Storage Capacity Estimation Issues and Methodologies for saline reservoirs

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CHINA-AUSTRALIA GEOLOGICAL STORAGE	CAGS II Training School 14th – 17th May 2014- Nanjing

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Why assess capacity?

- To evaluate the storage potential of a country or basin;

- To evaluate the best storage sites within the country or basin;

- To determine if the selected site has the potential capacity required for the proposed storage scheme(s).

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CO$_2$ trapping mechanisms in porous rocks

When CO$_2$ is injected into the subsurface, it will rise under buoyancy until it becomes immobilised by a combination of factors:

• Structural and stratigraphic trapping
• Residual trapping
• Solubility trapping
• Mineral trapping

Unless residual storage occurs, the buoyant free phase CO$_2$ will ultimately rise to accumulate under the top seal of the reservoir.
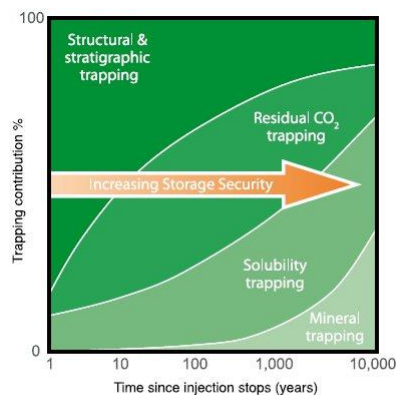

Figure 5.9 Storage security depends on a combination of physical and geochemical trapping. Over time, the physical process of residual CO$_2$ trapping and geochemical processes of solubility trapping and mineral trapping increase. IPCC SRCCS 2005
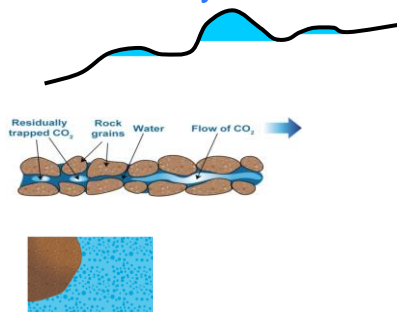
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What types of storage do we assess?

• Structural and stratigraphic closures only?

• Plus residual trapping?

• Plus dissolution?

• Plus mineral trapping?

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What types of storage do we assess?

- In any assessment it must be made clear what the estimation covers.
- Generally, high level assessments cover structural and stratigraphic trapping and the best also include an estimation of residual trapping.
- All four trapping mechanisms tend only to be covered by specifically designed software.

High Level

Detailed modelling
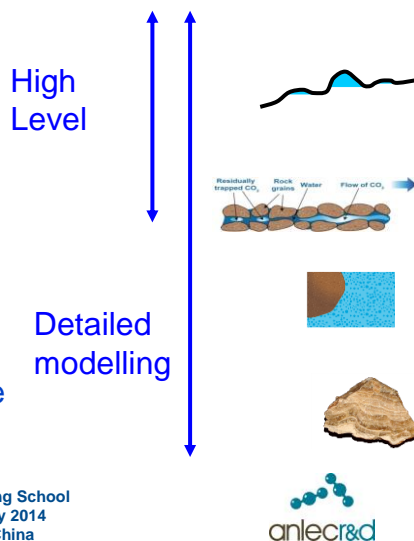
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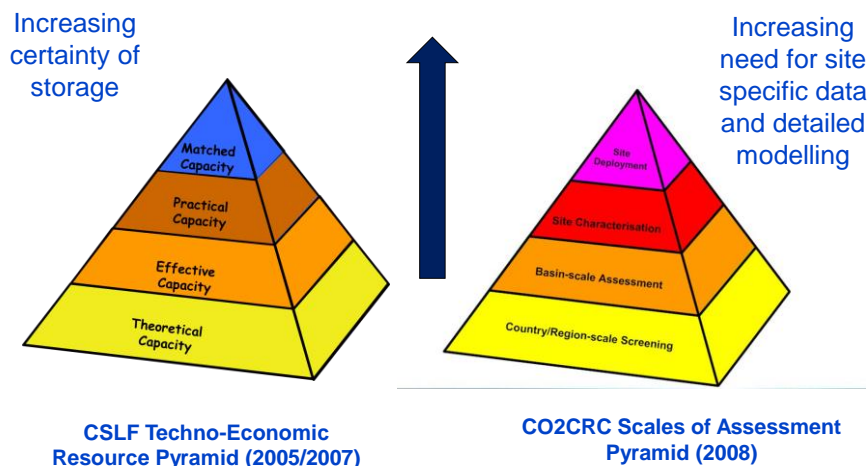

Capacity at different scales

Critical Issues:

1. The size of the region to be assessed;

2. The amount of subsurface data that is available;

3. The time frame over which the assessment must be made.

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Hierarchy of capacity assessment and confidence – two pyramids

Increasing certainty of storage

Increasing need for site specific data and detailed modelling

CSLF Techno-Economic Resource Pyramid (2005/2007)

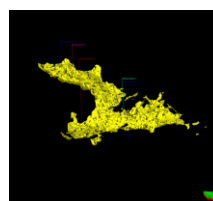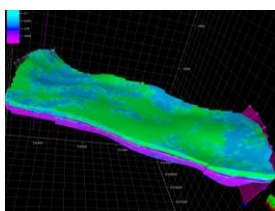CO2CRC Scales of Assessment Pyramid (2008)

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Basin scale assessment versus site characterisation

- Ideally, capacity assessments should be made on the basis of detailed geological and geophysical analysis and modelling.

- But, frequently, high level assessments are required for political, strategic or financial reasons.

- It may then be necessary to carry out a high level assessment of a particular basin, region or country.

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Basin scale assessment versus site characterisation

- Site characterisation or assessment requires detailed geological and reservoir simulation modelling to determine if the site has the capacity to contain the volumes which it is proposed to inject.

- Basin or regional scale may require a general formula to allow high level assessment of total potential capacity if data availability or time for assessment is limited.

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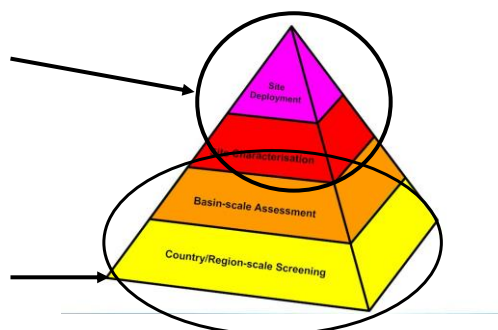
Expert analysis v computer modelling

This talk deals with assessment at a basinal and regional scale.
At this level all assessment must be made by consideration of the data and by expert analysis

Current geological and reservoir engineering software cannot handle the number of cells which would be required for detailed computer models at a basinal scale.

Dynamic Simulation of Caswell Model
Porosity 2000-01-01

0.242
0.218
0.193
0.169
0.145
0.121
0.097
0.073
0.048
0.024
0.000

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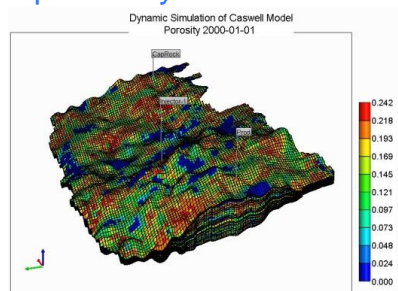
Open or closed aquifer systems

- Generally it has been assumed that most aquifers in the subsurface are "open" systems, in it that the saline waters within the reservoir can be displaced into a vast interconnected aquifer system that ultimately connects with the surface

- However it has been suggested that many if not most systems are closed and that injection will not displace pore water but will increase pore pressure which will ultimately constrain the volume of CO_2 that can be injected.

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Open or closed aquifer systems

- The methodologies discussed here all assume open aquifers
- However if an aquifer is closed, either by formation boundaries or by intra-formational compartmentalisation the total capacity will be restricted by the allowable pressure increase
- However it may not be restricted by the selective flow paths that form part of the Efficiency Factor.

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# Capacity of structural traps:
depleted fields and dry structures

- There is general agreement on capacity estimation methodology for physical structures.

- If it is a depleted field, it is assumed that capacity will be related to the volume of hydrocarbons extracted, less any constraints from injection pressure versus fracture pressure and from seal capacity differences between CO_2 and hydrocarbons.

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"Dry" structure

- A "dry" structure capacity can be estimated by conventional methods:
  - Area × average net thickness × average porosity × (1-Sw) × structural correction
- It is assumed that backpressure will force the CO_2 into the less permeable parts of the structure.
- Again this capacity may be reduced due to fracture pressure or seal capacity constraints.
- "Dry" structures can be considered a subset of saline aquifers.

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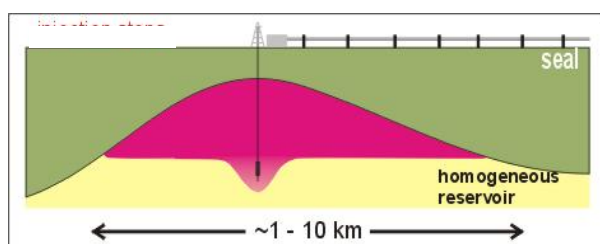
Conceptual saline reservoir CO_2 storage scenario

Residual and Solubility Trapping

seal

homogeneous reservoir

~10 - 100s kms
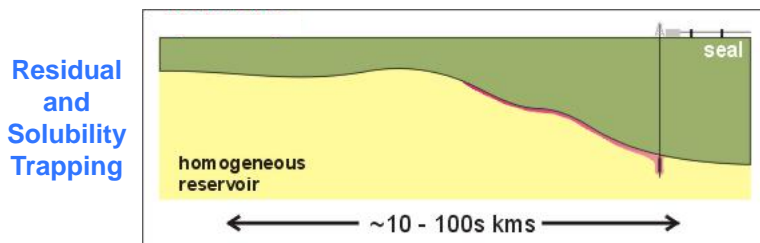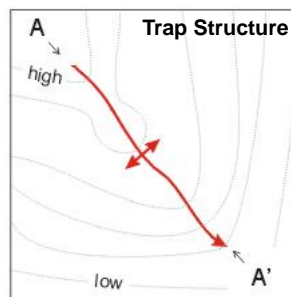
Large, open structure, long migration path

• **Residual and dissolution the major trapping mechanisms.**

• **Long term mineral trapping.**

• **Minor structural trapping.**

• **How can the capacity of these reservoirs be assessed?**

A

Trap Structure

high

low   A'

(Slide courtesy of Robert Root)

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Storage efficiency

• It is only possible to utilise a small proportion of the pore space in a formation:

• Because the CO_2 is less dense than formation water, it will rise in a relatively narrow column from the injection point until it reaches the base of the seal, and then spread out laterally.

• When moving through the formation both vertically and laterally, CO_2 will flow through the easiest path following the largest pore throats and not entering pores that have more restricted pore throats.

• Thus, even within the volume of the plume, only a percentage of
• the pores will contain CO_2.

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The Efficiency or Capacity Factor

In this simple model, the CO_2 is moving along under the base of the seal so it does not contact the main mass of the rock.
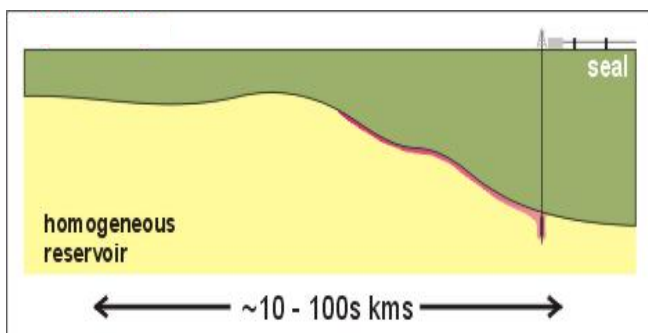
How much of the rock does the CO_2 "see"?

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Storage efficiency in a saline aquifer (2)

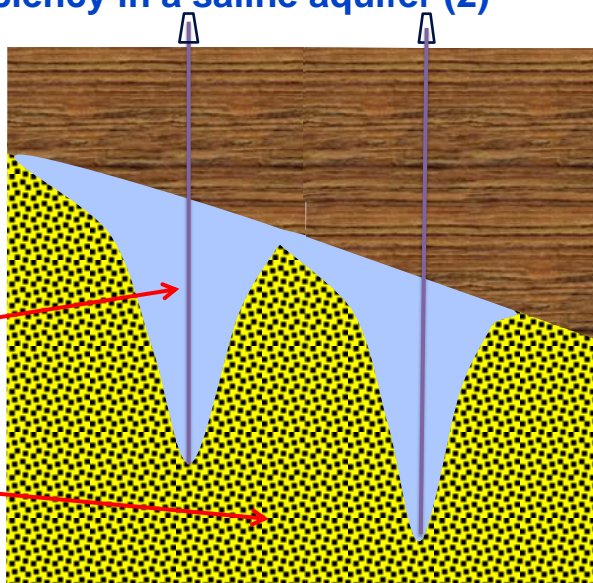Two factors contribute to the degree of overall saturation within the aquifer

Saturation inside the plume - ?- Possibly around 30%

Saturation outside the plume – 0%

Saline reservoir trapping

- Some percentage of trapping in structural and stratigraphic closures within the body of the rock and beneath overlying seal - may be below seismic resolution.
- Main trapping mechanisms will be residual and dissolution.

  - Critical issues then are:
    1. how much of the pore space in the path of the migrating plume will ultimately contain residual oil?
    2. How much of the total pore space of the rock will the migrating plume "see", because it will move preferentially through the most permeable zones?

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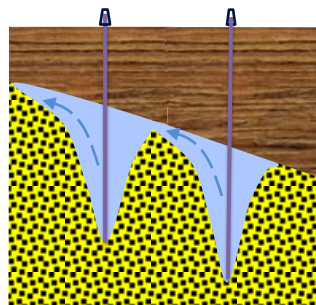
How much of the reservoir is available?

- Essentially, the two most widely used methods calculate the volume of the pore space in the area under consideration then apply a discount factor to allow for the pore space that realistically cannot be accessed for a variety of reasons, both large and small scale.

- Generally accepted that less than 4% of pore space is available even under optimum conditions.

- However larger figures are found in the literature.

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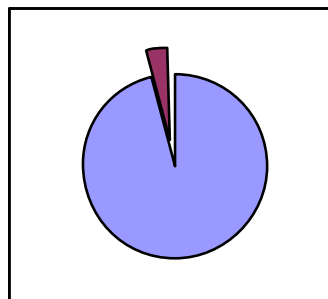
Capacity assessment in four basic steps

- Estimate the volume of the formation to be used as the reservoir.
- Estimate the average pore volume of the formation.
- Estimate the density of the CO_2 at formation depth.
- Estimate the percentage of the pore volume that the CO_2 will pass through when it is migrating or occupy when it becomes stationery.

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Deterministic or probabilistic estimation

- Deterministic assessment multiplies single values for the storage parameters and presents the result as a best estimate.
- Probabilistic assessment multiplies ranges of values and presents the result as statistical distribution:

P10-P50-P90

- Probabilistic assessment best presents the uncertainties inherent in the assessment.

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Key recently published methodologies

DOE 2006	USDOE Capacity and Fairways Sub-group – Regional Carbon Sequestration Partnerships
CSLF 2007	CSLF Task Force for Review and Development of Standard Methodologies for Storage Capacity Estimation
CO2CRC 2008	Generally based on the DOE methodology
USGS 2003/2006	Specific sequestration Volumes. A useful tool for CO_2 Storage Capacity Assessment
IEA/EERC 2009	Summary and overview of CSLF, DOE and other methodologies, Calculation of storage coefficients in the context of the resource pyramid.
CGSS 2010	Methodology developed for the 2009 Queensland CO_2 Geological Storage Atlas. Requires depth of data from Basin
USGS 2010	A probabilistic Assessment methodology for the Evaluation of Geologic Carbon Dioxide Storage.
IEA 2013	In press, based on USGS 2010 methodology

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Example: The DOE Formula

$$G_{CO2} = A \ h_g \ \phi_{tot} \ \rho \ \boxed{E}$$

1 - 4% or less?

Parameter	Units*	Description
G_{CO2}	M	Mass estimate of saline-formation CO_2 storage capacity
A	L^2	Geographical area that defines the basin or region being assessed for CO_2 storage-capacity calculation
h_g	L	Gross thickness of saline formations for which CO_2 storage is assessed within the basin or region defined by A
ϕ_{tot}	L^3/L^3	Average porosity of entire saline formation over thickness hg. Total porosity of saline formations within each geologic unit's gross thickness divided by hg
ρ	M/L^3	Density of CO_2 evaluated at pressure and temperature that represents storage conditions anticipated for a specific geologic unit averaged over hg
E	L^3/L^3	CO_2 Storage Efficiency Factor that reflects a fraction of the total pore volume that is filled by CO_2

Methodology for Development of Carbon Sequestration Capacity Estimates – Appendix A., DOE 2006

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The CSLF Formula

Total Capacity

$$V_{CO2t} = A \times h\, \Phi \times (1 - S_{wirr})$$

Effective Capacity

$$V_{CO2e} = C_c \times V_{CO2t}$$

Capacity Coefficient - this the same as the E Factor?

In the CSLF methodology this formula is only applied to the structural and stratigraphic traps that exist within the body of the reservoir and at the base of the seal

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DOE and CSLF Assessment Methods

- Both of these methods are very similar in that they calculate a pore volume for the basin or storage formation being considered and then discount to account for the sweep efficiency.
  - The **DOE** call this the efficiency factor **"E".**
  - The **CSLF** call this the capacity co-efficient **"C_c".**
- The "E" and the "C_c" are fundamentally the same, as are the two assessment methods.
- There are only "minor differences in computational formulation" (Bachu 2008).

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DOE or CSLF _ What is the difference? (1)

- "The methodologies proposed by the CSLF Task Force and the USDOE Subgroup are basically identical, with minor differences in computational formulation".
- Bachu 2008

- "Fundamentally, the CSLF and DOE methods are the same Method"

$$"VCO_2,DOE_e=VCO_2,CSLF_e"$$

- Gorecki (EERC) 2009

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But there is another catch

- The DOE methodology estimates the maximium storage available on the assumption that:
- "injection wells can be placed regularly through the basin/region to maximise storage"
- "there is no restriction placed on the number of wells that could be used"

- Are either of these reasonable assumptions??.

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USGS probabilistic assessment – 2010
IEA Recommended Methodology - 2013

- This methodology is probably the most rigorous proposed and has a well established precedent in the National Oil and Gas Assessment.
- However, in many cases it requires a level of knowledge and data that may not be available in the saline formation proposed for storage.
- Despite this, it is attractive as it uses monte carlo analysis of all critical factors to express the assessed capacity as a range
  P10-P50-P90.

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USGS probabilistic assessment – 2010
IEA Recommended Methodology – 2013

- Develops methodology similar to natural resource assessments in the USGS National Oil and Gas Assessment.

- Regards the "geological commodity" of "pore space in the subsurface" as a resource that can be assessed in a similar way to other natural resources.

- Uses " Monte Carlo" analysis to define Minimum, maximum and most likely values.

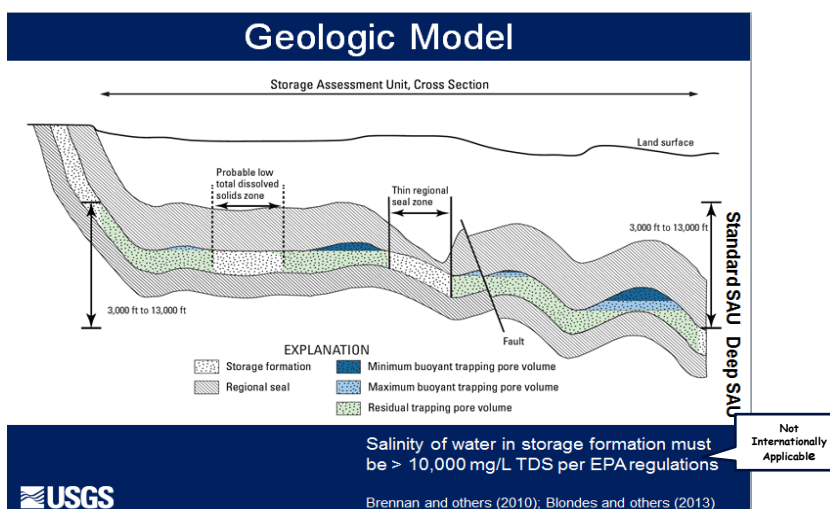**CAGS II Training School
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USGS probabilistic assessment – 2010
IEA Recommended Methodology - 2013

- Subdivides the basin into a series of storage assessment areas (SAU).
- Calculates the capacities of Discovered Physical Traps (PT_D) and undiscovered Physical Traps (PT_U) and saline formations (SF).
- Considered storage in the total trap volume of the physical traps but restricts the capillary (residual) trapping in saline formations to the most porous units of the formation.
- Require estimation of a carbon storage efficiency Factor (C_{se})

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Geologic Model

Storage Assessment Unit, Cross Section

Land surface

Probable low total dissolved solids zone

Thin regional seal zone

3,000 ft to 13,000 ft

3,000 ft to 13,000 ft

Standard SAU Deep SAU

Fault

EXPLANATION
Storage formation
Regional seal
Minimum buoyant trapping pore volume
Maximum buoyant trapping pore volume
Residual trapping pore volume

Not Internationally Applicable

Salinity of water in storage formation must be > 10,000 mg/L TDS per EPA regulations

USGS

Brennan and others (2010); Blondes and others (2013)

Slide courtesy of S. Brennan USGS

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The Critical Question

- What is the appropriate E or Cc or Cce value to use?

- The IEA-GHG commissioned this report from the EERC* in an attempt to give some guidance

- Energy and Environmental Research Centre – University of North Dakota
- IEA-GHG Technical Study Report No 2009/13

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DEVELOPMENT OF STORAGE COEFFICIENTS FOR CARBON DIOXIDE STORAGE IN DEEP SALINE FORMATIONS
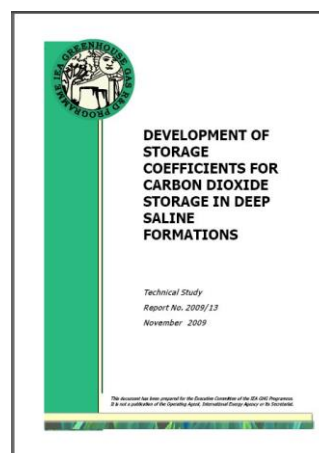
Technical Study
Report No. 2009/13
November 2009
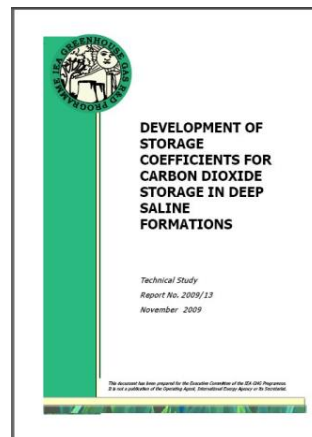
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The Critical Question

This report accepts that the DOE and the CSLF methodologies are essentially the same and sets out to determine storage coefficients for a range of facies and rock types within a number different model structures and traps

However all of this is model driven

DEVELOPMENT OF STORAGE COEFFICIENTS FOR CARBON DIOXIDE STORAGE IN DEEP SALINE FORMATIONS

Technical Study
Report No. 2009/13
November 2009

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The Critical Question

- The IEA/EEC* Report has calculated a series of <u>site-specific</u> coefficients for 3 different lithologies and 10 different depositional environments.

- These range from 4% to 15%.

- However, extrapolating site-specific coefficients over a larger area must take into account probable geological heterogeneity and compartmentalisation.

- Other studies suggest that a range of 1% - 4% is more likely.

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- * Gorecki et al 2009

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Where is the empirical data?

- Almost all of the **E** factors quoted are based on expert assessments from oil field experience and computer modelling.
- There is only one long running saline reservoir storage project in the world – Sleipner.
- And at Sleipner we are still very unsure of what CO_2 saturation is being reflected in the seismic image.
- Only when we have a portfolio of real storage projects will we be able to approach this number with any certainty.
- But a definitive answer may continue to elude us.

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References

- Bachu, S., Bonijoly, D., Bradshaw, J., Burruss, R., Holloway, S., Christensen, N.P., and Mathiassen, O.M., 2007, CO2 storage capacity estimation—Methodology and gaps: International Journal of Greenhouse Gas Control, v. 1, p. 430–443.
- Bachu, S. 2008 Comparison between Methodologies Recommended for Estimation of CO2Storage Capacity in Geological Media by the CSLF Task Force on CO2 Storage Capacity Estimation and the USDOE Capacity and Fairways Subgroup of the Regional Carbon Sequestration Partnerships Program-Phase III Report –Available online at *http://www.cslforum.org/publications/documents/PhaseIIIReportStorageCapacityEstimationTaskForce0408.pdf*
- Bradshaw, B.E., Spencer, L.K., Lahtinen, A.C., Khider, K., Ryan, D.J.,Colwell, J.B., Chirinos, A. and Bradshaw, J. (2009). Queensland Carbon Dioxide Geological Storage Atlas.
- Brennan, S.T., and Burruss, R.C., 2006, Specific storage volumes—A useful tool for CO2 storage capacity assessment: Natural Resources Research, v. 15, no. 3, p. 165–182, doi:10.1007/s11053–006–9019–0.
- Brennan, S.T., Burruss, R.C., Merrill, M.D., Freeman, P.A., and Ruppert, L.F., 2010, A probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage: U.S. Geological Survey Open-File Report 2010–1127, 31 p., available only at http://pubs.usgs.gov/of/2010/1127
- Burruss, R.C., Brennan, S.T., Freeman, P.A., Merrill, M.D., Ruppert, L.F., Becker, M.F., Herkelrath, W.N., Kharaka, Y.K., Neuzil, C.E., Swanson, S.M., Cook, T.A., Klett, T.R., Nelson, P.H., and Schenk, C.J., 2009, Development of a probabilistic assessment methodology for evaluation of carbon dioxide storage: U.S. Geological Survey Open-File Report 2009–1035, 81 p., available only online at *tp://pubs.usgs.gov/of/2009/1035/*
- Gorecki,C.D. et al, Development of Storage Co-coefficients for Carbon Dioxide storage in Deep Saline Formations and depleted Hydrocarbon Reservoirs, EERC Power Point presentation available online at :*www.ifp.com/content/download/68004/1473899/file/32_Gorecki.pdf*
- U.S. Department of Energy, National Energy Technology Laboratory, 2008a, Carbon sequestration atlas of the United States and Canada (2d ed.; Atlas II): 142 p., available online at *http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/2008%20ATLAS_Introduction.pdf.* .

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Thank you for your attention

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