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Estimating Storable Quantities for CCS Projects

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Introduction, Objectives and Content

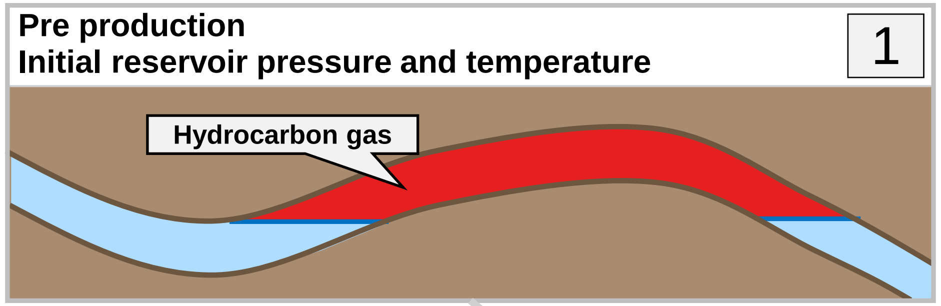
The objective of this presentation is to describe a pragmatic approach for estimating storable quantities of CO_2 from experience gained on a variety of CCS projects in different parts of the world.

(A matter of terminology: The author uses “storable quantities” to describe technical volumes and/or mass. “Capacity” is a defined term under SPE SRMS.)

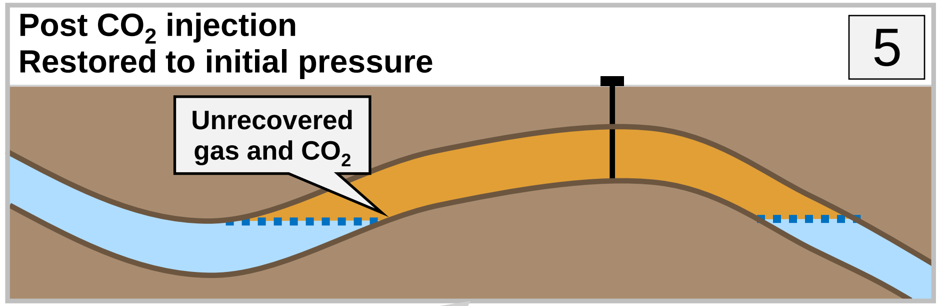
Contents:

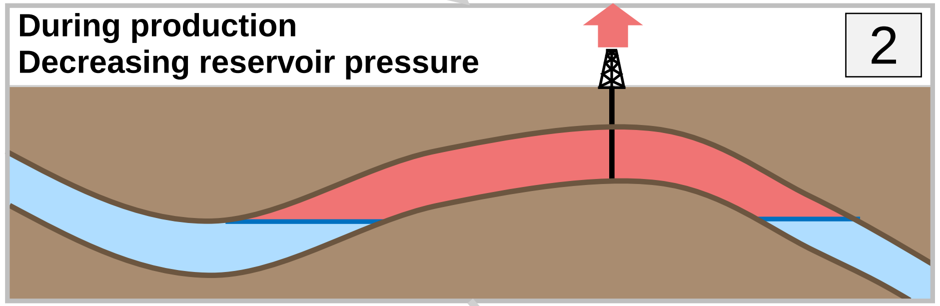
1. Depleted gas reservoirs.
2. Aquifers.
3. Concluding remarks.

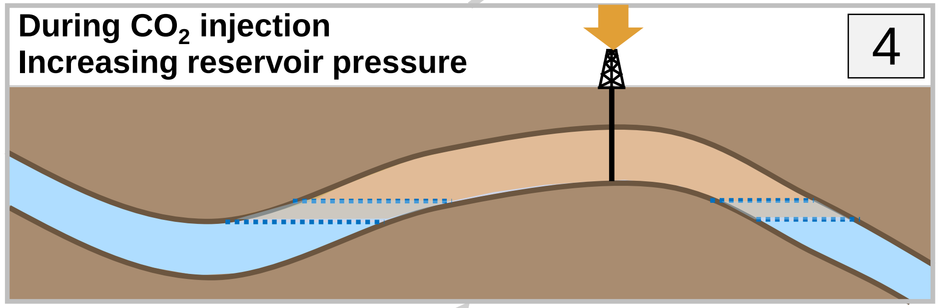
Conversion of a Depleted Gas Reservoir to CO_2 Storage



CO_2 is injected into a depleted gas reservoir to restore pressure to its original level.

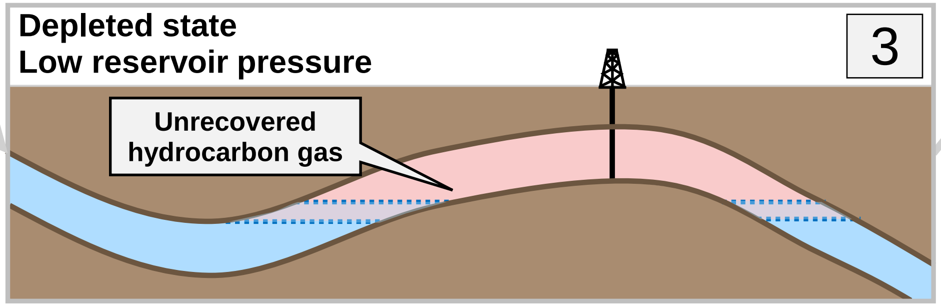






Two options:

1. Conventional geoscience estimation of pore volume.
2. Material balance.



We know how much came out so we should know how much can go back.

Diagram modified from: CCUS deployment challenges and opportunities for the GCC. January 2022.
A report prepared for the Oil and Gas Climate Initiative by AFRY & GaffneyCline.

Depleted Gas Reservoirs- Material Balance

The storable quantity of CO_2 in a depleted gas reservoir is:

$$CO2Mi = \frac{Gp}{Ei} * \rho CO2i$$

Data requirements:

- Produced HC gas volume.
- HC gas PVT.
- Initial reservoir pressure.
- Initial reservoir temperature.

Where:

$CO2Mi$ mass of storable CO_2 if the reservoir is returned to its original pressure [metric tonnes].

Gp volume of HC gas that has been produced at surface temperature and pressure [m^3].

Ei initial HC gas expansion factor [sm^3/rm^3].

$\rho CO2i$ density of CO_2 at the original reservoir pressure [$tonnes/m^3$].

If storage pressure does not equal initial reservoir pressure then:

$$CO2Msto = \left(\left(GRV * NTG * \emptyset * (1 - Swir)\right) * \left(1 - \frac{Ei}{Esto}\right) + \frac{Gp}{Esto}\right) * \rho CO2sto$$

Where:

$CO2Msto$ mass of storable CO2 if the reservoir is returned to any pressure [metric tonnes].

$GRV, NTG, \emptyset, Swir$ gross rock volume [m^3], net-to-gross ratio [fraction], porosity [fraction] and irreducible water saturation [fraction].

$Esto$ HC gas expansion factor at storage pressure [sm^3/rm^3].

$\rho CO2sto$ density of CO2 at storage pressure [$tonnes/m^3$].

Limitations of Material Balance

The material balance equations shown above do not account for:

Decreases

- ❖ Aquifer influx – can be very large.
- Heterogeneity – can be large.
- ❖ Condensate drop out – can be large in some cases.
- ❖ Impurities in injectant.
- ❖ Hysteresis in pore volume compressibility – expected to be small.

❖ To some extent could be accounted for by expanding material balance.

Increases

- Utilisation of aquifer surrounding pool – potentially large.
- ❖ Dissolution in connate water – small.

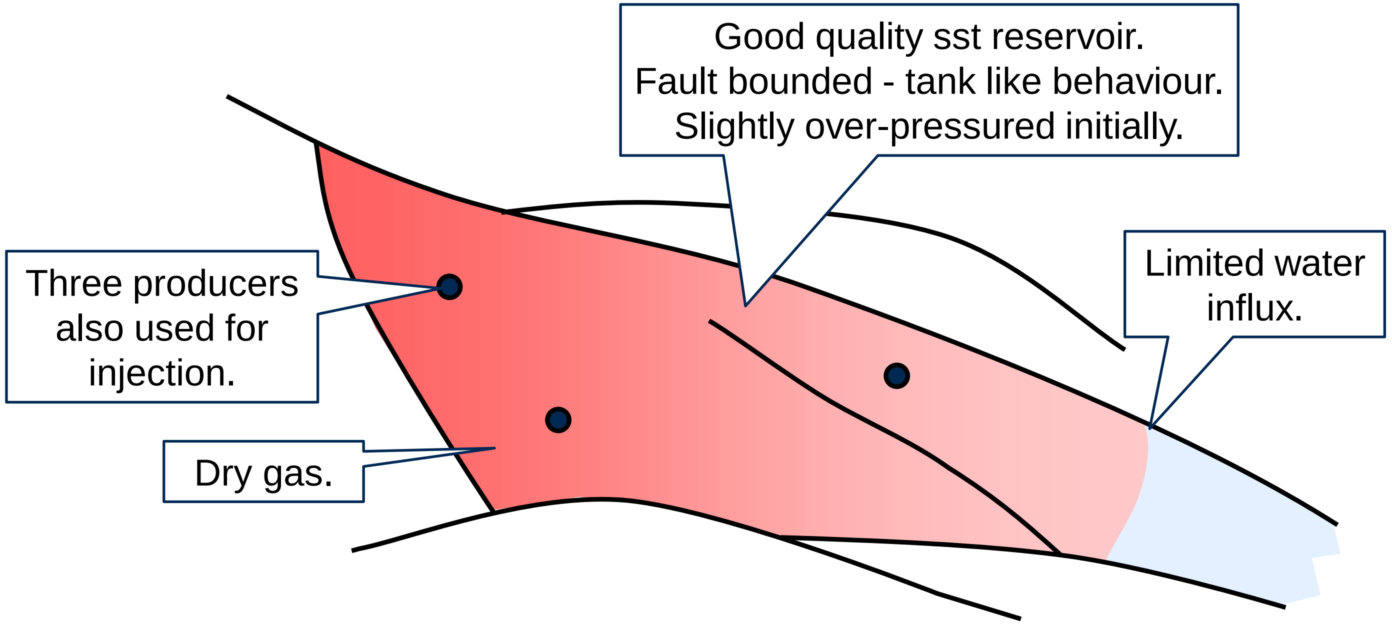
Other

- Thermal effects.
- Mixing with remaining HC gas (mixing, banking, segregation).
- Vaporization of connate water (with salt precipitation).

Dynamic simulation can be used to address most of these points.

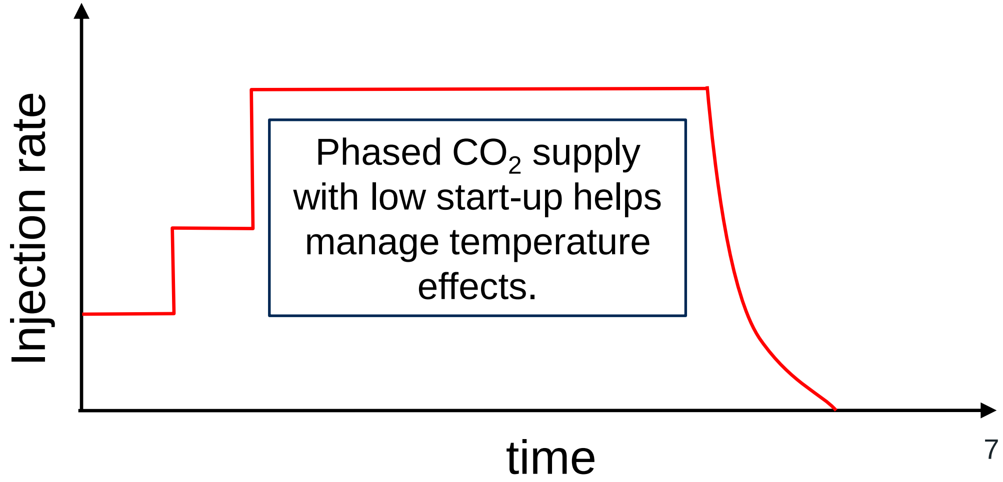
Depleted Gas Reservoirs- Example 1

Item	Quantity
CO_2 density at initial P&T (t/m^3)	**0.65**
Material balance CO_2 quantity (Mt)	**39.0**
Simulation CO_2 quantity (Mt)	**36.1**
Difference (%)	**-7%**



- Some water influx.
- Minor impurities in injectant.
- Some mixing with remaining HC gas.
- Tiny hysteresis effect.
- Good CCS storage candidate, but very deep and very depleted.

<u>In reality</u>: The storable quantity will be lower because the final pressure will not be permitted to exceed hydrostatic.



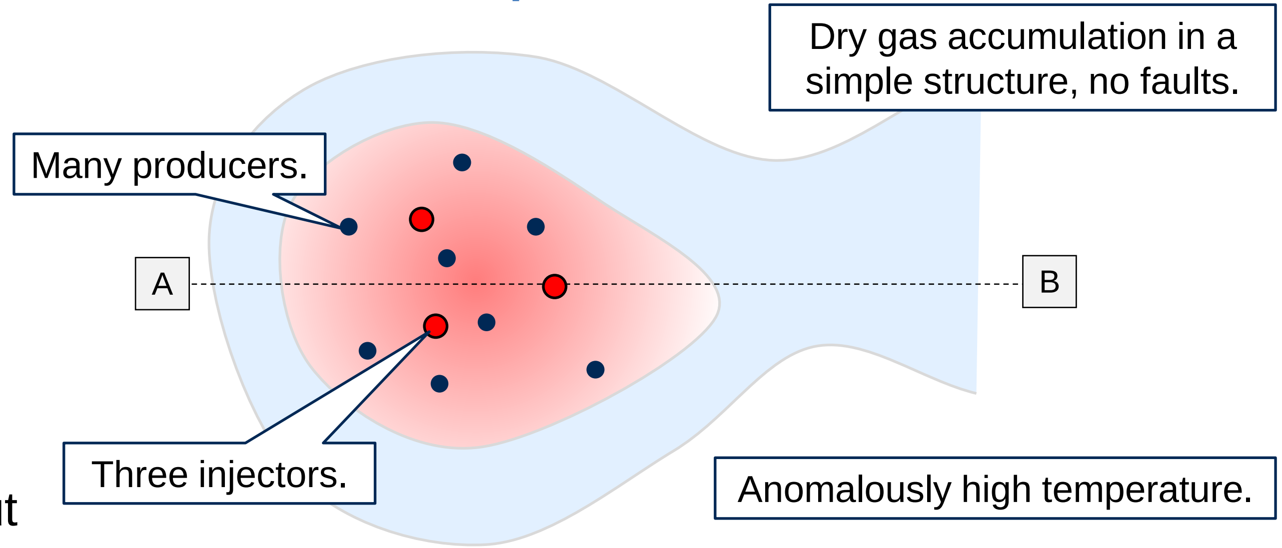
Depleted Gas Reservoirs- Example 2

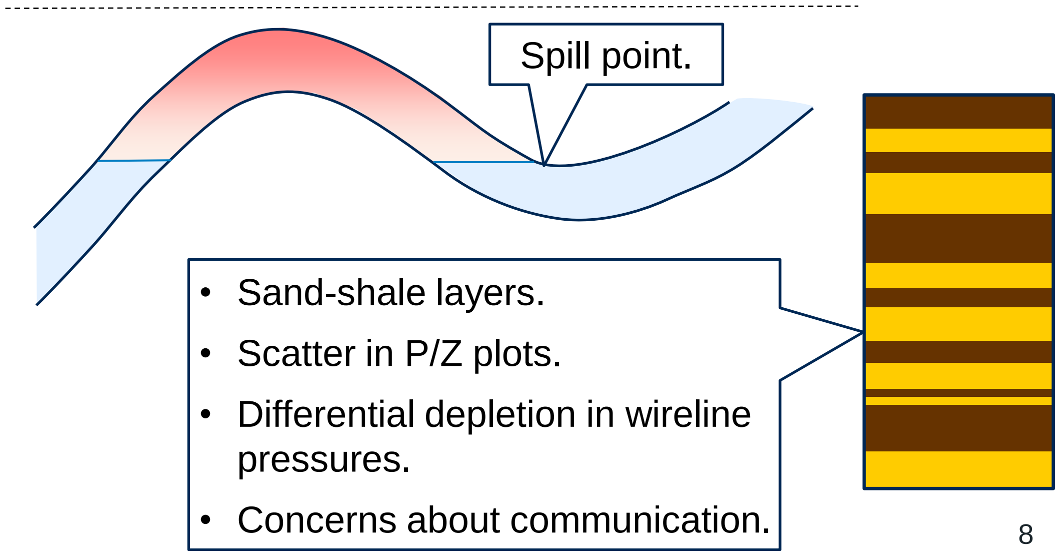
Item	Quantity
CO_2 density at initial P&T (t/m^3)	**0.33**
Material balance CO_2 quantity (Mt)	**17.4**
Simulation CO_2 quantity (Mt)	**14.8**
Difference (%)	**-15%**

- History match for gas production is reasonable, but heterogeneity is a concern for CCS.
- Simulation sensitivities to define range of uncertainty:

  11.4 - 14.8 - 17.0 Mt (low, mid, high).

<u>In reality</u>: More wells can be drilled, and storable quantities could be higher if the aquifer can be used.



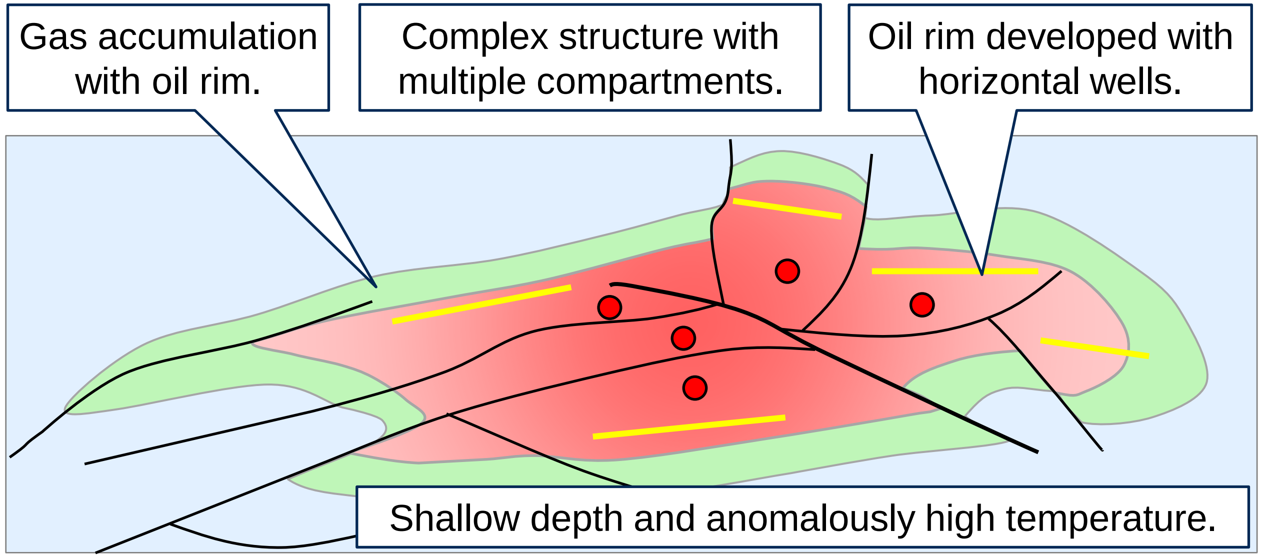


Depleted Gas Reservoirs- Example 3

Item	Quantity
CO_2 density at initial P&T (t/m^3)	**0.26**
Material balance CO_2 quantity (Mt)	**12.0**
Simulation CO_2 quantity (Mt)	**8.4**
Difference (%)	**-30%**

- Aquifer influx.
- Complex geology.
- Complex fluids.
- Very shallow depth and not much scope for increasing BHIP.

In reality: Not an optimal CO_2 storage site!



During production:

- Water encroached into oil.
- Oil encroached into gas.
- Gas blowdown.

Dynamic modelling:

- Good black oil history match of oil, water, gas, pressures.
- Converted to compositional formulation for CCS.

Aquifers – The Volumetric Equation

The storable quantity of CO_2 in an aquifer “container” can be estimated with the following volumetric equation:

$$\boxed{CO2Msto = PV * EF * \rho CO2sto}$$

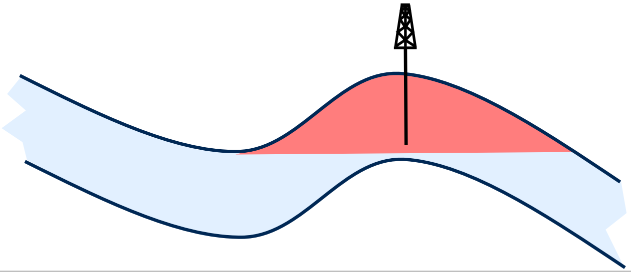
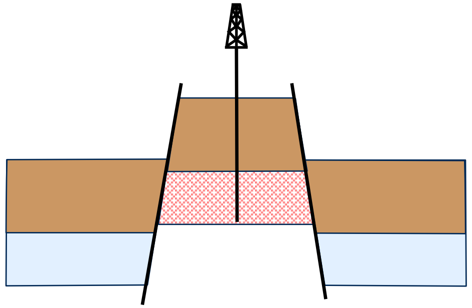
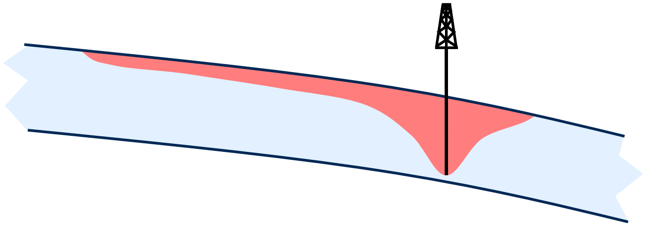
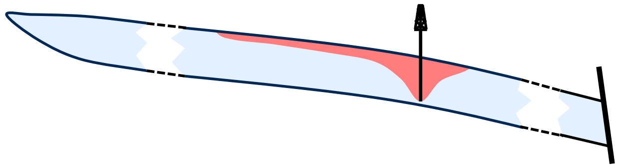
Where:

$CO2Msto$	mass of CO_2 that can be stored at the final storage pressure of the container [metric tonnes].
PV	pore volume of the storage container [m^3].
EF	efficiency factor - defined here as the ratio of the volume of CO_2 injected into an aquifer, to the pore volume of the aquifer at the final storage pressure. (Think of it as the saturation of CO_2).
$\rho CO2sto$	density of CO_2 at the final storage pressure of the container [tonnes/m^3].

Two equally important considerations:

1. Mechanism for trapping and immobilization of CO_2.
2. Nature of the container.

Aquifers – Types of Storage

		Open Aquifer	Confined Aquifer		
$\boxed{EF = (1 - Swir)}$ (max) Expect EF ~ **30 to 40%** of structure PV. Increase by spilling out.	Structural trapping	CO_2 displaces water and is trapped in mobile state. Pressure dissipates. 	CO_2 trapped in mobile state. Pressure increases. 	Structural trapping	$\boxed{EF = C_t * \Delta P}$ Expect EF ~ **0.5%** Increases with dissolution. Increase with brine extraction.
No simple expression for EF. Reported EF ranges typically **0.5% to 7%, (or more).** Definition of container determined by development plan.	Solubility & residual	CO_2 forms a plume, becoming immobilised. Pressure dissipates. 	CO_2 forms a plume, becoming immobilised. Pressure increases. 	Solubility & residual	Similar to adjacent case but pressure increases.
		Open Aquifer	Confined Aquifer		

Adapted from SRMS Application Guidelines Draft 2020

Concluding Remarks

Depleted gas reservoirs

- Analytical methods provide a good basis for benchmarking estimates of storable quantities.
- Dynamic model sensitivity analyses can provide insight into different processes.
- Dynamic models calibrated for production don't automatically provide reliable CCS forecasts.
- Storable quantities can be estimated accurately, usually with a relative low range of uncertainty.

Aquifers

- Analogues are still too sparse to provide a reliable basis for estimating storable quantities.
- Dynamic modelling is usually essential, supported by analytical end-points.
- For large open aquifers in particular storable quantities are determined by the development plan rather than by some "inherent" efficiency factor.

Depleted gas reservoirs offer relative low risk opportunities, but in the long run aquifers will provide the storage space that we need to make a material difference to CO_2 emissions.

Thank you for your attention

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