WHEN TRUST MATTERS

CCS STORAGE (saline aquifers vs depleted fields)

SUT Evening Technical Meeting

Diane Labregere

Perth, June 14th 2023

About me

- MSc in **Geophysics** engineering and MSc in research in **Hydrogeology** in France (2003-2004)
- Schlumberger Water Services in Paris (2004-2006)
- Schlumberger Carbon Services – Paris and Brisbane (2006-2009).
- Coal Seam Gas industry with QGC in 2009 in Brisbane (FDP RE)
- Offshore conventional with ConocoPhillips in 2012
  - Exploration Barossa
  - Reservoir management Bayu Undan
- Back to SLB (digital division) in 2014 in Jakarta then Perth
- DNV Australia since Nov 2022

What is CCS ?

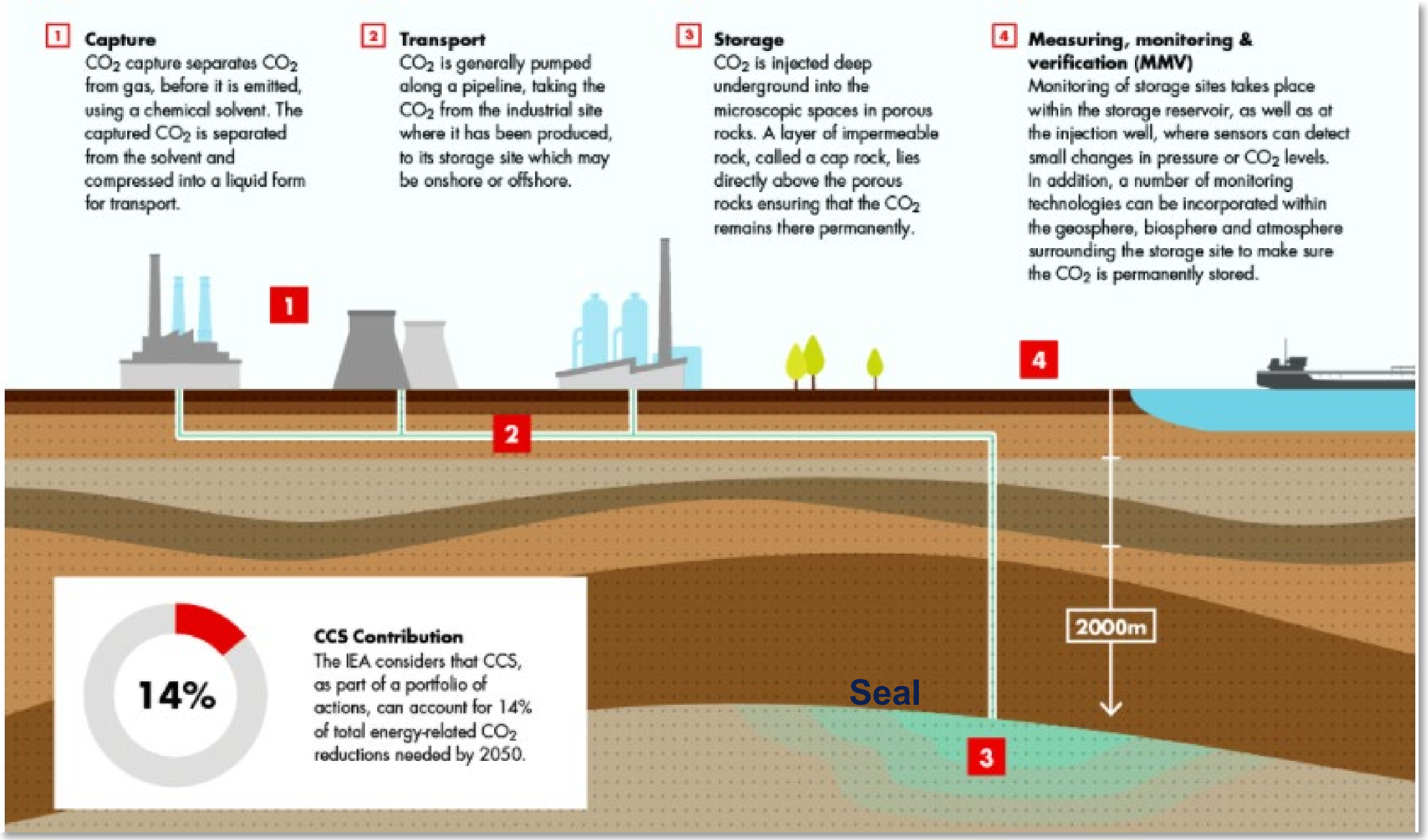
- Is the process of capturing waste CO_2, safety transporting and ***permanently storing it in deep geological formations*** (> 1000 m), for long term storage and preventing it being emitted back into the atmosphere

- **CCS is not new** – the oil and gas industry have for > 40+ yrs being injecting CO_2 under ground to improve hydrocarbon recovery.

- **Located:** On or offshore
- **Types of stores:** Depleted fields or saline aquifers

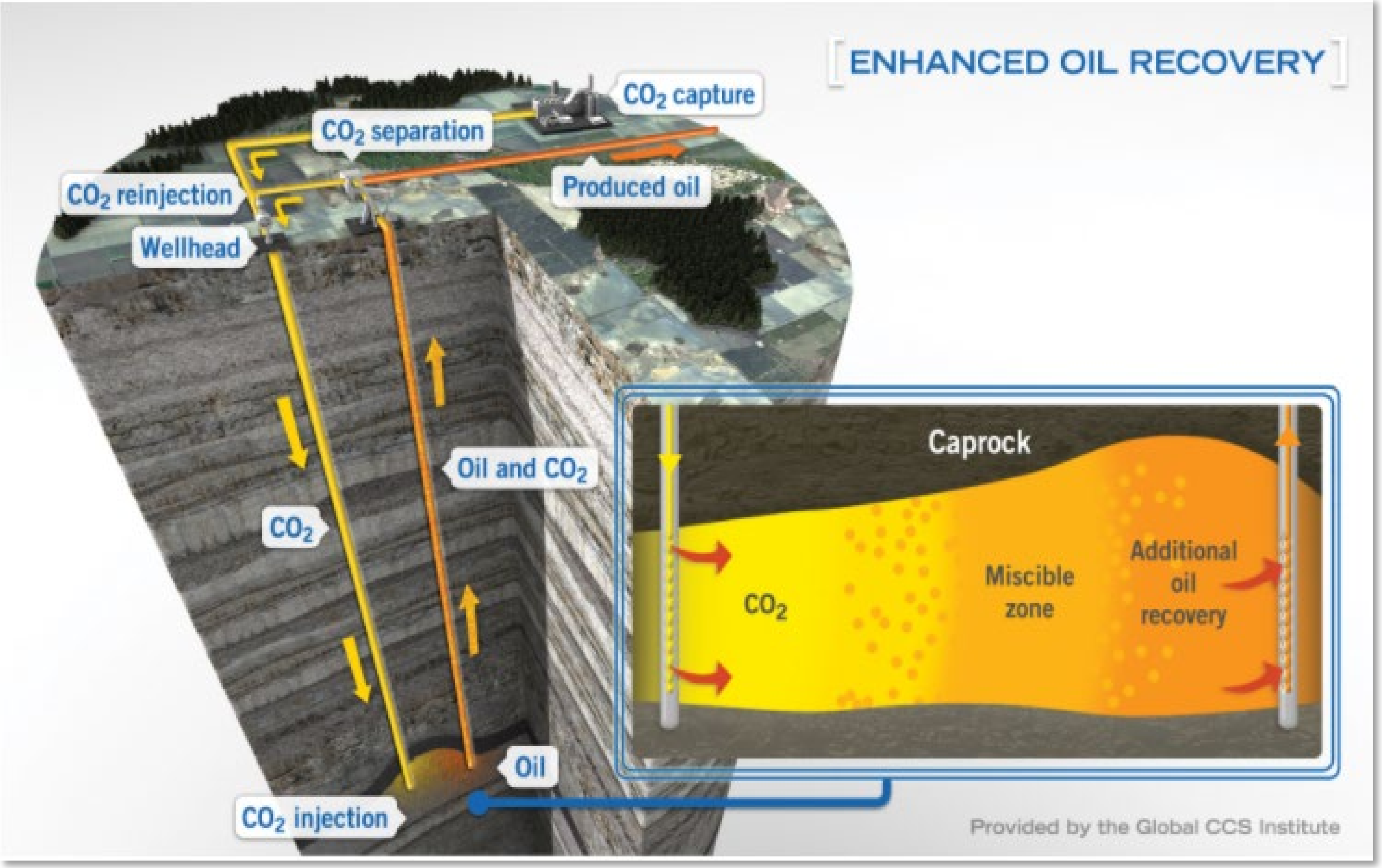
- **Capture:** Power plants, industrial source now research into direct air capture

- **Transport:** pipeline and or shipping (Northern Lights only example to date)



EOR – Enhanced oil recovery

- CO_2 can be used to improve hydrocarbon recovery, especially in oil fields. CO_2 is used as a working material to “push” the oil to the production wells more efficiently
- EOR typically recycles CO_2 and ***does not contribute significantly to long term storage***
- CO_2 is often released with oil extracted
- Only a small % of CO_2 is long term trapped occurs



Key CCS projects

W Texas EOR

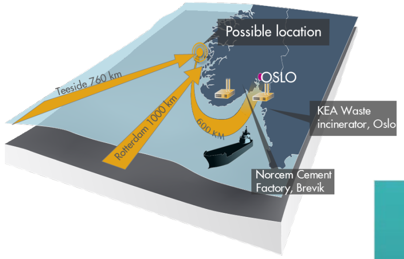
1970's → PRESENT

Sleipner

Gorgon

Quest

Northern Lights



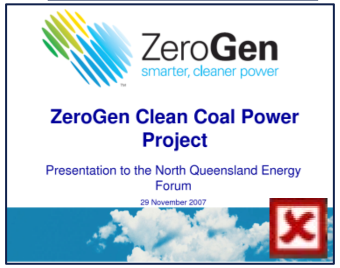
ARAMIS

Shell, Total, EBN & Gasunie
FID: 2023, 1ST CO_2 2026

[CCS projects around the world]

Barendrecht

ZeroGen



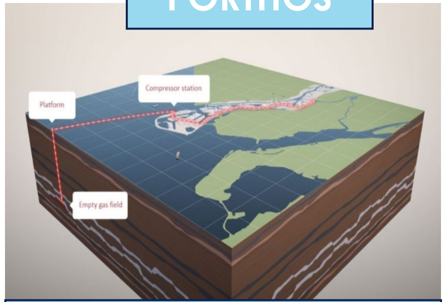
Draugen

Peterhead

Callide Oxyfuel Project (QLD)

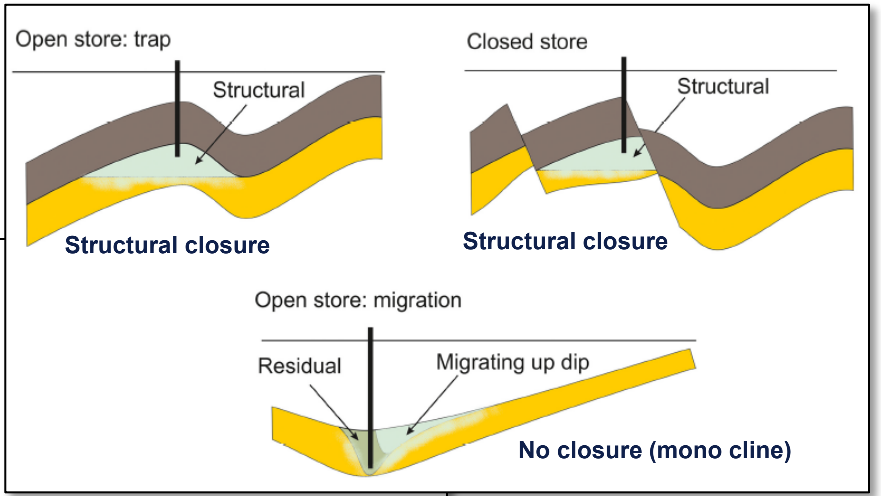
Storage canceled

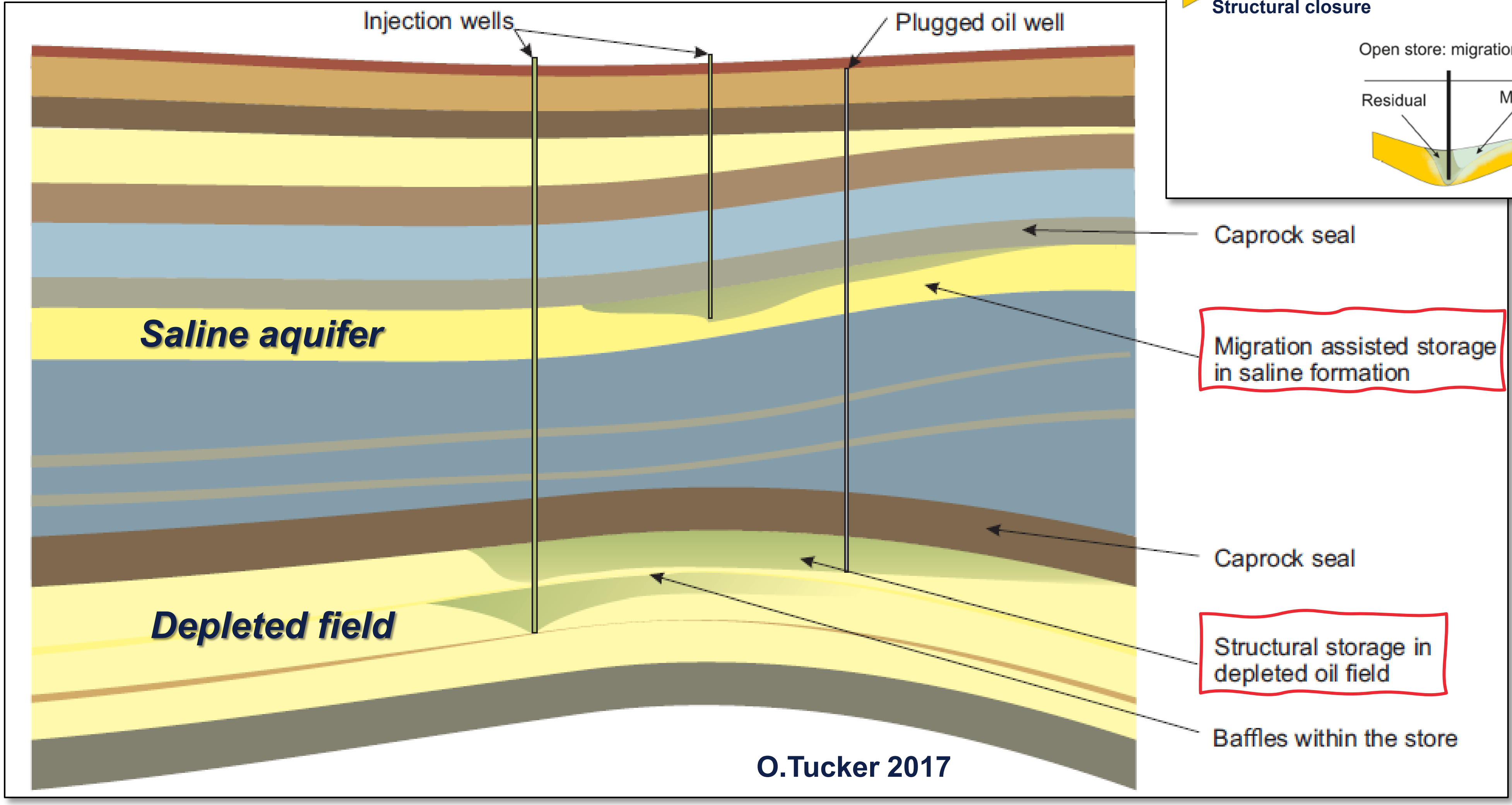
PORTHOS



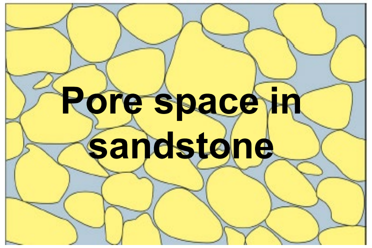
TAQA (P18), Shell, EBN & Gasunie (2.5 MTA)
1ST CO_2 2024

CO_2 storage types

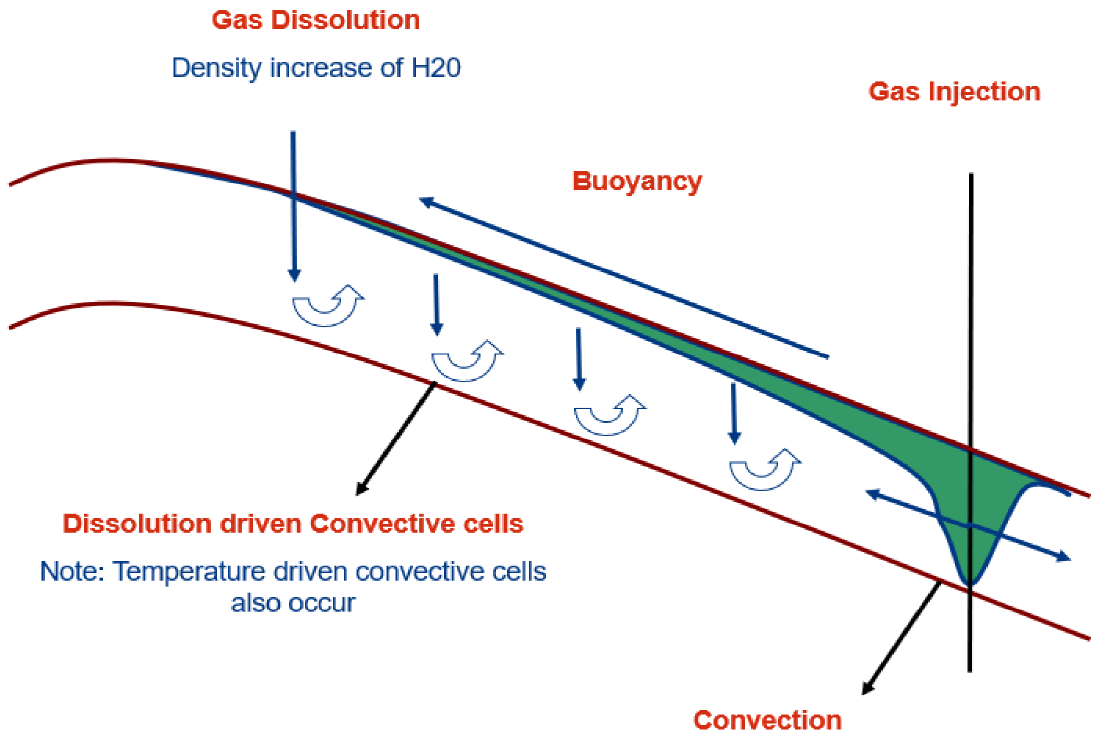




Store / reservoir

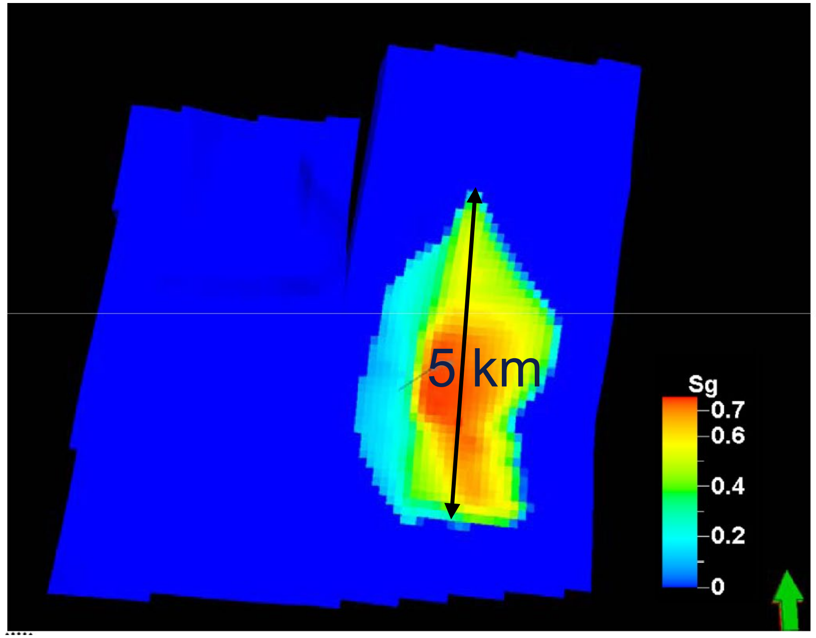


How does CO_2 move and become stored long term ?



Injected deeper > 850 m, preferably > 1000m, in order to inject in super critical form (35 deg C & 75 bars)

Key parameters effecting trapping mechanisms: Salinity, dip angle, temperature, reservoir plumbing – permeability and net thickness

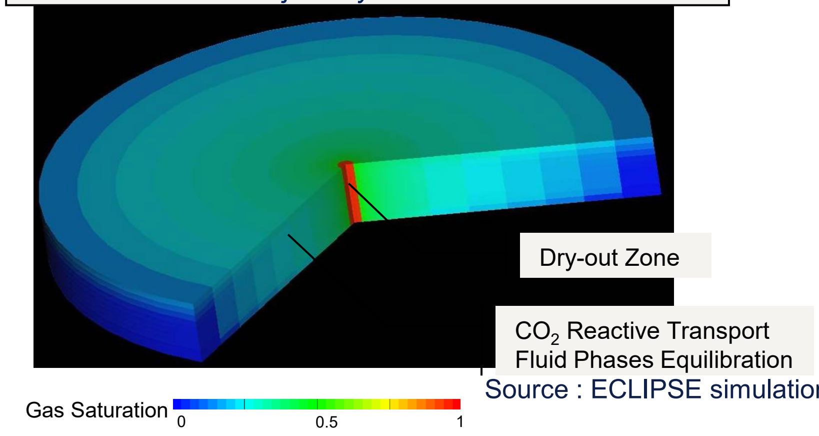


Source: Benchmark Study (H, Class et all, 2009)

7 Mt total

50 years

The Reservoir Dry-out Simulation near the Wellbore for Injectivity Prediction



Source : ECLIPSE simulation of dry-out effect

DNV

Trapping speed

Residual trapping

- Occurs in pore space and occurs first

Solubility trapping

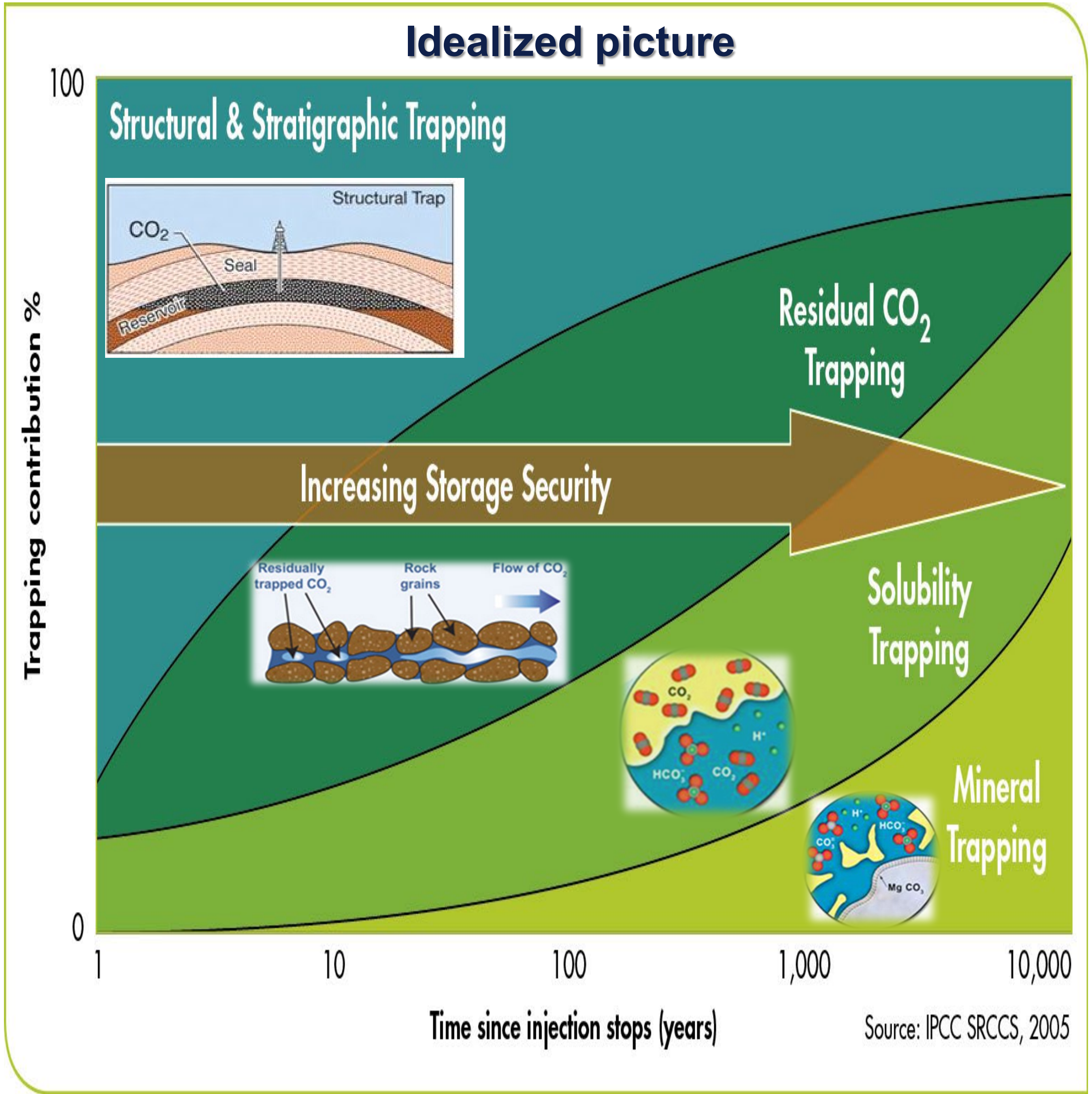
- Depends on salinity and migration extent

Mineral trapping

- Dependents on: rock mineral compositions, pressure and temperature effects
- Last mechanism to occur

Impact of storage structural

- Solubility and mineral trapping occurs faster in structurally open non depleted settings i.e. open aquifers



Storage site feasibility requirements

Containment

Can it contain CO_2

Do we understand the Geological (faults, seals, seismicity) and mechanical (wells) mechanisms for leakage. Can they be avoided or remediated ?

Capacity

Does the site have storage capacity required ?

Injectivity

Can it be injected at an *economic rate* over the lifetime of the project ?

Monitorability

Can CO_2 be monitored and remediated within economic limits ?

Stakeholder

Acceptable to stakeholders ?

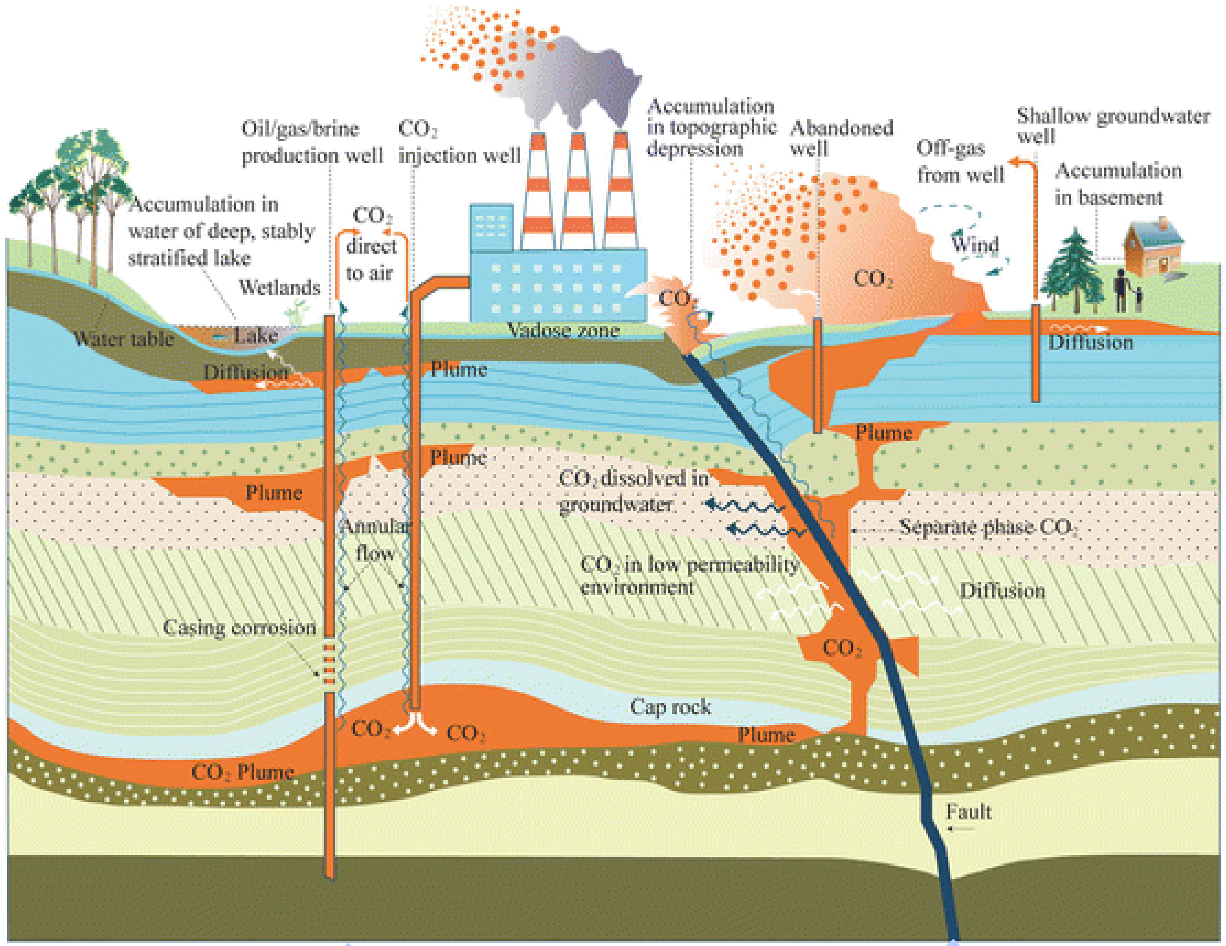
- **Lack of anyone of these elements prevents a storage site being feasibly matured**
- Stakeholder / Non-Technical Risk – can be the biggest risk to project development e.g., Barendrecht
- MMV and Corrective Measures Plan is a key part of a storage permit application and forms a central part of the Storage Development Plan (SDP) and Closure plan
- There is no one-size fits all, MMV plans are **risked based**, **site specific** and **adaptive** through time.

Storage complex methodology – safe storage, how can it leak ?

Shallow geosphere

Deep Geosphere

Sensitivity level



Wells

Faults

Storage complex – multiple reservoir seal pairs (primary and secondary stores and seals) to provide additional layers of storage security. Analogy: oil tank farm (bung walls, ditches etc..)

Not all storage sites can have multiple layers or may require it (e.g., salt basins), but it is desired where geologically possible

Store – CO2 injected layer (reservoir)

Seal – impermeable formation

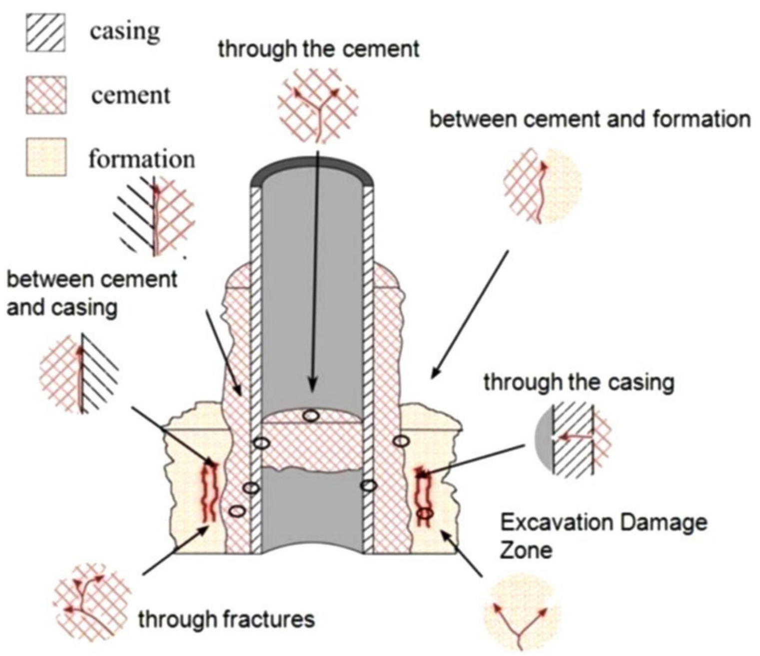
Ultimate seal – defines the vertical extent of the container complex

Main leak / seepage paths

- ***Wells – primary leak path to surface***
- Faults & fractures
- Seals (also called caprocks)

Saline aquifers vs. depleted fields pros and cons (slide 1)

Risk factor	Deep saline aquifers	Depleted fields
Containment - Well - Faults & seal	▪ Typically fewer legacy wells	▪ Typically higher density of legacy wells, as the field has been explored developed and produced
	▪ Faults and seals not geomechanically weakened through production - but depending on the distance from O&G fields are untested	▪ Due to depletion of HC, fields are geomechanically compromised ▪ Proven in the local area to hold HC
Capacity	▪ Regional capacity ranges typically higher ▪ Larger uncertainty range on capacity estimates prior to appraisal actives, linked to limited data on reservoirs (store) properties	▪ Typically offer smaller overall capacity, as the capacity is limited to the field size ▪ Uncertainty on capacity range less, due to better reservoir (Store) knowledge – fields are data rich environments compared to saline aquifers
Injectivity	▪ Greater uncertainty due to lack of data, cannot be DE risked until appraisal well conduct injectivity / injection test(s)	▪ Production data = confidence on dynamic injectivity rates early on in CCS storage maturation phase ▪ Depending on the amount of depletion, you may not be able to inject initially in a supercritical phase until the store is pressured to within the pressure envelope of supercritical phase injection. ▪ Alternately add additional heating and compression at the well head to protect the near well bore environment - injected CO_2 will still freely move, expand and cool rapidly (J-T cooling). These thermal effects can impact frac pressure of the store without careful management.

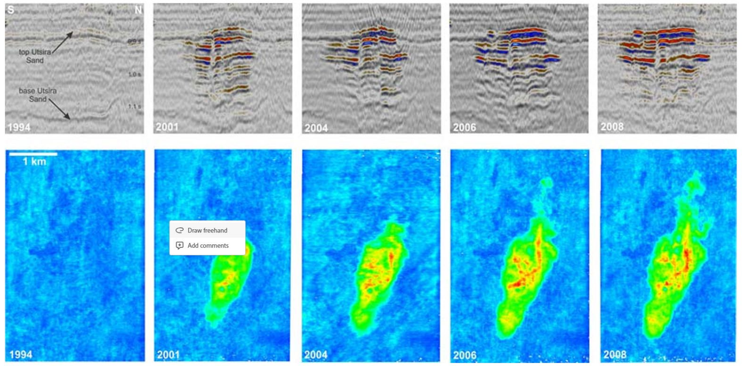


Well integrity risks schematic

(source: M. Bai et all.)

Saline aquifers vs. depleted fields pros and cons (slide 2)

Risk factor	Deep saline aquifers	Depleted fields
Monitorability	▪ Geophysical monitoring techniques not hampered by residual HC presence	▪ Remaining HC (gas) can inhibit geophysical (seismic) techniques – hard to differentiate the CO_2 plume ▪ However, it does not preclude the use of seismic outside for detecting CO2 leakage or migration outside the defined store or storage
Infrastructure	▪ Potentially higher cost as no infrastructure	▪ Infrastructure reused based on comparison not always result in lower costs for CSS (IEAGHG report) ▪ Cost of remediating wells, and modifying pipelines or platforms ▪ Remaining service life for pipeline and platforms
Other (HSSE and Appraisal costs)	▪ HSSE case simpler - no simultaneous operations occur if an aquifer is developed from a greenfield platform – only fluid on the platform is CO_2 ▪ Potentially higher derisking costs – additional appraisal activities (wells, seismic, geo technical studies etc..) prior to FID	▪ Likely more complex HSSE case, if a brownfield platform is reused, a dual safety case is required for both CO_2 and HC being present on the platform ▪ Depending on the number of legacy wells and state of abandonment – higher abandonment cost could occur prior to 1st injection – but limited appraisal cost as fields are data rich and unlikely to need to prove economic rates of injection due to wealth of HC production data.



Time-lapse "seismic" images of the CO_2 plume at Sleipner (source: Chadwick and Eiken)

What makes a good storage site

Geological considerations

- > 1000 m – to inject in super critical form (i.e. more capacity)
- A container complex exists – multiple barriers for storage security
- Low density of wells, faults and fractures and naturally active seismic areas
- Structurally as flat as possible for aquifers – slower plume movement
- Offshore: Shallow water < 100 m, lower cost wells and development

Transport considerations

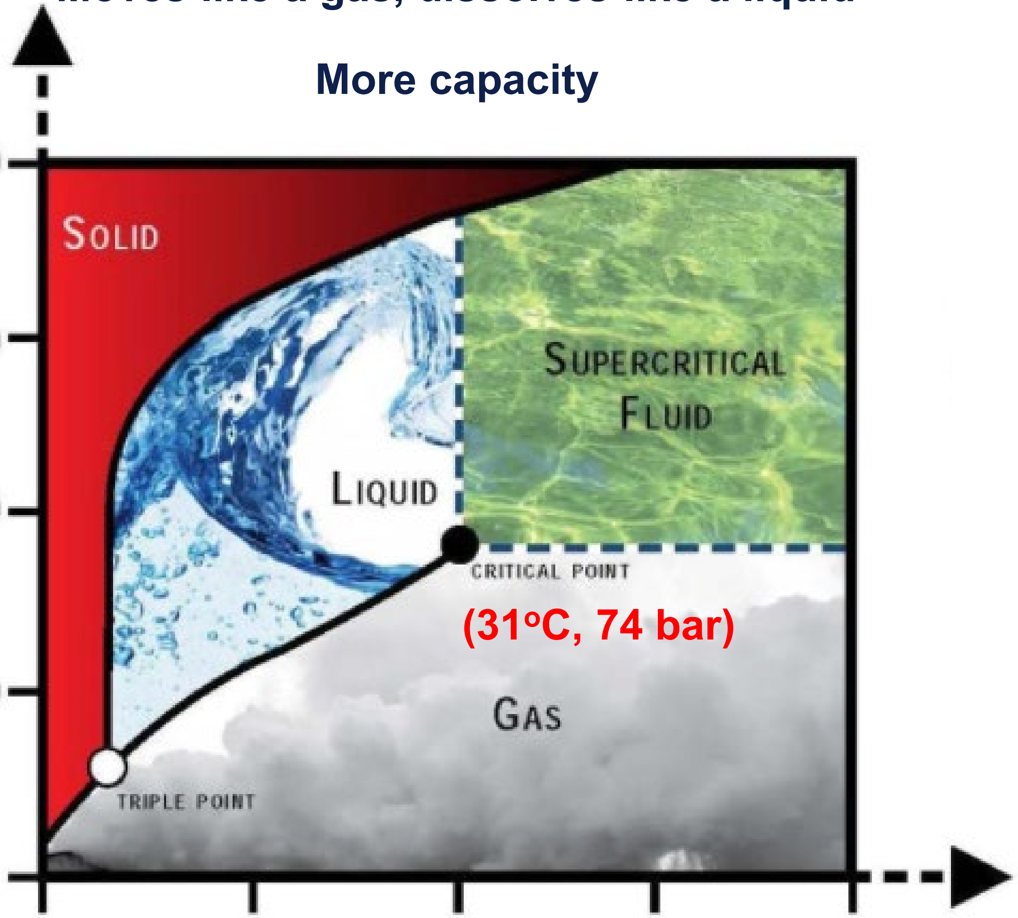
- Close to the source of CO_2 away
  - trade off between volume to be stored and cost of transport

Practical considerations – Hub developments

- Rules and regulations and price for carbon: Mature
- Away from other competing resources
- Public acceptance

Moves like a gas, dissolves like a liquid

More capacity



Additional resources

- 4 March 2022: IEAGHG Webinar: Criteria for Depleted Reservoirs to be Developed for CO_2 Storage – YouTube
- Criteria for Depleted Reservoirs to be Developed for CO_2 Storage – IEAGHG report 2022
- H. Class et all.
"A benchmark study on problems related to CO2 storage in geologic formations", Computer Geosciences, 2009
- S. Hurter, D. Labregere and J. Berge
" **Simulations of dry-out and halite precipitation due to CO_2 injection**",
AGU Fall Meeting, 10-14 December 2007, San Francisco, U.S.A. Abstracts, accepted for Oral Presentation
- D. Labregere, N. Marmin, S. Hurter, J. Berge and A. Lukyanov
"CO_2 storage in saline formation: the impacts of reservoir properties and geometry on CO_2 trapping mechanisms", APPEA 2009, 31 May-3 June 2009, Darwin, Australia
- M. Bai et all,
"A review on well integrity issues for CO2 geological storage and enhanced gas recovery", 2016, Renewable and Sustainable Energy Reviews, vol.59
- Chapter 10: Offshore CO2 Storage: Sleipner natural gas field beneath the North Sea (A. Chadwick, O. Eiken)

Useful links:
- IPCC report (2005)
- Global CCS Institute

Q&A