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MANAGING EMISSIONS ABATEMENT TOWARDS NET ZERO

23 NOVEMBER 2022

Agenda

Introduction

Zero Emissions Tracking & Assessment (ZETA) tool and emissions reduction

Future facilities designed through the lens of emissions reduction

Abatement: Emitters to Reservoir

ZETA TOOL AND EMISSIONS REDUCTION

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JOEL MAISEY

Minimising GHG emissions – Why?

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Increasingly operators/owners need to be able to demonstrate emissions reductions for both ongoing operations, and new projects. Driven by:

- Regulatory compliance (e.g. UK Government)
- Lenders and Investors – benchmarking and setting limits on GHG
- Stakeholder expectations

"...Industry should go considerably faster and farther in reducing their own carbon footprint, or risk losing their social licence to operate"

North Sea Transition Authority (UK) Stewardship Expectation 11 - Net Zero (March 2021)

Emphasis on:

- Measuring, reporting and tracking of GHG emissions.
- From the exploration and appraisal phase – starting with the licence application and strategies for minimising GHG emissions.
- Through development, production and decommissioning strategies – gas recovery/energy hubs/measurement, power generation and flaring and venting reduction.
- Demonstrating delivery – both Regulators/Lenders and
- Annual UKCS Stewardship survey, Performance benchmarking, consent and authorisation processes.

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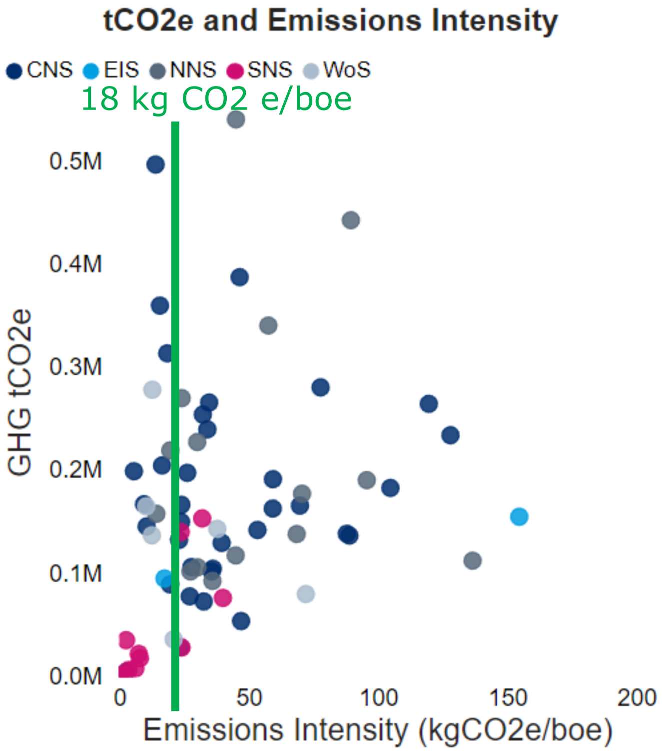
Where we are for offshore UK:

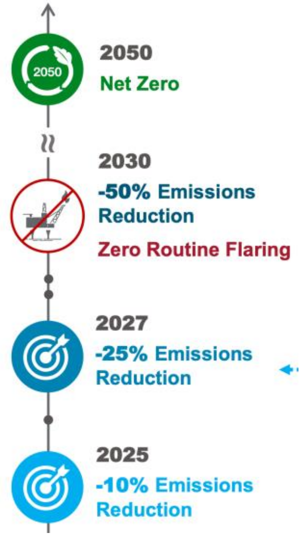
- 25.1 kgCO2e/boe – 2021
  - 18kg Coe/boe becoming the target for financiers
- 14.9% emissions reduction in 2021
- 49.8% of assets are over 25 years old



Where we are going for offshore UK:

- 50% reduction in offshore emission by 2030
  - Upstream O&G activities in the UK account for 4% of UK emissions
- Practical initiatives
  - Electrification of existing facilities
  - NSTA require lifecycle emissions estimates for new developments

North Sea Transition deal



Supporting our clients through the Energy Transition

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Analysing development emissions
(Brownfield & Greenfield)

- GHG emissions analysis from exploration through operations.
- Performed at any stage of facility lifecycle.

Emissions benchmarking for reporting & design
(Brownfield & Greenfield)

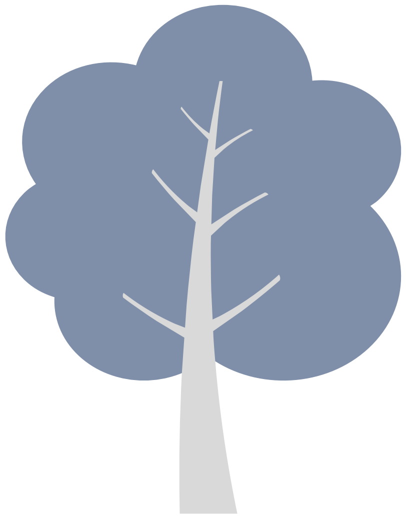
- Benchmarking against existing facilities.
- Benchmarking design development options.

Low GHG facilities design
(Brownfield & Greenfield)

- Design studies into use of technology, configuration & operational approaches to reduce development GHG.
- Support with Regulatory Authorities (e.g. OGA in UK).

Net zero roadmap
(Brownfield & Greenfield)

- Strategies for emission reduction measures over project lifecycle:
  - Current technologies.
  - Future technologies.
  - Renewable infrastructure growth.



Estimating & Analysing GHG emissions

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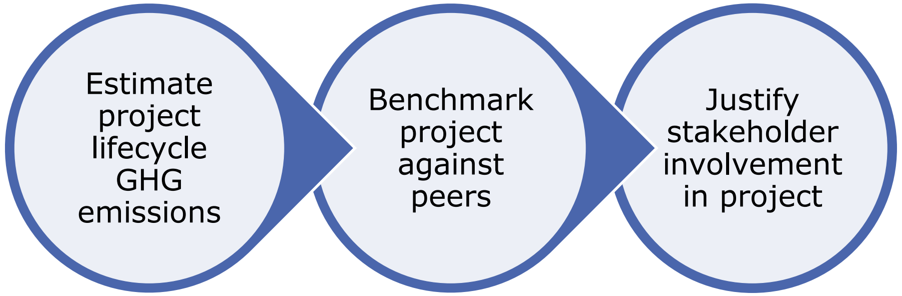
Crondall has developed a tool to <u>estimate</u> and <u>benchmark</u> Scope 1, 2 & 3 greenhouse gas emissions for offshore developments - Zero Emissions Tracking and Assessment (ZETA) tool.

Supporting Operators to provide practical solutions to reduce emissions and develop implementation strategies

Supporting Financiers in assessing environmental impact of projects



GHG emissions estimation methodology

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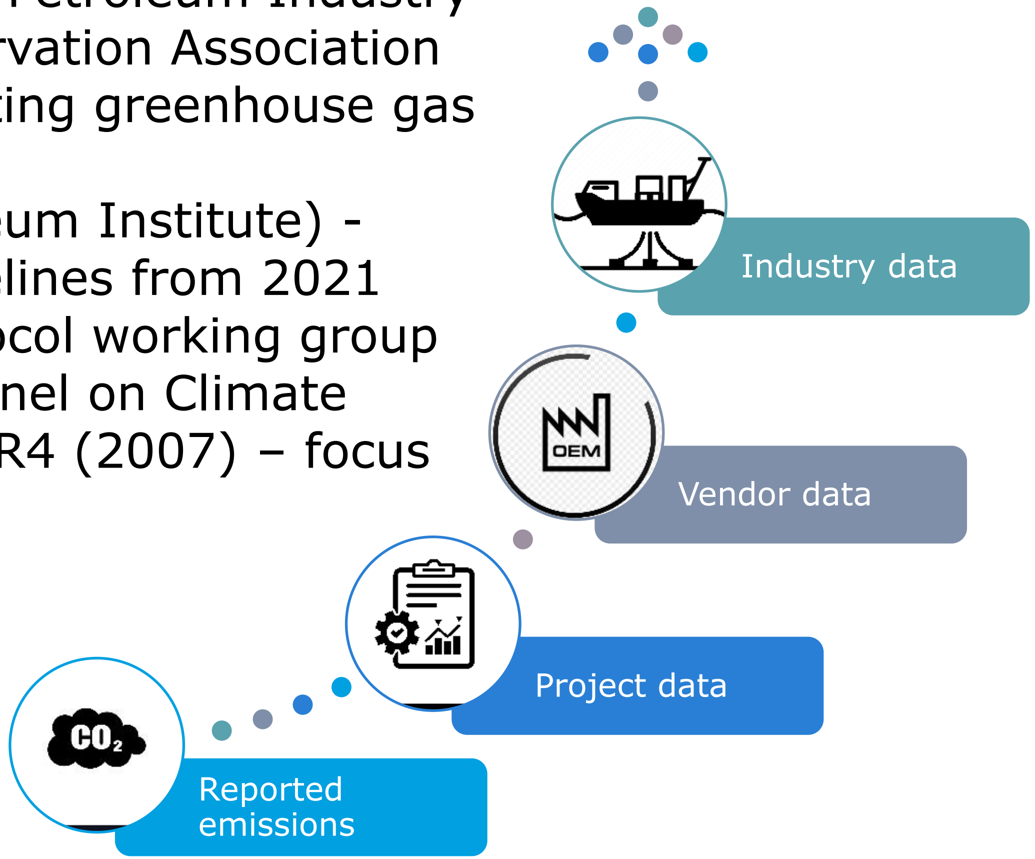
Framework:
- IPIECA (International Petroleum Industry Environmental Conservation Association - guidelines for reporting greenhouse gas emissions)
- API (American Petroleum Institute) - GHG estimation guidelines from 2021
- Greenhouse gas protocol working group
- Intergovernmental Panel on Climate Change (IPCC) e.g. AR4 (2007) – focus areas for GHG



Data sources:
- Operator recorded data
- Project design data
- Vendor input/specification
- Industry data – historic or basin specific, US/UK govt etc.

ZETA tool validation:
- IOGP data validation
- Environmental consultants review on projects
- Client review on NS project
- Lease operate contractor review vs own internal tool

Zeta tool example outputs

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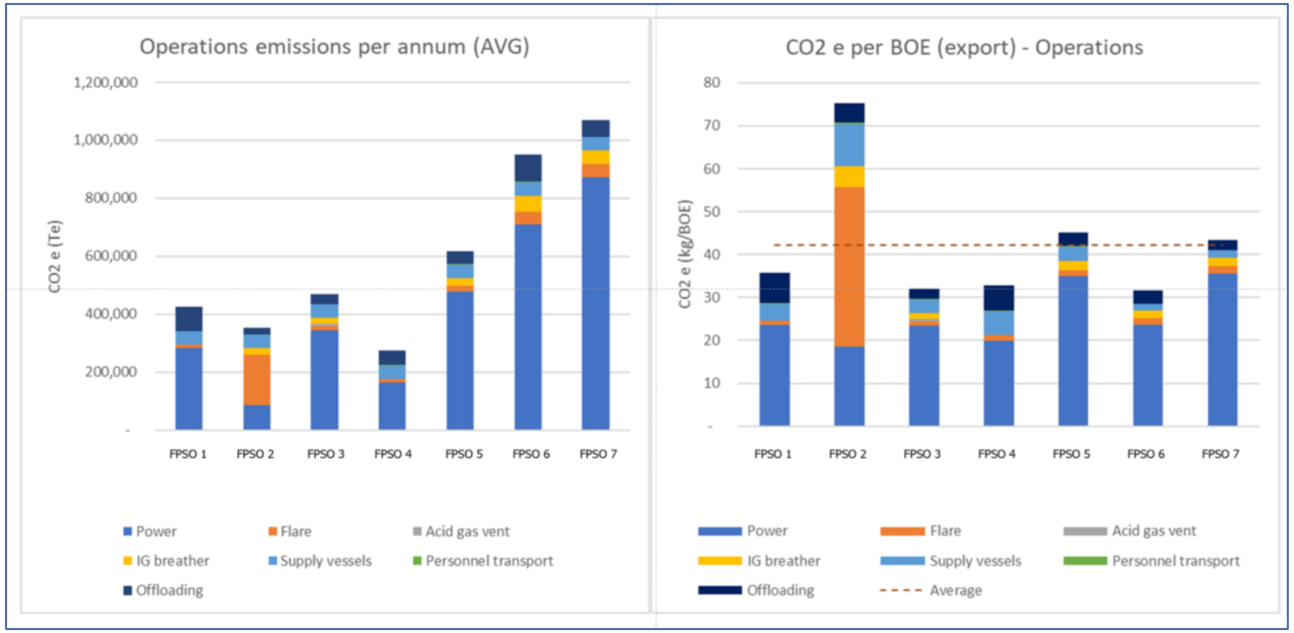
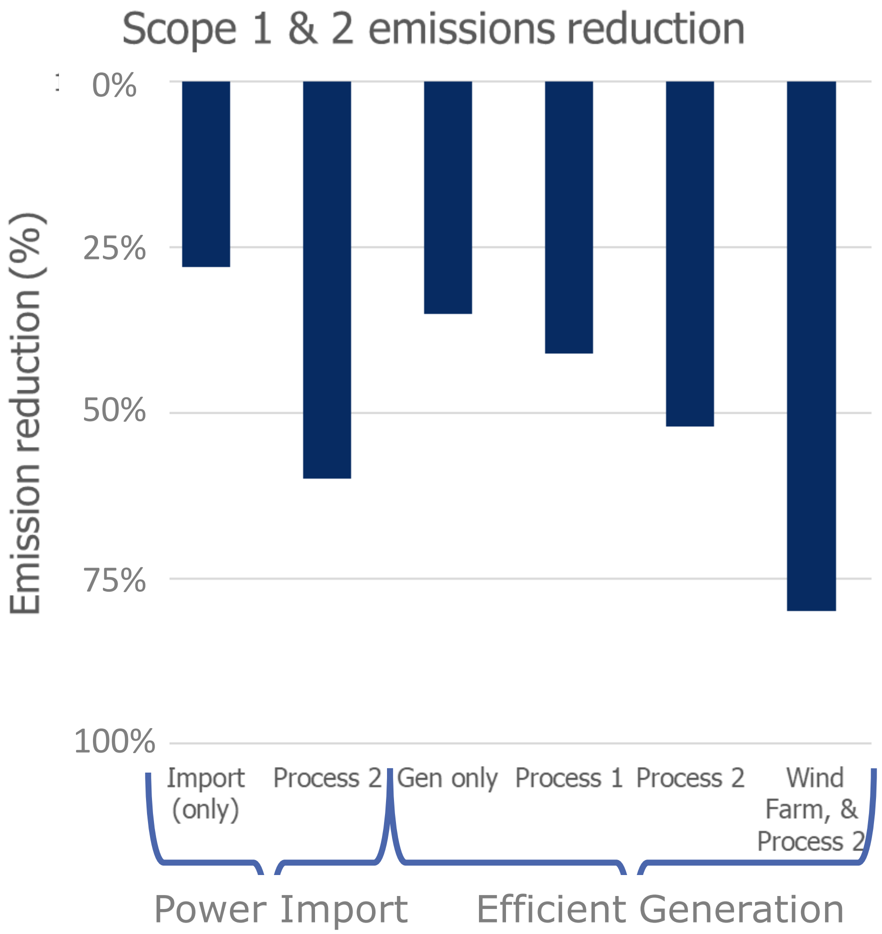
ZETA tool Benchmarking



ZETA tool for facility design



Roadmap for achieving NetZero

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Re-assessing the design of oil & gas facilities through the lens of CO_2 emissions reduction

Electrification & Electrical Architecture				Energy use optimisation			Process technologies			Flaring	Carbon capture	
Generation efficiency	Alternative generation	Alternative distribution	Power import capability	Heat recovery optimisation	Heat pump optimisation	Smarter heating systems	Oil-water separation technology	Oil degassing technology	Compressor efficiency	Minimising flaring & venting	Compact, modularised technology	Energy integration management

FUTURE FACILITIES DESIGNED THROUGH THE LENS OF EMISSIONS REDUCTION

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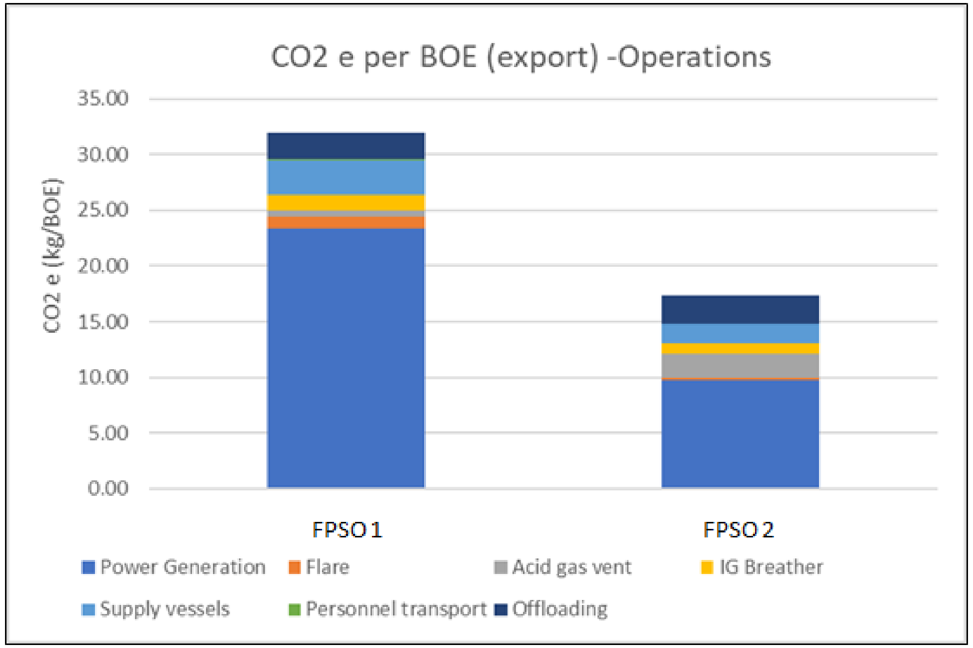
BRENDAN ROBERTSON

FPSO GHG Emission Sources

Operational intensity emissions (CO_2/boe) large VLCC-sized FPSO (scope 1 & 2)



FPSO	Oil Prodn	Gas Prodn	Power Generation	Closed Flare	Cargo Vent Recovery
2	100 kbbl/d	177 MMscfd	Combined cycle GTG	Yes	No
1	70 kbbl/d	142 MMscfd	Conventional GTG	No	No

Scope 1 GHG emission sources:

- Power generation – *the big prize*
- Mechanical drives (if used)
- Flare – *low hanging fruit*
- Cargo tank vents – *low hanging fruit*
- Boilers (if used)
- Direct CO_2 vents from acid gas removal (if used) – *difficult to abate unless re-injection is feasible*

Process heat is usually satisfied by recovery of waste heat from power generation exhausts. Hence, there is little incentive to optimise heating systems.

Reducing GHG Emissions from Power Generation

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1. Partial renewable power import

- Up to 50% GHG savings at installed capacity around 35% of power demand.

2. Efficient power generation

- Up to 50% GHG savings using more efficient power generation, such as combined cycle gas turbines or possibly gas engines.

3. Full renewable power import

- Approx. 75% GHG savings at installed capacity at 100% of power demand.

4. Onboard CCUS

- Approx. 90% GHG savings if all exhaust emissions captured & injected.

All of these schemes significantly reduce waste heat available for process heating.

If power import schemes are being considered for later life, the design should be future-proofed to allow this.

Power Generation

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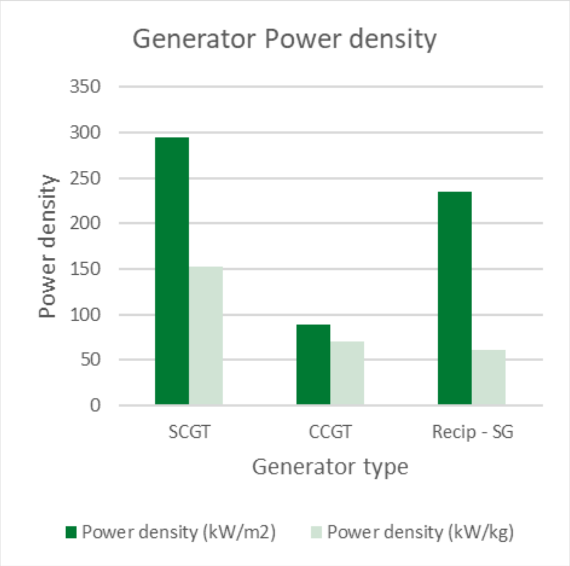
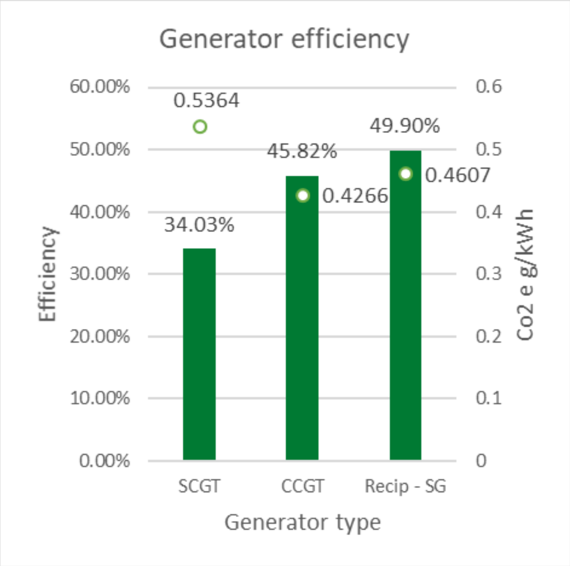
Design considerations;
- Power generation is typically largest contributor to emissions
- Provide process heat through WHR or alternative means
- Minimise maintenance to align with low personnel strategy
- Consider future power import

Generators considered;
- Simple Cycle Gas Turbine (SCGT)
  - Low efficiency, but provides abundant waste heat for process
  - Well understood in the industry with low maintenance for specific models
- Offshore Combined Cycle Gas Turbine (CCGT)
  - High efficiency, provided it is operated in CCGT mode
  - Efficiency dependent upon high Load Factor (LF)
  - Waste heat available, but trade-off between efficiency / power delivery
- Reciprocating engines
  - High efficiency, provides sufficient waste heat
  - Efficiency over broader LF than SCGT or CCGT
  - Increased maintenance for higher power demands, due to number of engines required





Selected solutions;
- Dependent upon power demand, process heat requirements, and facility
  - CCGT for high power demands >30MW
  - Reciprocating engines for <30MW, or large process heat requirements

Process Heating Systems - Enabling Net Zero

The future generation of truly net zero FPSOs seem likely to rely upon either electrification or carbon capture. Since both will have little or no waste heat available, reduction of process heat demand is important.

Process heating reduction initiatives:

- Phase (oil-water) separation to total fluid rates through inlet heaters.
- Use of heat recovery exchangers – fairly widespread already.
- Consider using heat pumps – recovering heat from low grade sources, using electrical power to upgrade it to be useable for process heating.

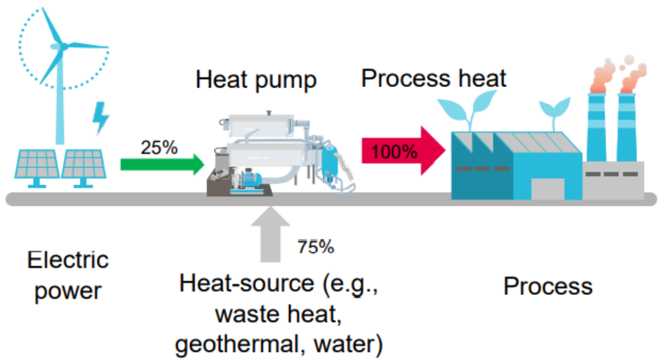
Heat Pumps Offshore

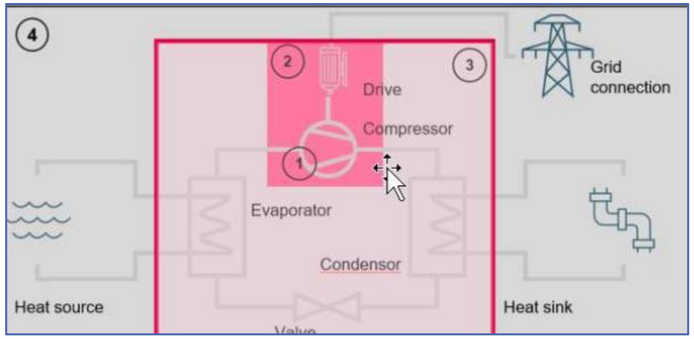
There is a high level of interest at present to use heat pumps in combination with renewable power & a heat source (e.g., waste water or geothermal) to generate zero-emissions heat.

Heat pumps work by utilising low-grade heat sources such as cooling water return to heat a working fluid (refrigerant). The refrigerant evaporates and is compressed to a higher pressure and useful temperature. The refrigerant (at useful temperature) is used to heat the process fluids, condenses & is throttled back to a lower pressure/temperature & the cycle repeats.

The principal components of a heat pump are:

- Compressor & motor.
- Heat exchangers.
- Piping & valve systems.
- All components well-proven & in use offshore.
- For the likely temperatures on a FPSO, refrigerant could be CO_2 or ammonia.





MAN **RG/IGV** type Heat Pump

Images courtesy of MAN Energy Solutions

Heat Pumps Offshore

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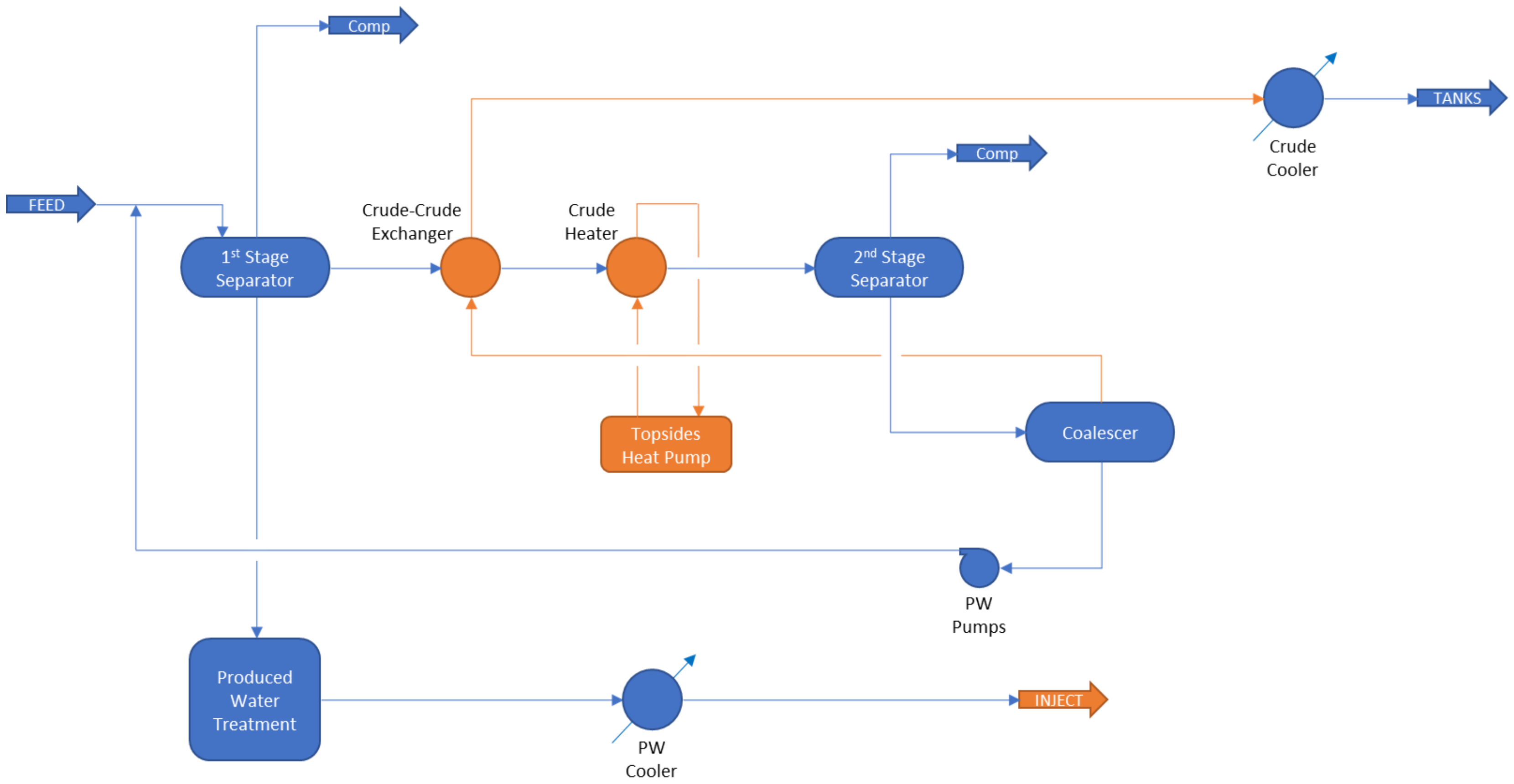
Example flow sheet using heat pump for a harsh environment FPSO concept design developed by Wood & Crondall Energy. This particular example generated~15MW of process heating by extracting heat from seawater cooling overboard discharge. Compressor duty ~ 4MW.



ABATEMENT
EMITTERS TO RESERVOIR

23 NOVEMBER 2022

DR MURRAY ANDERSON

Content

Aim to highlight some of the main issues to be addressed in carbon dioxide transportation and disposal.

1. **Background**
2. **Comment on carbon dioxide stream properties**
3. **Pipeline transportation issues**
4. **System operability**

BACKGROUND

UK Industrial Decarbonisation – Published Strategy

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UK Government Published "Industrial Decarbonisation Strategy" in March 2021

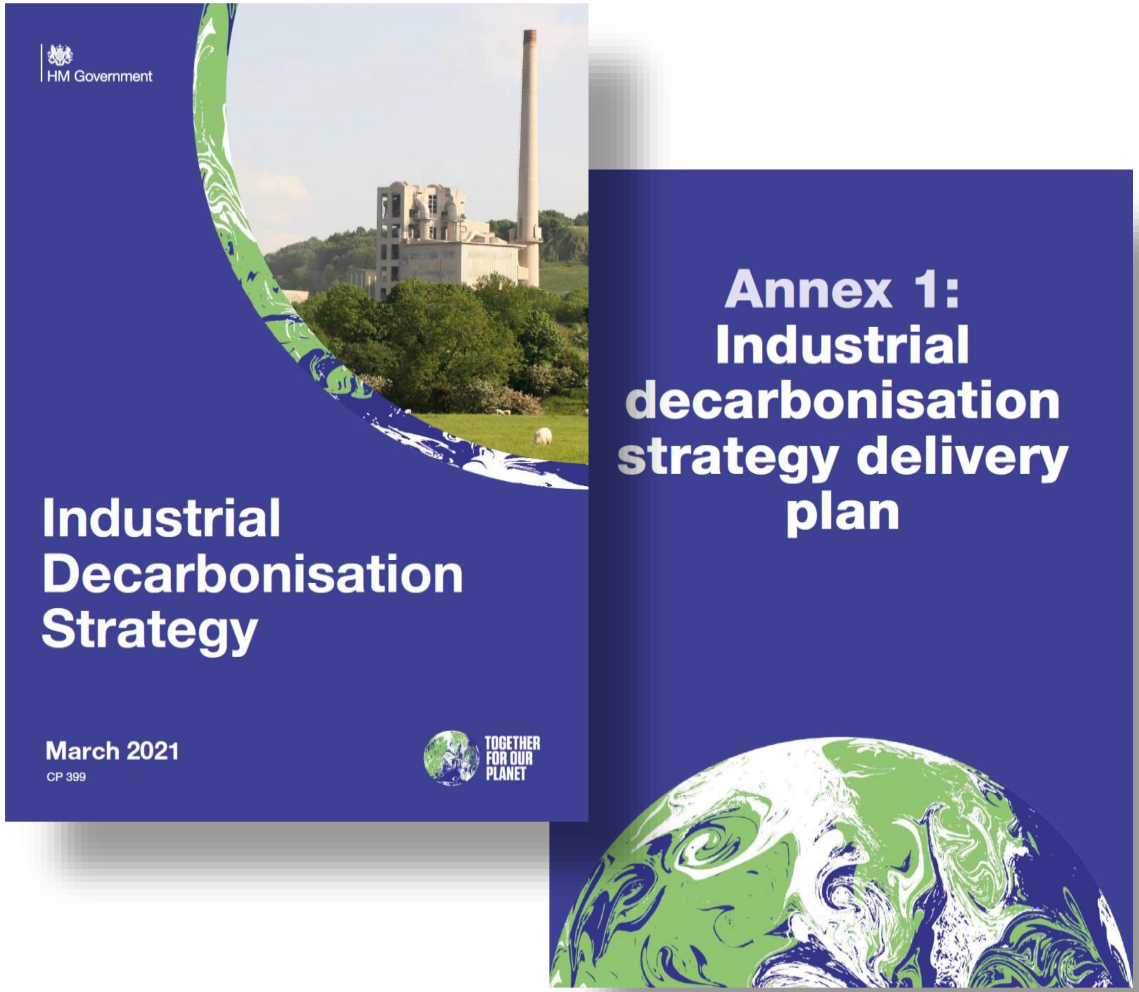
The Delivery Plan identifies

- Carbon Capture, Usage and Storage
- Low Carbon Hydrogen

as key elements of industrial decarbonization.

Carbon Capture is essential for energy-intensive, hard to abate industries:

- steel
- petrochemicals
- aluminum
- cement
- fertilizers



https://www.gov.uk/government/publications/industrial-decarbonisation-strategy

UK Industrial Cluster Sequencing and Implementation

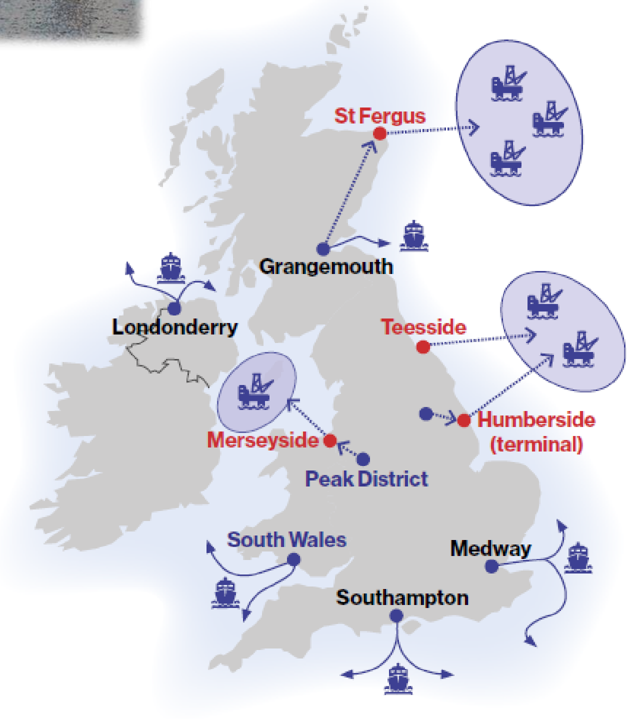
19 October 2021:

Minister of State for Energy, Clean Growth and Climate Change confirmed the UK commitment to funding CCUS at pace and at an industrial scale in a Parliamentary Statement

The statement identifies Hynet (Merseyside) and East Coast Cluster (Teeside/Humberside) to be taken forward into Track-1 negotiations. Scottish Cluster (St. Fergus) is identified as a reserve cluster.

Press reporting on CCUS included comments about "easy to implement by putting existing infrastructure into reverse".

But how true is that?



CARBON DIOXIDE STREAM PROPERTIES

What is Carbon Dioxide?

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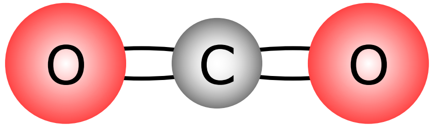
Carbon Dioxide:

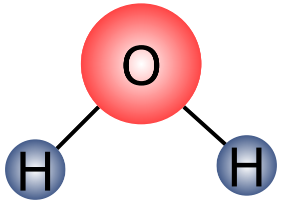
Chemical Formula CO_2
Colourless, odourless gas
Highly soluble in water
Atmospheric concentration 410 ppm (global average)



Molecular Wt. 44 g/mol

Water:

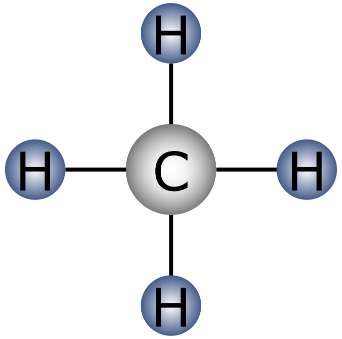
Chemical Formula H_2O
Colourless, odourless liquid/vapour
Atmospheric concentration 0 to 40,000 ppm



Molecular Wt. 18 g/mol

Methane:

Chemical Formula CH_4
Colourless, odourless gas
Atmospheric concentration 0 to 1.87 ppm



Molecular Wt. 16 g/mol

Carbon Dioxide Emitter Streams

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		DelpHYnus	Hynet	NEP	Scottish Cluster	V Net Zero
CO2 Stream	**Carbon Dioxide**	min 96mol%	≥95.0%	max 100%	99.4vol%	min 91% gas min 96% dense
Non-condensable	**Hydrogen**	≤20,000ppmv (2vol%)	≤10,000ppmv (1vol%)	≤20,000 (2%)	≤5,000ppmv	≤20,000 (2mol%)
	Carbon Monoxide	<2,000ppmv	<1,000ppmv	≤2,000ppmv	≤1,000ppmv	not specified, see non-condensables
	Total volatiles (non-condensable) N_2, Ar, CH_4	<40,000ppmv (4%) including H_2	<40,000ppmv (4%) including H_2 and CO	saturation pressure not to exceed 80barg	≤6,000ppmv includi ng O_2, H_2 and CO.	saturation pressure not to exceed 80barg
Trace Impurities	**Water**	<50ppmv	≤50ppmv	≤50ppmv	≤50ppmv	≤50ppmv
	Oxygen	<10ppmv	≤10ppmv	≤10ppmv	≤20ppmv	≤10ppmv
	SO_x/NO_x	≤100ppmv each	≤30ppmv each	≤100ppmv each	≤10ppmv each	≤100ppmv SO_x <20ppmv NO_x
	Hydrogen Sulphide	<19.56ppmv	<5ppmv in total	≤80ppmv (gas) ≤20ppmv (dense)	≤10ppmv	≤20ppmv (dense)

Carbon Dioxide Phase Behaviour

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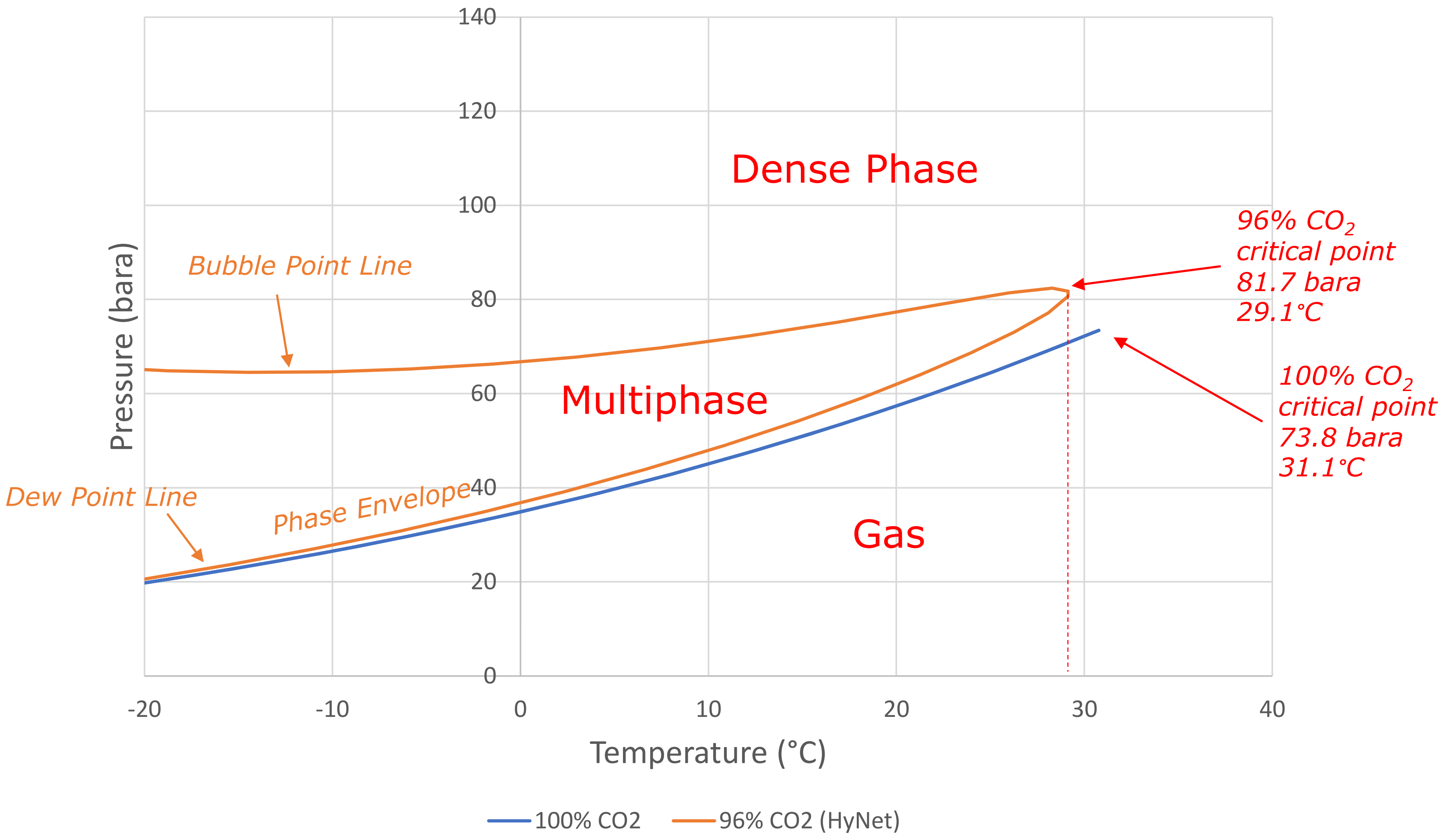

Hydrogen Fraction in Gas Phase

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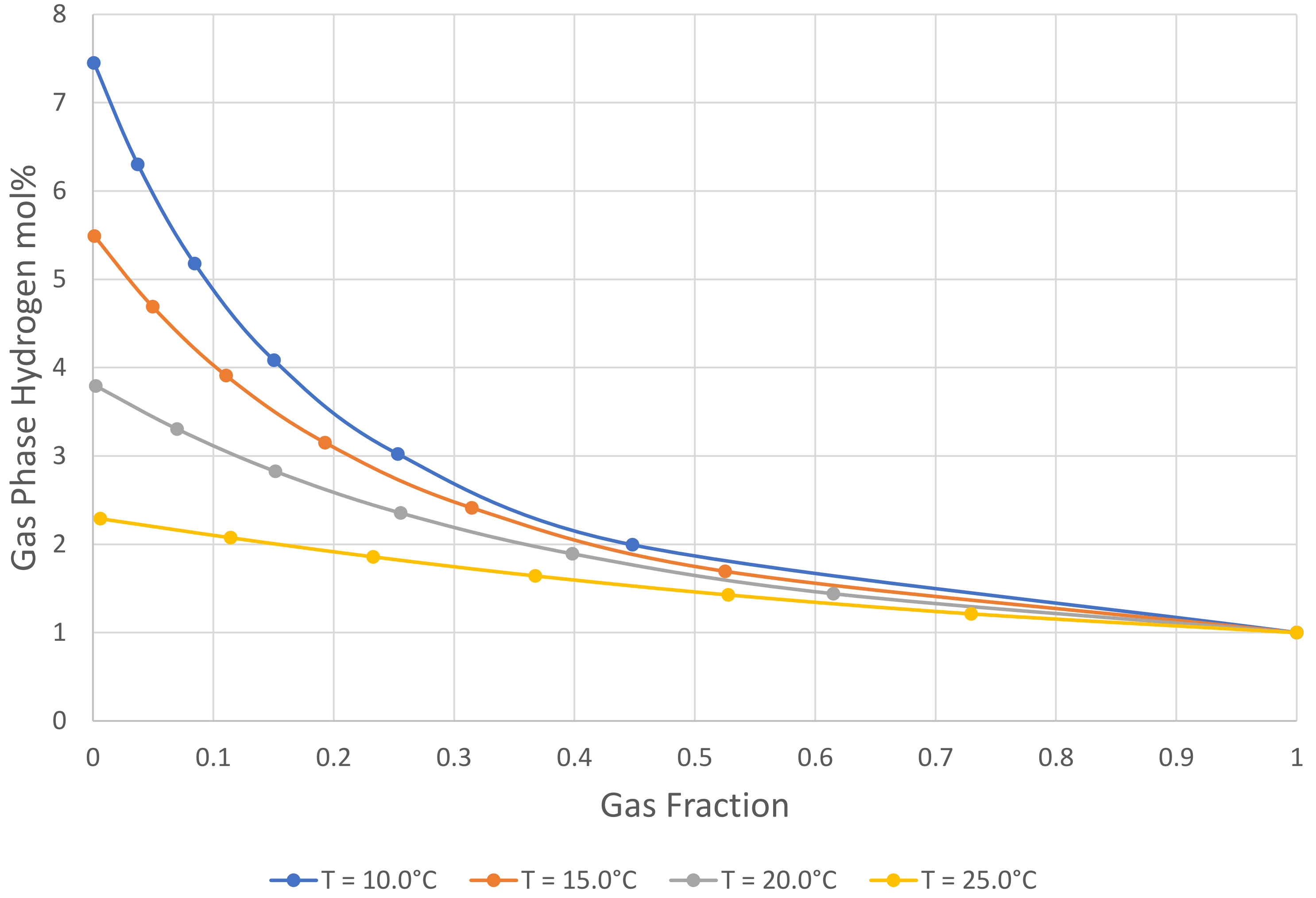

Fluid Property Estimates

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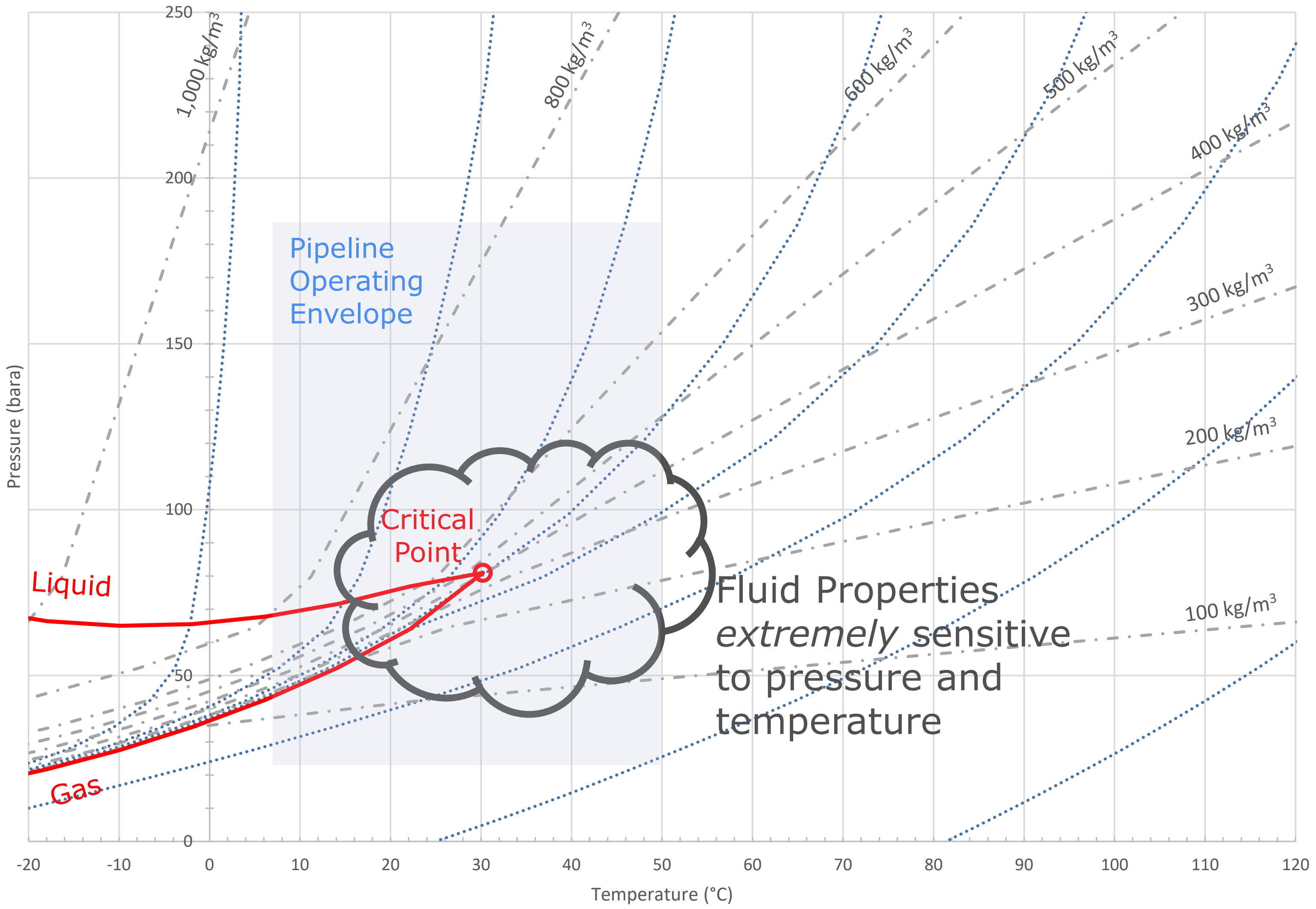


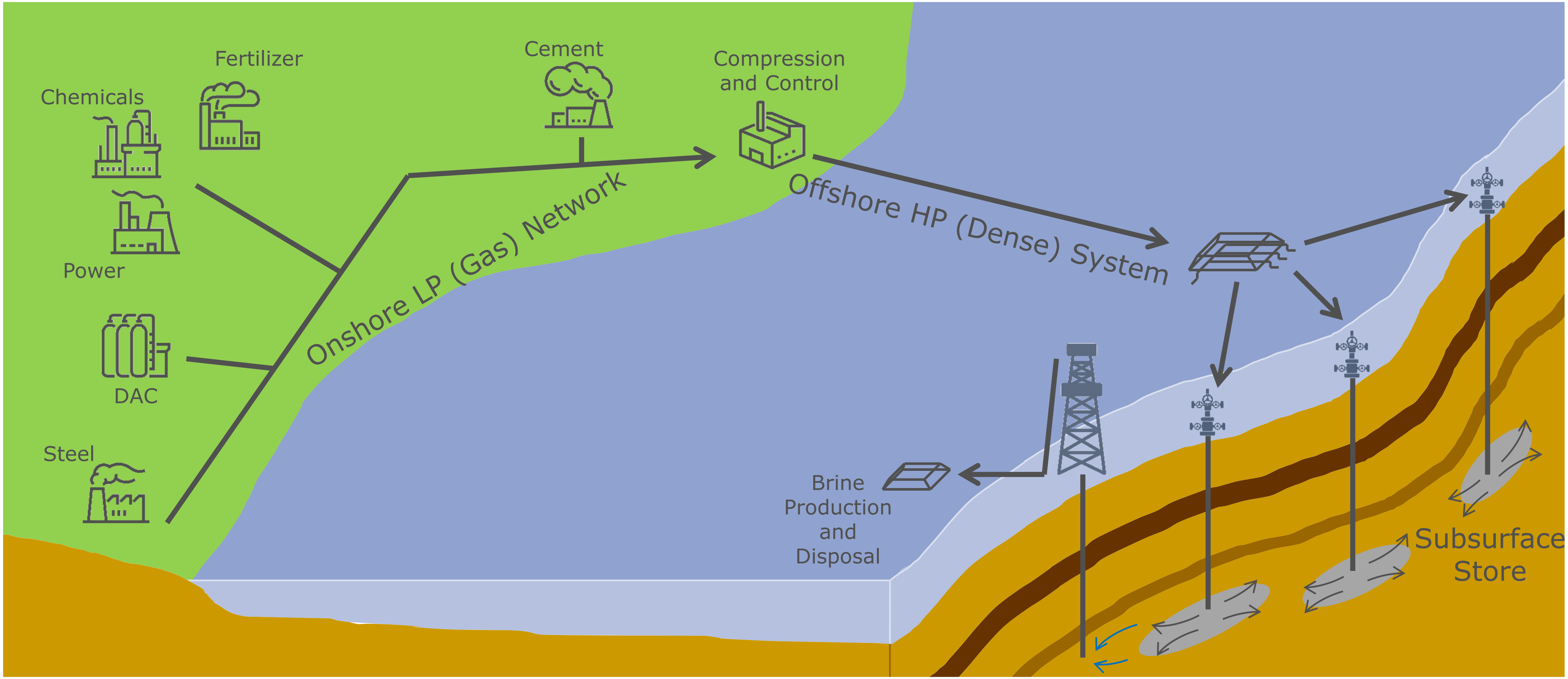
Three issues:

- Small changes in composition (non-condensibles) can change the chart
- Small errors in pressure and temperature estimate lead to big errors in density or enthalpy estimate.
- The chart probably isn't accurate anyway (state equation modelling and measured validation)

The overall sensitivity of any modelled result has to be checked: does a small change in one parameter lead to a significant change in operation?

PIPELINE TRANSPORTATION

CCUS Cluster



Pipeline Phase Change Risk

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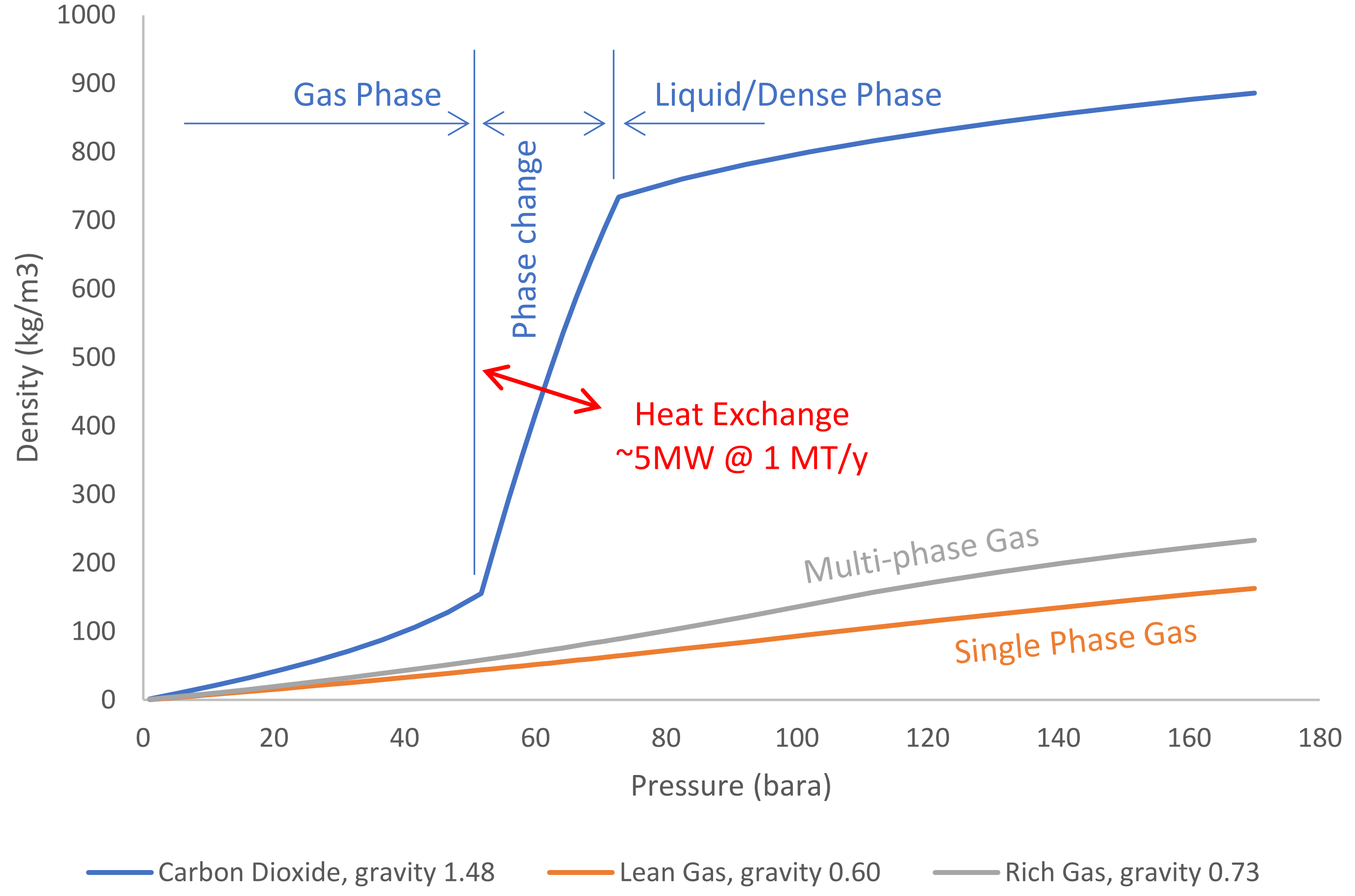
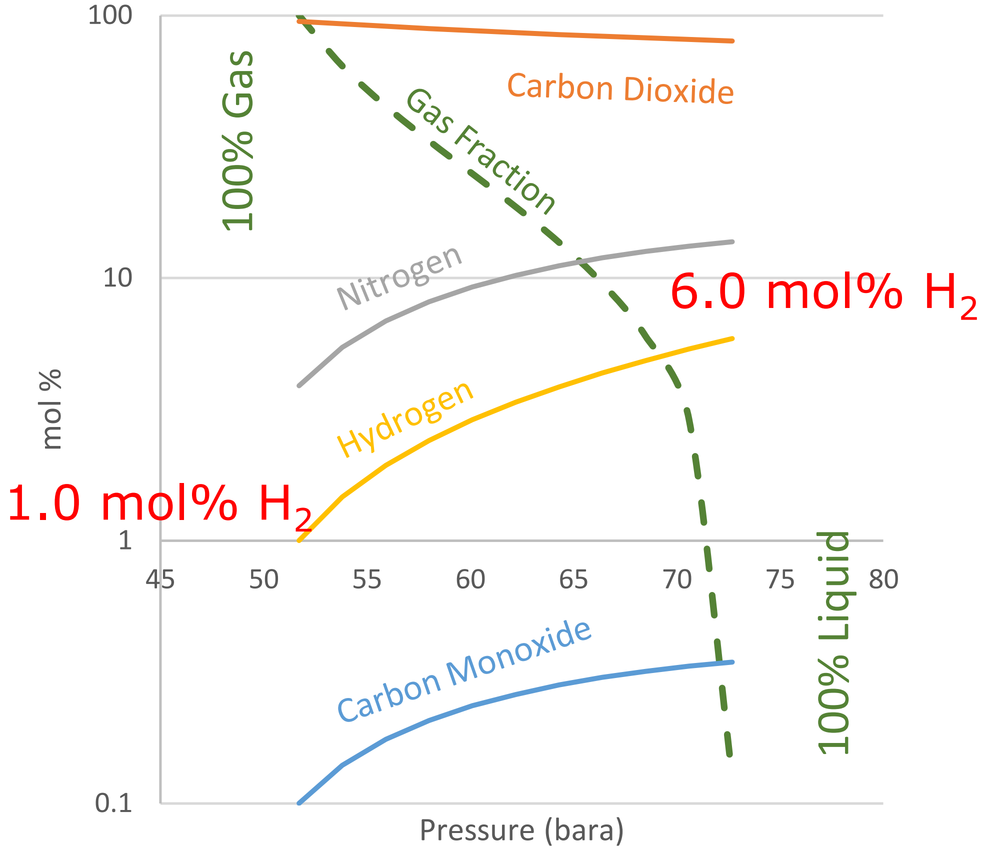


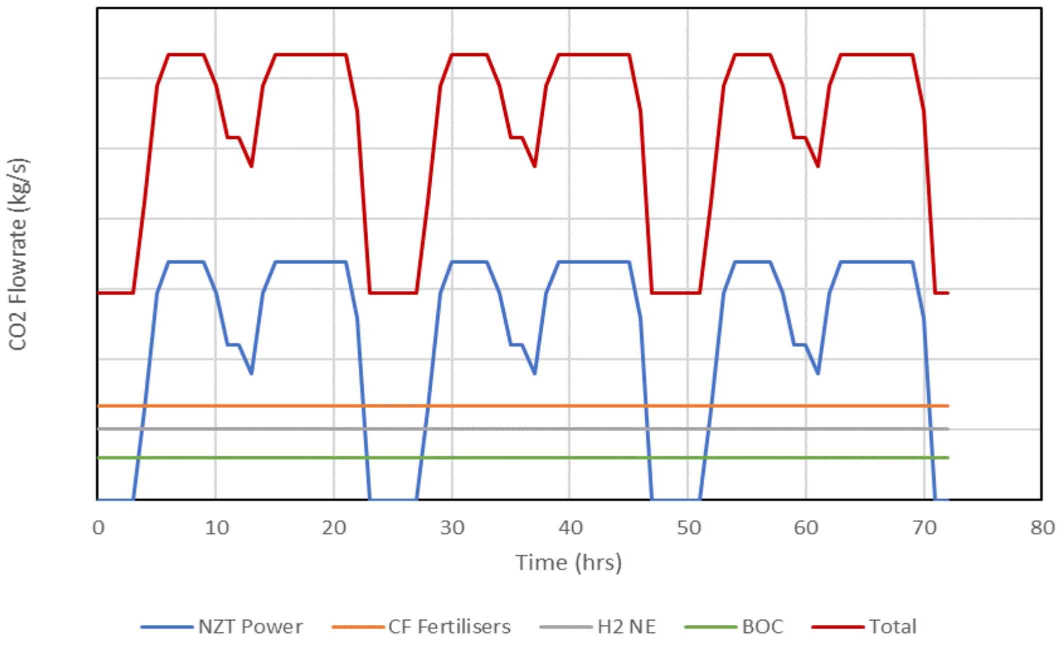
Overall Mixture Density at 12°C



Gas Phase Composition at 12°C

SYSTEM OPERABILITY

Emitter Flowrates



- Design flowrates ~10 MTpa
- Initial development phase peak rates ~4 MTpa
- First gas available may be ~0.5 MTpa to ~2.0 MTpa
- Dispatchable power flowrate will fluctuate significantly throughout 24-hour period
- Initial gas rates are significantly below design flow rate
- Swings in initial gas rate are significantly

Offshore Pipeline

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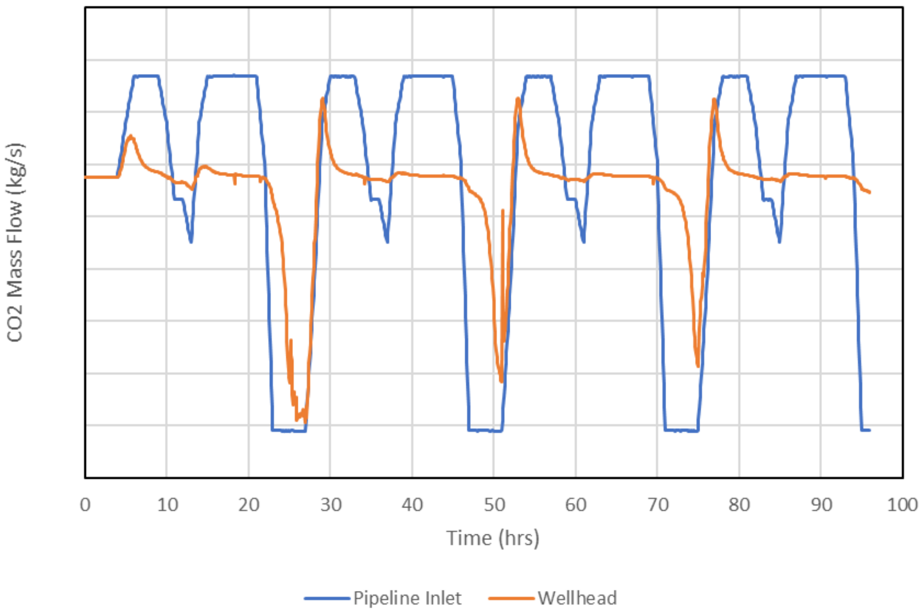

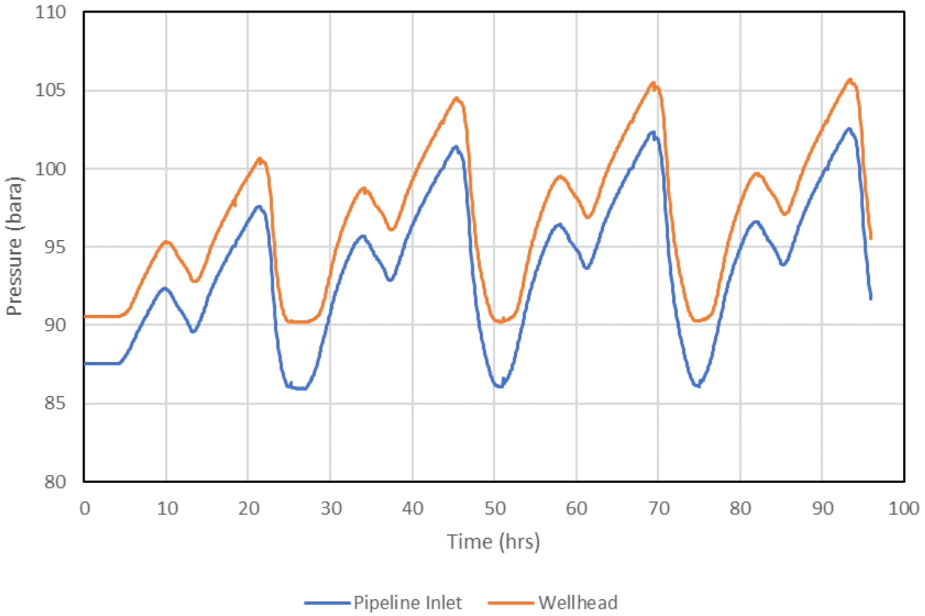

Control valve at well attempts to control the flowrate entering the injection wells to average ~3 MTpa

As flowrate from dispatchable power stops, the pipeline pressure drops and the flowrate at the wellhead drops rapidly within a few hours

Storage capacity in the pipeline (line-pack) is very limited

If multiple injection wells are online

- shut-in individual wells
- turndown multiple wells

Frequent shut-in/turndown of wells increases the likelihood of subsea valve failure and/or pipeline fatigue

- cycling of choke valves
- high frequency of cycling of wing valves
- risk of drawing formation water into well

Pressure fluctuations in the pipeline are of the order of 15 bara

- back pressure on beach compressor cycles
- complex onshore control system

KEY POINTS

Why is CO_2 transport difficult?

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CO2 molecules are much heavier than natural gas or water molecules

Transportation specifications will have up to 4% impurities

- Phase change envelope expands
- Bubble point (saturation line) moves to higher pressure (~80barg)
- Operating margin between saturation point and maximum operating pressure becomes small

CO2 is a gas at atmospheric conditions but liquifies easily

- systems need to operate either in gas-phase or dense-phase but avoid multiphase
- depleted gas stores may be at gas-phase conditions
- aquifer supported stores may require brine management to avoid local over-pressure

Problematic phase changes

- hydrogen rich gas bubbles that can embrittle conventional steel
- multiphase flow with associated fatigue loading and liquid management issues
- well instabilities, possibly including inverted density profiles (high-density liquid above low-density gas)
- severe low temperatures, potentially requiring heat input at the wellhead

Imbalances between onshore emitter flows and offshore injection rates

- emitters may give intermittent production, but wells require steady flow with a minimum turn-down.

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