PACECCS

How to Manage the Wet/Dry Interface in an Operational CCS Cluster

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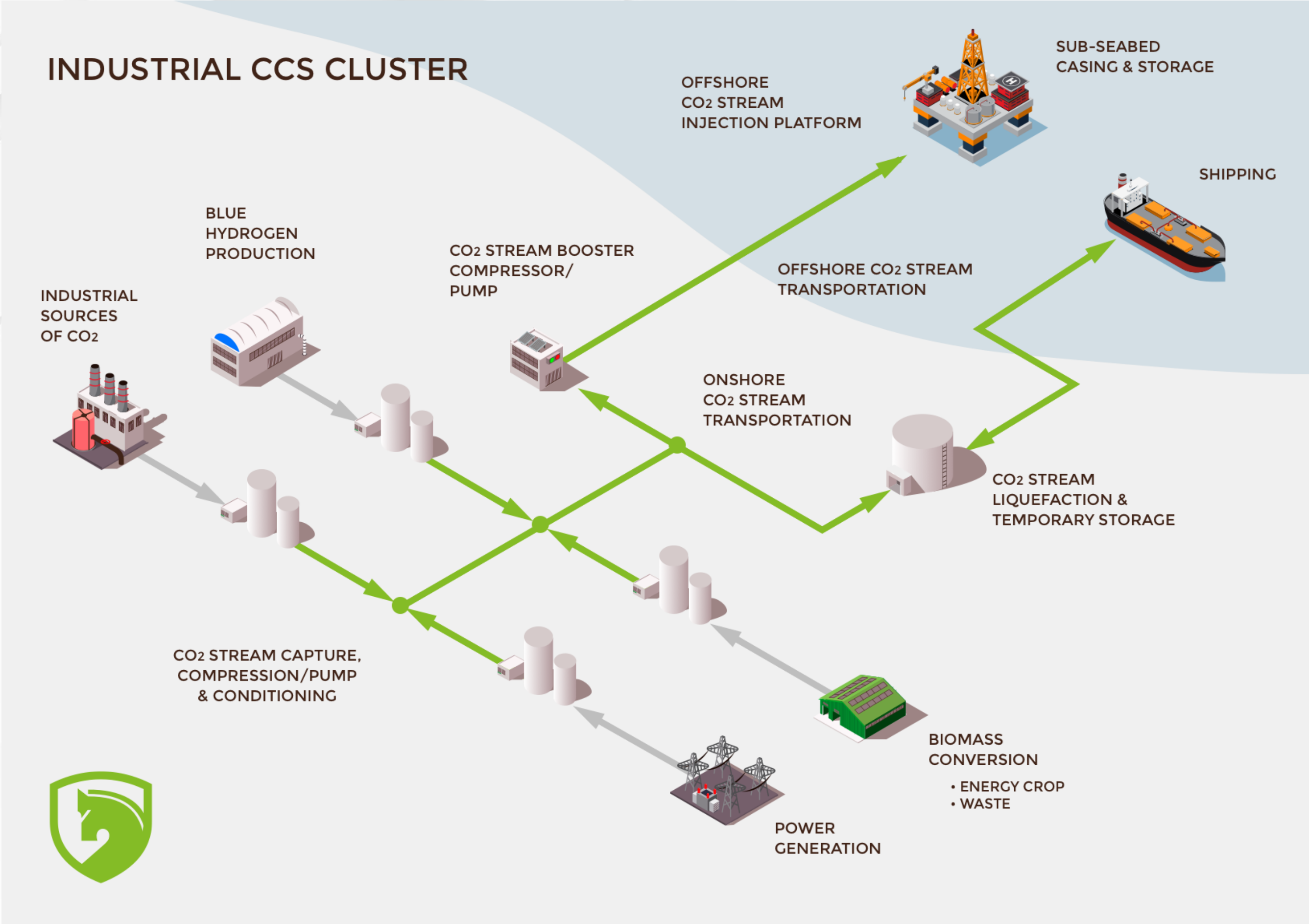
CCS Network

A CCS network connects a CO_2 source to CO_2 storage.

- A CO_2 source may be a cluster of industrial emitters.
- CO_2 storage is usually a depleted hydrocarbon reservoir or deep saline aquifer.
- Transport via a combination of pipelines and shipping.



What is the Wet/Dry Interface?

- Break point between wet CO_2 and dry CO_2

- Where corrosion risk is eliminated/significantly reduced
- Where material selection can change from SS to CS

- Wet CO_2: any point where free water can occur
- Dry CO_2: no free water possible

Corrosion in CCS

There are three sources of aqueous corrosion risk to CCS projects, which are presented here in approximate order of corrosiveness

1. Corrosion from strong acids, such as sulphuric acid and nitric acid. These acids can be produced due to chemical reactions between impurities in CO_2 from industrial sources.

2. Corrosion from free water. This is the corrosion risk experienced on the Gorgon project. Carbon steel corrosion rates can be very high.

3. Corrosion from an induced aqueous phase, usually dominated by TEG or methanol. This corrosion risk has been identified on several CCS projects globally. Carbon steel corrosion rates are modest, estimated by Pace on projects to be in the range of 1 mm/yr.

Corrosion & material selection

Corrosion risk assessment for CCS has some challenges:

- Limited experience: CO_2 capture and transport is not EOR
- Composition is not fully known, with a theoretically infinite number of options
- There are some knowledge gaps on impurities and their corrosion effects
- Lots of reuse of existing infrastructure

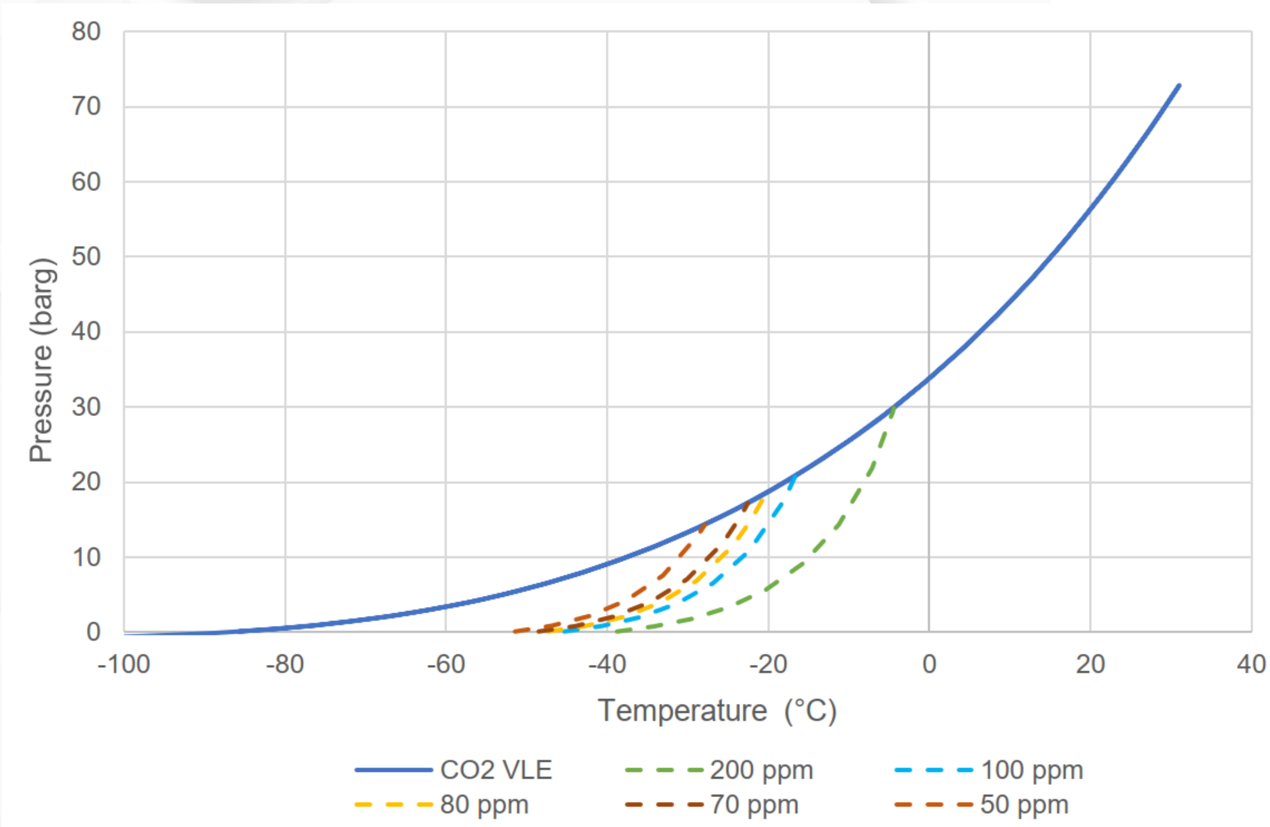
But the solution is simple enough:

- Thermodynamics
- Process engineering
- Corrosion expertise

Gas Phase CO_2 Pipeline Operation

Water Dew Point

- Dew point curves for binary water-CO_2 mixtures



Dew Point Specification

- The goal of dehydration is to meet the water content specification
- The water dewpoint from one supplier ≠ the water dewpoint in the pipeline

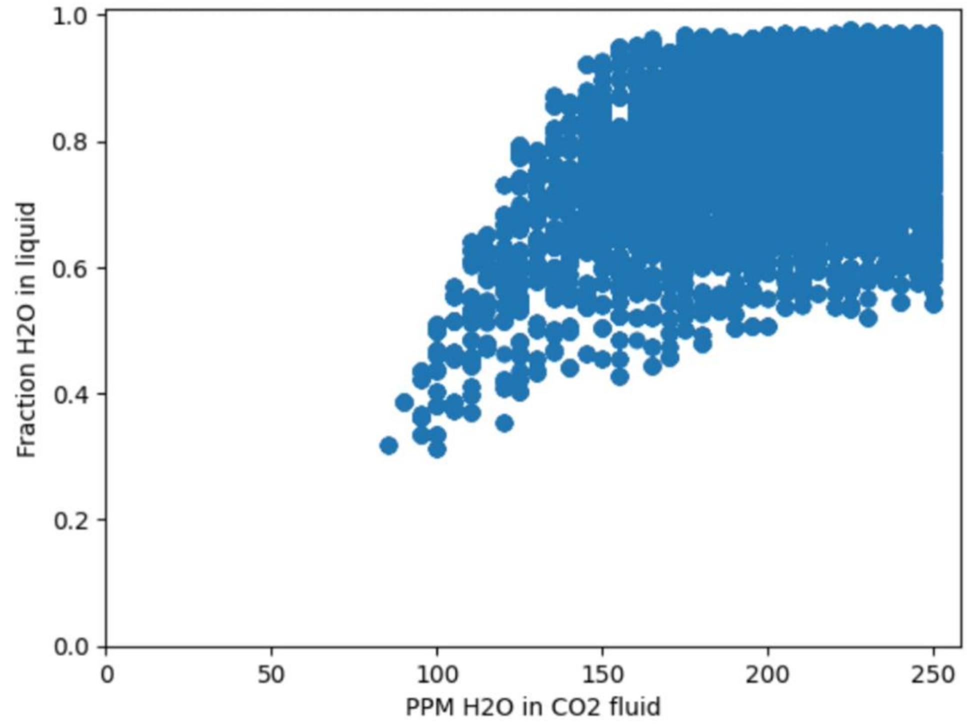
- Each emitter composition is different, with different impurities at different concentrations at varying points in time
- With multiple emitters there are infinite different compositions possible within the CCS cluster pipeline

- How do we ensure that free water is avoided within the dry CO_2 section?
- Evolutionary algorithm reviewing all potential compositions to determine likelihood of a water dew point for the cluster

Evolutionary Algorithm

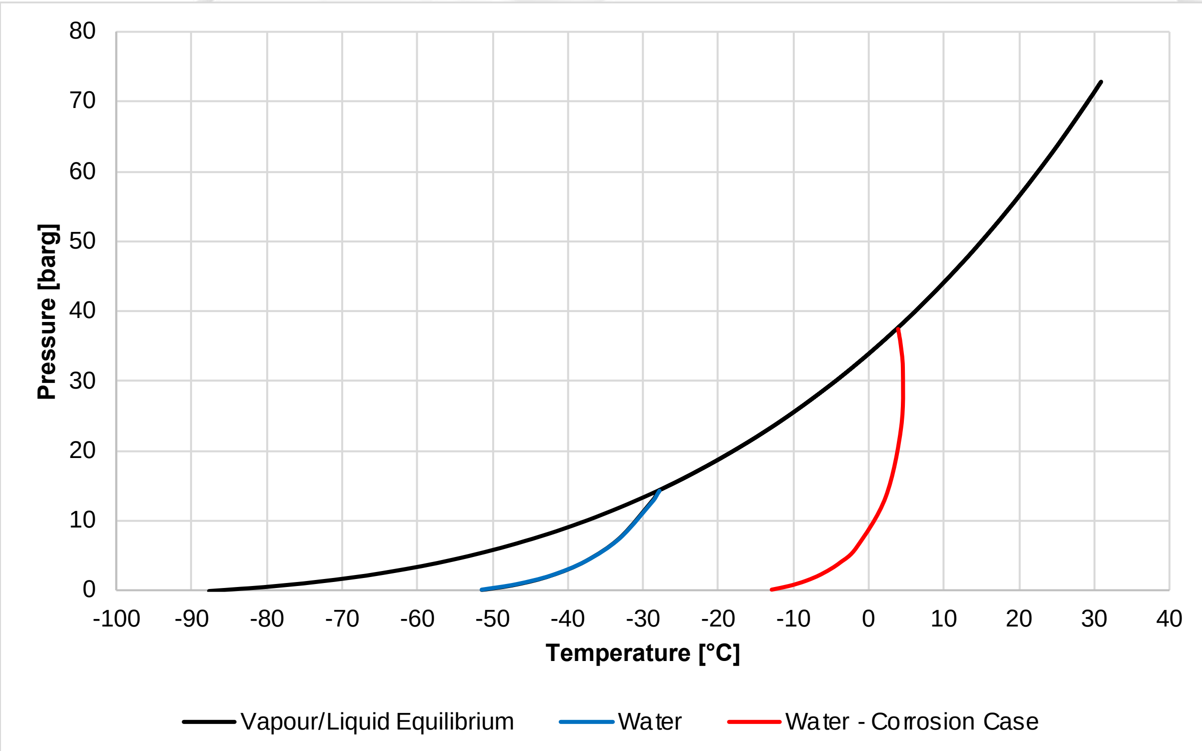
The results below have been producing using Pace evolutionary algorithm to explore the impact on aqueous dewpoint.

- Below shows aqueous dewpoint at approximately 80 ppm water is possible
- Pure water dewpoint: 250 ppm
- This is a potentially corrosive aqueous liquid



Induced Aqueous Phase

TEG is a minor impurity but can be responsible for a significant increase in water dew point.



Temperature [°C]	0
Pressure [bara]	27
TEG [ppb mol]	1
Methanol [ppm mol]	0
H_2S [ppm mol]	1
MDEA [ppb mol]	0
NO_2 [ppm mol]	0
SO_2 [ppm mol]	0
COS [ppm mol]	127
Water [ppm mol]	50
CO_2 [mol%]	99.98

Example dehydration trip levels

- Based on the evolutionary algorithm we can determine alarm and trip points for each individual emitter to ensure no free water within the dry CO_2 section
- Example emitter dehydration alarm/trip requirements

Level	Proposed Value	Operator Action	Remedial Action Time
Specified maximum	<50 ppm mol	No action, but seek to determine if there is an upward trend	6hr – 48hr
High level alarm	50 ppm mol	Investigate cause	30min – 6hr
High high alarm	55 ppm mol	Alert operations/maintenance staff	<30 min
Trip	60 ppm mol	Reject CO_2 stream	Immediate

Dense Phase CO_2 Pipeline Operation

Dense Phase Operating Scenarios

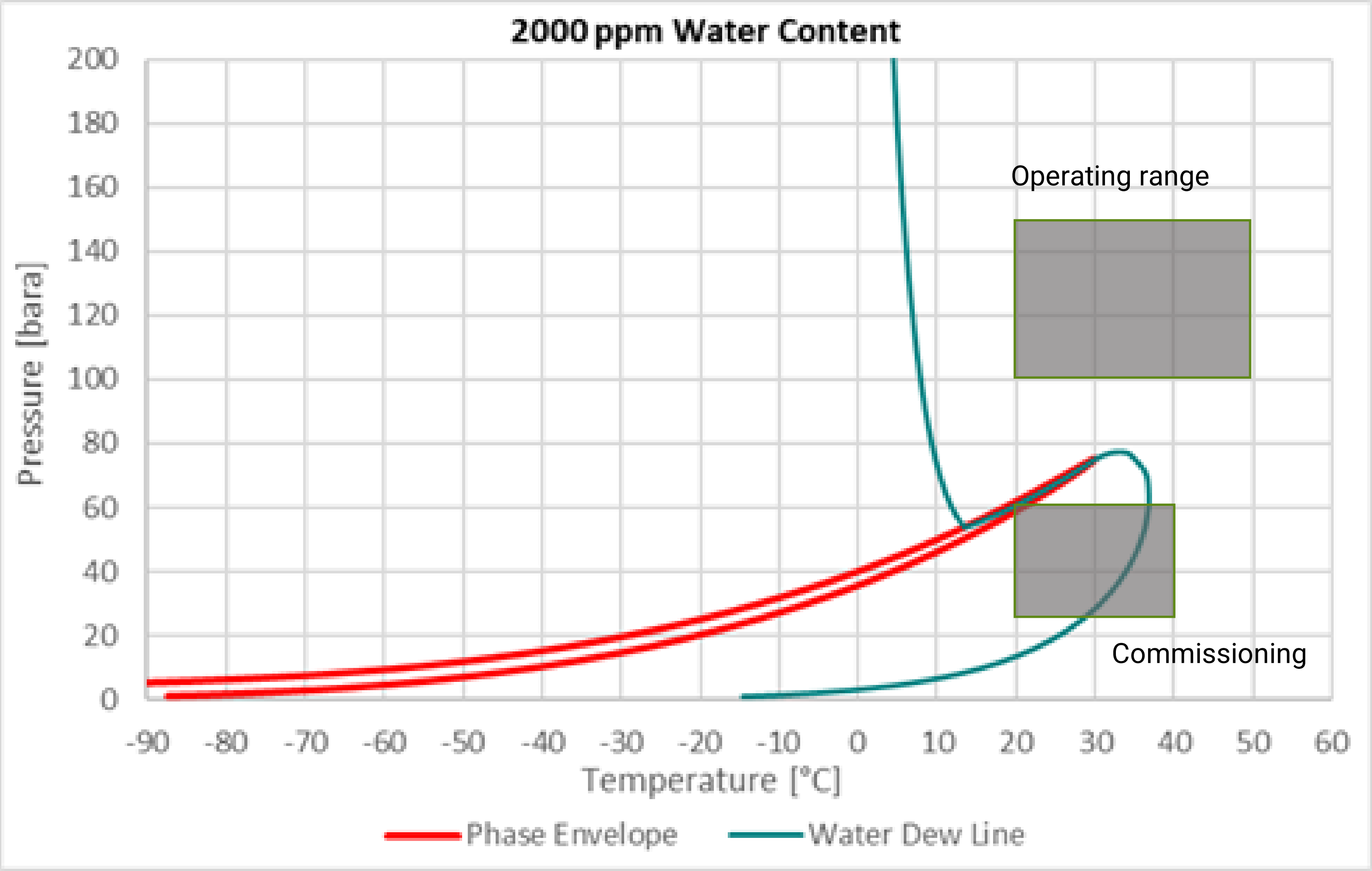
Consider all possible operating modes including pre-commissioning, commissioning, and other short-term modes

CCS isn't oil & gas – transient cases are design cases

Examples include:

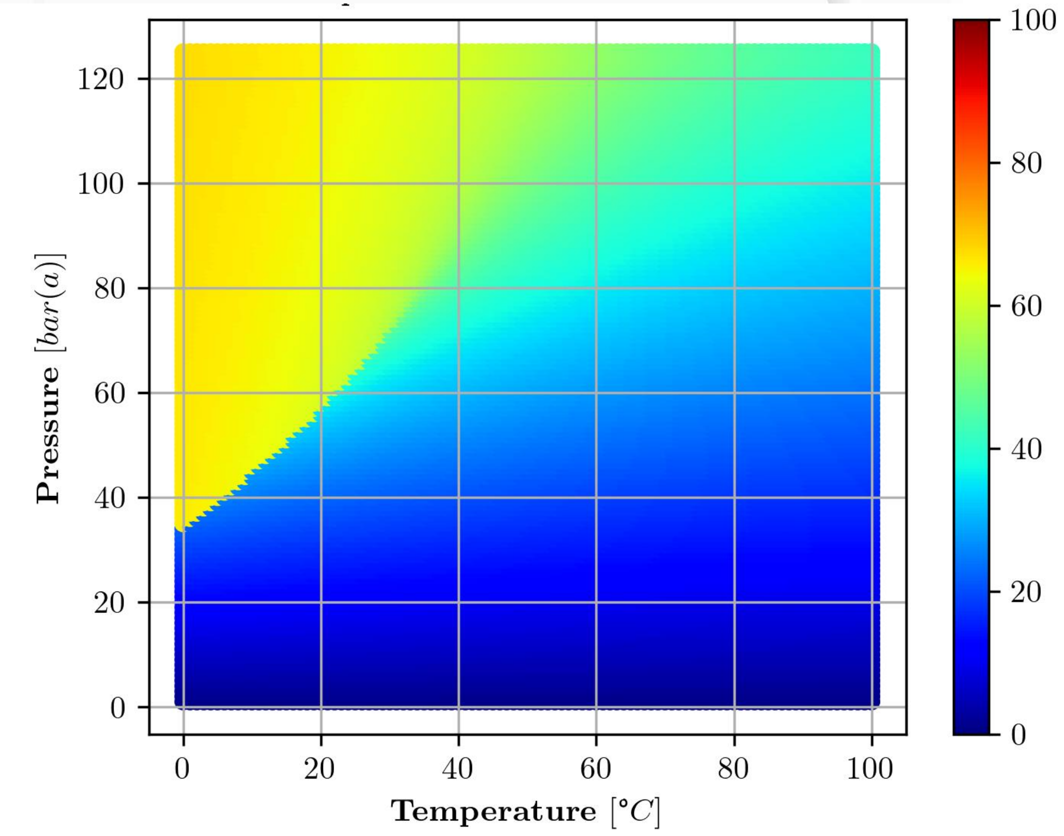
- Normal operation (pipeline in dense phase)
- Shutdown (pipeline settle-out to the bubble point)
- Start-up (pipeline gas phase, increasing to dense phase)
- Commissioning (low pressure transition from nitrogen to CO_2)
- Depressurisation (pipeline dense phase, decreasing to gas phase with low temperatures)
- Compressor recycle (process piping gas phase)
- Compressor blowdown (process piping gas phase with low temperatures)

Gorgon Corrosion



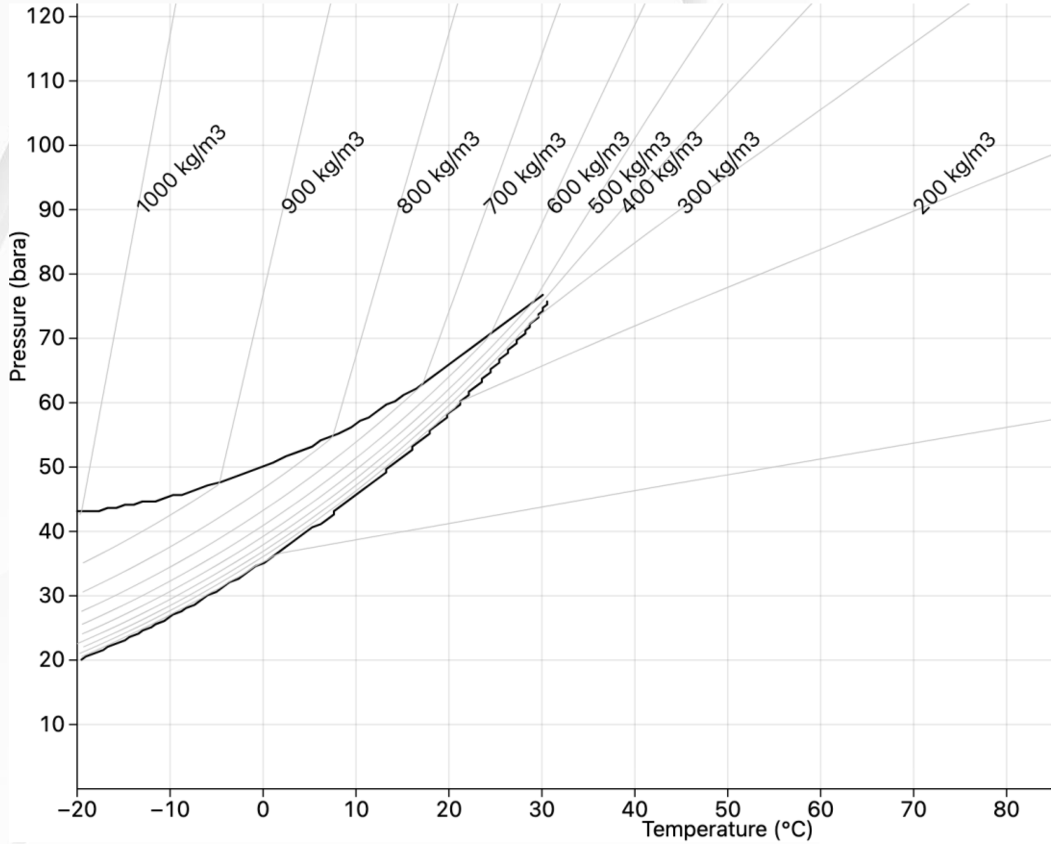
Solubility of polar molecules in CO_2

- Polar molecules (like water, TEG, methanol) are relatively insoluble in gas CO_2
- Polar molecules (like water, TEG, methanol) are relatively soluble in liquid CO_2
- Solubility changes quickly in the Widom Line area



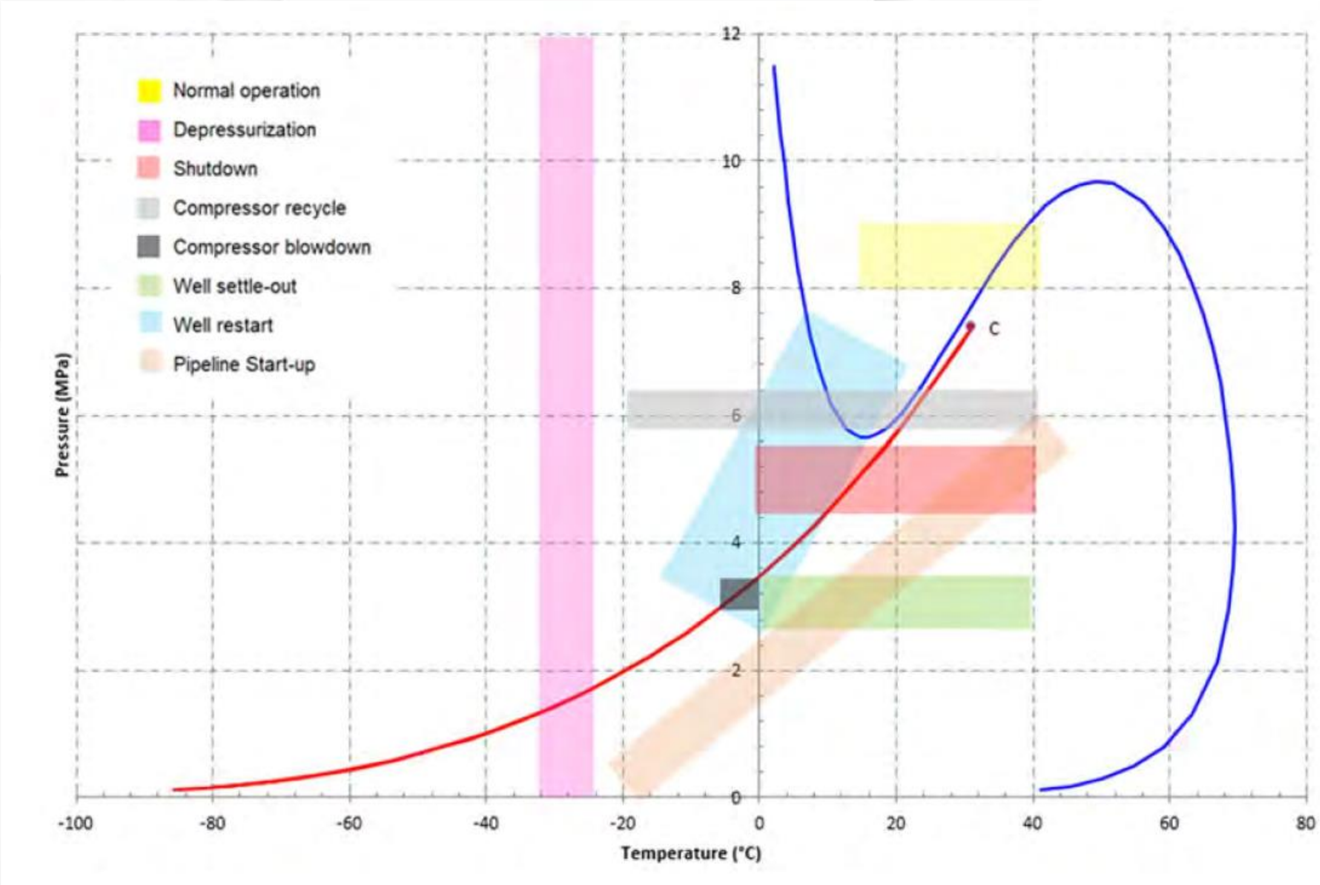
The Widom line

- The Widom line is where the density changes most rapidly in the supercritical zone.
- Roughly, above the Widom line is closer to liquid, below is closer to gas.
- Change in CO_2 polarity means that aqueous liquids are much more likely in the “gas” area.



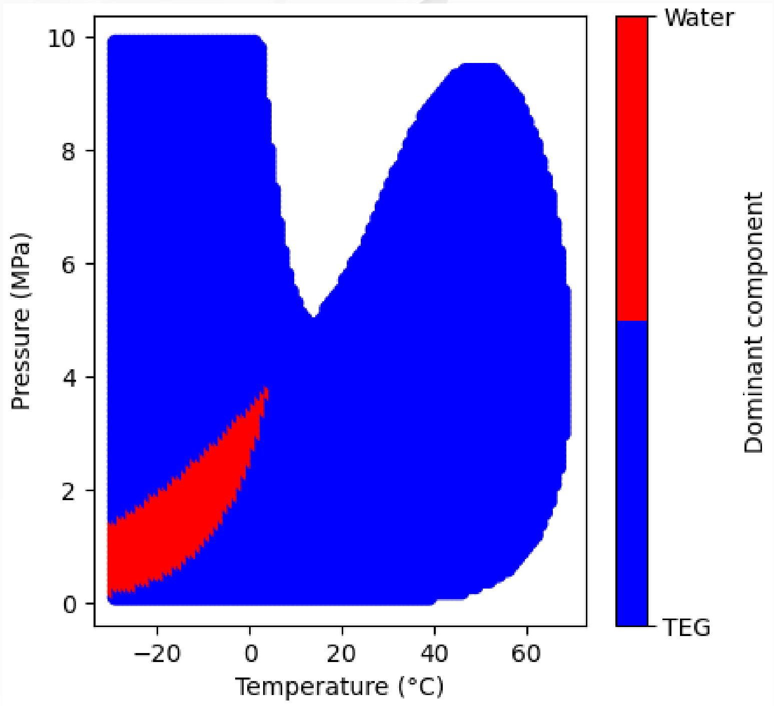
Aqueous Phase Dewpoint

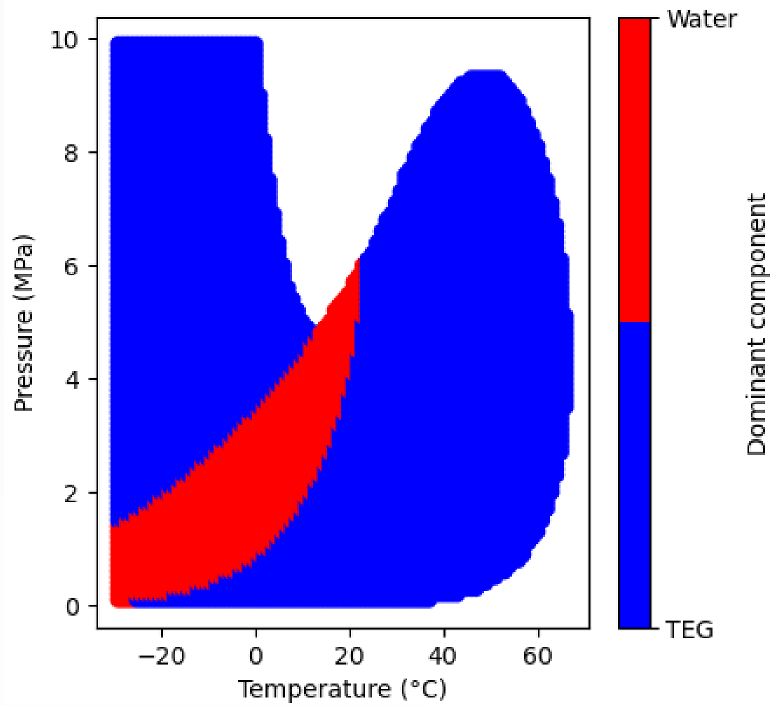
- Typical dense phase cluster operational scenarios
- Aqueous phase dewpoint (100ppm water, 2.3 ppm TEG, 50ppm H_2S)



Is the aqueous phase an issue?

- For the 250 ppm case (right), a corrosion water-dominated phase is possible at pipeline settle-out conditions, when the ambient temperature is 20 °C (68 °F).
- For 100 ppm water (left), the range where a water-dominated phase is possible is much smaller, and below the minimum ambient temperature.





Managing the Wet/Dry Interface in an Operational CCS Cluster

Impact of free water in the Dry Section

If free water gets into the dry carbon steel section of a cluster:

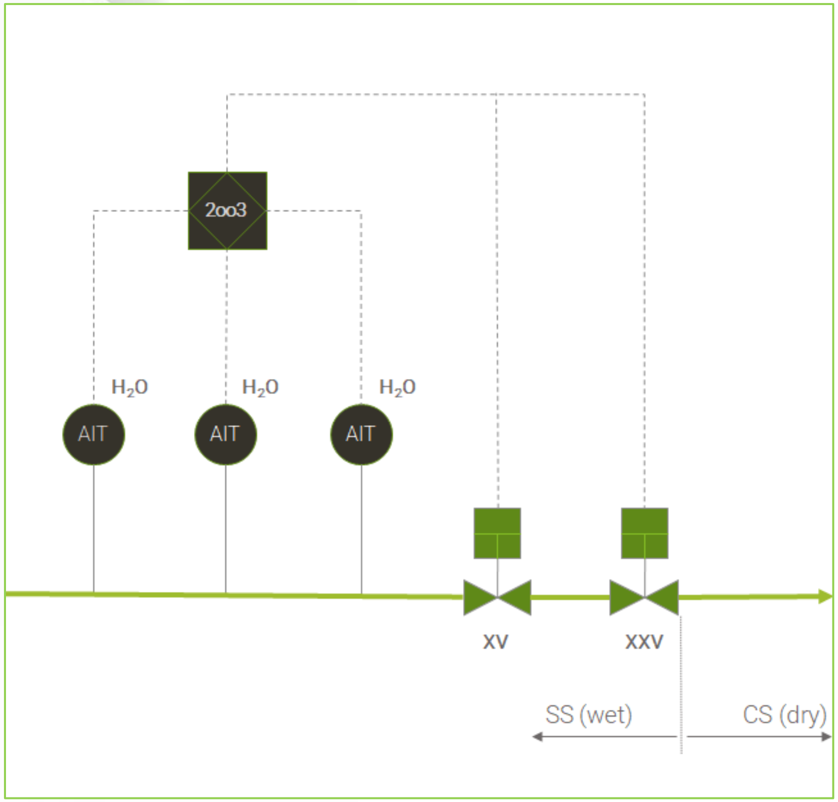
- Rapid corrosion can lead to significant safety implications due to leak
- Astronomical costs in repair and replacement of pipelines
- Commercial impacts of T&S offline and who is responsible

Gorgon CCS was single source to sink project and costs ran into billions… the impacts are multiplied for a CCS cluster

Must protect the CCS cluster to ensure this does not happen

Wet/dry Interface – A new "HIPPS" for CCS?

- Consider the wet/dry interface as a **high integrity protection system**
- Separate the wet system from the dry system & provide appropriate protection
- Assess the most appropriate location for the wet/dry interface on a project by project basis
- Ensure all modes of transient operation are considered
- Most likely to be located in the emitter scope before entering T&S
- Ensures T&S system is protected from free water
- Provide alarms & trips to prevent water exceeding set levels
- Consider corrosion coupons in wet section to monitor potential impact in dry section



Conclusions

- Consider the wet/dry interface as a high integrity protection system
- Consider the dew point for the overall system
- The water dewpoint from one supplier ≠ the water dewpoint in the pipeline

- Must consider ALL transient operational scenarios, not just steady state
- Ensure each emitter meets the specification – no blending or dilution credit
- Isolate and trip any individual emitter prior to reaching the point where free water occurs

- Water specification and wet/dry interface location needs to be assessed on a case-by-case basis
- Each project and risk appetite is different

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Thank You

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