Technical aspects of depleted fields

Aramis and Peterhead experience

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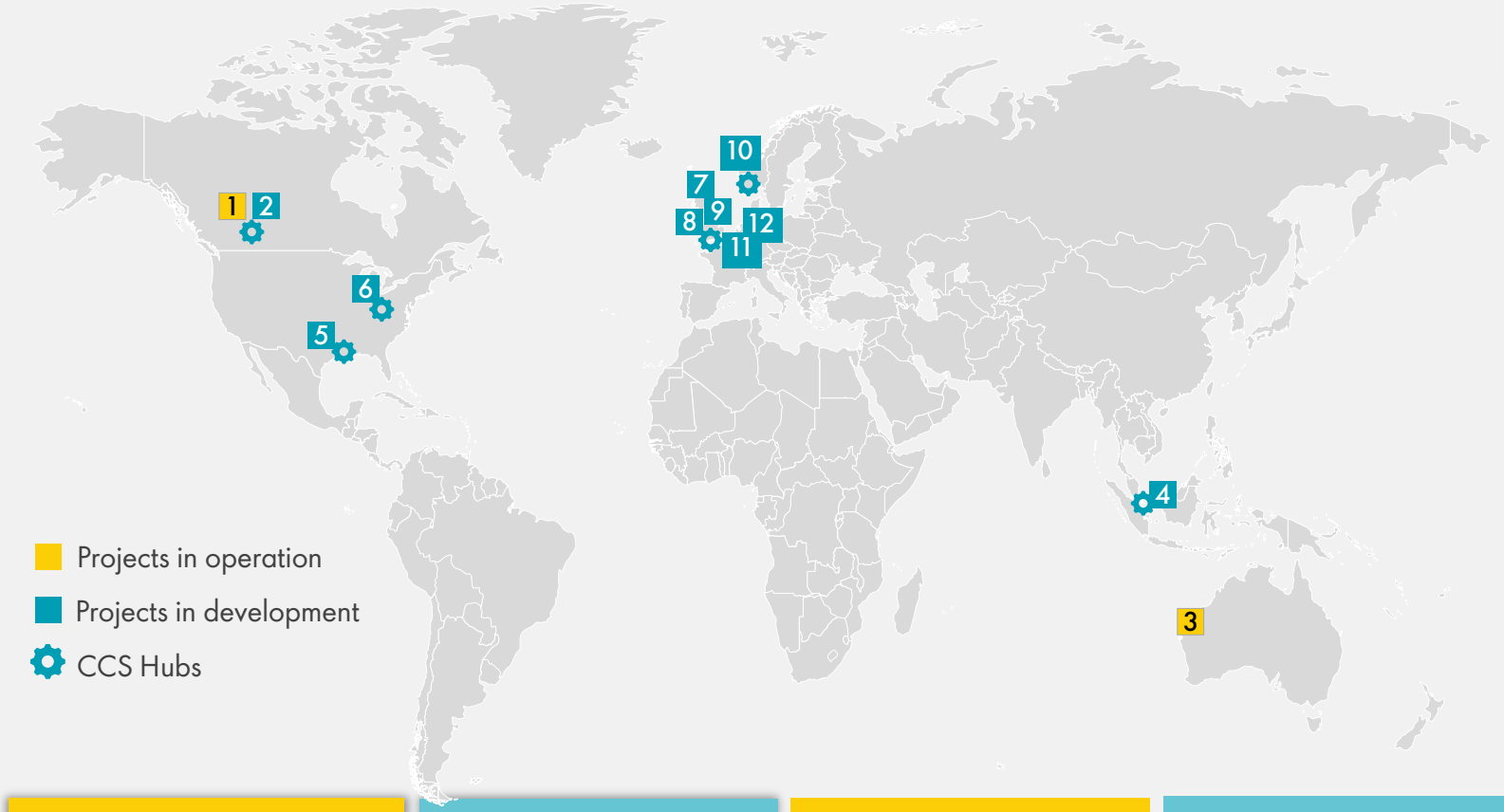
Shell's CCS involvement globally



1. Quest

In Alberta, Shell Canada operates Quest, a CCS facility that captures, transports and stores more than a million tonnes of CO_2 every year from the Scotford Upgrader.

2. Polaris *

A CCS project planned for Scotford in Canada to capture CO_2 from Shell's Scotford refinery and chemicals plant.

3. Gorgon

Shell Australia holds a 25% stake in the Gorgon liquified natural gas project that uses CCS to capture CO_2 produced.

4. Southeast Asia Hub *

Shell is exploring the creation of a CCS hub in Singapore to help customers reduce CO_2 emissions, including emissions from the Shell Energy and Chemicals Park Singapore.

5. Louisiana Hub *

Development of a CCS project in Louisiana focused on Shell's CO_2 footprint at the Norco, Convent, and Geismar facilities. It will also act as a CCS hub for other emitters in the region.

6. Ohio River Valley *

In the tri-state area of Pennsylvania, Ohio and West Virginia, Shell is developing a hub linked to our CCS project at the Shell Polymers plant in Monaca, Pennsylvania.

7. Acorn *

In Scotland, Shell UK, Storega and Harbour Energy are equal partners in the Acorn project, to provide critical CCS and hydrogen infrastructure for the UK.

8. South Wales Industrial Cluster *

Shell UK is part of the South Wales Industrial Cluster (SWIC), a group looking to decarbonise the region using, amongst other technologies, CCS.

9. Northern Endurance Partnership *

Shell UK is part of the Northern Endurance Partnership, working to develop the offshore CCS infrastructure to decarbonise two major industrial clusters in the UK.

10. Northern Lights

A collaboration between Shell, TotalEnergies and Equinor to transport CO_2 from industrial plants to store in a reservoir in the Norwegian North Sea.

11. Aramis *

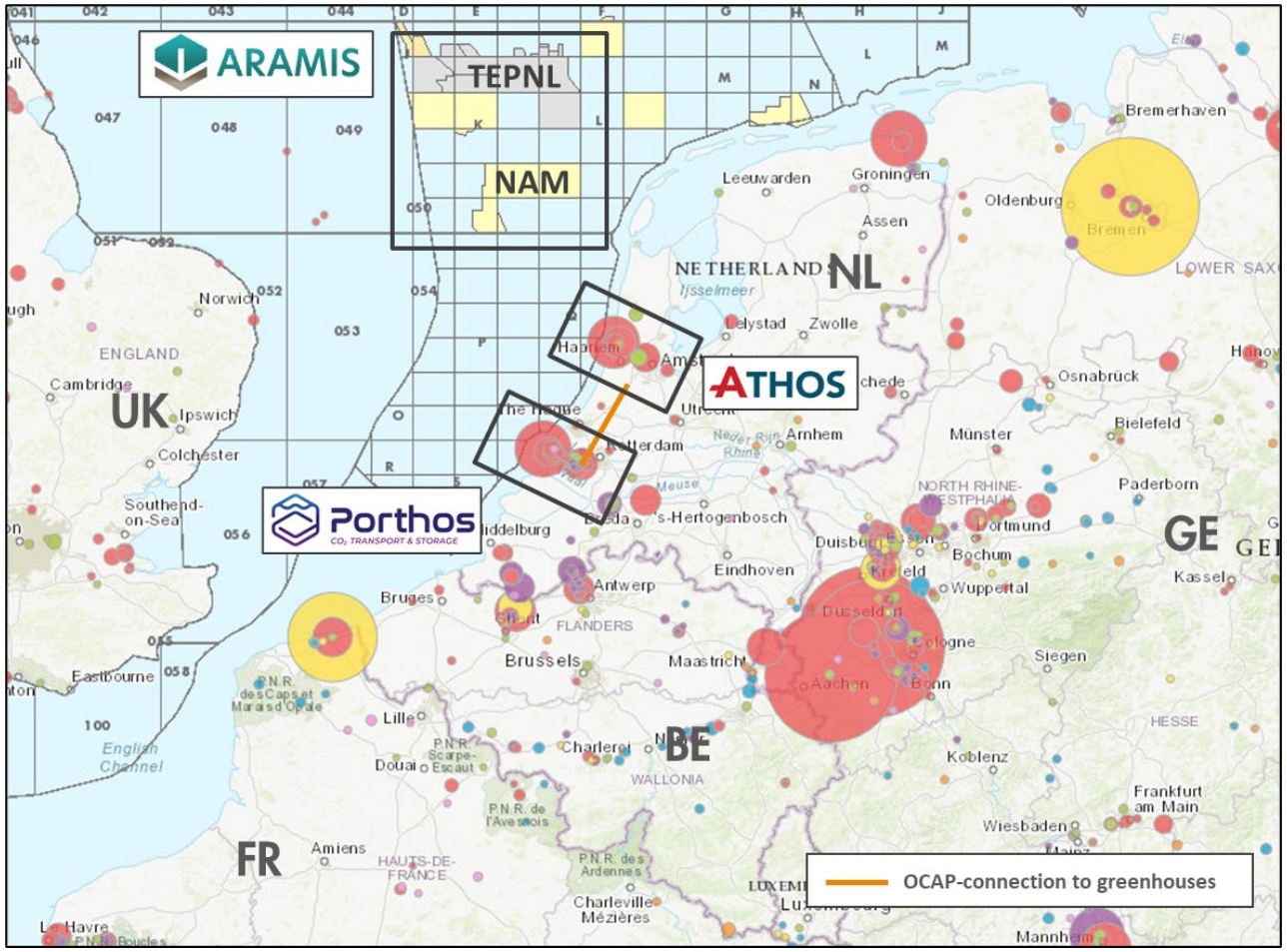
Shell Netherlands, TotalEnergie, Energie Beheer Nederland and Gasunie formed a partnership to enable large-scale CO_2-reduction for industry in the Netherlands.

12. Porthos *

A joint venture between EBN, Gasunie and the Port of Rotterdam Authority looking to transport CO_2 from industrial plants in the Port of Rotterdam, including Shell's Pernis refinery, to store in empty gas fields beneath the North Sea.

* Pre-FID

THE THREE MUSKETEERS AND CCS



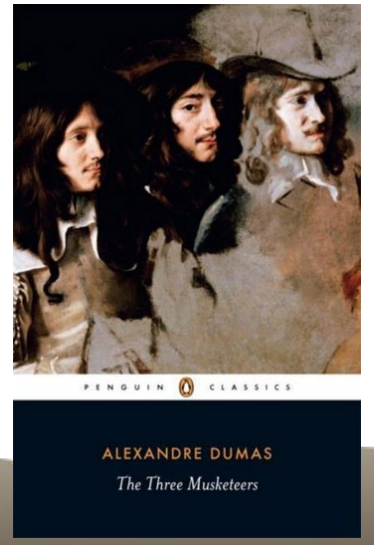
Emissions based on 2018 ETS-data coloured by sector: Power/Energy (red), Steel (yellow), Chemicals (purple), Waste (Green), Minerals (Blue)

Public driven initiatives:

- Porthos (2017)
- Athos (2018) - **Project is stopped**

Aramis started as a private initiative:

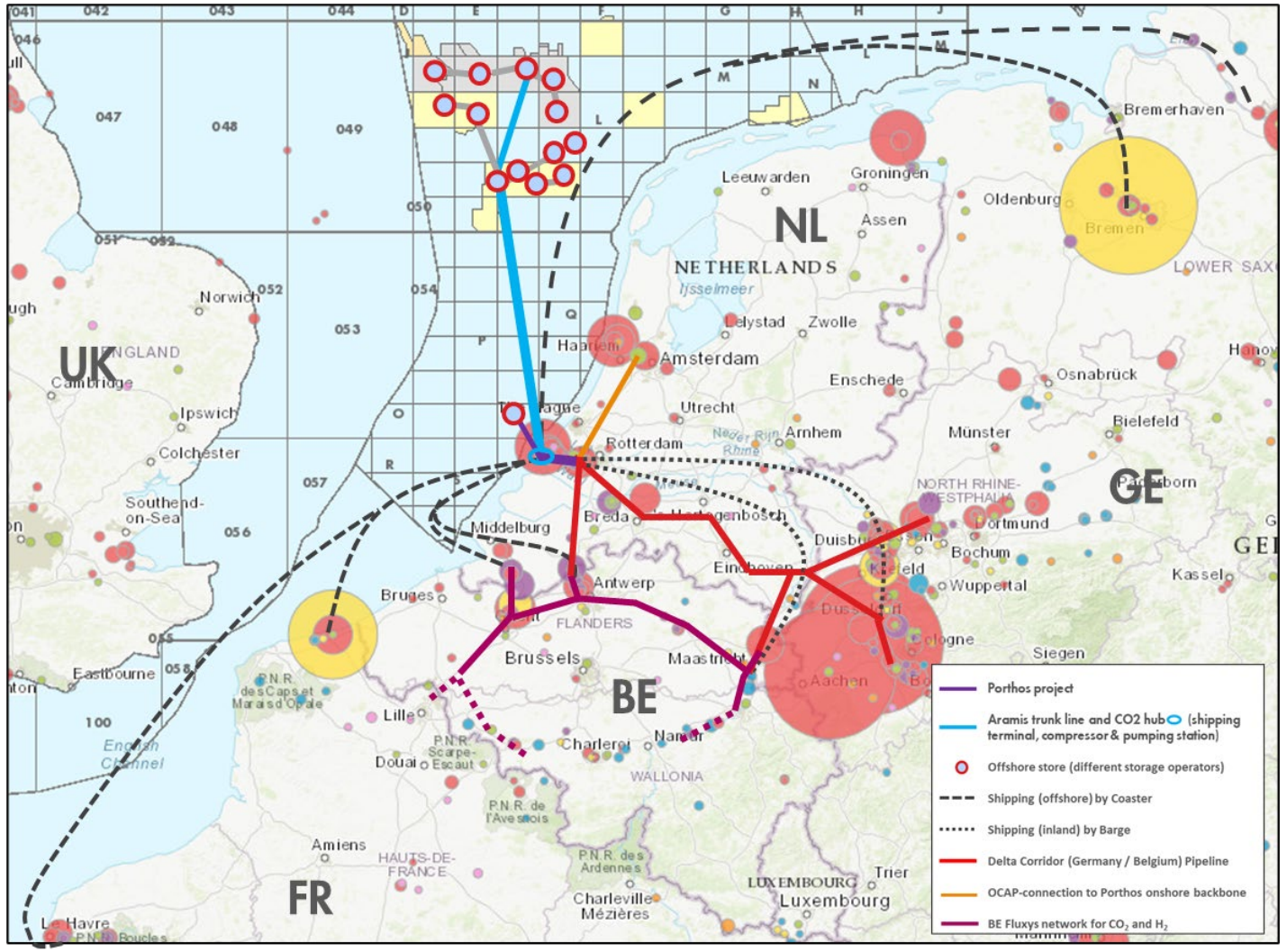
- Starting from the offshore Store
- Agreements elevated to corporate level TotalEnergies and Shell
- Now a Public/Private cooperation with recent formal announcement: www.aramis-ccs.com



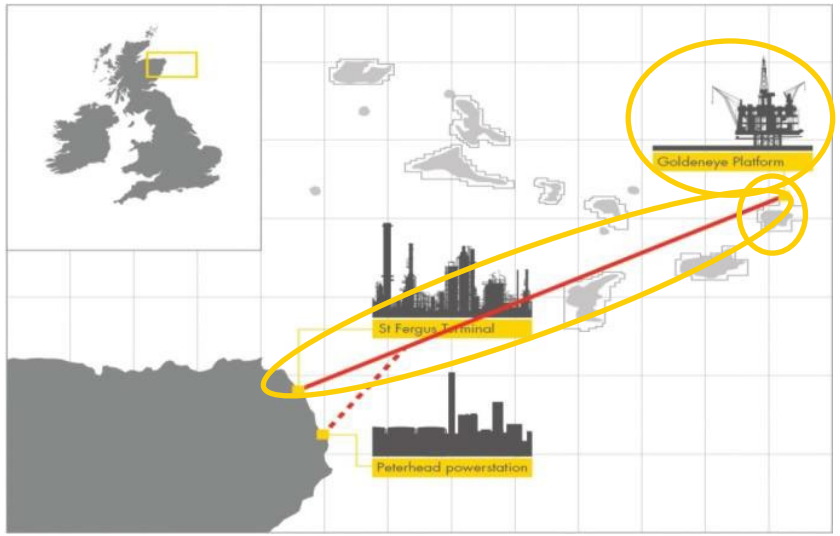
VISION FOR CCS NL

Large-scale and flexible CO_2 Transport and Storage solution connecting industrial clusters.

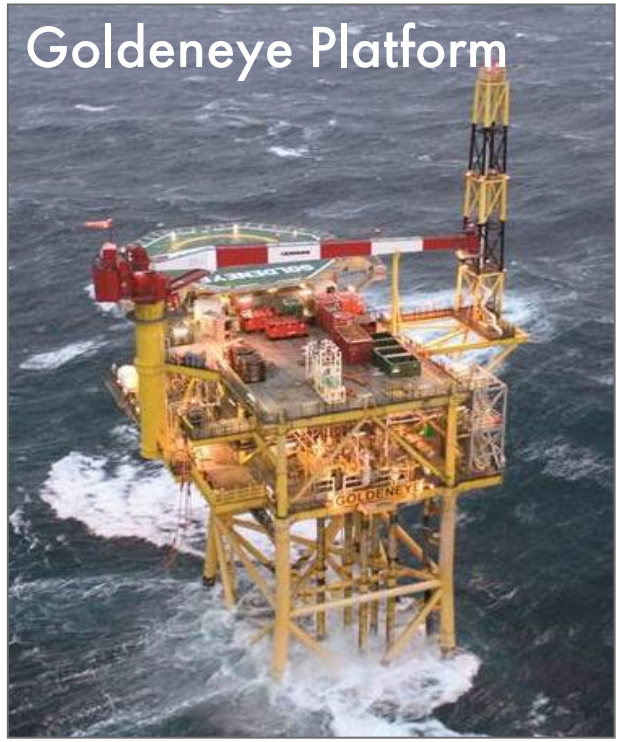
- Invest in oversized offshore pipeline
- ~5 Mtpa required to be able to launch the project
- Synergy with other planned infrastructure developments allowing tie-ins at both ends of the system

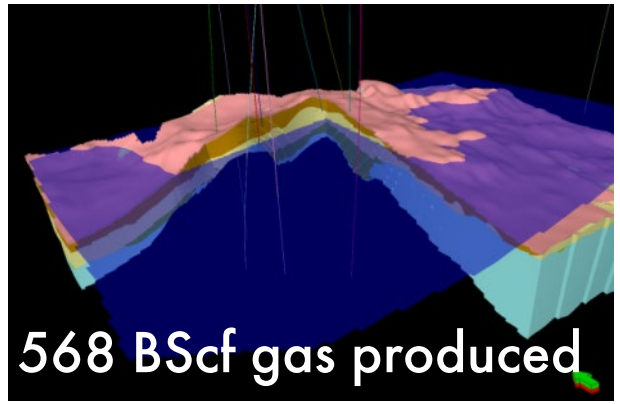


Former Peterhead CCS project – reuse



- Assets that would have been reused:
  - 102km of 20 inch pipeline + methanol line
  - Platform which started life in 2004
  - Depleted gas field with pressure history starting in 1996, production history from 2004
  - Five production wells
  - Core, seismic, sea bed surveys



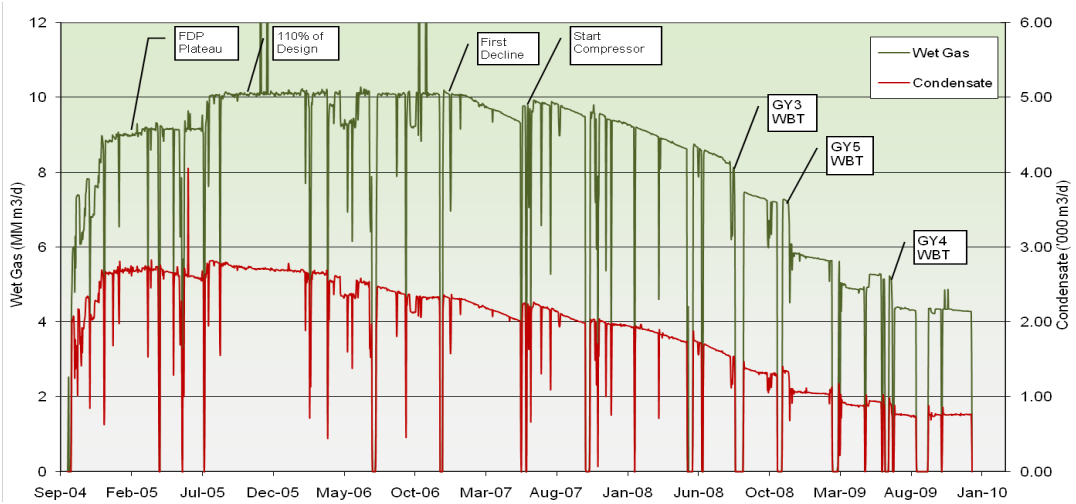


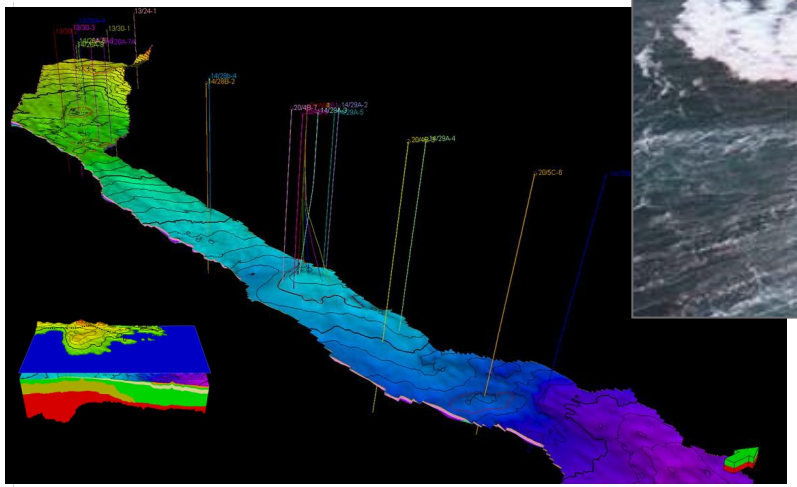
- Planned to be the first full-scale CCS project on a gas-fired power station
- Capture at Peterhead Power Station; storage in depleted Goldeneye gas reservoir
- Storage permitting completed, and "opinioned" at EU level
- "FID ready" but halted when funding withdrawn by UK Government, 25th November 2015

Depleted fields have a lot of attractions

Goldeneye example

- Proven seal – 50 million year test
- All the appraisal and well data
- Performance since start of production
  - "6 year production test"
- Facilities and wells





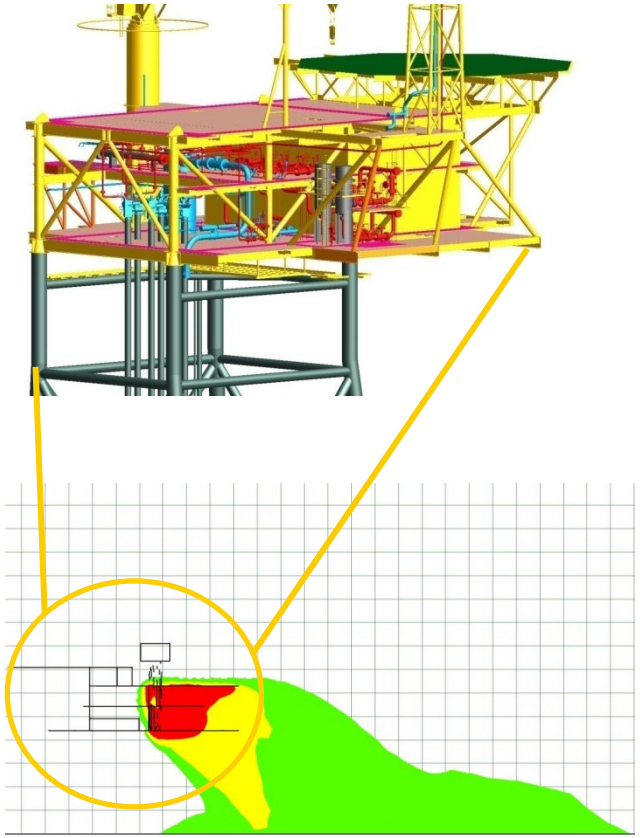
What can be re-used?

Re-use can be divided into

- Engineered system
  - Platform
  - Pipelines
  - Umbilicals
  - Wells
- Knowledge
  - Characterisation data
  - Reports
  - Samples
- Natural system
  - Geology, the store itself

Platforms – considerations

- Safety case changes as a CO_2 release is different from hydrocarbons
- Refits can be required to manage risk of brittle fracture and elastomer changes
- Dual use certification might be required
- Different owners could co-exist
- Potential for period of mothballing, or compensation for loss of hydrocarbon resources
- Platform already part of the marine infrastructure
- Life extension for another thirty years
- Decom tax regime



- Shows max extent of 10% (red), 3% (yellow) & 1.5% (green) CO_2 clouds
- Hole size = 50mm, whole platform inventory
- Wind speed = 3m/s from left to right
- The grid shown has a 5m spacing

Pipeline – considerations

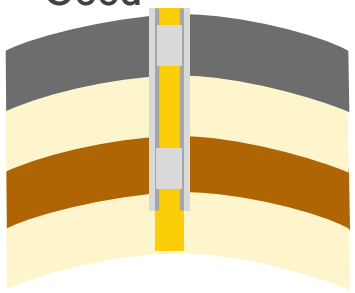
- Existing beach crossings – minimal disruption to environment
- Cost and carbon savings from re-use of infrastructure
- Metallurgy and wall thickness
  - Corrosion and life extension
  - Running ductile fracture resistance
- Pressure rating
  - Can the pipeline be use for dense phase or just for gas phase
- Pipeline cleaning of production residue and inspection must be planned from the start; as must filtration
- Installation of sub-sea isolation valves and later expansion
- Still need to apply for change of service, perform an impact assessment, new safety permitting of offset distances
- Regulations need to permit CO_2 pipelines!

Well reuse – considerations

- Casing utilisation/wear – how many more trips can the well take?
- Congestion under the platform, can we side track?
- Seabed quality under the platform – can slots be recovered?
- External casing corrosion after 50 years of service

Impact of legacy wells on the natural geological system

Good



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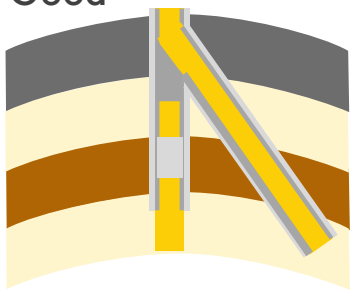
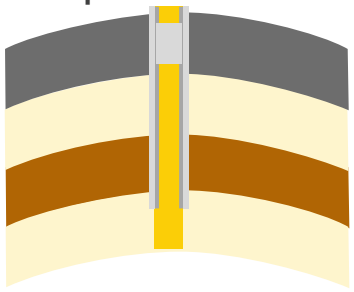


Repairable



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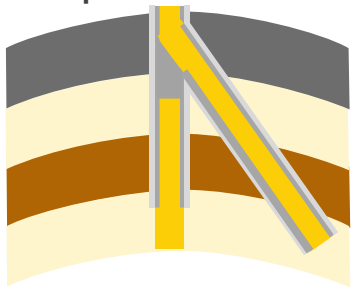
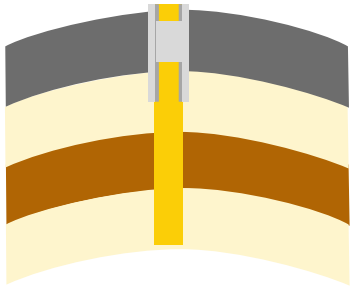


Avoid?



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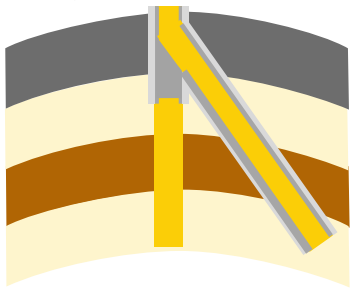


Key challenges for "inaccessible wellbores"

- Re-entry of abandoned wells offshore seldom feasible, almost never cost effective
- Seldom possible to follow an old open hole
- Intersection wells not normally possible on open hole sections

Questions on placement

- Were plugs set across caprock: "reinstating caprock seal"
- Were plugs set shallow: "derating the store"

Quality of records?

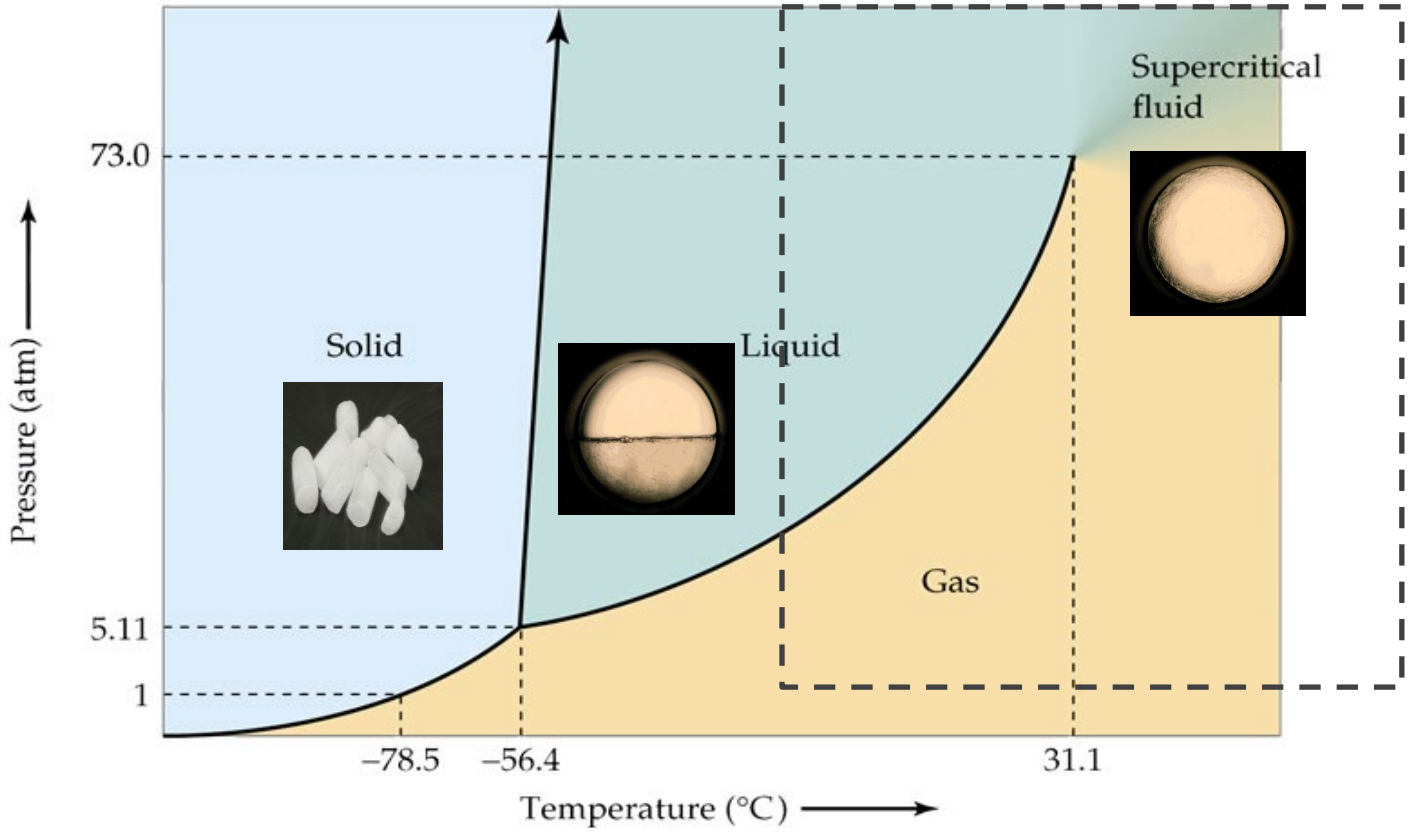
- Cementation reports
- Cement quality behind casing – Cement Bond Logs
- Were plugs tested

Managing depletion

Working with CO_2

- Capture as a gas e.g. 25°C, 1 atmosphere.
- Remove water and impurities like O_2
- Compress to liquid for transport in pipeline
- Refrigerate to liquid for transport in ships
- Inject at about 120 – 150 atm
- Have to work across the phase transition

- Different to methane
  - Gets vey cold when released – significant Joule Thomson effect, down to –78°C
  - Does not ignite, but can expand rapidly as it boils off – non-igniting BLEVE
  - Acid forming when mixed with H_2O

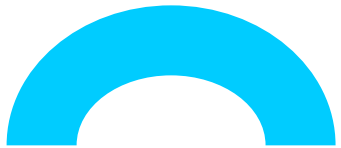


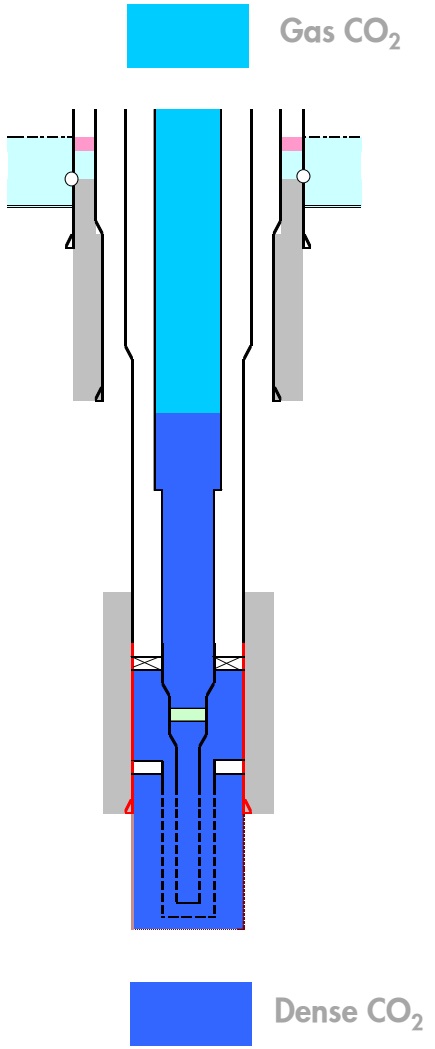
Three scenarios for depleted fields

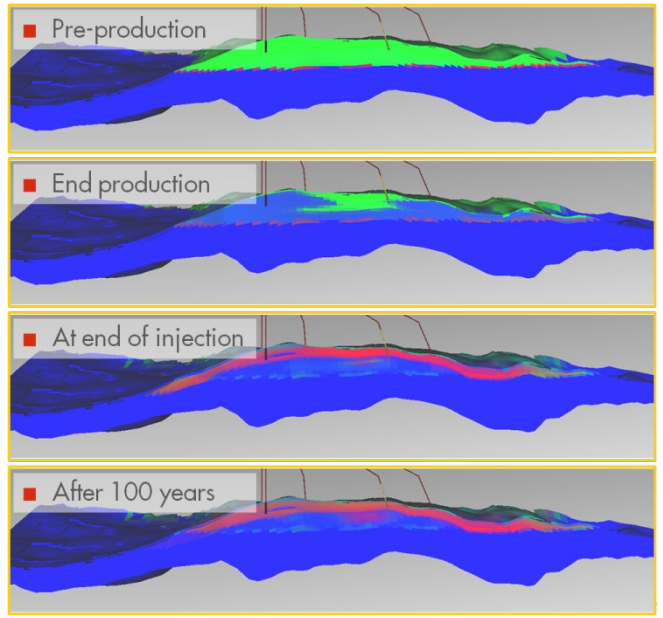
- Hydrostatic
  - CO_2 in liquid phase at surface
  - CO_2 in dense phase in store
  - Liquid injection
  - Quest

- Moderate depletion
  - CO_2 in gas phase at surface
  - CO_2 in dense phase in store
  - Cooling across choke
  - Goldeneye, Aramis

- Significant depletion
  - CO_2 in gas phase in store
  - Lifetime management
  - Porthos, Aramis future phases

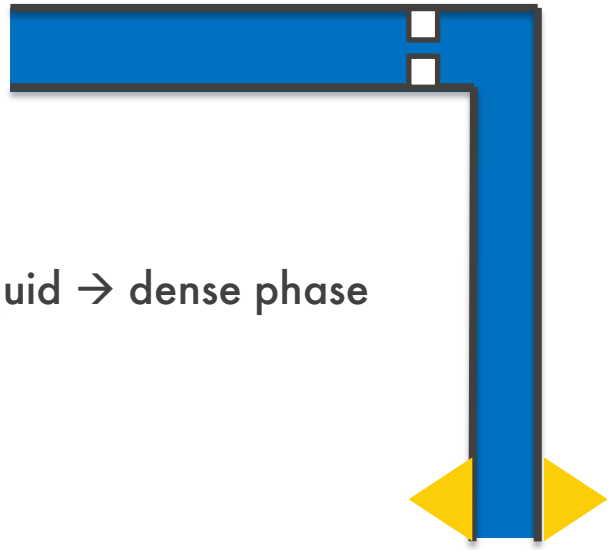


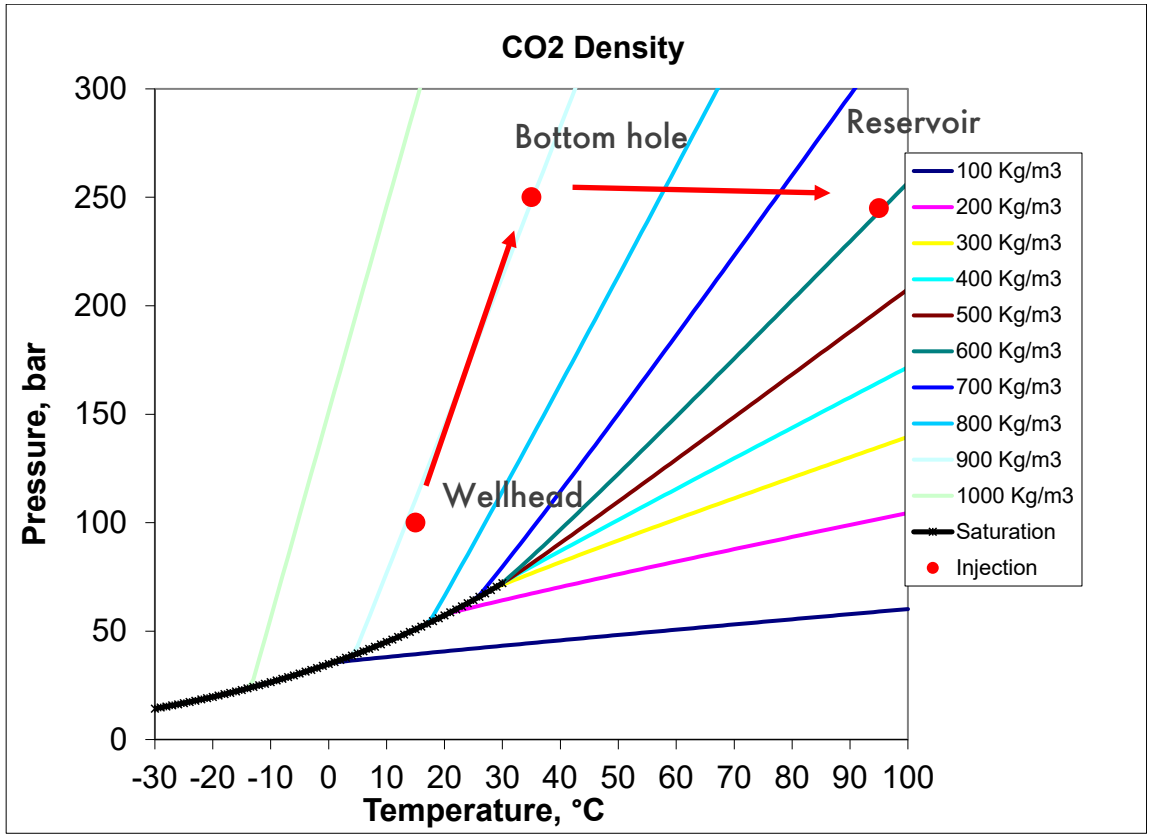




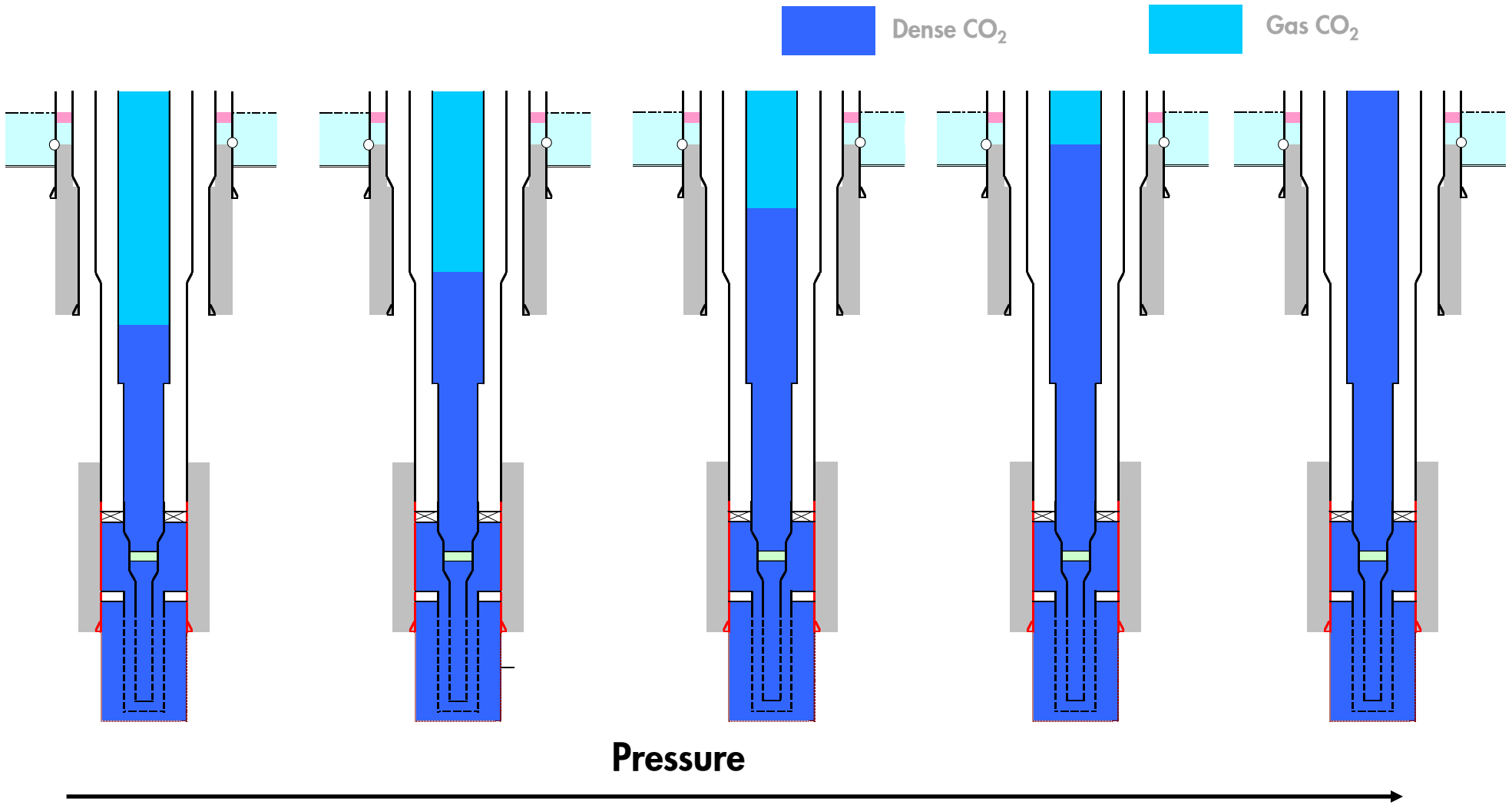
High Pressure Injection (≥ Hydrostatic)

- Experience (EOR projects, Quest, Gorgon, Snhovit)
- Relatively 'easy' to operate/optimise
- No issues with transients
- Injection pressure depends on T (and reservoir characteristics)
- CITHP might be higher than ITHP

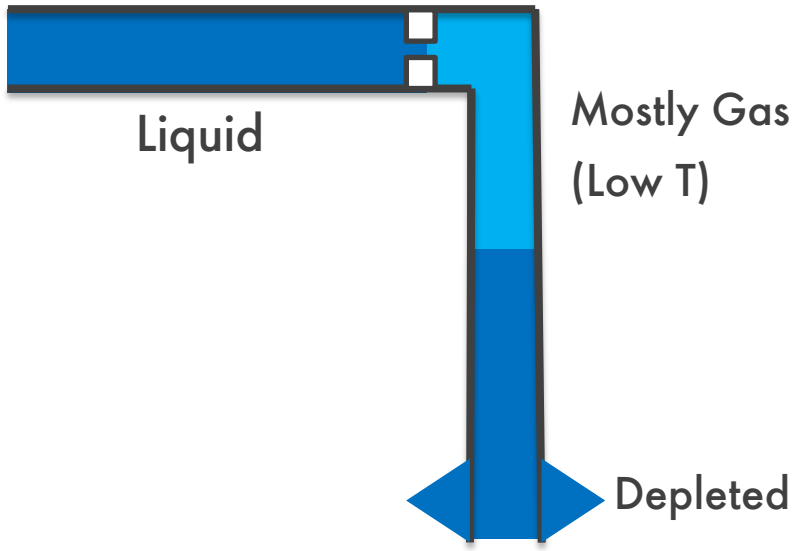




Depleted Reservoirs: Closed-In Conditions

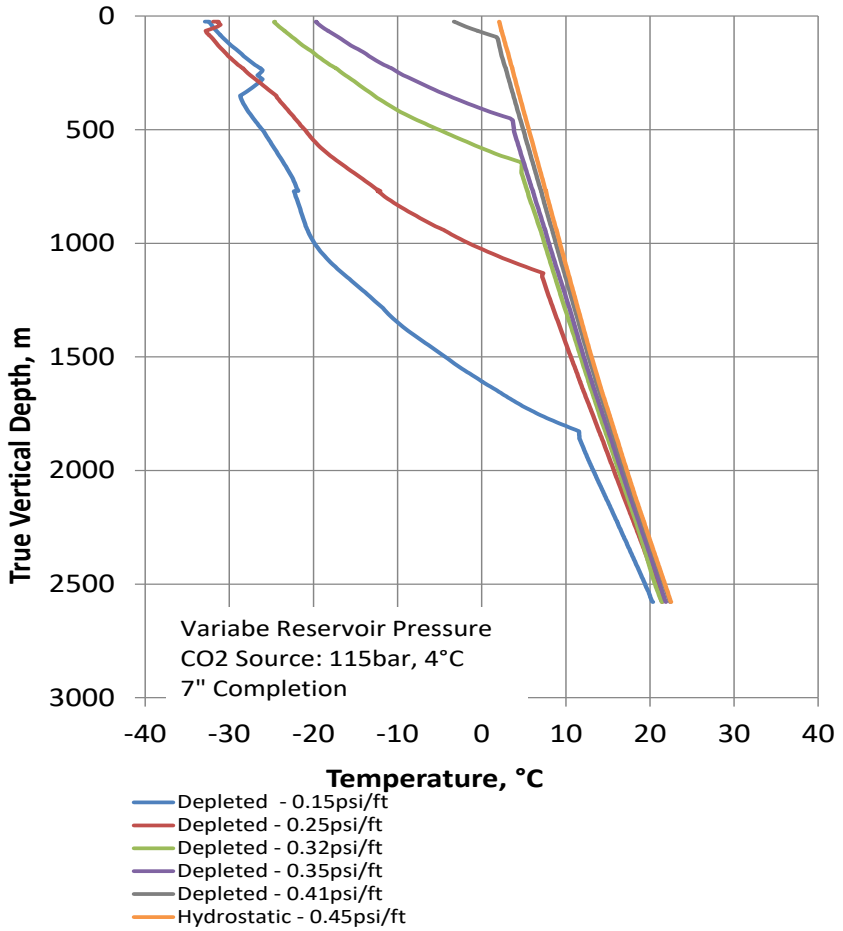


Depleted - Uncontrolled Injection in Depleted Reservoirs

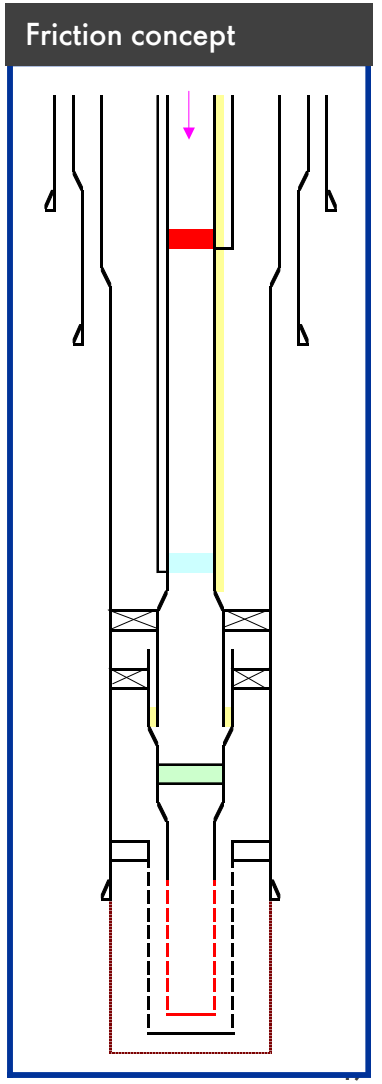


- It can get 'cold' even under steady state conditions
  - Depleted reservoirs, JT expansion – Low T in the top part of the well
  - This presents issues related to integrity in the wells
  - Not all elements designed for low T
- Phase behaviour management

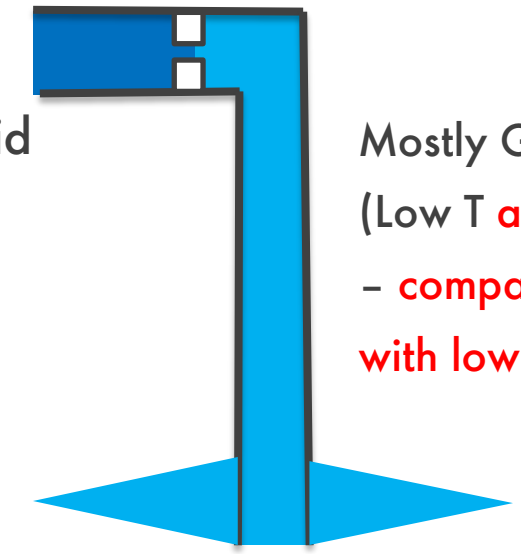
Significant cooling



Friction concept



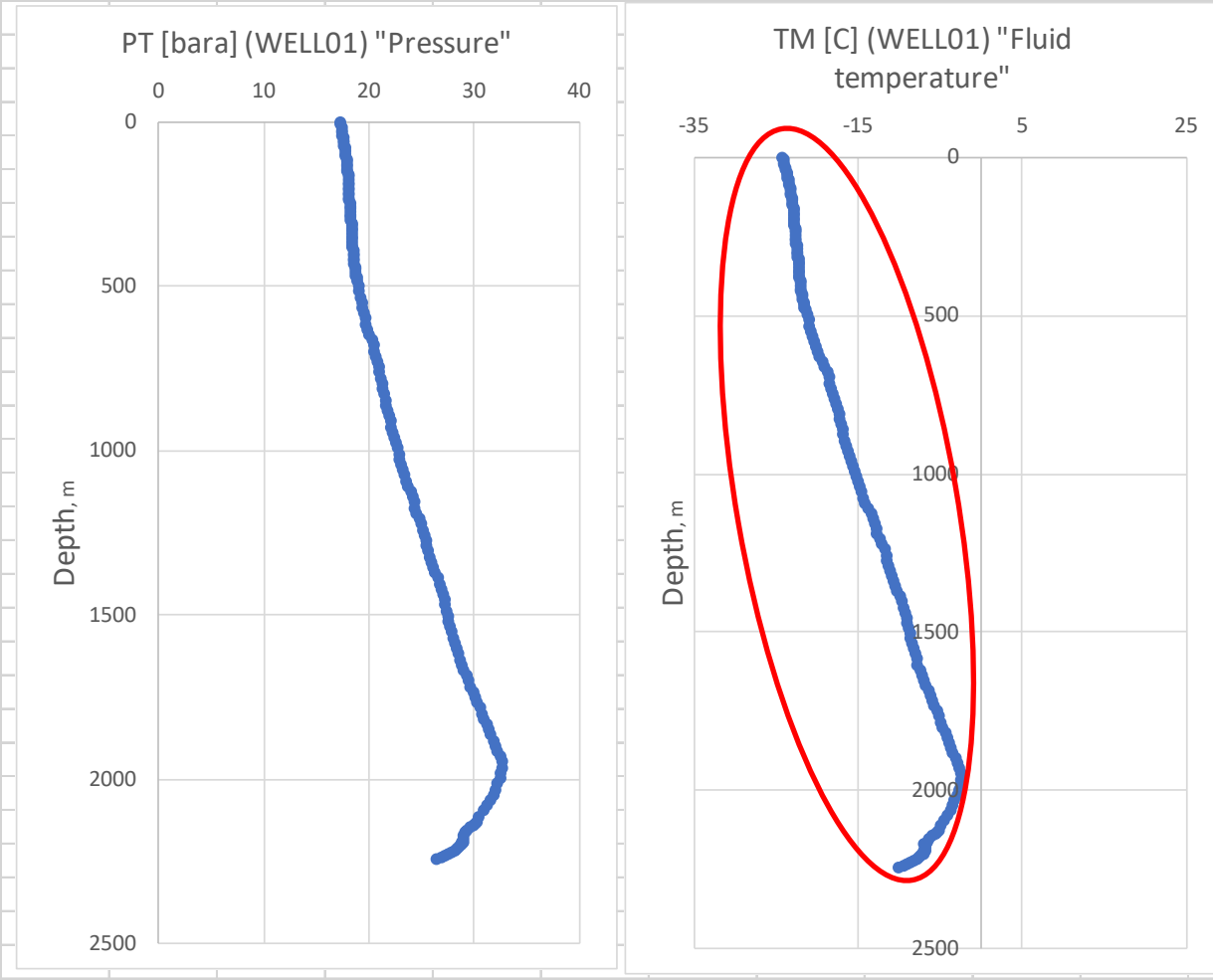
Significantly Depleted Reservoirs (<45bar)
Issues injecting with dense phase pipeline transport



- JT cooling upper completion
  - Similar than depleted reservoir but bigger length in the well of sub-zero temperatures and (perhaps) colder temperatures
  - Well Integrity issues (well elements, B-annulus)
  - It can be solved with friction (and perhaps d/h choke in the future)

- Low Temperature in the bottom part of the well
  - Well elements compatibility (cement under research – specially for IBHT< 0 C).
  - Injectivity issues (hydrates/ice)
    - Perforation
    - Formation

Cold Injection. No phase control. [0.5 Mtpa, Pipeline: 5C/80bar]



Solution space

- Pre-filling in gas phase
  - Density and rates lower
  - More wells or slower fill
  - Contractual links or phased development
  - How to transport gas to the store?
- Significant heating
  - GHG emissions related to energy
  - Platform weight
  - Energy supply
  - Costs
- Inject cold
  - Hydrate and ice formation
  - Thermal cycling of rock-cement interfaces
  - Local formation fracturing in the store – sand face integrity

Depleted fields present a significant opportunity for early development

- Resources are discovered – hydrocarbons were produced
- Sustained injection performance risks are minimal – store is tested
- Developments are already accepted by society
- Technical aspects of re-use and phase management are understood

- Record keeping critical
- Physical data needs to be preserved
- Decommissioning is an opportunity to
  - gain more information,
  - preserve the geological store integrity
- Infrastructure maintenance costs need to be considered
- Action is required to maintain and preserve the option for reuse

Questions and Answers

CO_2 phase envelope needs to be managed and influences facilities and well design choices