ESTIMATING CO2 STORAGE CAPACITY IN SALINE AQUIFERS

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OUTLINE OF PRESENTATION

1. **Background**
2. **Issues for Consideration**
3. **Alternative CO2 Storage Mechanisms**
4. **Illustrative Example**
5. **Summary**

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BACKGROUND

Deep, saline aquifers, located far below the potable water table, are expected to become one of the primary geological storage option for anthropogenic CO_2.

While considerable uncertainty surrounds the reservoir properties, flow regimes and capacities of the saline aquifers in the U.S., the general consensus is that:

- **Their storage capacity is very large.**
- **Their geographical locations are widespread, and**
- **Their reservoir properties will be favorable.**

ISSUES FOR CONSIDERATION

One should not, without further in depth study, accept at "face value" all of the favorable attributes currently ascribed to saline aquifers:

1. ***<u>Variable Aquifer Reservoir Properties.</u>*** The geographical extent of usable saline aquifers may be less extensive than generally assumed. For example, the Mt. Simon saline aquifer undergoes a facies change from sandstone to carbonate in eastern Ohio, greatly reducing its attractiveness as a storage option.

   Increasing our understanding of the variable reservoir properties of the saline aquifers will be essential for assisting power plants to properly site their CO_2 storage wells.

ISSUES FOR CONSIDERATION (Cont'd)

2. ***Closed Versus Open Aquifer Systems.*** A number of the geological intervals containing a saline aquifer may be "open systems". CO_2 injected into these "open systems", unless trapped by other mechanisms, could migrate updip over time and escape to the atmosphere.

   For example, the geological interval containing the Frio saline aquifer reaches the surface approximately 100 miles inland from the Gulf Coast of Texas. Half-way to the outcrop, the formation becomes shallow, causing a phase change of the CO_2 with substantial expansion of volume and mobility.

   Understanding the aquifer's structural setting and the CO_2 flow directions will be essential, particularly in "open aquifer systems."

ISSUES FOR CONSIDERATION (Cont'd)

3. ***CO2 Storage Mechanisms.*** Solubility of CO_2 in the aquifers saline water has been viewed as the primary CO_2 storage mechanism. As such, large water and aquifer volumes are required, particularly if the waters are highly saline which limit CO_2 solubility.

   Reservoir simulation and practical experience show that the injected CO_2 will rapidly gravitate to the top of the reservoir, limiting its contact with the reservoir and thus also limiting the storage capacity of the aquifer.

   Understanding how the inherent reservoir properties of the aquifer control the movement and reservoir contact of the injected CO_2 at each storage site is another area deserving study,

ALTERNATIVE CO2 STORAGE MECHANISMS

In addition to solubility of CO2 in the aquifer's saline waters, two additional mechanisms exist that could greatly expand the CO2 storage capacity and favorable nature of saline aquifers. They are:

- Trapping the CO2 in the reservoir's pore space (similar to trapped residual oil in an oil reservoir).
- Trapping of the CO2 by the reservoir's structure or stratigraphy (similar to the trapping of natural gas in a conventional gas reservoir).

ILLUSTATIVE EXAMPLE

In the following set of slides, we will illustrate, using reservoir simulation and engineering calculations, the flow and reservoir contact of the injected CO2 and the relative role of each of the CO2 trapping and storage mechanisms:

- Solubility
- Pore space trapping
- Structural trapping

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METHODOLOGY

1. Basic Data.

- **“Mt. Simon type” of saline aquifer**
- **Reservoir properties:**
  - **5,000 feet of depth**
  - **Slightly under-pressured**
  - **Porosity of 10%, for 90 feet of net sand**
  - **Temperature of 102º F**
  - **Salinity of water of 30,000 ppm**
  - **Vertical/horizontal permeability of 50 to 1**

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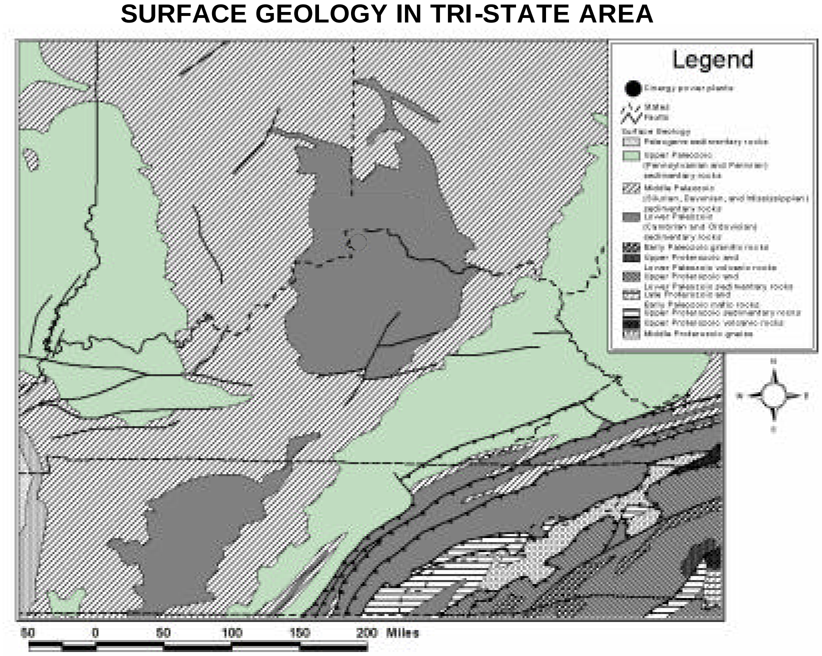
SURFACE GEOLOGY IN TRI-STATE AREA



Source: Advanced Resources International, 2003; Based on USGS Data

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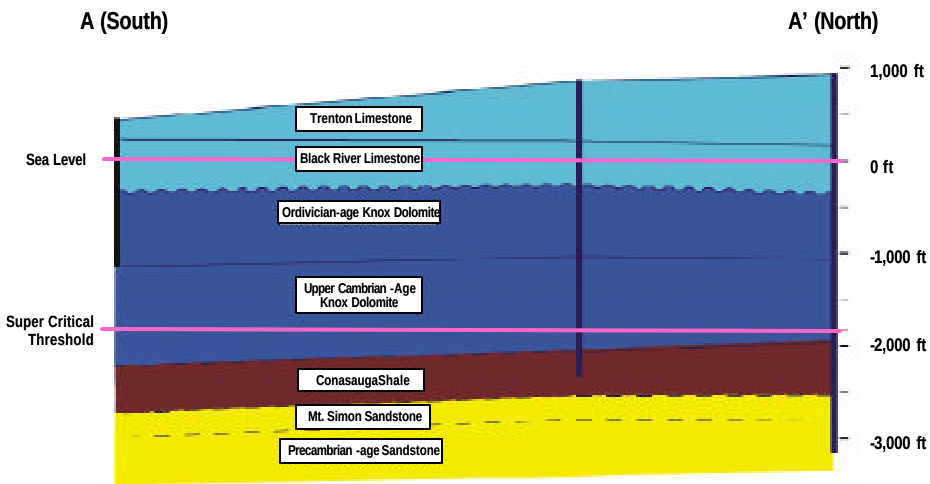
GEOLOGIC CROSS-SECTION THROUGH TRI-STATE AREA

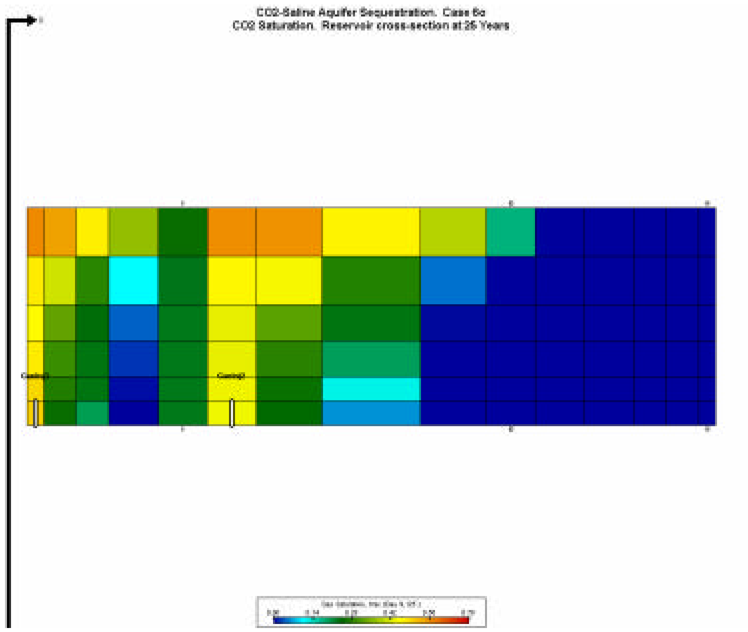


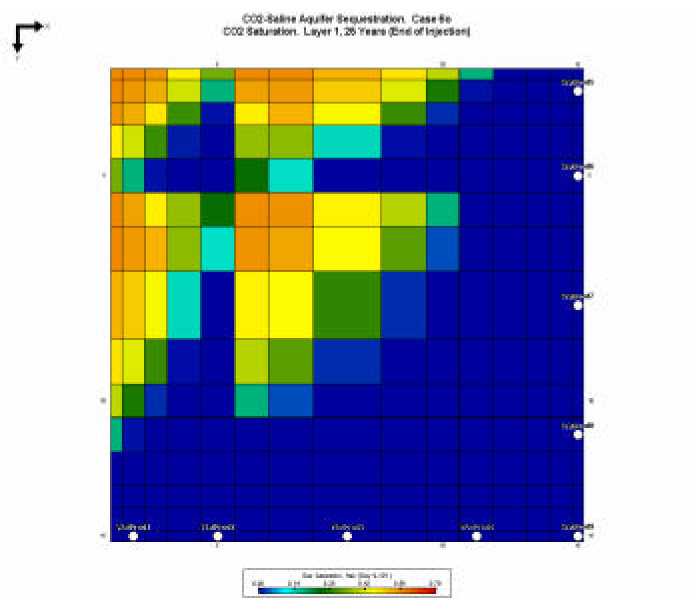
Source: Advanced Resources International, 2003; Based on KGS Wel Data.

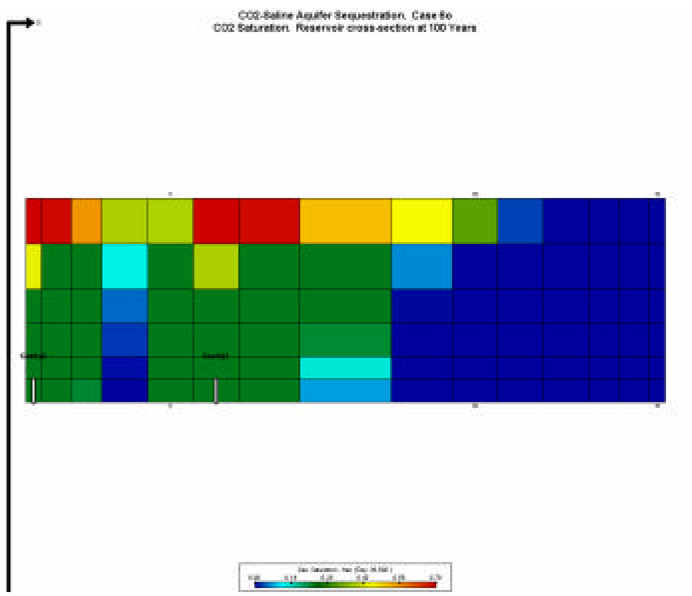
METHODOLOGY

2. *Operating Conditions.*

- Utilize two CO2 injection wells
- Assume an unbounded aquifer system
- Inject CO2 into the aquifer for 25 years
  - 1.2 Mmcfd per well
  - 25,000 tons per year per well
- Shut in the aquifer for 75 years
- Examine distribution of CO2 and its concentration
  - End of 25 years
  - End of 100 years


CO2-Saline Aquifer Sequestration. Case 6c
CO2 Saturation. Reservoir cross-section at 25 Years


CO2-Saline Aquifer Sequestration. Case 6c
CO2 Saturation. Layer 1, 25 Years (End of Injection)



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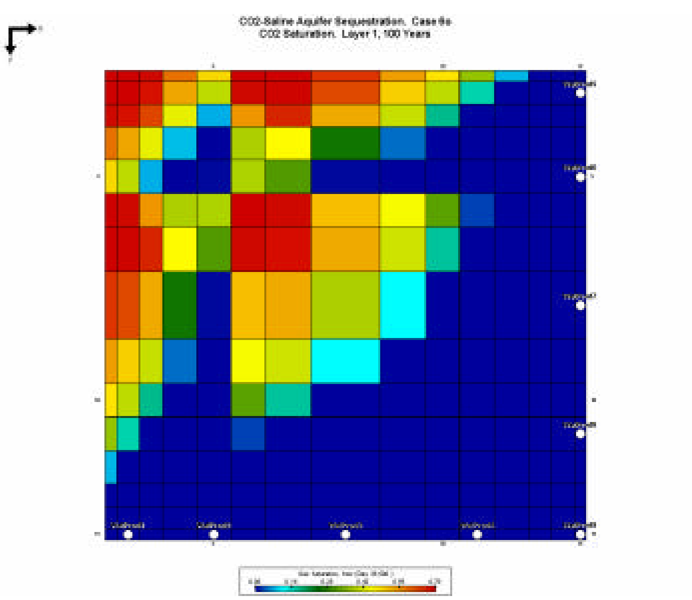

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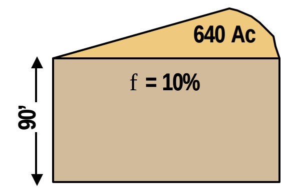
ILLUSTRATIVE EXAMPLE OF CO2 STORAGE

1. Total Reservoir Volume (Barrels/Bcf/tons CO2):

At first glance, a square mile of aquifer (surface area) would appear to have tremendous capacity to store CO2, nearly 6 MM tons per square mile:

- 640 A * 90' = 57,600 AF
- 7758 B/AF * 0.1 = 775.8 B/AF
- 57,600 AF * 775.8 B/AF = <u>44.7 MMB water</u>
- At 1,900 psi and 102°F: 1 Barrel = 2.26 Mcf CO2
- 44.7 MMB * 2.26 Mcf/B = <u>101 Bcf (5.9 MMt CO2)</u>



(One Square Mile of Surface Area)

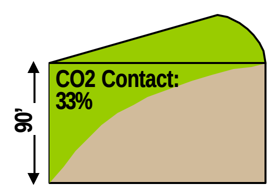
ILLUSTRATIVE EXAMPLE OF CO2 STORAGE (Cont'd)

2. CO2 in Solution (Bcf/tons CO2):

However, only a portion of an aquifer's waters will be contacted by CO2.

Reservoir simulation shows for this particular reservoir and geologic situation the reservoir's contact with CO2 (E) is 33%.

CO2 in Solution



(One Square Mile of Surface Area)

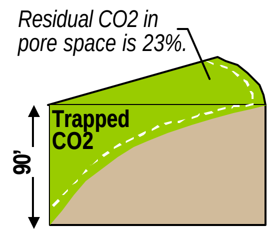
- At 1,900 psi & 30,000 ppm TDS: 1 Barrel holds 140 cf
- Max: 44.7 MM B * 140 cf/B = <u>6.3 Bcf of CO2</u>
- Actual: E * 6.3 Bcf = <u>2.1 Bcf (0.12 MMt)</u>

ILLUSTRATIVE EXAMPLE OF CO2 STORAGE (Cont'd)

3. CO2 as Trapped Gas (Bcf and tons CO2):

A second storage mechanism is trapping of CO2 in the reservoir's pore space.

Reservoir simulations shows for this particular reservoir setting, the residual CO2 saturation S $_{CO2}$) is 23% and that 80% of the CO2 contacted volume contains at least this value.



(One Square Mile of Surface Area)

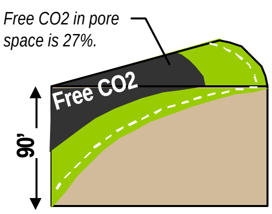
(E) (80%)(44.7 MMB)*(2.26 Mcf/B)*(S $_{CO2}$) = 6.1 Bcf (0.36 MMt)

ILLUSTRATIVE EXAMPLE OF CO2 STORAGE (Cont'd)

4. CO2 as Free Gas (Bcf/tons CO2):

The third storage mechanism is containment of free CO2 at the reservoir's upper layer.

Reservoir simulations shows that 33% of CO2 contacted reservoir is at CO2 saturation of 50%, providing a 27% free gas saturation at the upper boundary of the aquifer.



(One Square Mile of Surface Area)

(E) (33%) (44.7 MMB)*(2.26 Mcf/B)*(0.50 – S $_{CO2}$) = 3.0 Bcf (0.16 MMt)

ILLUSTRATIVE EXAMPLE OF CO2 STORAGE (Cont'd)

5. Total CO2 Storage.

Combining the three CO2 storage mechanisms, the example aquifer has a CO2 storage capacity of 0.65 MMt per square mile of surface area.

- CO2 trapped in pore space is potentially the dominant mechanism.
- Free gas trapped along the boundary layers of the reservoir is the second most important mechanism.
- CO2 in solution is the third storage mechanism.

Storage Mechanisms	BCF	MM tons
CO2 in Solution w/ Brine	2.1	0.12
CO2 Trapped in Pore Space	6.1	0.36
Free CO2 at Reservoir's Upper Boundary	3.0	0.17
TOTAL	**11.2**	**0.65**

SUMMARY

Several significant insights are illustrated by this analysis:

1. **Trapping of residual, dense-phase CO2 in the reservoir's pore space is potentially a most significant storage mechanism in saline aquifers:**
   - **Extent of CO2 trapping will vary according to the reservoir's pore structure and rock characteristics,**
   - **Considerable additional research is required to reliably define this mechanism.**
2. **Free gas at the bounding layer of the aquifer is a second important CO2 storage or escape mechanism:**
   - **Structure and stratigraphy may further enhance free CO2 storage volume and physically trap the free phase CO2.**
   - **Unconfined aquifer systems need to be thoroughly characterized to understand CO2 flow and thus preclude future CO2 escape.**
3. **Extremely large aquifer surface volumes are required if CO2 in solution becomes the only available storage mechanism.**

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