CO₂ Storage Potential in the Mt Simon Sandstone, Western Kentucky

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Presentation Outline

• Overview of Western Kentucky geology
• Review of CO₂ storage reservoir issues in western Kentucky
• Geology of the Mt Simon Sandstone
• Some issues with the Mt Simon Sandstone as a CO₂ storage reservoir in western Kentucky
• Alternative CO₂ storage reservoirs in western Kentucky
Our site evaluation needs to consider that there are at least three distinct geologic areas of interest in and adjacent to the Western Kentucky Coal Field.
There are major differences in depths to potential CO$_2$ storage reservoirs in the project area.
Western Kentucky Stratigraphic Units with CO₂ Storage Potential

- **Potential CO₂ sinks/ reservoirs**
- **Caprock-containment interval**
- **Unconformity**
- **Sink or seal (depends on location)**
- **Metamorphic and igneous rocks (mostly seal)**
CO\textsubscript{2} Storage Issues

**Potential Escape Mechanisms**

- **A.** CO\textsubscript{2} gas pressure exceeds capillary pressure & passes through siltstone
- **B.** Free CO\textsubscript{2} leaks from \( A \) into upper aquifer up-fault
- **C.** CO\textsubscript{2} escapes through "gap" in caprock into higher aquifer
- **D.** Injected CO\textsubscript{2} migrates up dip, increases reservoir pressure & permeability of fault
- **E.** CO\textsubscript{2} escapes via poorly plugged old abandoned well
- **F.** Natural flow dissolves CO\textsubscript{2} at CO\textsubscript{2} / water interface & transports it out of closure
- **G.** Dissolved CO\textsubscript{2} escapes to atmosphere or ocean

**Remedial Measures**

- **A.** Extract & purify groundwater
- **B.** Extract & purify groundwater
- **C.** Remove CO\textsubscript{2} & re-inject elsewhere
- **D.** Lower injection rates or pressures
- **E.** Re-plug well with cement
- **F.** Intercept & re-inject CO\textsubscript{2}
- **G.** Intercept & re-inject CO\textsubscript{2}

**Figure T.S.S.** Potential leakage routes and remediation techniques for CO\textsubscript{2} injected into saline formations. The remediation technique would depend on the potential leakage routes identified in a reservoir (Courtesy CO\textsubscript{2}CRC).
Western Kentucky Stratigraphic Units with Reservoir Seal Potential

- **Potential CO\textsubscript{2} sinks/ reservoirs**
- **Caprock seal containment interval**
- **Unconformity**
- **Sink or seal (depends on location)**
- **Metamorphic and igneous rocks (mostly seal)**
Fault Proximity Issues

Faults can act as both storage reservoir seals and pathways for CO$_2$ leakage to shallower intervals and the surface.
Old Well Bore Issues

Existing wells >2,500 ft

Old well bores with inadequate abandonment are a potential leakage pathway to the surface.
The Mt. Simon Sandstone is the deep saline reservoir being targeted for CO₂ storage in much of the Midwest. It is deepest in the subsurface and thinnest in western Kentucky.
Inferred Transport of the Mt Simon and Lamotte Sandstones in the Illinois Basin and adjacent regions. (Ojakangas, 1963, Fig. 9)
Quartz-overgrowth cement forms in sandstones at temperatures >90-100 °C (>200 °F).

(Bjørlykke and Egeberg, 1993)
Porosity development in the Mt Simon Sandstone.

(Hoholick et al., 1984)
Test conditions for the CO₂ flood tests included: Illinois Basin brine solution; temperature = 35°C, PcO₂ = 1,400 psig; and 1,500 hour duration. The impact of the CO₂ flood on the physical properties of the Mt. Simon core samples, namely porosity, permeability, and compressive strength, ranged from modest to dramatic (Table 2).

<table>
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<th>Core depth</th>
<th>Porosity, pct</th>
<th>Permeability, mD</th>
<th>Compressive strength, kpsi</th>
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<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Δ, %</td>
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<tr>
<td>4106.0</td>
<td>13.3</td>
<td>na</td>
<td>nc</td>
</tr>
</tbody>
</table>
Mount Simon Sandstone Reservoir

Data from wells drilled in deeper portions of the Illinois Basin indicate that cements in the Mt. Simon Sandstone are quartz and potassium feldspar overgrowths with lesser hematite, kaolinite, chlorite, chert, and carbonate (Metarko, 1980; Hoholick et al, 1984; Makowitz and Milliken, 2003; Makowitz, 2004; Kunledare, 2005).

Cutting at 6660 ft from Allied Chemical well #1 Fee, Vermillion County, Illinois. Quartz grains (Q) with euhedral quartz overgrowth (O). Quartz grains are rimmed with secondary hematite cement. Dark areas between grains is smectitic clay-lined porosity.

Kersting (1982, Fig. C-2)
However, in the vicinity of the Western Kentucky Coal Field, the Mt Simon Sandstone is at a depth that reduces its potential for CO$_2$ storage.
The Mt Simon Sandstone occurs north of the Rough Creek Graben and generally north of the Western Kentucky Coal Field. The thickest potential CO2 storage reservoir in the Mt Simon Sandstone is also where it is at its greatest depth.
The Exxon Jimmy Bell #1 well was drilled on the northern margin of the Rough Creek Graben in Webster County. It encountered 750 ft of low porosity Mt Simon Sandstone at a depth of 13,490 ft immediately above granitic basement rocks.
Exxon Jimmy Bell #1

Cutting from 13,700 ft shows quartz grains (Q) with concave contacts due to pressure dissolution at grain boundaries rimmed with smectitic clays (C). Authigenic apatite crystals (A) grew between quartz grains.

Cutting from 14,220 ft shows microquartz (M) filling the pores between quartz grains (Q).
Three shallower tests of Mt. Simon Sandstone drilled just east of the coal field suggest limited reservoir potential.
The DuPont #1 WDW injection well was drilled near Louisville and encountered 761 ft of Mt Simon Sandstone at a depth of 5193 ft. After testing, the Mt Simon was abandoned and the well recompleted on injection in the Knox Limestone.
Although a core from this well showed low porosities averaging 5.5%, analysis of electric logs suggests that there was ~150 ft of Mt Simon Sandstone with porosity >10% in the well. There is also evidence suggesting that the Mt Simon Sandstone reservoir was damaged by fresh water injection during testing.
Minimum Criteria for a CO₂ Storage Zone

• **Base of the sealing interval ≥2500 ft**
  – Sufficient lithostatic pressure to ensure CO₂ remains in a supercritical state at ≥1070 psia and 88 °F
  – Sufficient sealing strata overlying the storage zone to mitigate the possibility of leakage to shallower intervals and the surface

• **Porous and permeable storage zone**
  – Storage capacity of supercritical CO₂ ~10,000 T/Ac-ft for each incremental percent porosity
  – Greater porosity and permeability at shallower depths allow lower injection pressures and costs

• **Remote from geologic and man-made features that might compromise the integrity of the storage reservoir**
  – Faults and fractured intervals
  – Mine shafts
  – Buildings
Mt Simon Sandstone Reservoir Depth and Pressure

www.beg.utexas.edu/environglty/co2seq/12bmtsimon.htm
Mt Simon Sandstone Porosity

Data sources (828 samples):
- Metarko (1980; 89 samples)
- Shebl (1985; 9 samples)
- Makowitz (2004; 27 samples)
- Kunledare (2005; 690 samples)
- DuPont #1 WDW (13 samples)
The western Kentucky geothermal gradient is ~1 °F/100 ft of depth (36 measurements). In the prospective range of the CO2 storage reservoir the temperature will be ~85-140 °F.
Western Kentucky Reservoirs P-T Trend
Water in the Mt Simon Sandstone reservoir of western Kentucky is extremely high salinity, about six times that of sea water.

**CO₂ Solubility versus Salinity**

- **DuPont #1 WDW**
  - TDS 212,000; pH 3.7; sp cond. 150,000; Cl 130,000

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Fig. 10.—Isocon map (in mg/l—total dissolved solids) of interstitial waters in the basal sandstones with samples locations (modified from Orsanco, 1976, Map 7).

Metarko (1980, Fig. 10)
The Mt Simon Sandstone reservoir is in an area of considerable faulting and existing oil field development.

Well depths (ft)
- 2,500-4,000
- 4,000-5,000
- 5,000-6,000
- 6,000-8,000
- >8,000

Existing wells >2,500 ft

Faults

Western Kentucky Coal Field
Alternative Storage Possibilities

- **Strata outside of the Rough Creek Graben**
  - Knox Group carbonate reservoirs
  - St Peter Sandstone
  - High Bridge Group carbonate reservoirs
  - Potential for re-entering, deepening, and sampling abandoned exploratory wells

- **Strata inside the Rough Creek Graben**
  - Central to the Western Kentucky Coal Field
  - Few deep tests
  - Unknown reservoir characteristics
  - Potential for re-entering, deepening, and sampling abandoned exploratory wells
There are at least three distinct geologic areas of interest in and adjacent to the Western Kentucky Coal Field with potential CO\textsubscript{2} storage reservoirs.
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Rough Creek Graben

Figure 15-8. Schematic cross section showing trap types in the Rough Creek graben area.

Bertagne and Leising (1991, Fig. 15-8) with annotation
St. Peter Sandstone is dominantly a fine-grained quartz sandstone with shale and carbonate interbeds. Cements are carbonates, authigenic anhydrite, and silica (Hoholick, 1980; Hoholick et al., 1984)
Knox Group Carbonates

Algal vugular porosity

Dissolution and brecciation porosity

Fracture porosity

All cores are from the DuPont #1 WDW, Louisville, Kentucky
Har-Ken well Peabody Coal #14
Muhlenberg County

- Drilled to 6700 ft in March 1985
  - 16 inch conductor pipe at 30 ft
  - 10¾ inch casing cemented at 184 ft
  - 7¾/8 inch hole drilled to TD
- Nine intervals tested by open hole DST 1540-2842 ft
- Plugged and abandoned in April 1985
  - Casing cut off 3 ft below surface
  - Cement plug 3-80 ft
  - Mud 80-360 ft
  - Cement plug 360-400 ft
  - Mud 400-1350 ft
  - Cement plug 1350-1750 ft
  - Mud 1750-6700 ft TD

Re-entry Candidate
Conclusions

• There are several potential storage issues to address when choosing a CO2 storage test site
• The Mt Simon Sandstone is a potential candidate as a storage reservoir but is not the only one
• There are many deeper abandoned exploratory wells in the Western Kentucky Coal Field to review for re-entry and testing of CO₂ storage potential in reservoirs other than the Mt Simon Sandstone
Conclusions

Now what is the message there? The message is that there are known ‘knowns.’ There are things we know that we know. There are known ‘unknowns.’ That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we don't know we don't know. So when we do the best we can, we pull all this information together and we then say, ‘Well that's basically what we see as the situation, that is really only the known knowns and the known unknowns.’ And each year, we discover a few more of those unknown unknowns.

Secretary of Defense Donald Rumsfeld, Press Conference at NATO Headquarters, Brussels, Belgium, June 6, 2002