodity
  - Infrastructure
  - Maturation of technology and regulations
Preeminence of Deep Saline Aquifer Sequestration of CO₂

Industry participation in infrastructure development possible if CO₂-EOR is viable

Global annual CO₂ emissions ≈ 8 * 10⁹ tons

Earth Policy Institute

**Carbon Sequestration Options**

<table>
<thead>
<tr>
<th>Formation Type</th>
<th>10⁹ Metric Tons</th>
<th>%</th>
</tr>
</thead>
<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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</tbody>
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Pressure

Temperature

Supercritical CO$_2$

@ depths $>2200$ ft ($>1071$ psi and $87.8^\circ$F) CO$_2$ becomes a supercritical fluid

Supercritical CO$_2$ has properties of both gas and liquid
-- like gas it will fill any given volume
-- its compressibility properties resemble that of liquid
-- 3.6% volume of gas phase
-- density is $\sim0.5$ g/cc (brine $>1$ g/cc)

solid
"Dry Ice"

liquid

supercritical fluid

gas

Pressure

75 psi
-70 F

@ depths $>2200$ ft ($>1071$ psi and $87.8^\circ$F) CO$_2$ becomes a supercritical fluid
Majority of injected CO$_2$ gets trapped as residual gas saturation followed by CO$_2$ dissolved in brine solution. CO$_2$ mineralization is a slow process.

**DOE definition** → “Commercial-scale” sequestration over project life – >30 million tons CO$_2$, (~510 million MCF)

Our study will estimate the amount of CO$_2$ (tons) that will sequestered in various states using site-specific geology, rock, and water properties.

*Ozah, 2005 – In situ CO$_2$ distribution after 50 years of injection*
Migration of supercritical CO$_2$ at different stages of CO$_2$ flooding compared to cumulative injected CO$_2$ volume (Ueda et al., 2007)

-- Note upward trajectory of CO$_2$ fluid and dispersion of “plume”

even after several pore volumes
Frio Pilot Injection (Texas) -- free phase supercritical CO$_2$ plume

Current tools (geologic modeling, reservoir simulation, wireline logging, 3D seismic) are capable of tracking subsurface CO$_2$ migration.

Hovorka et al., 2006
CO₂ Sequestration in Heterogeneous Aquifer
Seismic Monitoring Results - Sleipner field (North Sea)

Every time the CO₂ plume meets a thin shale layer, it spread out laterally. This lateral dispersion results in additional sequestration and plume degradation - CO₂ dissolving into fresh brine and getting trapped in fine pores of the rock. Torp & Gale, 2003

Shale layers (stratification) and aquitards – are present in the Arbuckle aquifer system.

Gas producing zone – High CO₂ content
Deep Saline Aquifer

3D Seismic survey at Sleipner
1996 1999 2001

Reservoir model of CO₂ after 3 years
Source: SACS, Best Practice manual 2003
Locating sites for CO₂ sequestration

**Physical Traps for CO₂**

**Geological Storage**

- **Level I Trap**
- **Level II Trap**
- **Level III Trap**

**Least attractive option if CO₂ plume resides on crest of dome above oil, unless CO₂ injection is optimized for EOR**

**Most attractive option (gently dipping monoclines) to attenuate CO₂ plume through flow in aquifer that is well characterized and modeled**

Density of supercritical CO₂ is ~0.5 g/cc
Faults and fractures will be mapped in the 17+ county study area:

1. Satellite imagery
2. Gravity/magnetic
3. Structure, isopach, and petrophysical maps

Site selection critical to minimize risks associated with $CO_2$ injection

Not all fractures/faults reach the surface – some do and need to be identified

Inventory of all plugged wells critical – REPLUG if needed.
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.

Lateral movement of gas plume resulted in pressure attenuation (650 psi to 130 psi)
Hutchinson Gas Leak – Slide 2

West-to-East Autocorrelated Structural Cross Section
Color Gamma Ray

Yaggy Gas Storage

3-finger dolomite (fractured carrier bed)

Equus Beds

Gypsum beds–caprock

Pathway of gas plume

650 psi

130 psi

Hutchinson Salt

Color Gaps = no stratigraphic correlation, e.g. unconformity

Relief wells

City Of Hutchinson

2 miles

100 feet

(100x vertical exaggeration)

By Olea in Watney et al. (2003)
Hutchinson Gas Leak – Slide 3 (extra)

Core and well log data
Gas-bearing well
DDV #67
Center of Wilson Road seismic line

Core and well log data
Gas-bearing well
DDV #67
Center of Wilson Road seismic line

Core gamma ray
Core permeability
Gamma ray
Sonic Log (slowness/travel time)

Core data
Well log data
Core from DDV #67

3-finger dolomite interval - gas conduit - fractured

Bed "B"

Bed "C"

dolomite clasts

subaerial Exposure surface

Base 3-fingers dolomite interval

1 feet

gypsum

dolomite
Gypsum-rich interval
“CAPROCK”
immediately above
3-finger dolomite
DDV #63
Observation Well OB #2
- Highest recorded pressure, 250 psi, during monitoring stage
- Adjacent to Yaggy Gas Storage Facility

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- Gas zone, layer “C” of 3-finger dolomite—cavitation indicated on caliper log. Zone cased and perforated 409-412 ft

- Partial fractures

- Sonic DT 240 40

- Halliburton’s Electro Micro Imager w/Sonic
Risk Analysis – Faults
Plume Breaches Cap Rock via Fault/Weak zone

Simulated plume after breach → smaller and has lower pressure.
If injection stops before plume reaches fault → then no leakage occurs.

What are the chances that the plume will breach successive cap rocks?
Is CO₂ sequestration tonnage economic before plume reaches fault?

Tsang et al., 2008
Risk Analysis - Simulation

Plume Intersects Inclined Fault and Caprock – Fault does not extend to surface

CO₂ leaks into fault and creates a “virtual CO₂ source”.

CO₂ migrates updip and gets attenuated – additional trapping in solution and as residual gas

Chang & Bryant, 2009
Weyburn CO$_2$-EOR - Canada

Analysis of Natural Faults and Fractures

**Solid Green** – fault trends from seismic & HRAM (high resolution aeromagnetic)

**Broken Green** – trends from HRAM

**Purple** – surface lineaments

**Red oval** – Souris Valley fault (fault identified by seismic and HRAM coincide)

**Broken Red** – weak correlations between data sets

Not all sub-surface faults/fractures reach the surface

IEA GHG Weyburn Summary Report 2000-04

~20 miles across base of map
Carbon dioxide (CO₂) plume undergoes pressure reduction upon breaching cap rock. Also, additional CO₂ gets trapped in the fine pores of aquitards.

*Tsang et al., 2008*
Regionally Extensive Caprock --
Lower Permian Hutchinson Salt Member

Additionally, KGS maps show that total Permian evaporite thickness ranges from 400 to 2000 ft in south-central KS. These evaporites serve as ideal cap rocks. Located between shallow freshwater aquifers and hydrocarbon bearing strata and possible intervals of CO$_2$ sequestration.
“Evaluation of CO$_2$ sequestration potential in deep saline Ozark Plateau Aquifer System (OPAS) in south-central KS - *depleted oil fields and the deep saline Arbuckle aquifer*”

-- American Recovery & Reinvestment Act

**DOE share:**
$4,974,352

**Match by KGS and partners:**
$1,251,422

**Principal Investigators:**
Lynn Watney & Saibal Bhattacharya

**Duration:**
December 8, 2009 to December 7, 2012
Project Objectives

- Build 3 geomodels -
  - Mississippian oil reservoir at Wellington field (Sumner County) - depleted
  - Arbuckle saline aquifer underlying Wellington field
  - Regional Arbuckle saline aquifer system over 17+ counties

- Conduct simulation studies to estimate CO$_2$ sequestration potential -
  - Arbuckle saline aquifer underlying Wellington field
    - Miscible CO$_2$ flood in Wellington field (along with incremental oil recovery)

- Identify potential sites for CO$_2$ sequestration in Arbuckle saline aquifer -
  17+ county area

- Estimated CO$_2$ sequestration potential of Arbuckle saline aquifer – 17+ county area

- Risk analysis related to CO$_2$ sequestration

- Technology transfer

No CO$_2$ will be injected in this project
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

Other DOE projects, ongoing and future, relate to CO₂ capture and transportation.

KS companies are working on proposals including demonstration projects related to CO₂ sequestration by CO₂-EOR and injection into underlying saline aquifers.
Central Kansas Uplift
Sedgwick Basin
Hugoton
Embayment

Core and well data on full Arbuckle at El Dorado Field/ Frontier Refinery

Westar Jeffrey Energy Center
Sunflower Electric Holcomb Station power plant
Wheatland Electric Injection well (new)

Core, logs, and injectivity data in Arbuckle disposal
Core, injectivity, aquifer modeling of Arbuckle from OXY-Chem brine injection facility
Core and well data on full Arbuckle at El Dorado Field/ Frontier Refinery
Arbuckle Saline Aquifer & EOR-CO2 Mississippian chert/dolomite reservoir in Wellington Field

Contours = thickness of Arbuckle Group
...thickest in southern Kansas

DOE-CO2 Project Study Area
Wellington Field (Sumner County) + 17+ Counties

50 miles
Project Study Area with Oil and Gas Fields
Wellington Field (Sumner County) + 17 Counties

Regional study → ~20,000 sq. miles
Project Time Line

Regional geomodel development of Arbuckle saline aquifer
Collect, process, interpret 3D seismic data - Wellington field
Collect, process, interpret gravity and magnetic data - Wellington field
Drill, core, log, and test - Well #1
Collect, process, and interpret 2D shear wave survey - Well #1
Analyze Mississippian and Arbuckle core
PVT - oil and water
Geochemical analysis of Arbuckle water
Cap rock diagenesis and microbiology
Drill, log, and test - Well #2
Complete Wellington geomodels - Arbuckle and Mississippian reservoirs
Evaluate CO2 sequestration potential in Arbuckle underlying Wellington
Evaluate CO2 sequestration potential in CO2-EOR in Wellington field
Risk assessment - in and around Wellington field
Regional CO2 sequestration potential in Arbuckle aquifer - 17+ counties
Technology transfer

No CO2 injection will take place in this project
**Abstract**
The proposed study will focus on the Wellington Field, with evaluation of the CO₂-EOR potential of its Mississippian chert ("chat") reservoir and the sequestration potential in the underlying Cambro-Ordovician Arbuckle Group saline aquifer. A larger geomodel study of the Arbuckle Group saline aquifer will then be undertaken for a 17-county area in south-central Kansas to evaluate regional CO₂ sequestration. This study will demonstrate the integration of seismic, geologic, and engineering approaches to evaluate CO₂ sequestration potential.

**Project Area**

[Map of Kansas with Wellington Field highlighted]
Well Count – Regional 17+ County Area

Hugoton Embayment

Southern Central Kansas Uplift & Pratt Antcline

Sedgwick Basin

Western Cherokee Basin

Wellington Field

95,117 wells

30 mi.
Current Well Distribution
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**: 48 wells (to date)
Top of Arbuckle Structure

Top of Mississippian Structure

14,105 wells

30 mi.

35,415 wells

Wellington Field

Cross section
Strata comprising Arbuckle saline aquifer vary from porous flow units/aquifers to aquitards and aquitards.

Caprocks = thicker shales e.g., Chattanooga Shale, succession of Pennsylvanian and Permian shales and evaporites

Permo-Penn. shales
Permian evaporite beds

Franseen et al. (2004)
Lobza & Schieber (1999)
Three well stratigraphic cross section with datum on top of the Mississippian carbonates showing –

• gray scale gamma ray,
• lithology as multicolor image track,
• mineralogy percentage in color,
• porosity as variable thickness black profile.

Index map, South-Central KS & North-Central OK

All well data saved in LAS 3.0 format
Isolating sites for potential CO$_2$ sequestration through regional mapping

Mississippian Subsea
25 ft C.I.

3rd Order Residual of Mississippian Subsea
25 ft C.I.

Wellington Field

SUMNER

3 mi.
3D seismic completed (Paragon) – April 10, 2010
High Resolution Gravity/Magnetic (Lockhart) - March & June, 2010
2D shear wave seismic (Lockhart) – June, 2010
Initial mapping of reservoir being studied for CO$_2$-EOR at Wellington Field
Kansas’ DOE-CO2 project will utilize information from USGS’ Anadarko Basin Project, which has reached the first phase of completion.
Evaluation of CO₂ sequestration potential requires an integrated, interdisciplinary effort.

Estimating CO₂ capacity requires careful targeting of sites and quantitative characterization and dynamic modeling.

Safety and risk analysis are vital components in sequestration projects to address environmental concerns.

In Kansas, CO₂ sequestration may become a major activity offering economic benefits.