Australian Government

Geoscience Australia

# An Overview of $CO_2$ Storage Capacity Assessment Methodologies for Saline Aquifers

Rick Causebrook
Section Leader
International CCS
Geoscience Australia

Training School of CAGS
Beijing, PRC
April 18th-20th 2012

# Why assess capacity?

1. To evaluate the storage potential of a country or basin;
2. To evaluate the best storage sites within the country or basin;
3. To determine if the selected site has the potential capacity required for the proposed storage scheme(s).

# $CO_2$ 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.

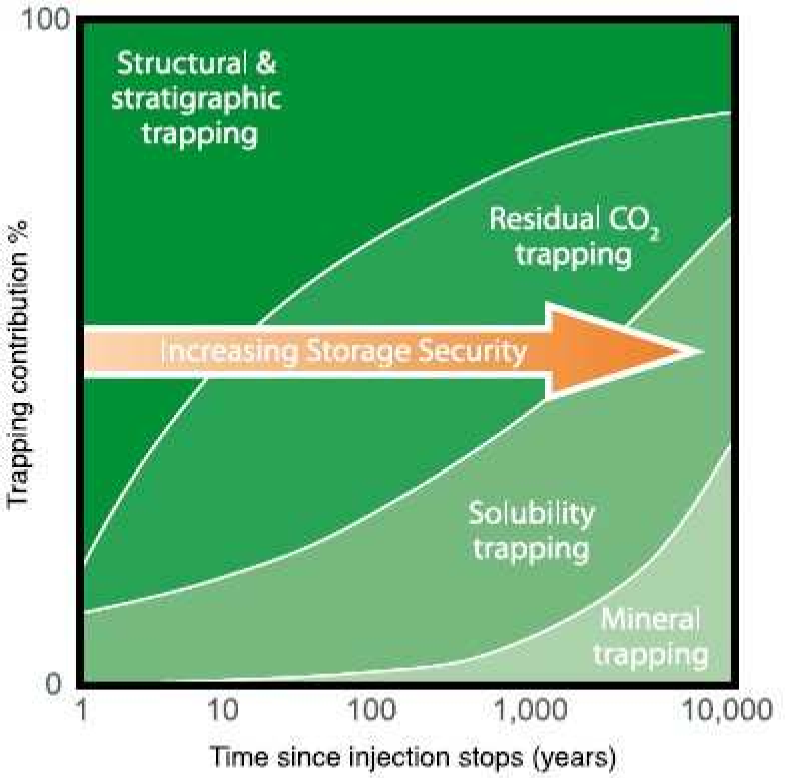
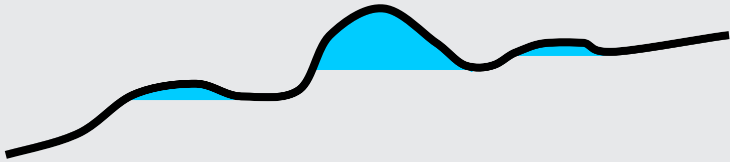



**Figure 5.9** Storage security depends on a combination of physical and geochemical trapping. Over time, the physical process of residual $CO_2$ trapping and geochemical processes of solubility trapping and mineral trapping increase.

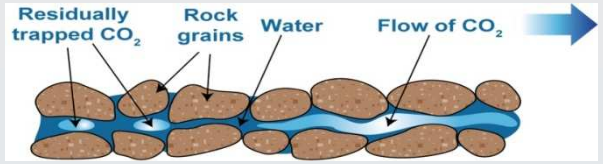
IPCC SRCCS 2005

# What types of storage do we assess?

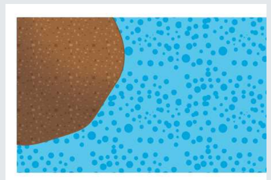
- Structural and stratigraphic closures only?



- Plus residual trapping?




- Plus dissolution?



- Plus mineral trapping?

# 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.

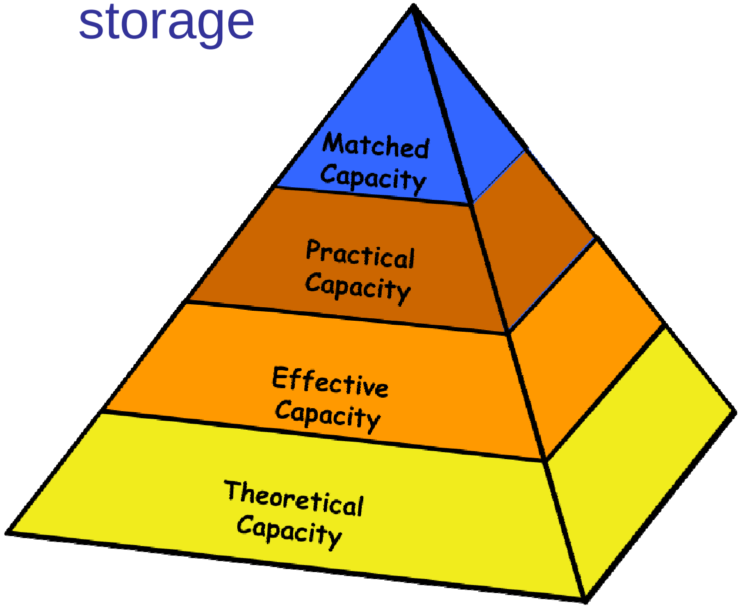
# Capacity at different scales

**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.

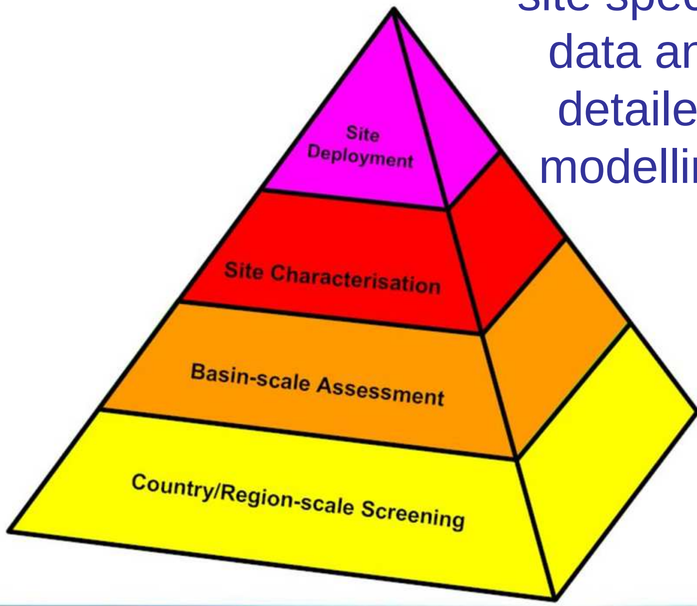
# Scales of capacity assessment and confidence – two pyramids

Increasing certainty of storage




CSLF Techno-Economic Resource Pyramid (2005/2007)

Increasing need for site specific data and detailed modelling




CO2CRC Scales of Assessment Pyramid (2008)

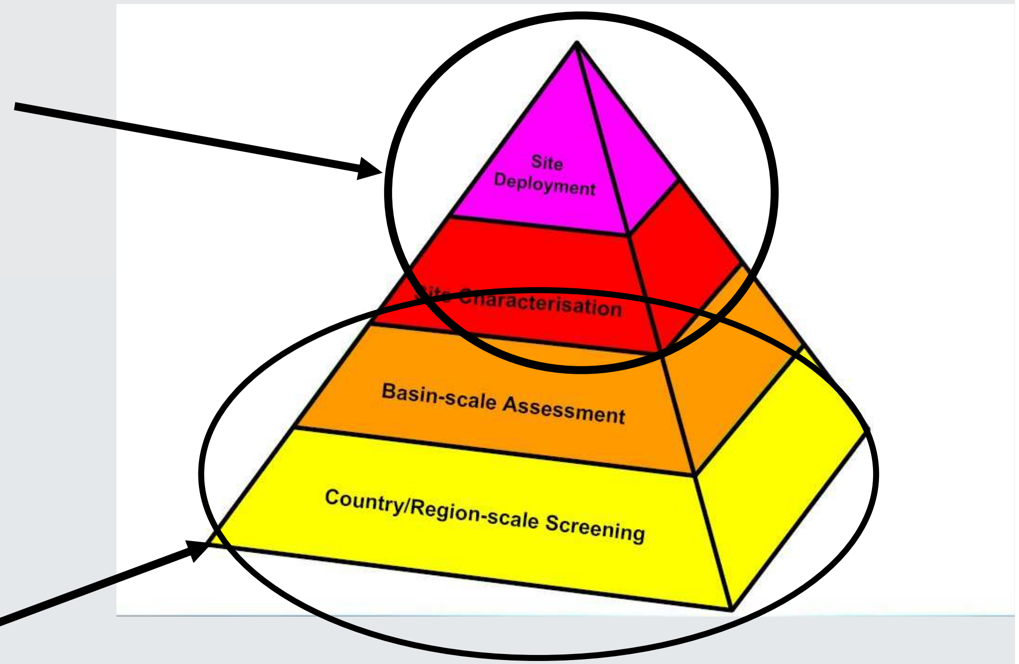
# Basin scale assessment versus site characterisation

- 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.

# Basin scale assessment versus site characterisation

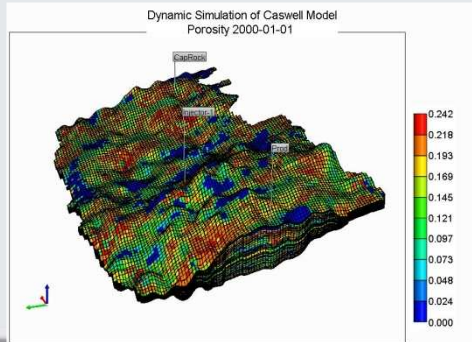
- Site characterisation or assessment requires detailed geological and reservoir simulation modelling to determine if the site has the capacity to contain the volumes which it is proposed to inject.

- 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.



# 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 detailedcomputer models at a basinal scale.

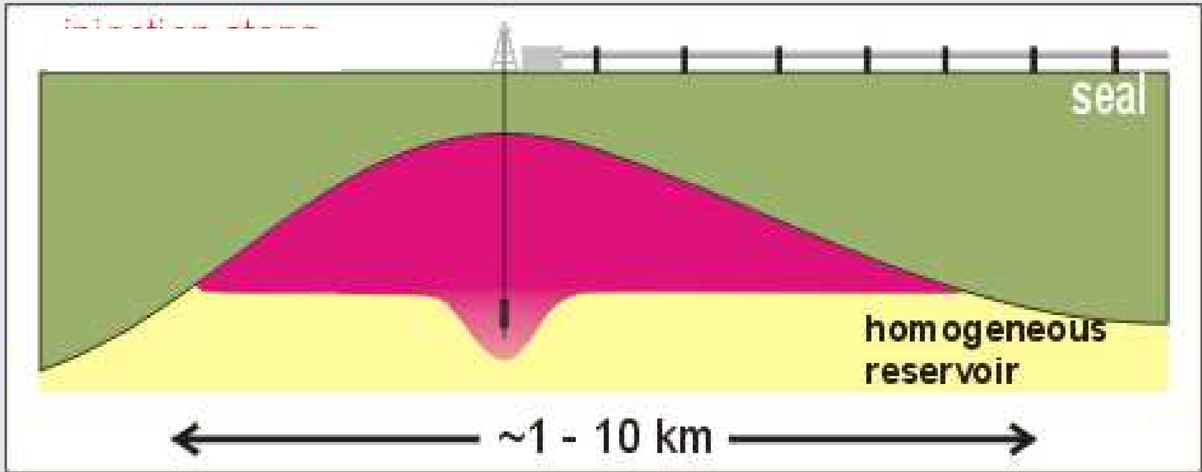


# Capacity of structural traps: depleted fields and dry structures

- 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.

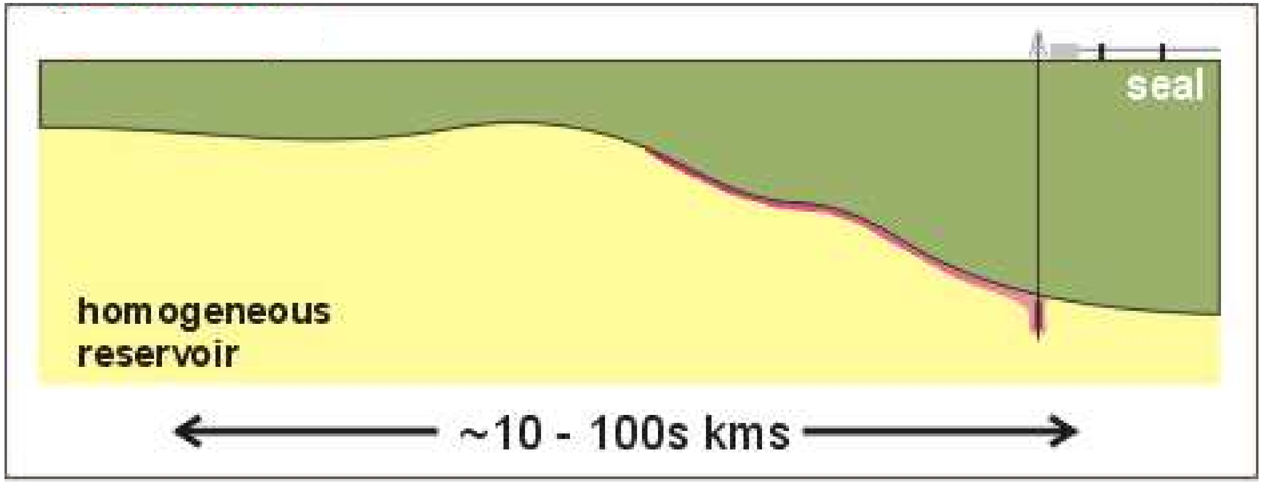
# "Dry" structure

- 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.



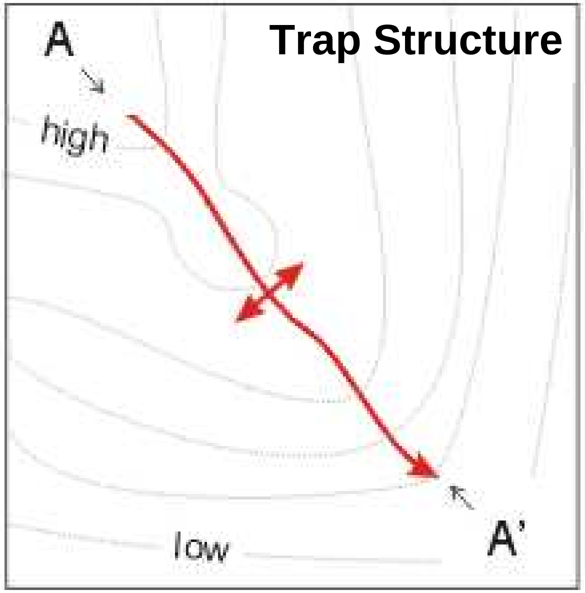
# Conceptual saline reservoir $CO_2$ storage scenario

**Residual and Solubility Trapping**




Large, open structure, long migration path

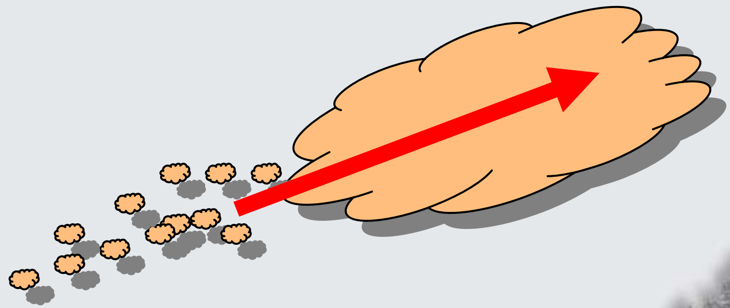
- Residual and dissolution the major trapping mechanisms.
- Long term mineral trapping.
- Minor structural trapping.
- How can the capacity of these reservoirs be assessed?




(Slide courtesy of Robert Root)

# 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?



# Storage efficiency

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

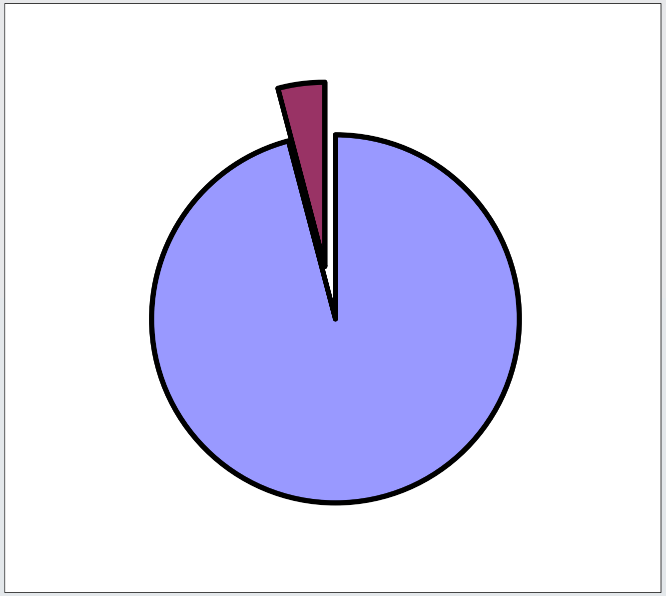
1. Because the $CO_2$ is less dense than formation water, it will rise in a relatively narrow column from the injection point until it reaches the base of the seal, and then spread out laterally.

2. 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.

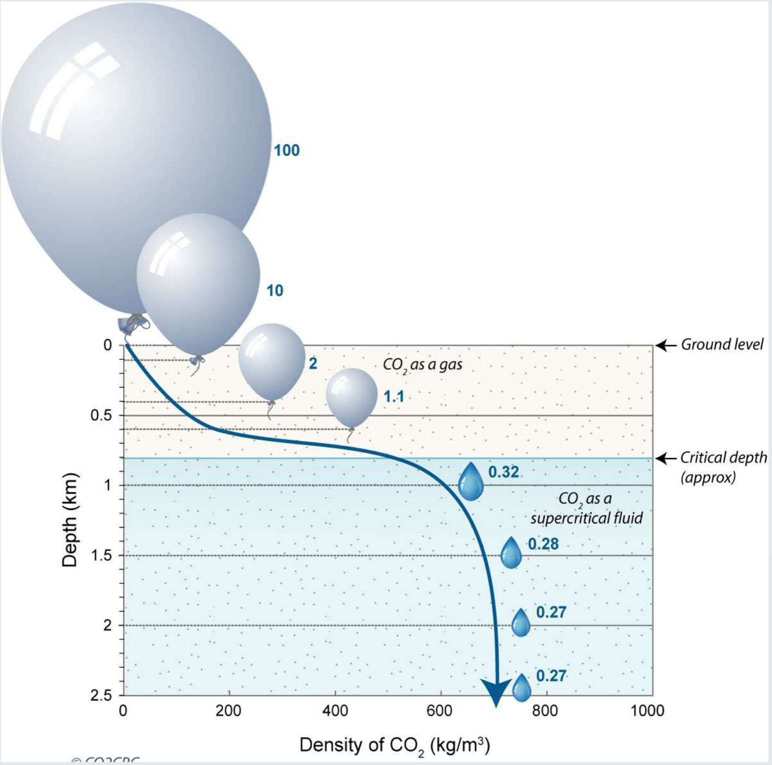
Thus, even within the volume of the plume, only a percentage of the pores will contain $CO_2$.

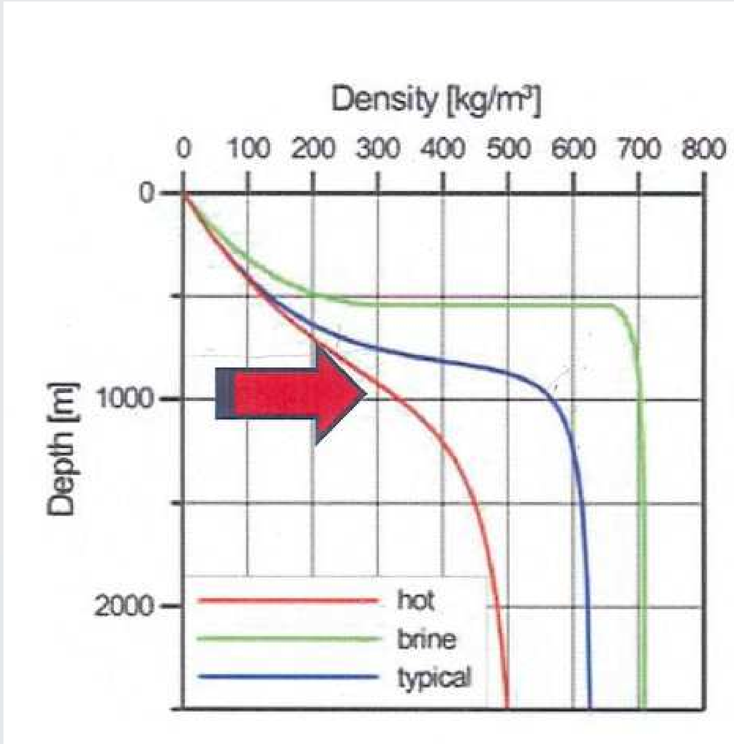
# How much of the reservoir is available?

- 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.



# Density, temperature and depth




- At Pressures higher than 7.2 MPa and Temperatures higher than 31.1°C, $CO_2$ becomes a supercritcal fluid: gas like but with up to 400× the density.
- Generally these conditions are found below about 800m in the subsurface.

At 1000m, the density of the $CO_2$ can range from around 320 to 700 kg/m$^3$ depending on the geothermal gradient and the salinity (density) of the formation water.

# Capacity assessment in four basic steps

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

# Deterministic or probabilistic estimation

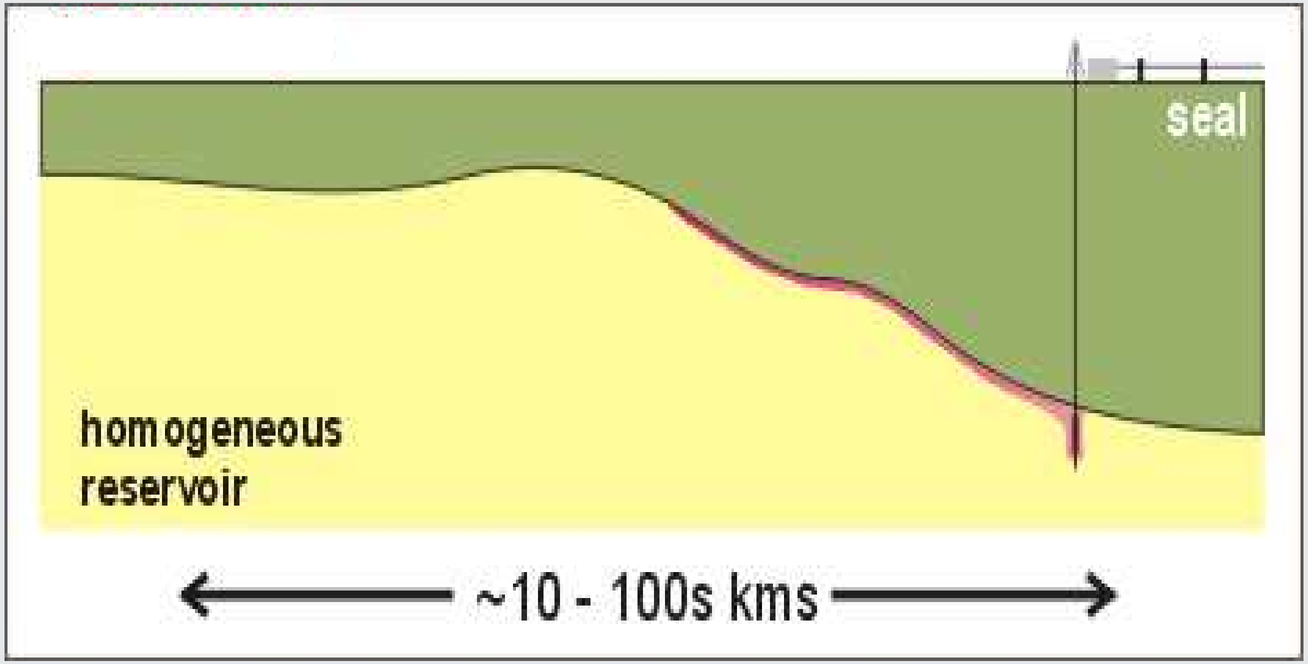
- Deterministic assessment multiplies single values for the storage parameters and presents the result as a best estimate.
- Probabilistic assessment multiplies ranges of values and presents the result as statistical distribution:

P10-P50-P90

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

# 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"?

# 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. |

# Example: The DOE Formula

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

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 |
| $\phi_{tot}$ | $L^3/L^3$ | Average porosity of entire saline formation over thickness hg. Total porosity of saline formations within each geologic unit's gross thickness divided by hg |
| $\rho$ | $M/L^3$ | 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

# 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).

# Assessment methodologies requiring more data

- Specific Sequestration Volumes
- USGS Probabilistic Assessment - 2010

# Specific sequestration volumes

- Brennan and Burruss (2006).
- Does not assess the capacity of a basin as a whole but determines what amount of pore space would be required to store a given volume of $CO_2$ at a specific temperature and pressure.
- This methodology is very good for rapidly assessing if a basin or sub-basin has the capacity to deal with the emissions from a specific point source or group of point sources.
- However it will not easily give total potential storage capacity if that is what is asked for.

# USGS probabilistic assessment - 2010

- 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.

# The Critical Question

- What is the appropriate **E** or **$C_c$** value to use?
- The IEA/EEC* Report has calculated a series of site-specific 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.

* Gorecki et al 2009

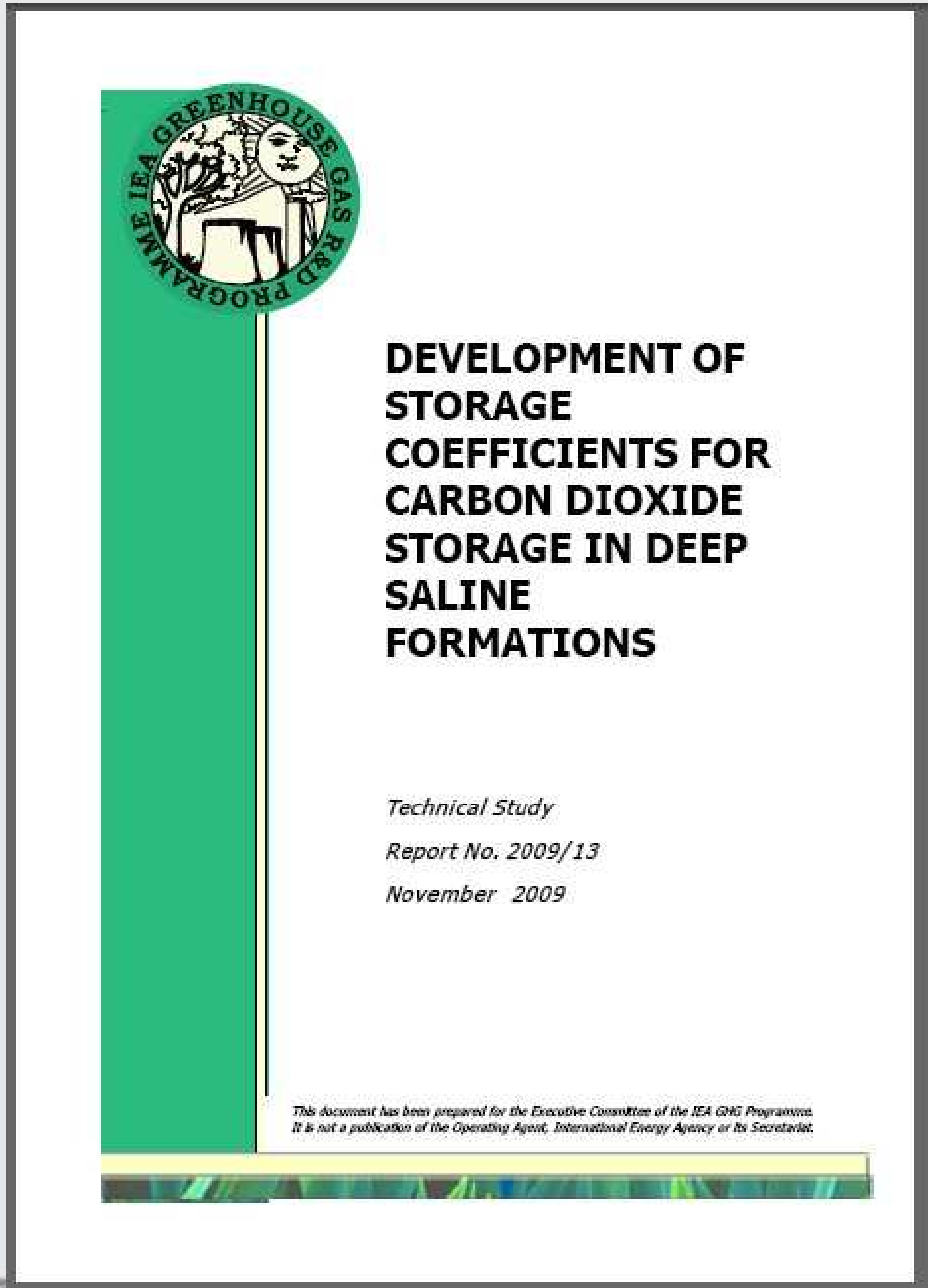
# The Critical Question

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

- The IEA-GHG has tried to give some guidance

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

However all of this is model driven


IEA GREENHOUSE GAS R&D PROGRAMME

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

*Technical Study*

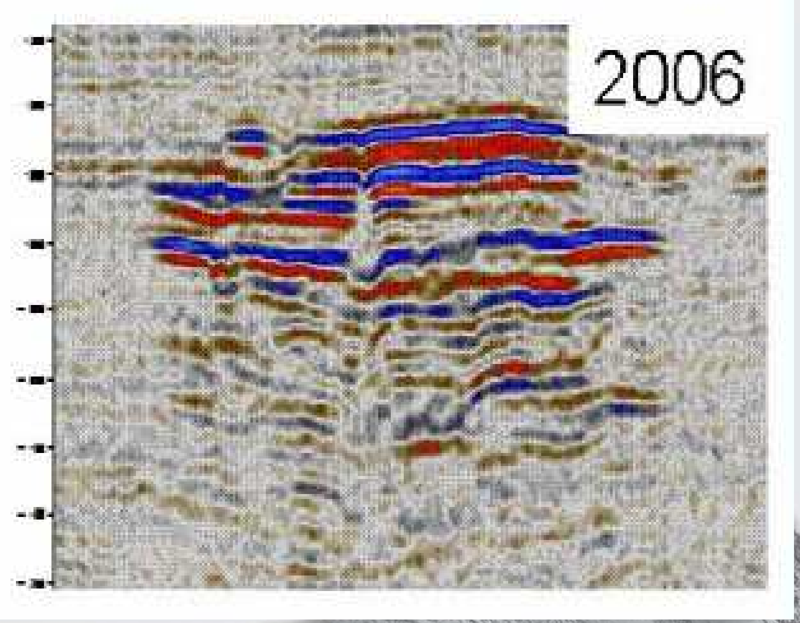
*Report No. 2009/13*

*November 2009*

*This document has been prepared for the Executive Committee of the IEA GHG Programme. It is not a publication of the Operating Agent, International Energy Agency or its Secretariat.*

# 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.



# 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.* .