Unlocking fair CO_2 trade in CCS:
lessons learned in fiscal metering and thermophysical properties

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SINTEF Energi
NFOGM fagdag, March 2024

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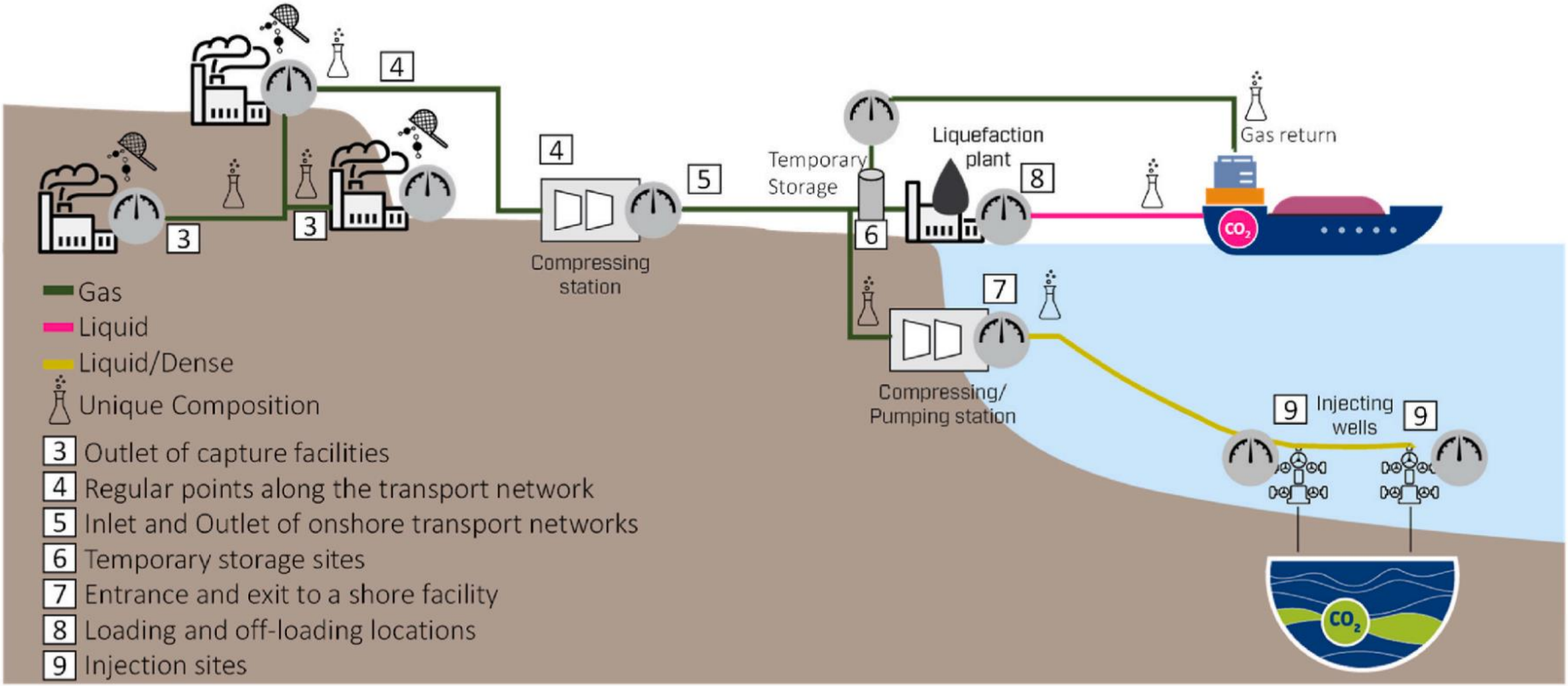
Content

- Challenges
- Contributions to the solution
  - NCCS
  - Task 8: Fiscal Metering and thermophysical properties
    - Experimental Facilities (ECCSEL +)
    - Fiscal Metering
    - Thermophysical Properties

Challenges


4
4
5
3
3
Compressing
station
Temporary
Storage
6
Liquefaction
plant
8
Gas return
CO2
7
Compressing/
Pumping station
9
Injecting
wells
9
CO2
Gas
Liquid
Liquid/Dense
Unique Composition
3 Outlet of capture facilities
4 Regular points along the transport network
5 Inlet and Outlet of onshore transport networks
6 Temporary storage sites
7 Entrance and exit to a shore facility
8 Loading and off-loading locations
9 Injection sites

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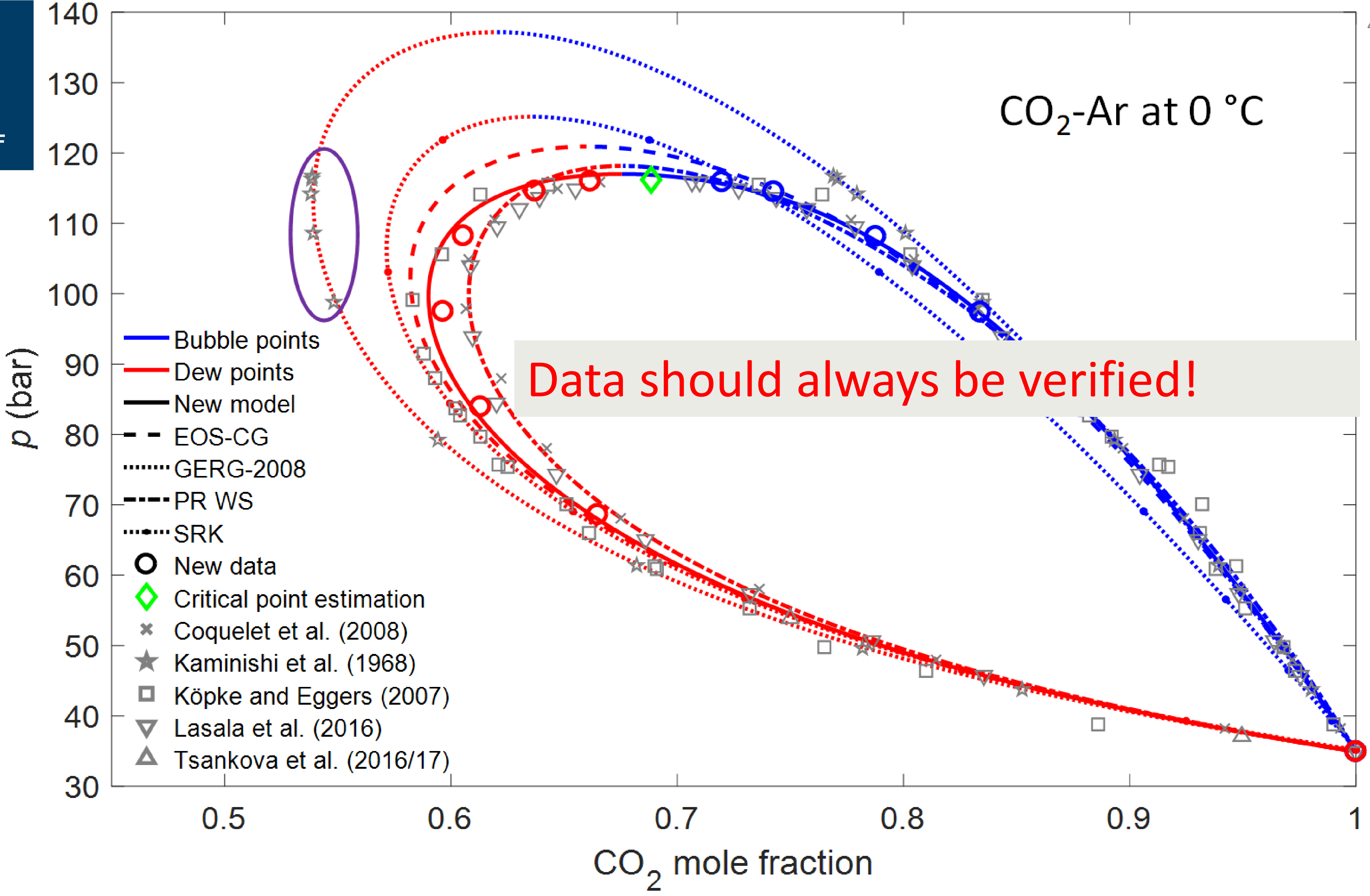
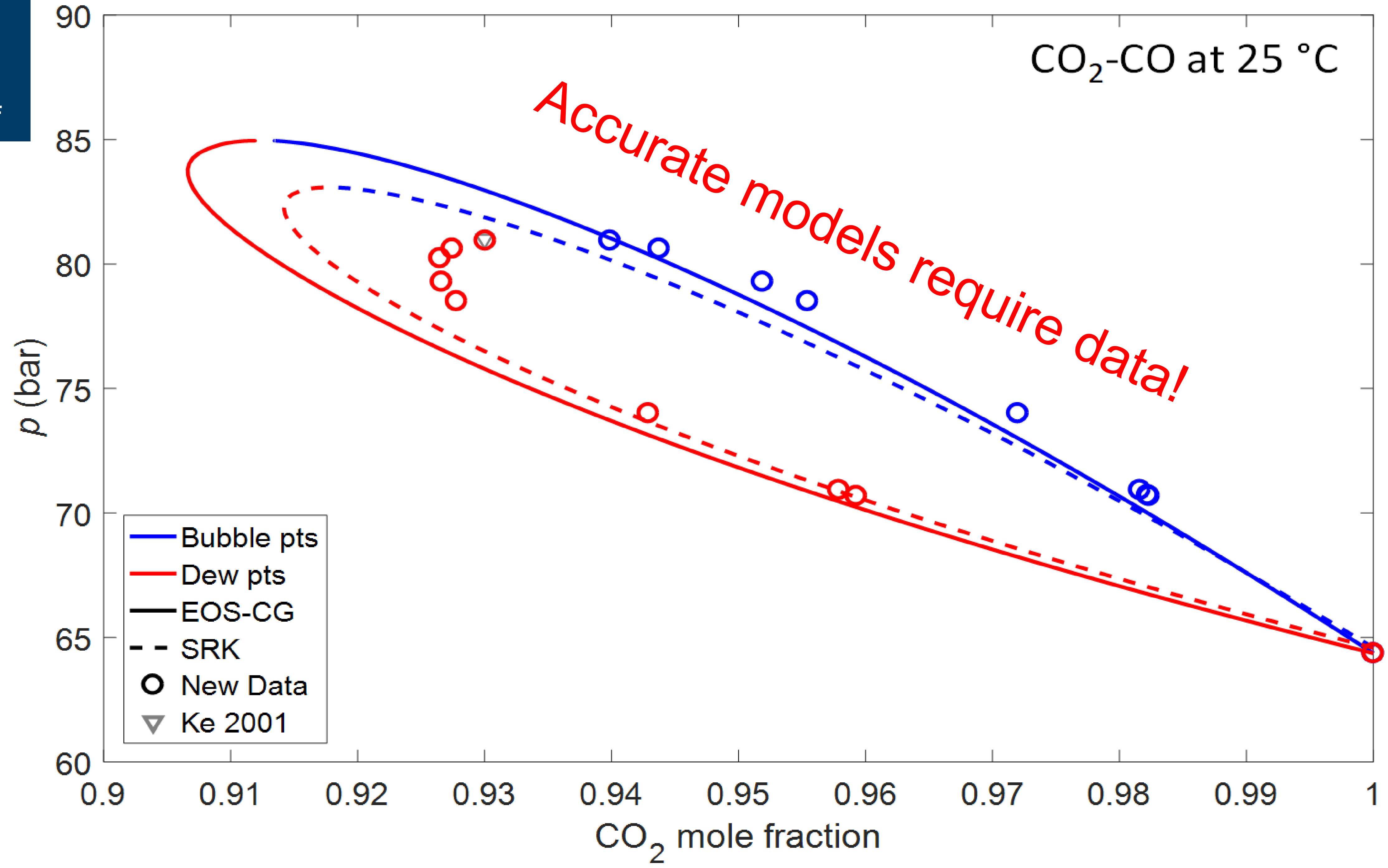
CO_2-Ar VLE



Data should always be verified!

CO_2-CO VLE

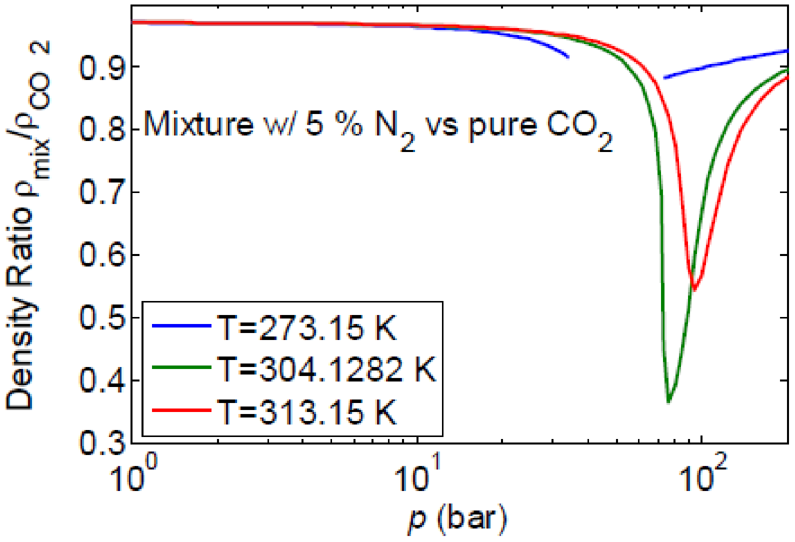


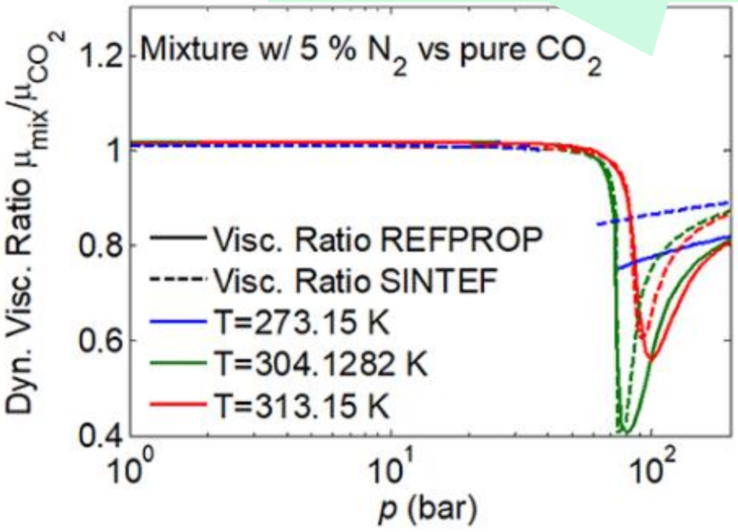
CO2-CO at 25 °C
Accurate models require data!
p (bar)
90
85
80
75
70
65
60
0.9
0.91
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1
CO2 mole fraction
Bubble pts
Dew pts
EOS-CG
SRK
New Data
Ke 2001

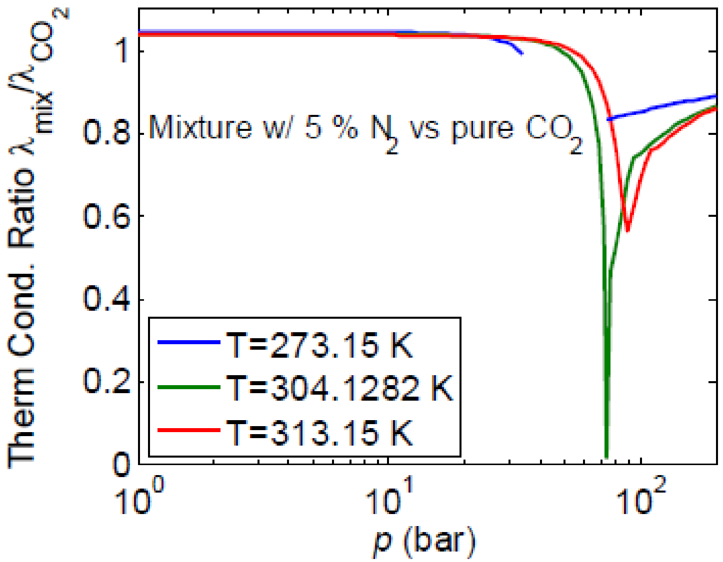
Challenges

(2019) For CO2 mixtures “there is very little data for liquid viscosity and none for thermal conductivity”

Poor data → different models may produce very different predictions







Estimated density, dynamic viscosity and thermal conductivity of carbon dioxide mixed with 5 % nitrogen

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Why we do what we do

- Small amount of impurity can greatly influence the thermophysical properties of CCS streams for typical operating conditions
- Viscosity data is relevant for flow through small pores (reservoirs and capture processes)
- Thermal conductivity is important for injection of cold liquid CO_2 into reservoirs and ship design
- Viscosity and thermal conductivity are key for the performance of heat exchangers, pressure drop in solvent columns, adsorption and membrane processes.
- Density measurements can be a source of added uncertainty in custody transfer (EoS-metering)
- Verified and traceable fiscal meters ensure fair trade and CCS business case

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NCCS Task 8

- **Fiscal Metering**
  - Traceability chain
  - Technology uptake
- **Thermophysical properties**
  - Phase equilibrium measurements
  - EoS development and validation
  - Accurate Viscosity/Density measurement

users

TOTAL
wintershall dea
Oslo
GASSCO
vår energi
fortum
equinor
Lundin Norway
NORCEM HEIDELBERGCEMENT Group

research institutes

NGI
TNO
BGS 1835
NIST National Institute of Standards and Technology
SINTEF
Lawrence Livermore National Laboratory

universities

NTNU
THE UNIVERSITY OF WESTERN AUSTRALIA
UiO: University of Oslo
RUHR UNIVERSITÄT BOCHUM
RUB
UNIS
MIT
TUM
University of Zurich[UZH]

- CO_2 value chain and legal aspects
- Solvent technology – environmental issues
- Low emission H_2 production
- Conditioning through liquefaction
- Gas turbines
- CO_2 capture process integration
- CO_2 transport
- **Fiscal metering and thermodynamics**
- Structural derisking
- CO_2 storage site containment
- Reservoir management and EOR
- Cost-efficient CO_2 monitoring technology

associated partners

eccsel
Norges Rederiforbund Norwegian Shipowners' Association
NORCE
Norsk olje&gass
U.S. DEPARTMENT OF ENERGY
UKCCS RESEARCH CENTRE

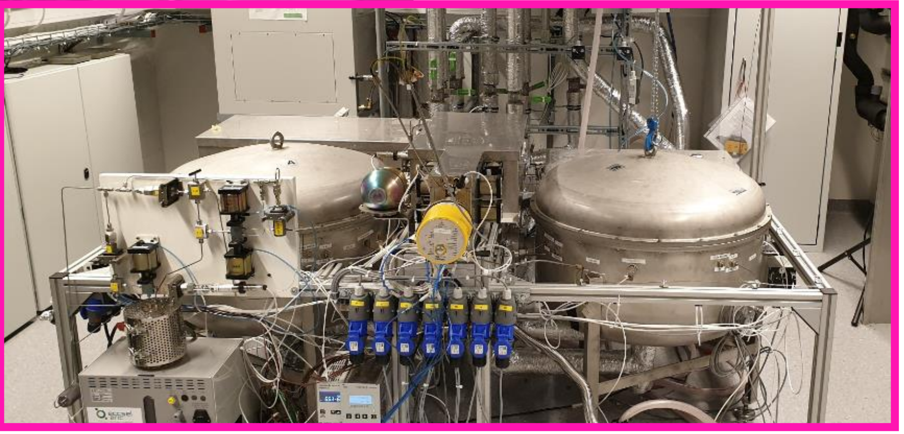
vendors

STRATUM RESERVOIR
AKER CARBON CAPTURE
ANSALDO ENERGIA
allton
KROHNE
LarvikShipping
Baker Hughes
COORSTEK
QUAD GEOMETRICS

Experimental Facilities

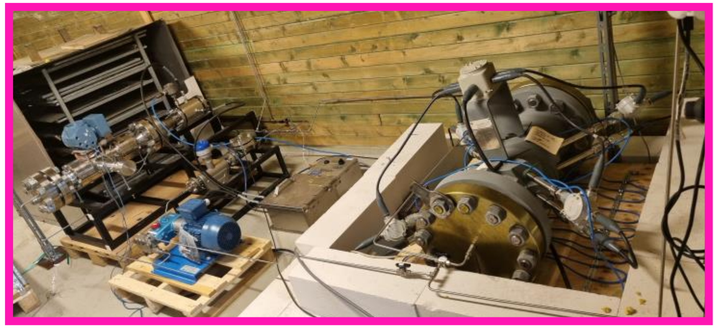
CO_2Mix

- Operating work-horse
- < 200 bar, -60 to 200 °C
- Fluid phase + solids + toxic
- Mixture prepartion (ppm accuracy)



Visc-Dens

- < 800 bar, -60 to 150 °C
- Liquid, gas
- Pure fluids & mixtures



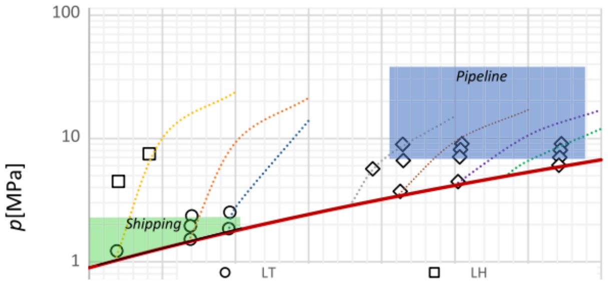
FloMet *

- < 100 bar, -40 to 25 °C
- Liquid or gas
- Pure fluids & mixtures

*not part of ECCSEL

Built by NCCS + Spin-ins

Technology Uptake
Fiscal Metering (ultrasonic meter)



As the density of the liquid CO_2 decreased, approaching that of gas, the signal degraded significantly

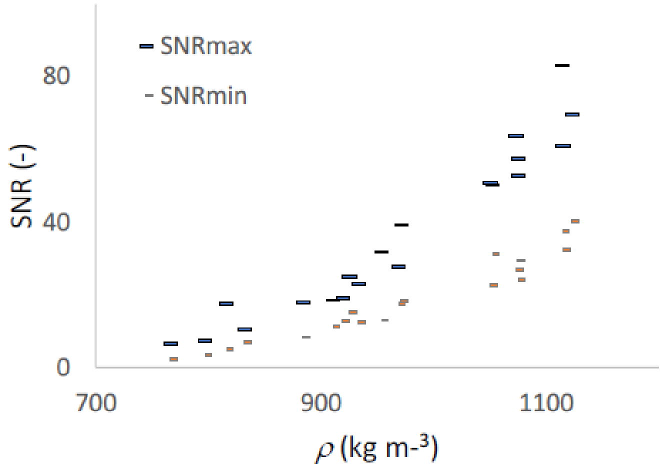


Fig. 5 – Maximum and minimum signal-to-noise (SNR) for all test points

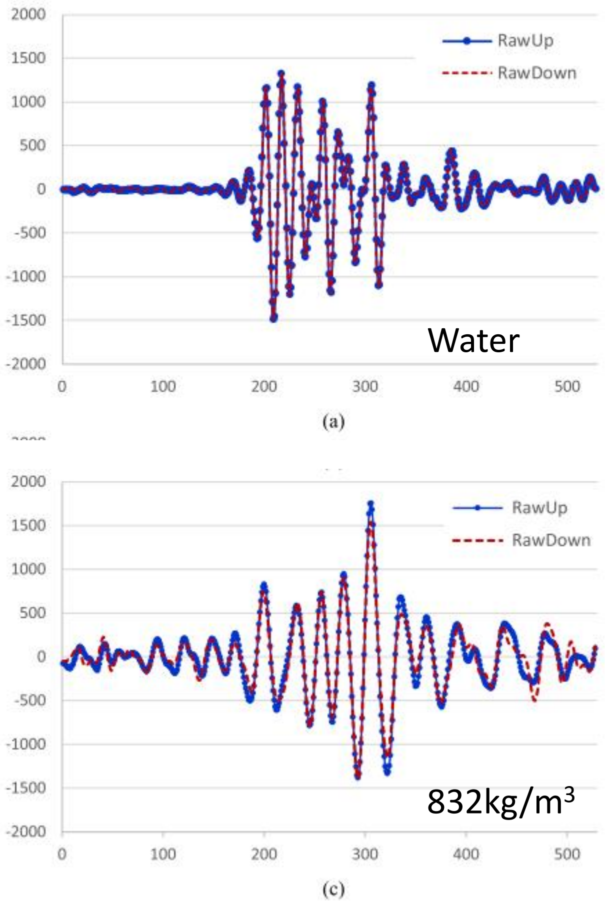
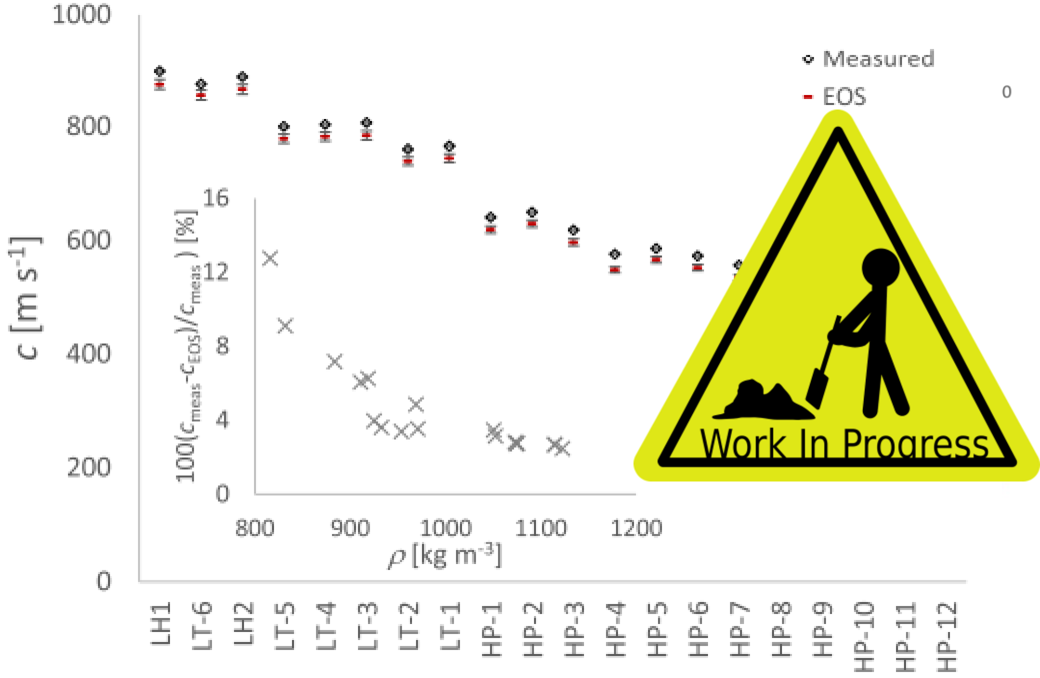
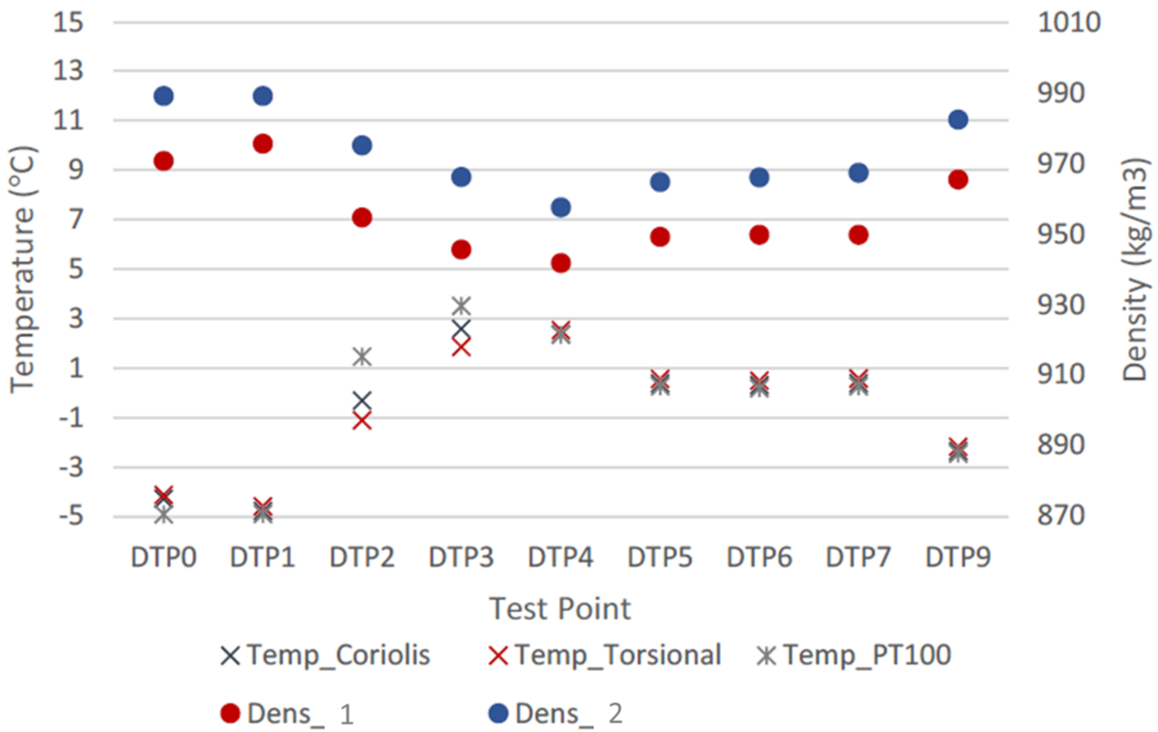


Fig. 10. Channel 3 Raw signals from transducers showing upstream and downstream through transmission signals from (a) static water calibration SNR of 51.2, (b) test point LH-2 SNR of 45.9, and (c) test point HP-9 with SNR of 8.1.



Technology uptake
Fiscal Metering (density meters)

Parameter	Meter 1	Meter 2
Density Range	0-1500 kg/m3	0-1200 kg/m3
Accuracy	1 kg/m3	1 kg/m3
Repeatability	0.1 kg/m3	0.3 kg/m3
Pressure	Up to 200 barg	Up to 100 barg
Temperature	233 – 395 K	203 - 503 K



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Traceability

- Fiscal metering facility

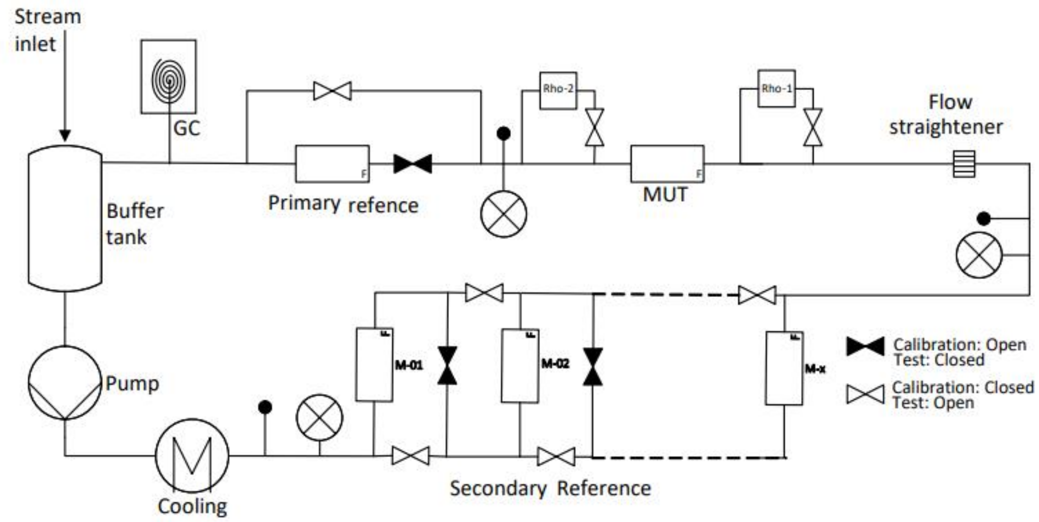

Figure 2: Schematic of an experimental facility for CO_2 metering

Feed study completed

Trondheim CCS Conference
CO_2 Capture, Transport and Storage

TCCS-11 - Trondheim Conference on CO_2 Capture, Transport and Storage
Trondheim, Norway - June 21-23, 2021

ENABLING CCS VIA FISCAL METERING

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[3] Baker Hughes, Billerica, Massa

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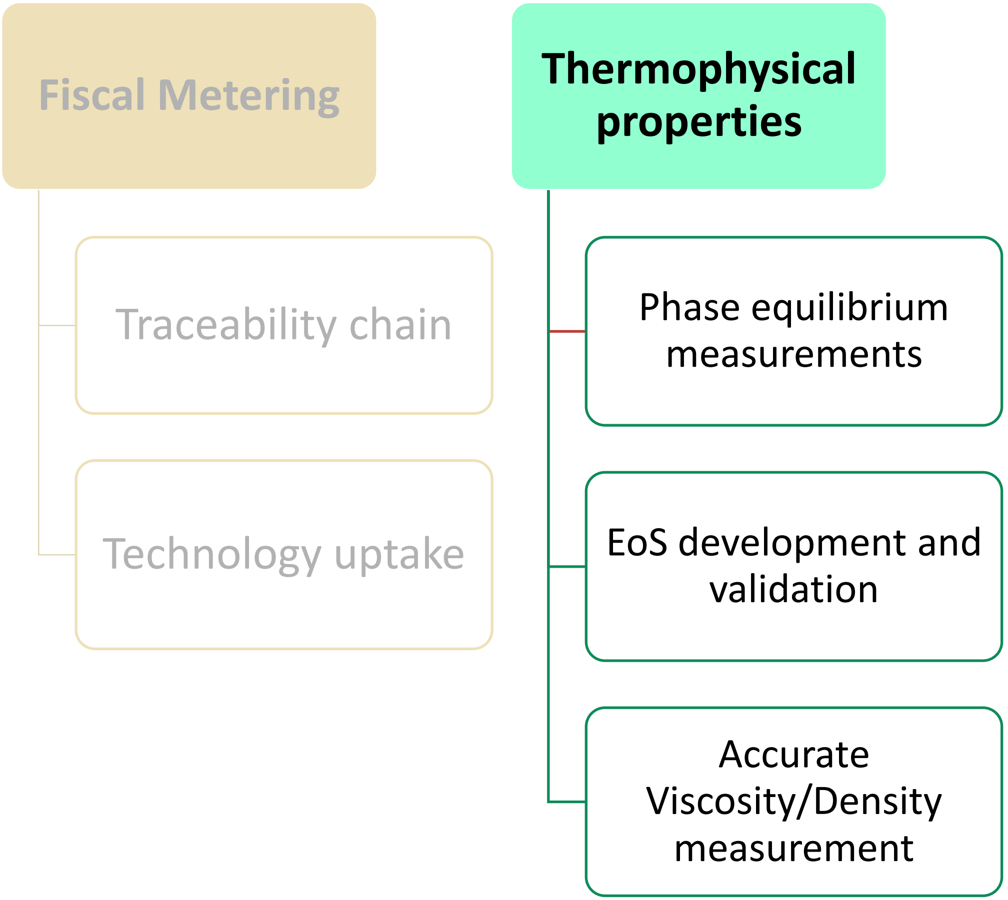
Table 2: Specifications for CO_2 fiscal meter test facility

Parameter	Specification
Mass flow accuracy	0.25 %
Volumetric flow accuracy	0.25 %
Accuracy in density	1.2 kg/m3
Max flow rate (t/h)	600
Min flow rate (t/h)	50
Max flow (m3/h)	800
Phase state	Liquid / dense phase
Pressure (bara)[a]	Up to 120
Process temperature (°C)	4 to 40
Ambient temperature (°C)	-20 to 25
Composition range (mole fractions)	
CO_2	$\geq$75 mol%
N_2	$\leq$ 25 mol%
Ar	$\leq$ 25 mol%
H_2 (TBC)	$\leq$ 10 mol%
CH_4 (TBC)	$\leq$ 23 mol%
H_2O	$\leq$ 350 ppm
O_2	$\leq$ 10 ppm
H_2S	0
CO[b]	-
SOx[b]	-
NOx[b]	-
Amines	0
Reference fluids	Pure water
Meter pressure drop (bar)	< 2
Test section length	20 m
Development length (upstream / downstream meter)	15 m /4 m
Pipe dimension (inches)	10

Traceability

- Primary flow Reference for CCS - PREFERENCE
- A novel primary reference targeting liquid CO_2 flow meter calibration for large flow rates has already been designed NCCS
- PREFERENCE aims to progress CO_2 metrology by experimentally testing a primary reference prototype designed to overcome the challenges of liquid and dense phase CO_2 calibration.
- PREFERENCE will optimise and experimentally verify the functionality of a novel primary flow reference prototype.
- Manufacturing underway
- Commissioning and tests in 2025

NCCS Task 8


Fiscal Metering
Traceability chain
Technology uptake
Thermophysical properties
Phase equilibrium measurements
EoS development and validation
Accurate Viscosity/Density measurement

Data situation

CCS FMEs

		Chlorine	Hydrogen Chloride	Diethanolamine	Monoethanolamine	Methanol	Ammonia	Sulphur Trioxide	Sulphur Dioxide	Nitrogen Dioxide	Nitrogen Oxide	Hydrogen Sulfide	Methane	Hydrogen	Carbon Monoxide	Argon	Oxygen	Nitrogen	Water
Major Components	Carbon Dioxide	x	x	o	o	x	x		x	x	x	x	▲	x	▲	▲	▲	▲	▲
	Water	o	x	x	x	x	x	x	x	o	o	x	x	x					
	Nitrogen	o	o	o	o	x	x		x	o	x	x	x	x					
	Oxygen	o	o	o	o	x	o		x	o	o	o	x	x					
	Argon	o	o	o	o	x	x		x	o	o	o	x	x					
	Carbon Monoxide	o	o	o	o	x	x		o	o	o	x	x	x					
	Hydrogen	o	o	o	x	x	x		x	o	o	x	x						
	Methane	o	o	o	o	x	x		x	o	o	x							
Minor Components	Hydrogen Sulfide	o	o	o	o	x	o		o	o	o								
	Nitrogen Oxide	o	o	o	o	o	o		o	o									
	Nitrogen Dioxide	o	o	o	o	o	o		o										
	Sulphur Dioxide	x	x	x	o	x	o	x											
	Sulphur Trioxide																		
	Ammonia	o	o	o	x	x													
	Methanol	o	x	x	x														
	Monoethanolamine	o	o	x															
	Diethanolamine	o	o																
	Hydrogen Chloride	x																	
	Chlorine																		

Thermodynamic Reference & Engineering Data

▲ SINTEF data

- Covered by EOS-CG (yellow)
- Covered by GERG-2008 / Tillner-Roth & Friend for Ammonia (green)
- Covered by new upcoming models from University of Washington and NIST (orange)
- No dedicated mixture-model available (red)
- x Data available (DDB and/or TRC)
- o No data in DDB and TRC
- Sulphur Trioxide should be rejected; database not sufficient to fit the pure fluid (grey)
- Pure Fluid Equations under development (purple)

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Phase Equilibria

RUHR UNIVERSITÄT BOCHUM RUB

NTNU

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Author	Year	Species	Property / type	Link
Y Joos, A Austegard, J Stang	2024	CO_2 -H_2O CO_2-brine	VLE	Writing up
B Betken, A Austegard, F Finotti, C Caccamo, B Khosravi, and R Span	2024	H_2-CH_4	Viscosity	In press
B Khosravi; A Austegard; J Stang; J Jakobsen	2024	CO_2	Viscosity	In press
B Khosravi; B Bedken; R Span; J Jakobsen; S Løvseth	2022	CO_2 - N_2 CO_2 - H_2	Viscosity	https://doi.org/10.1016/j.fluid.2022.113519
Kim, D; Løvseth, S; Arami-Niya, A; May, E.	2021	CO_2-N_2 CO_2-CH_4	Thermal conductivity	https://doi.org/10.1021/acs.jced.1c00270
S Ottøy, T Neumann, J Stang, J Jakobsen, A Austegard, S Løvseth	2019	CO_2-N_2-CH_4	VLE	https://doi.org/10.1016/j.fluid.2019.112444
S Løvseth, A Austegard, S Westman, J Stang, S Herrig, T Neumann, R Span	2018	CO_2-Ar	VLE	https://doi.org/10.1016/j.fluid.2018.02.009
E Petropoulou, E Voutsas, S Westman, A Austegard, J Stang, S Løvseth	2018	CO_2-CH_4	VLE	https://doi.org/10.1016/j.fluid.2018.01.011
SF Westman, A Austegard, HGJ Stang, SW Løvseth	2018	CO_2-CO	VLE	https://doi.org/10.1016/j.fluid.2018.05.006
SF Westman, HGJ Stang, SW Løvseth, A Austegard, I Snustad, I Ertesvåg	2016	CO_2-O_2	VLE	https://doi.org/10.1016/j.fluid.2016.04.002
S Westman, J Stang, S Løvseth, A Austegard, I Snustad, S Størset, I Ertesvåg	2016	CO_2-N_2	VLE	https://doi.org/10.1016/j.fluid.2015.09.034
Sigurd Weidemann Løvseth, H.G. Jacob Stang, Snorre Foss Westman, Ingrid Snustad, Anders Austegard,	2014	CO_2-N_2	VLE	https://doi.org/10.1016/j.egypro.2014.11.281

3 PhD exchanges completed

2 New PhDs planned in GigaCCS

Updated modes in TREND (RUB) + Thermopack (SINTEF)

Thermopack (git hub)

Final thought

The realisation of CCS requires:

- metrology,
- thermophysical models,
- technological innovations,
- understanding of the regulatory framework

to ensure the transfer of liability, costs and risks, and build trust between operators along the value chain.

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Teknologi for et bedre samfunn