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LINKING CAPTURE TO STORAGE - OFFSHORE PIPELINE CONSIDERATIONS IN CCUS

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Outline

1. Worldwide track record of CO_2 pipelines
2. The unique phase diagram of CO_2 and its implications for transport in pipelines
3. The importance of fluid composition
4. Material compatibility
5. Fracture resistance considerations
6. Operational considerations: the pipeline as part of a system
7. Summary

Worldwide CO_2 Pipeline Inventory

CO2 pipelines are **not new** – extensive track record, especially onshore USA

Only 2 offshore CO_2 pipelines in operation

CO_2 mostly used for EOR

Typically dense phase conditions

Facility name	Lifecycle stage	Country	State / district	CO_2 capture capacity (millions tonnes per year)	Operation date	Industry
Terrell Natural Gas Processing Plant	Operating	UNITED STATES	Texas	0.4-0.5	1972	Natural gas processing
Enid Fertilizer	Operating	UNITED STATES	Oklahoma	0.7	1982	Fertiliser production
Shute Creek Gas Processing Plant	Operating	UNITED STATES	Wyoming	7.0	1986	Natural gas processing
Sleipner CO2 Storage	Operating	NORWAY	North Sea	1	1996	Natural gas processing
Great Plains Synfuel Plant and Weyburn-Midale	Operating	CANADA	Saskatchewan	3.0	2000	Synthetic natural gas
Snøhvit CO2 Storage	Operating	NORWAY	Barents Sea	0.7	2008	Natural gas processing
Century Plant	Operating	UNITED STATES	Texas	8.4	2010	Natural gas processing
Air Products Steam Methane Reformer	Operating	UNITED STATES	Texas	1.0	2013	Hydrogen production
Coffeyville Gasification Plant	Operating	UNITED STATES	Kansas	1.0	2013	Fertiliser production
Lost Cabin Gas Plant	Operating	UNITED STATES	Wyoming	0.9	2013	Natural gas processing
Petrobras Santos Basin Pre-Salt Oil Field CCS	Operating	BRAZIL	Off the coast of Rio de Janeiro	Approx. 1.0	2013	Natural gas processing
Boundary Dam Carbon Capture and Storage	Operating	CANADA	Saskatchewan	1.0	2014	Power generation
Uthmaniyah CO2-EOR Demonstration	Operating	SAUDI ARABIA	Eastern Province	0.8	2015	Natural gas processing
Quest	Operating	CANADA	Alberta	Approx. 1.0	2015	Hydrogen production
Abu Dhabi CCS Project (Phase 1 being Emirates Steel Industries)	Operating	UNITED ARAB EMIRATES	Abu Dhabi	0.8	2016	Iron and steel production
Petra Nova Carbon Capture	Operating	UNITED STATES	Texas	1.4	2017	Power generation
Illinois Industrial Carbon Capture and Storage	Operating	UNITED STATES	Illinois	1.0	2017	Ethanol production
Gorgon Carbon Dioxide Injection	In construction	AUSTRALIA	Western Australia	3.4-4.0	2017	Natural gas processing
Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream	In construction	CANADA	Alberta	0.3-0.6	2018	Fertiliser production
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream	In construction	CANADA	Alberta	1.2-1.4	2018	Oil refining
Sinopec Qilu Petrochemical CCS	In construction	CHINA	Shandong Province	0.4	2019	Chemical Production
Yanchang Integrated Carbon Capture and Storage Demonstration	In construction	CHINA	Shaanxi Province	0.4	2020	Chemical Production

Phase Envelope of Pure CO_2

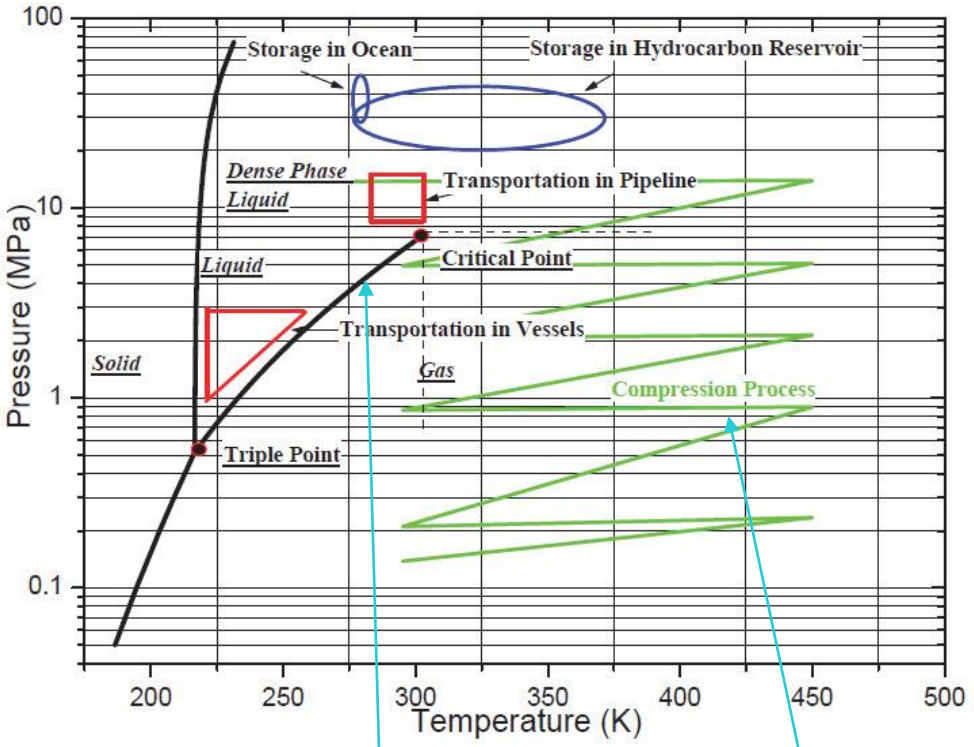
CO_2 has unique phase change characteristics

Dense phase CO_2 flows very well: large throughputs at pressures lower than typical design pressure of offshore gas pipelines (90-150 bar)

BUT

De-pressurisation is problematic: system should be designed to operate in dense phase **OR** gas phase at all times.

This drives operating and intervention philosophy, and barrier requirements



Phase boundaries are sensitive to impurities

Special CO_2 compressors needed

Effect of Impurities

(Ref IPC2008-64063, Seevam & Hopkins)

Real world carbon capture processes do not deliver pure CO_2

Stringent dryness requirement (-40C dewpoint) to ensure no free water

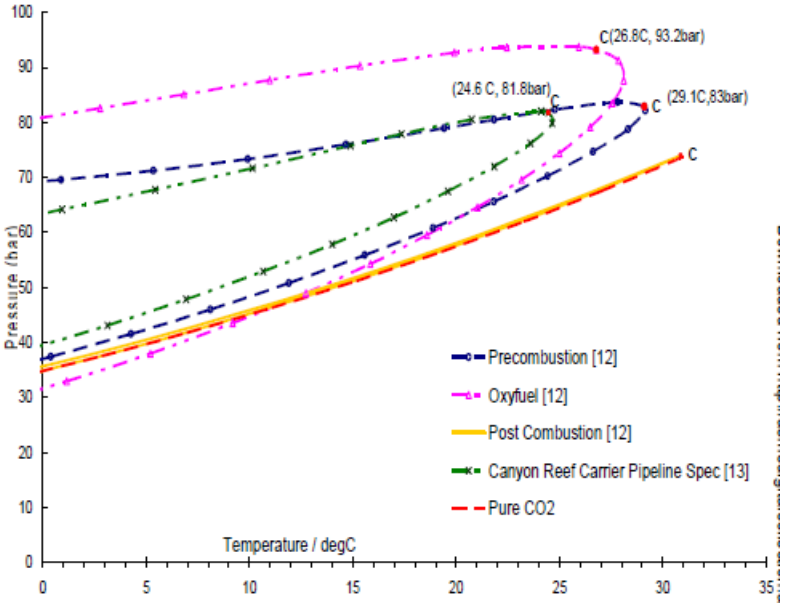
Impurities have a strong influence on phase diagram – saturation pressure can be much higher

Impurities vaporise before CO_2: aggressive conditions can result

Density, viscosity and thermodynamic properties also affected (higher pressure drop)

Thermohydraulic modelling requires **good knowledge of composition**: difficult in a cluster with multiple sources.

Comp	Post Combustion	Pre-combustion	Oxyfuel
CO_2	>99% v%	>95.6v%	>90v%
CH_4	<100ppmv	<350ppmv	0
N_2	<0.17v%	<0.6 v%	<7v%
H_2S	Trace	<3.4 v%	trace
C2+	<100ppmv	<0.01v%	0
CO	<10ppmv	<0.4 v%	trace
O_2	<0.01vl%	Trace	<3 v%
NO_X	<50ppmv	0	<0.25v%
SO_X	<10ppmv	0	<2.5v%
H_2	Trace	<3 v%	Trace
Ar	Trace	<0.05 v%	<5 v%
S	N/A	N/A	N/A



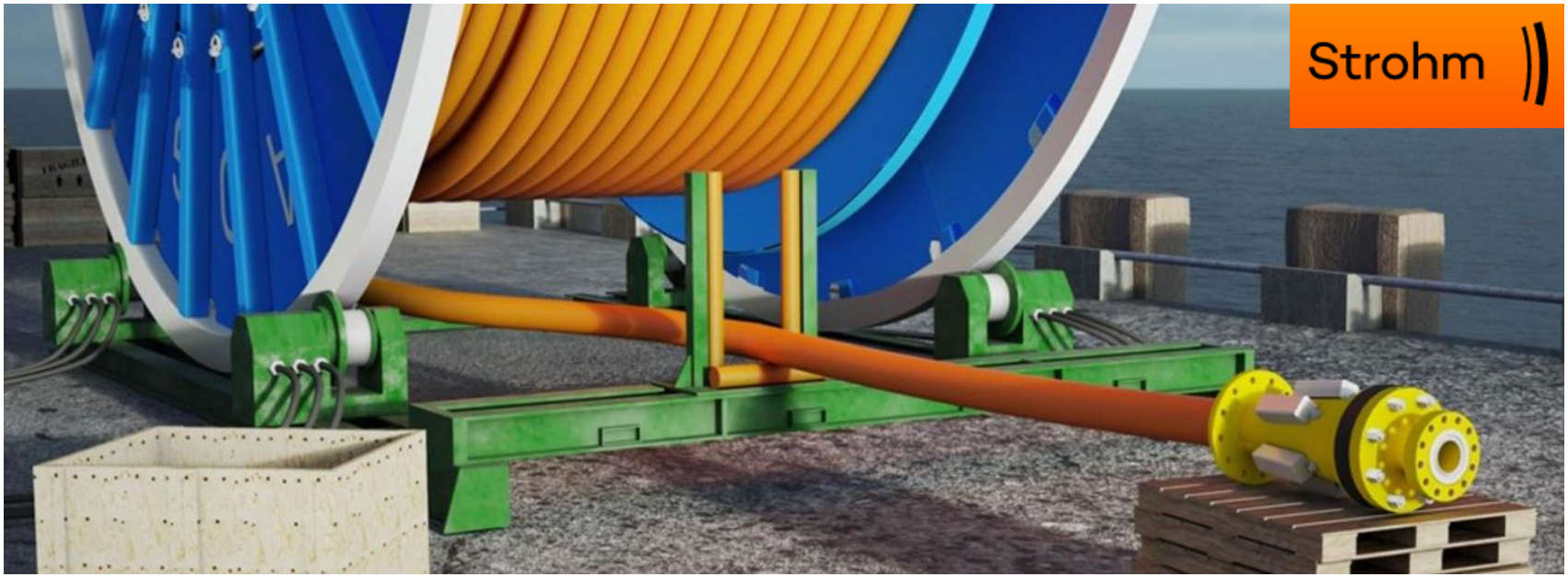
Line Pipe Material

Carbon steel with good toughness is OK for expected CCS gas compositions ***as long as it is dehydrated (no free water)***

Where there is potential for free water, solid CRA or CRA clad/lined is required. (304, 315, 13Cr, 22Cr, 25Cr, Inconel all suitable)

PE liners could be an alternative in some situations.

Spoolable TCP is also a good option for small sizes (eg 6” well jumpers) – already qualified for CO_2 exposure



Beware Elastomers

CO_2 is an excellent solvent, and aggressively attacks conventional elastomers commonly used for PIG cups and O-rings

- Cyclic swelling
- Explosive decompression

Special materials are available to mitigate these risks – seek specialist advice

Running Ductile Fracture

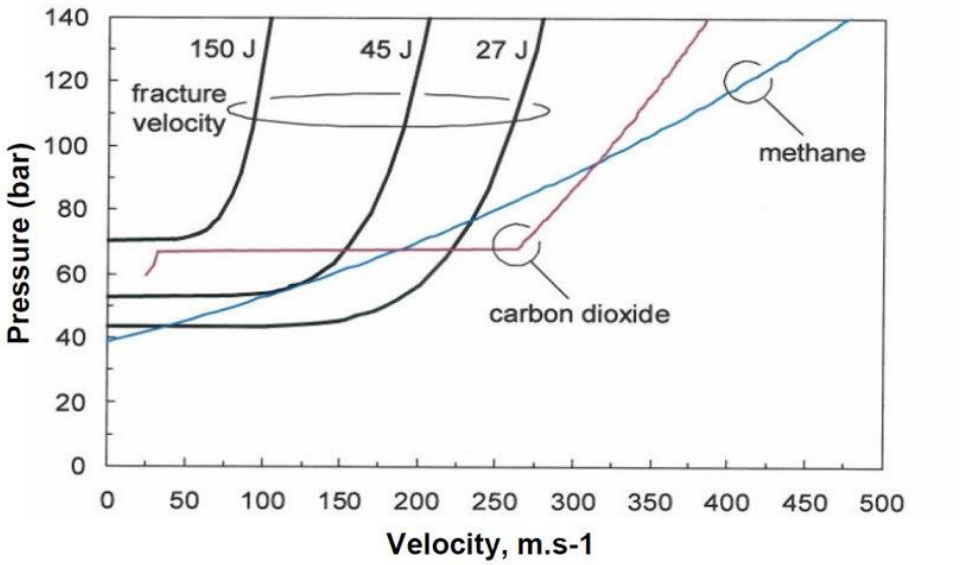
This is an issue for gas pipelines, but can be a bigger issue for dense phase CO_2

Leak causes rapid pressure drop until saturation line reached – then pressure is maintained so crack driving force does not reduce

High toughness needed if hoop stress is high at saturation pressure (drives wall thickness)

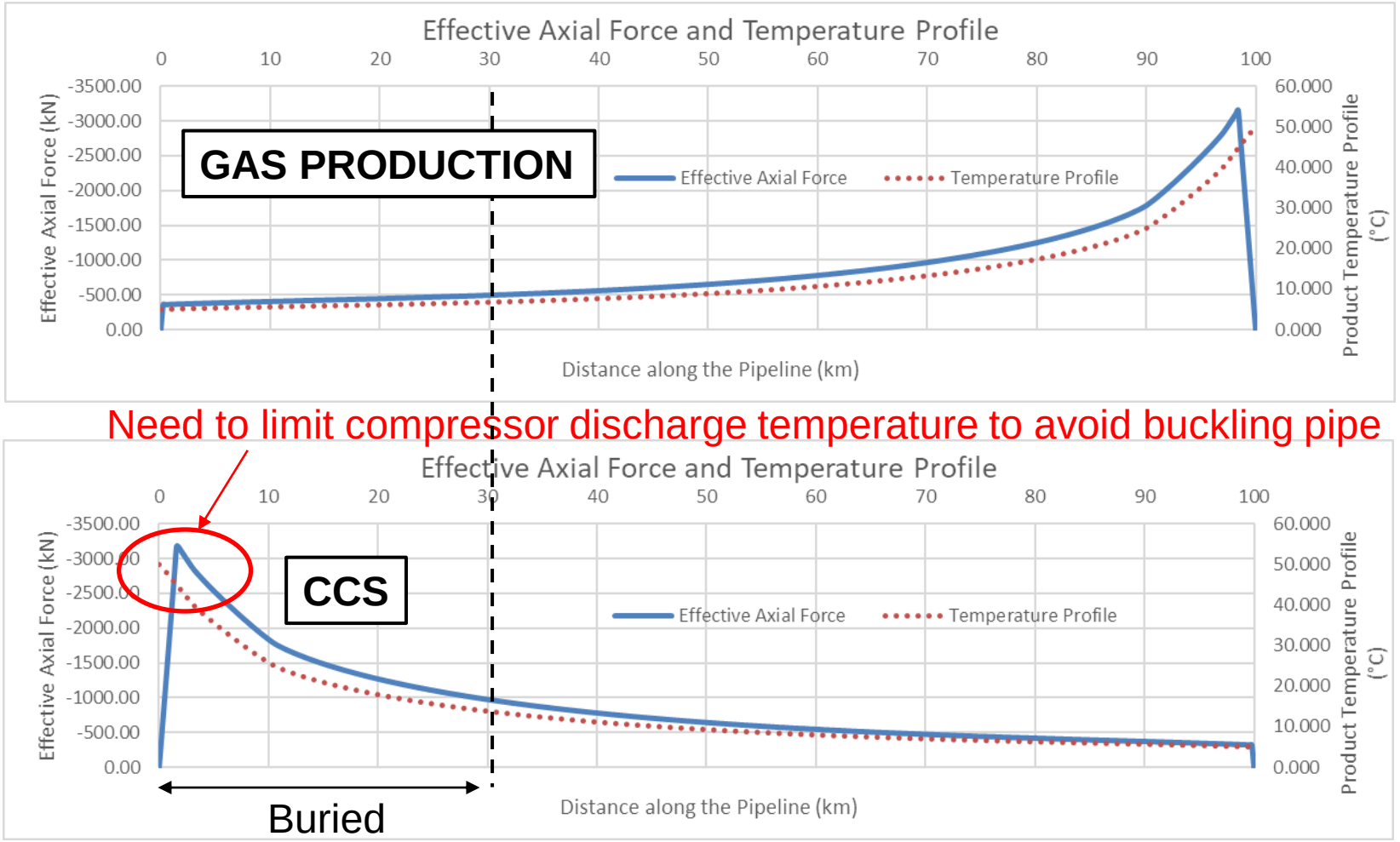
Impurities (eg N_2) increase saturation pressure

Crack arrestors needed in some cases



CCS Service Conditions

Pressure typically somewhat lower than gas export service ***but the temperature profile is reversed***



The Role of the Pipeline in System Operability and Stability

CCS will not deliver stable CO_2 rates to the pipeline inlet (demand fluctuations, trips, maintenance….)

Dense phase conditions must be maintained throughout system, into reservoir, at all times

Constant adjustment of injection rates to match pipeline inlet rates is not desirable (long step-out control systems)

Line pack in is often used in gas transmission systems to manage variable supply and demand: use the pipeline as a storage vessel

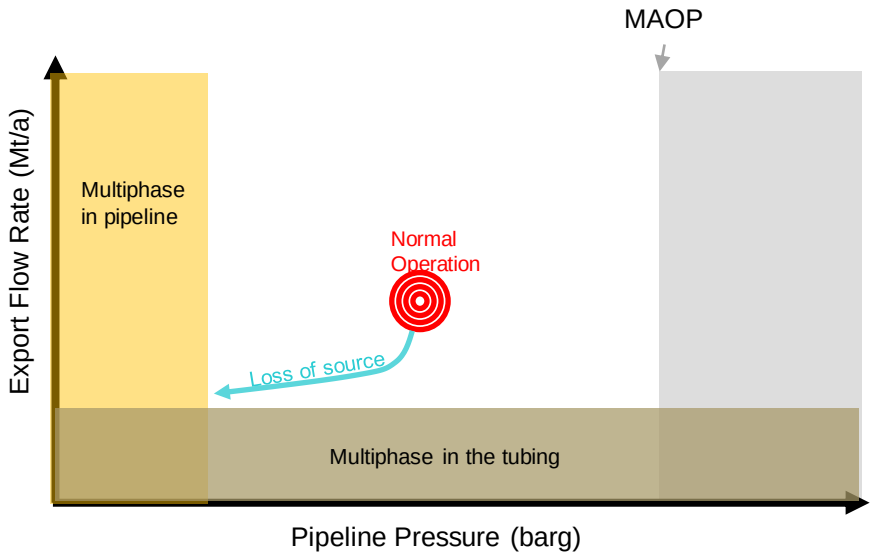
Can line pack improve overall reliability and operability of CCS, with dense phase CO_2?

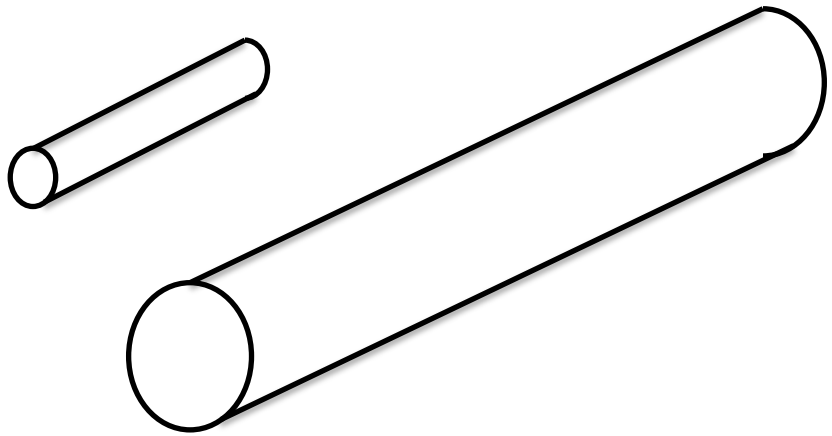
Dense Phase CO_2 Line Pack in Numbers

A really simple (but representative) example:

	Pressure, barg	Temperature, degC	Density, kg/m3
Min Pressure	80.0	8.0	915.4
Max Pressure	150.0	8.0	963.0
Change			**47.6**

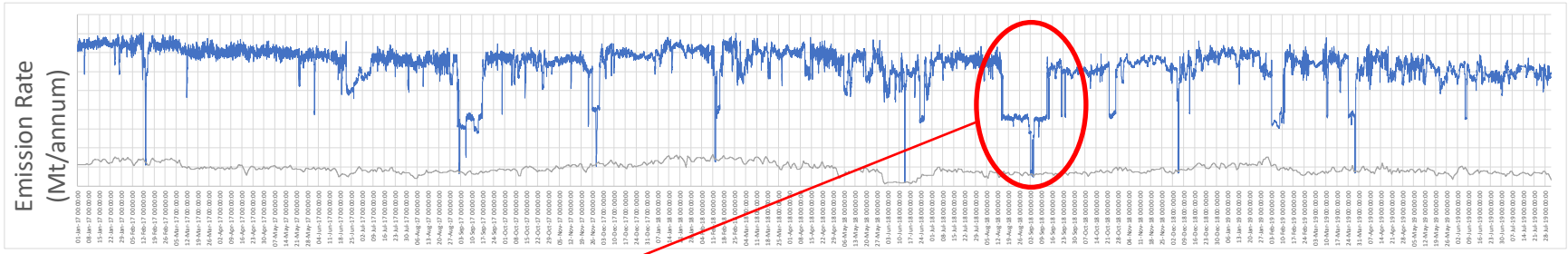
	Pipeline sized for flow rate	Oversize long pipeline
Length, km	50.0	250.0
OD, in	16	30
Volume, m3	5700.5	99314.7
Line Pack, mt	**271.5**	**4729.9**
Nominal rate, mt/yr	4.00E+06	4.00E+06
Nominal rate, mt/hr	456.6	456.6
No touch time, hr	**0.59**	**10.36**

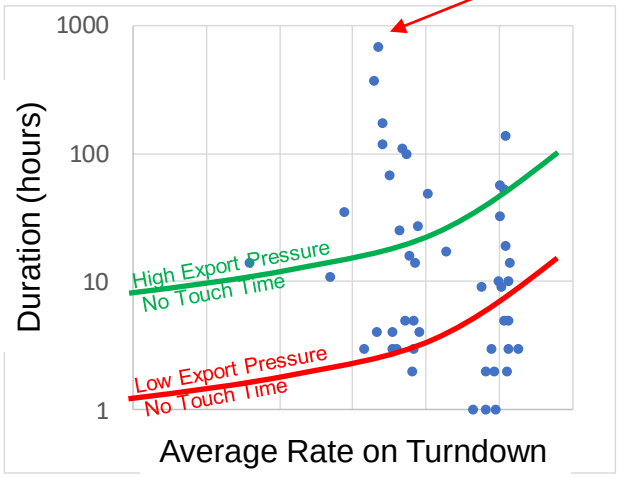




Effect of Line Pack on System Operation
Assessment of Typical CO_2 Delivery Profile

Historic emission Rate Data is available for many CO_2 emitters





This data was analysed in order to compare the different Export Pressure operating strategies

- What is the offshore no touch time?
- How many cases per year required no change at the wellhead (no touch time > turndown duration)?

Insights:

Line pack from higher operating pressure and larger pipeline can make CCS more stable and easier to operate.

Line pack comes at a cost: compression, fatigue

Summary

1. There is good track record of CO_2 pipelines going back 50 years, mostly in USA, mostly onshore.
2. CO_2 has unique phase properties: long pipelines work well in dense phase at high pressure, but take a ***long*** time to de-pressurise. Limited capacity in low pressure gas phase. Two-phase operation should be avoided.
3. Impurities have a big effect of fluid properties: higher pressures needed to maintain dense phase. Good knowledge of composition is important in design.
4. Carbon steel is a good choice if free water is avoided. High toughness is needed to avoid running ductile fracture: may necessitate more wall thickness than required for pressure containment (further compounded by impurities).
5. Some line pack is available in dense phase. Over-size pipelines (eg from re-purposing) bring useful operability benefits: helps to manage CO_2 supply variations.