Equipment and Pipeline Integrity for CCS

Understanding and controlling key threats A Process Safety Perspective

Michael Malavazos

SOUTH AUSTRALIA
Government of South Australia
Department for Energy and Mining

CCS Technical Standards –
Regulatory Requirement to demonstrate good industry practice

Capture, transport and storage including Monitoring, Reporting and Verification:

- Focusing on recognized industry best practice
- Ensure equipment is fit for purpose
- Process Safety Management focus – controls remain effective to maintain CO_2 flow, and keep it in the pipe and reservoir

ISO/TC 265 standards portfolio

Carbon capture

ISO/TR 27912 CO_2 capture systems, technologies and processes

ISO 27919-1 Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant

ISO 27919-2 Evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant

ISO/TR 27922 Overview of CO_2 capture technologies in the cement industry

ISO XXXX Performance evaluation of CO_2 capture connected with a CO_2 intensive plant

ISO XXXX Performance index and standard test method of absorption solvent performance for CO_2 capture

Transportation

ISO 27913 Pipeline transportation systems [proposed for revision]

ISO/TR XXXX CO_2 shipping and trans-shipping

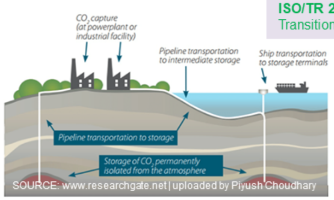
Underground storage

ISO 27914 Geological storage [proposed for revision to include quantification and verification]

ISO 27916 CO_2 storage using enhanced oil recovery (CO_2-EOR)

ISO/TR 27923 Geologic storage of CO_2 injection operations and infrastructure

ISO/TR 27926 CO_2-EOR - Transitioning from EOR to storage



Key
Black: Published document
Green: Document under preparation
Grey: New proposed project
Red: Project cancelled

Status: June 2021

Overarching aspects

ISO 27917 Vocabulary — Cross cutting terms

ISO/TR 27925 Flow assurance

ISO/TR 27918 Lifecycle risk management for integrated CCS projects

ISO/TS 27924 Risk management for integrated CCS projects

ISO/TR 27915 Quantification and verification

ISO 27920 Quantification and verification

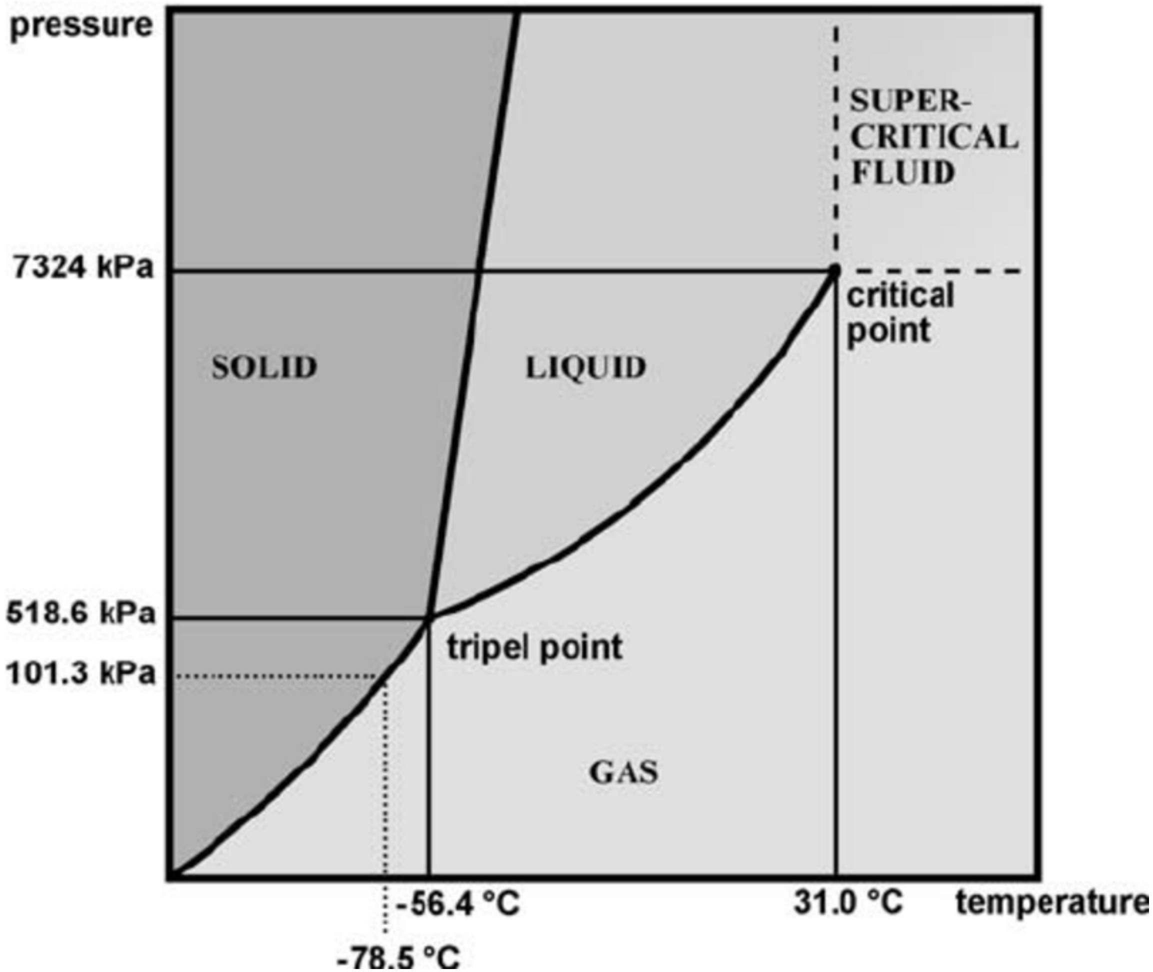
ISO/TR 27921 CO_2 stream composition

Important technical CCS matters

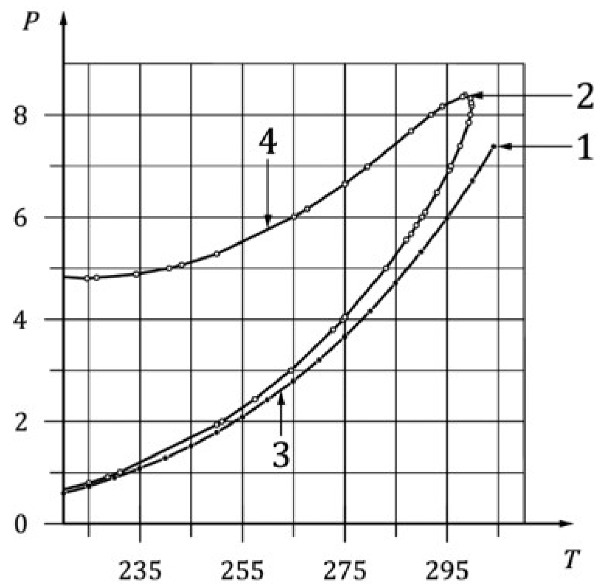
- Above all, objective is to maintain greater than 95% CCS network availability – community confidence
- Understand the underground geology and how CO_2 plume will hydrodynamically behave
- Know your CO_2 stream specification/composition and impurities
- Impurities affect phase behaviour – in turn can lead to uncontrollable corrosion during:
  - Start-ups: – incl. commissioning
  - Shut-downs: planned and unplanned
  - Depressurisation events: planned and unplanned
- Material selection and dehydration: addressing corrosion risks – don't forget what happened at Gorgon!

Source: Experience and ISO/TR 27925

Pure CO2 Phase Behaviour



Effects of impurities on fluid properties



Key

P pressure (MPa)

T temperature (K)

1 critical point of CO_2

2 critical point of a mixture of 94 % CO_2 and 6 % N_2

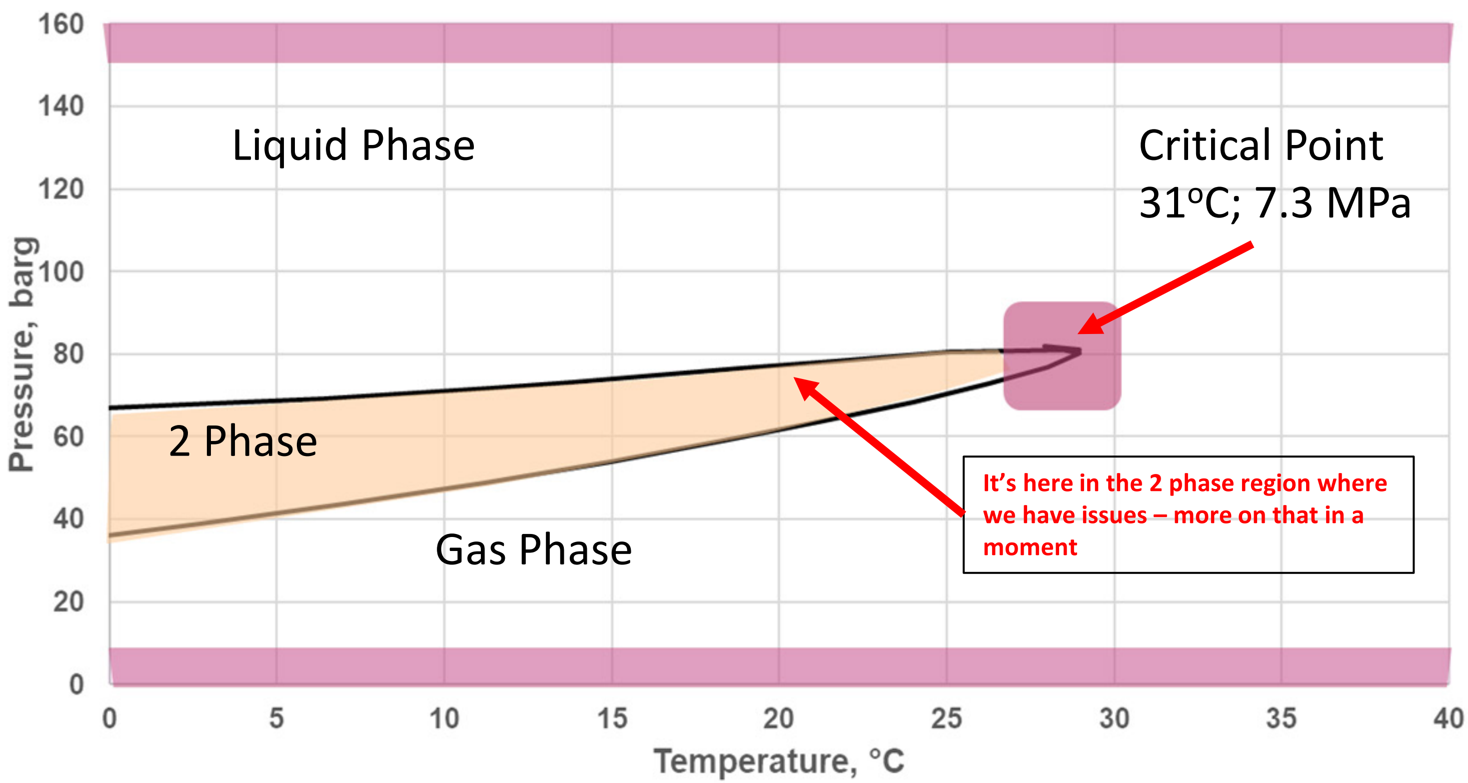
3 liquid-gas phase boundary for pure CO_2

4 boundary of liquid-gas coexistence field for CO_2 and N_2 mixture

Figure 4 — Example of a phase diagram for pure CO_2 and a mixture with 6 mol % of N_2

Source: ISO/TR 27925

Multi-phase Operation Envelope



Source: PACE CCS

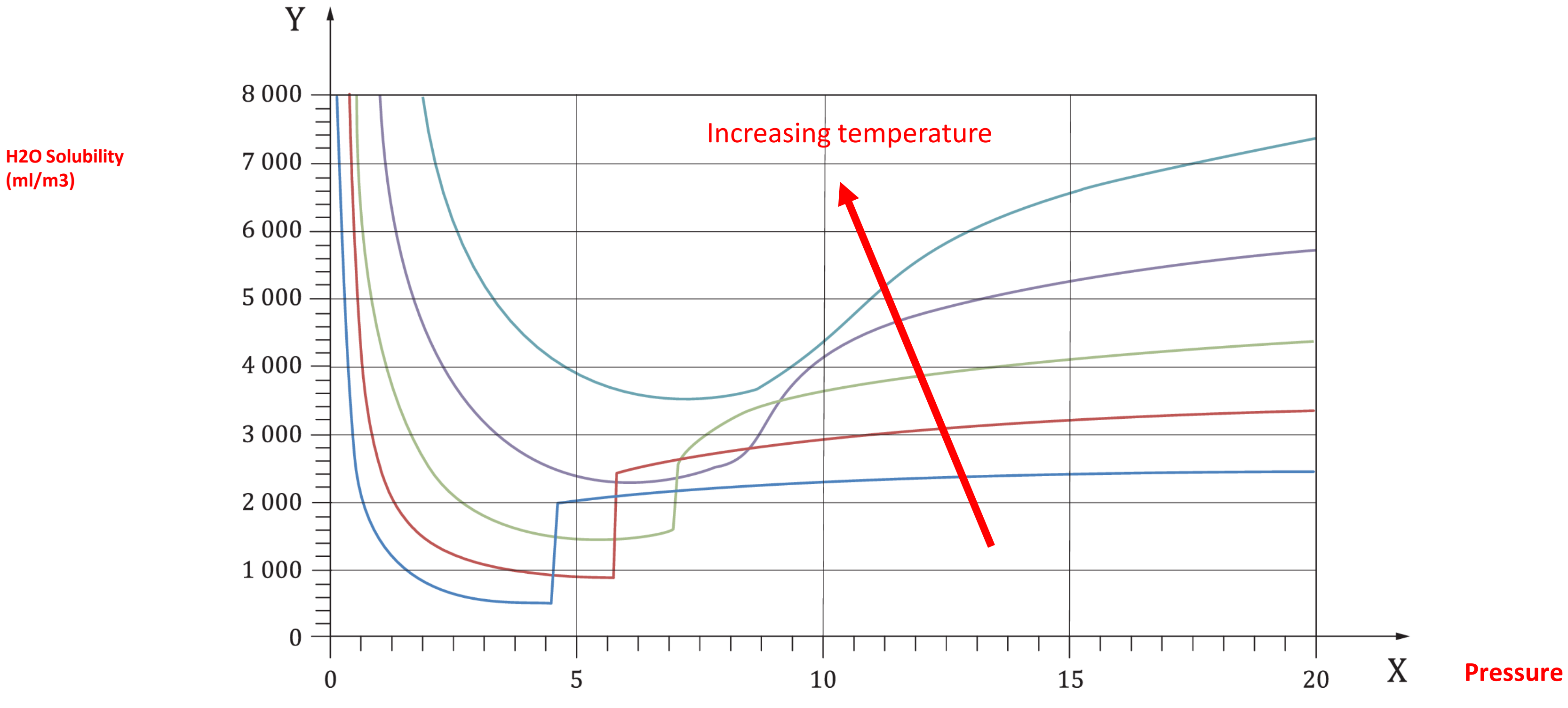
Effects of impurities on fluid properties

Typical impurities – dependent on source:

- Water
- Nitrogen
- Hydrogen
- Oxygen
- Carbon Monoxide
- Methane/Ethane
- Propane + hydrocarbons
- Sulphur oxides and hydrogen sulphide
- Ammonia and Amines
- Methanol
- Glycol (TEG)
- Volatile Organic Compounds

Source: ISO/TR 27925

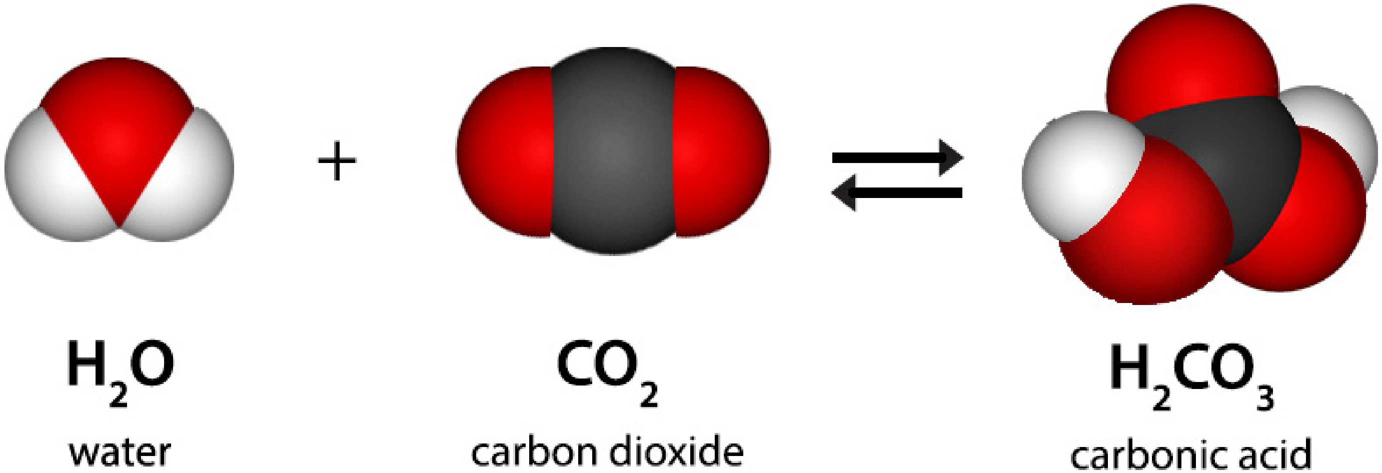
Need to avoid formation of corrosive aqueous phases – keep H_2O below solubility threshold



Source: Oosterkamp A., Ramsen J. (2008). "State-of-the-art overview of CO2 pipeline transport with relevance to offshore pipelines (Open report)", Report no. POL-O-2007-138-A, 2008, Polytec

Why do we worry above free water?

Presence of gas phase, water is no longer soluble in the CO_2 stream and:



Carbon steel plus carbonic acid = corrosion

Impurity specifications over time:

Component	Dynamis 2008[29] ml/m³	NETL (for design) 2013[30] ml/m³	CarbonNet project 2016[31] ml/m³	Goldeneye/ Peterhead 2014 (2016)[33] ml/m³	Northern lights 2019[34] ml/m³
H_2O	500	500	100	50	30
H_2S	200	100	100	0,5	9
CO	2 000	35	900 to 5 000	10	100
O_2	<40 000	10	20 000 to 50 000	1 (5)	10
SO_x	100	100	250 to 2 500	10	10
NO_x	100	100	200 to 2 000	10	10

Key

NETL: National Energy Technology Laboratory

Lessons learnt over time →

Source: ISO/TR 27925

Latest Impurity specification – 2023:

Table A.1 — Example of a gaseous phase CO_2 stream specification that will meet the requirements of 6.7.2

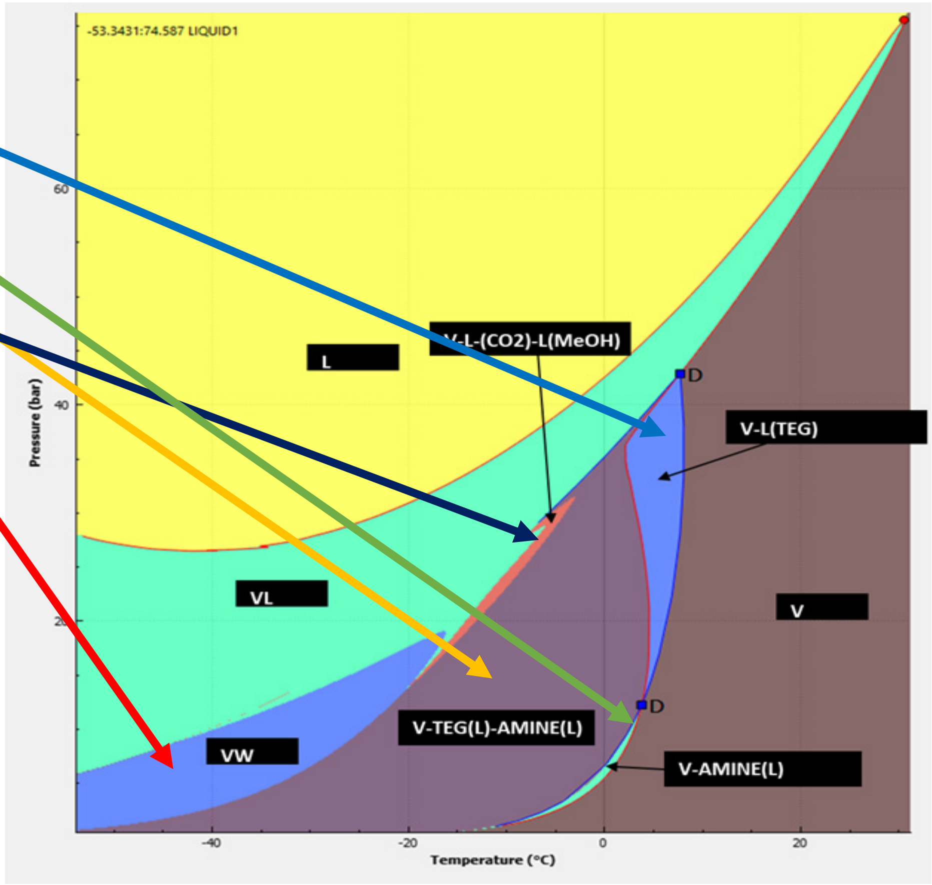
COMPONENT	HAZARD(S) IN A CCS CONTEXT	UNITS	LIMIT
CO_2	Asphyxiation at higher concentrations	mol%	≥ 95,0
N_2[a]	Occupies pipeline capacity	mol%	4,0
H_2[a,b]	Occupies pipeline capacity	mol%	1,0
Ar[a]	Occupies store pore space inefficiently	mol%	4,0
CO[a]	Health and Safety: Toxic gas	mol%	0,2
Methane[a]	Occupies store pore space inefficiently	mol%	4,0
Ethane[a]	Occupies store pore space inefficiently	mol%	4,0
Propane & Other Ali-phatic Hydrocarbons[c]	Liquid drop-out is possible	mol%	0,15 in total
H_2O	Enables corrosion of carbon steel	ppm mol	50
O_2[b,d]	Enables oxidation of carbon steel Enhances bacterial growth in storage strata	ppm mol	10
NOx (NO, NO_2)[e]	Degradation of store caprock Takes place in the production of nitric and sulfuric acid	ppm mol	10
SOx (SO, SO_2, SO_3)[f]	Degradation of store caprock Reactions with NO_2 can produce sulfuric acid	ppm mol	10
H_2S[g]	Health and Safety: Toxic gas with foul odour	ppm mol	5
COS	Health and Safety: Toxic gas with foul odour	ppm mol	100
CS_2	Health and Safety: Toxic gas with foul odour	ppm mol	20
NH_3	Can react to form solid ammonium salts	ppm mol	10
BTEX[h]	Health and Safety: Toxic	ppm mol	15 in total
Methanol	Can introduce a liquid corrosive phase	ppm mol	350
Solid Particulates[i,j]	Can reduce store permeability Damage to compressor components	mg/Nm^3	1 in total

Source: ISO 27913 – CO_2 Pipeline Standard Annex 1

Importance of understanding phase behaviour

There are five different aqueous possibly present in typical CCS fluids:

- Water-rich (corrosive)
- Glycol-rich (corrosivity varies)
- Amine-rich (corrosivity varies)
- Glycol-amine (non-corrosive)
- Methanol-CO2 (non-corrosive)



Source: PACE CCS

Case Study: Gorgon Australia

Highlights:

- 4 MTPA CO_2 injection rate
- Two-year delay in start-up due to corrosion in downstream capture equipment, pipeline and well
- 8 MT CO_2 vented
- Unknown costs

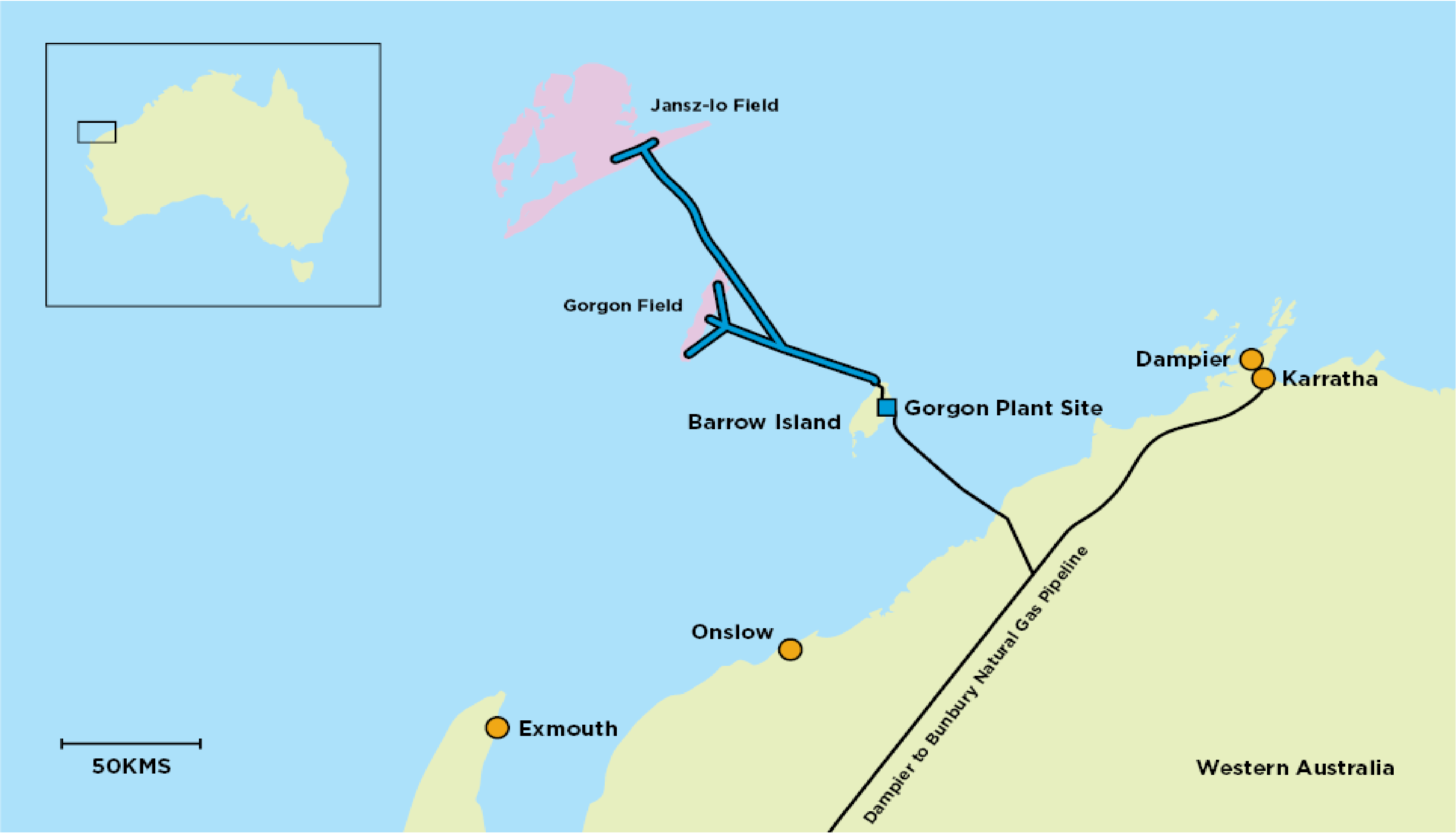
Why did it happen:

- Failure to understand CO_2 thermodynamics
- Failure to consider CO_2 corrosion risk
- CAPEX and OPEX over integrity management

➢ **We want to learn from incidents!**

Source: adapted from PACE CCS

Gorgon Case Study



Background

- Gorgon is an LNG project, with high CO_2 in the gas stream.
- The LNG and CO_2 capture are on Barrow Island, with lots of depleted oil wells. Oil production started in the early 1960s.
- CO_2 is captured and injected into nearby onshore wells.
- The LNG plant and the CCS plant commissioned and started up at the same time.

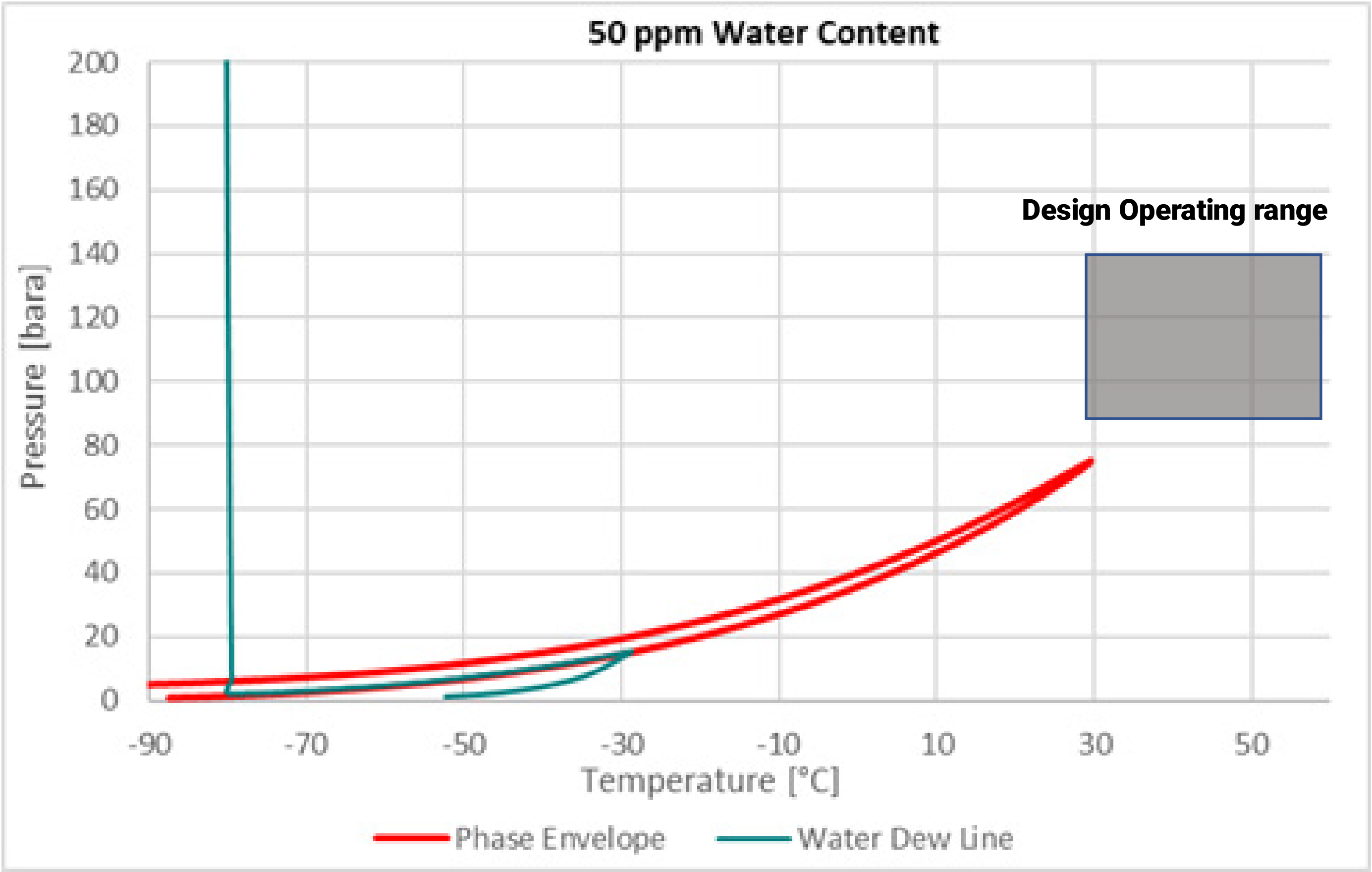
Background

Capture plant technology:

- Amine unit to remove CO_2 from the hydrocarbon stream
- Initial design and FEED included TEG unit to dehydrate the CO_2
- Compressor to put the CO_2 into the dense phase
- No significant impurities other than water.
- Design basis CO_2 stream specification:

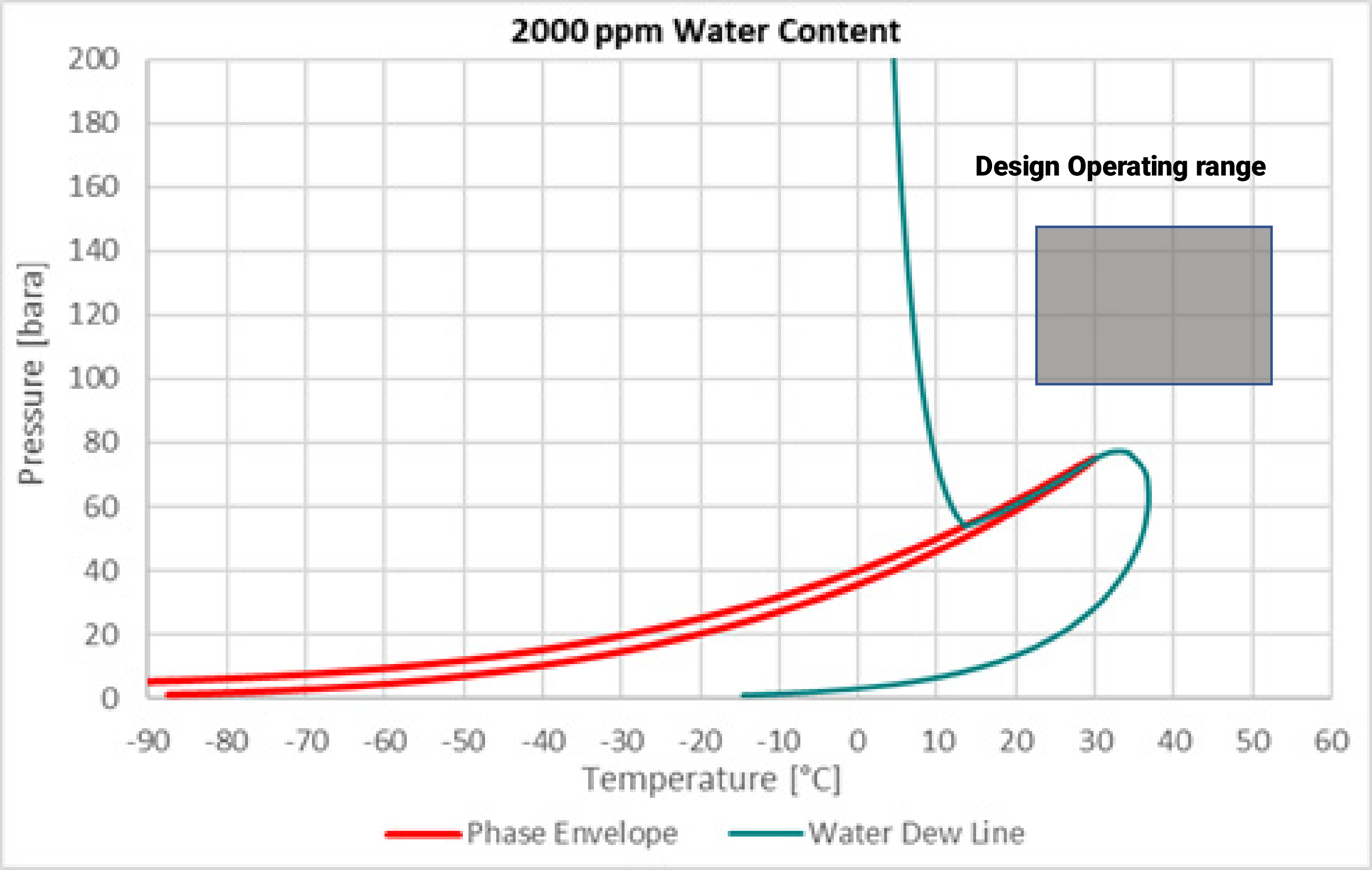
CO2	98.00%
methane	1.57%
ethane	0.13%
propane	0.04%
butane	0.02%
N2	
H2O	50 ppm

Design Basis water dewpoint at 50 ppm water in gas stream



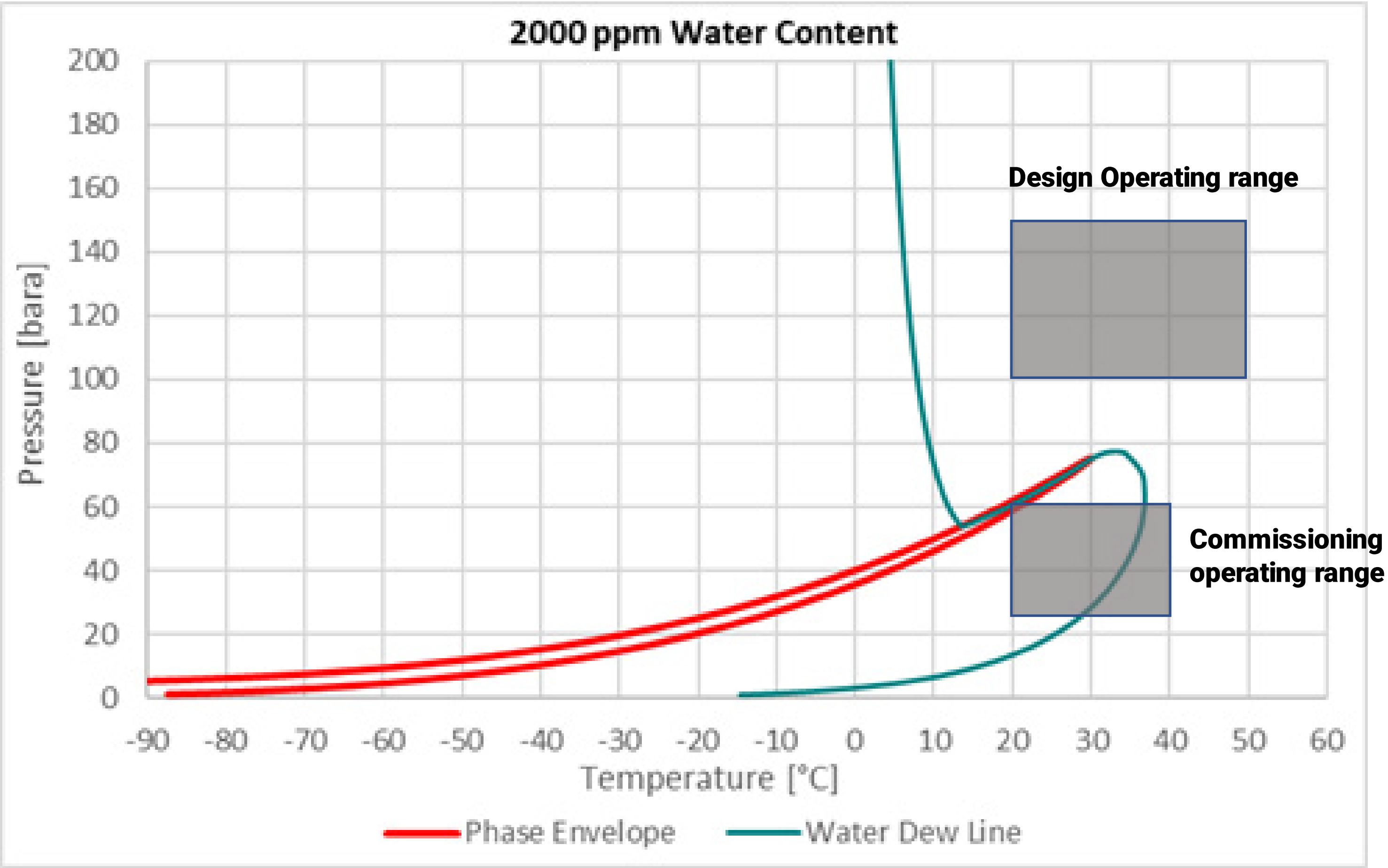
Source: PACE CCS

Water dewpoint at 2000 ppm water in gas stream – post construction without TEG dehydration unit



Source: PACE CCS

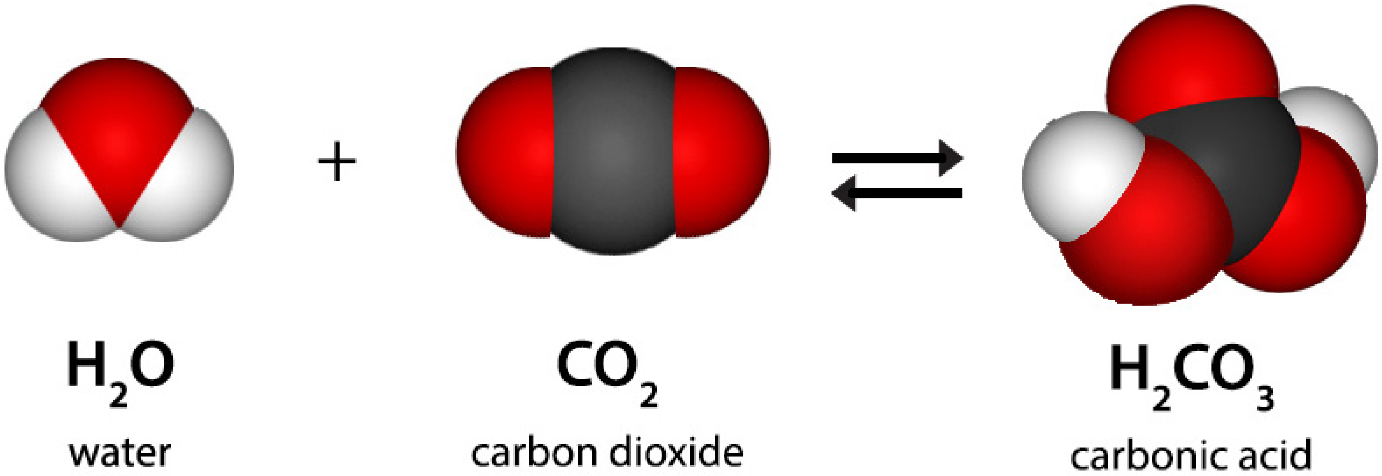
Water dewpoint at 2000 ppm water in gas stream – commissioning without TEG dehydration unit



Source: PACE CCS

Why do we worry about free water?

Presence of gas phase, water is no longer soluble in the CO_2 stream and:



Carbon steel plus carbonic acid = corrosion

i.e. Actual corrosion rates > 10 mm/year versus Planned corrosion < 0.1 mm in 25 years

Background – causes

- After engineering was complete, Chevron held a value engineering session to identify last-minute savings and improvements.

- The conclusion: it looks like dehydration isn't required! The CO_2 coming out of the amine unit is dry enough to prevent condensation at expected operating conditions – see above phase diagram.

- This conclusion was challenged by the engineering team responsible for the design - but over-ruled – did management understand the threat of high water content?

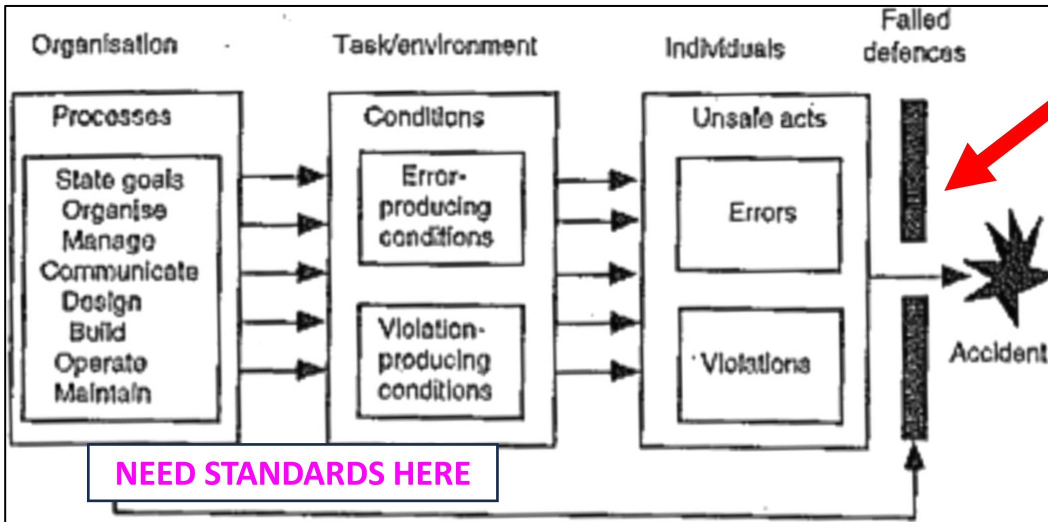
- The Gorgon team removed the TEG dehydration unit, saving CAPEX and OPEX.

Source: PACE CCS

A classic James Reason Swiss Cheese Model example

"WHY" things Happen

"HOW" things Happen



Example of such defences: SRV's, trip switches, safety XV valves, wall thickness, maintain safe operating conditions – in this case H_2O ppm (BCPS/SIIS), bunds etc.

"WHAT" Happens

Example of such organisational and systemic conditions include: poor training; poorly written or deficient procedures; poor design; poor construction or commissioning practices; lack of appropriate competencies and training; communication failures; fatigued workers; lack of supervision; inadequate monitoring and maintenance; poor hazard awareness; timeline pressures; cost pressures etc.

Examples of such unsafe acts include failures to: - follow correct procedures; carry out test of SCE; maintain equipment; respond to alarms; check process is not deviating outside safe operating envelope; conform to PTW, undertake MOC.

Important points to understand if pursuing CCS:

- CO_2 stream composition – what impurities are present
- Effects of these impurities, pressure and temperature on phase behaviour
- Change in phase of CO_2 resulting from pressure and temperature variations due to:
  - Start-ups: – incl. commissioning
  - Shut-downs: planned and unplanned
  - Depressurisation events: planned and unplanned
- CAPEX/OPEX vs integrity

Contacts

Michael Malavazos

Department for Energy and Mining

11 Waymouth Street,
Adelaide, South Australia 5000
GPO Box 320
Adelaide, South Australia 5001
T: +61 8 8463 3000
E: demreception@sa.gov.au

SOUTH AUSTRALIA

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