The Transferability of Calibration between water and liquid & dense phase CO2 fiscal flow measurement

Russell Brown, TÜV SÜD National Engineering Laboratory
Gabriele Chinello, TÜV SÜD National Engineering Laboratory

Flow Measurement Focus Group, 2023-12-06

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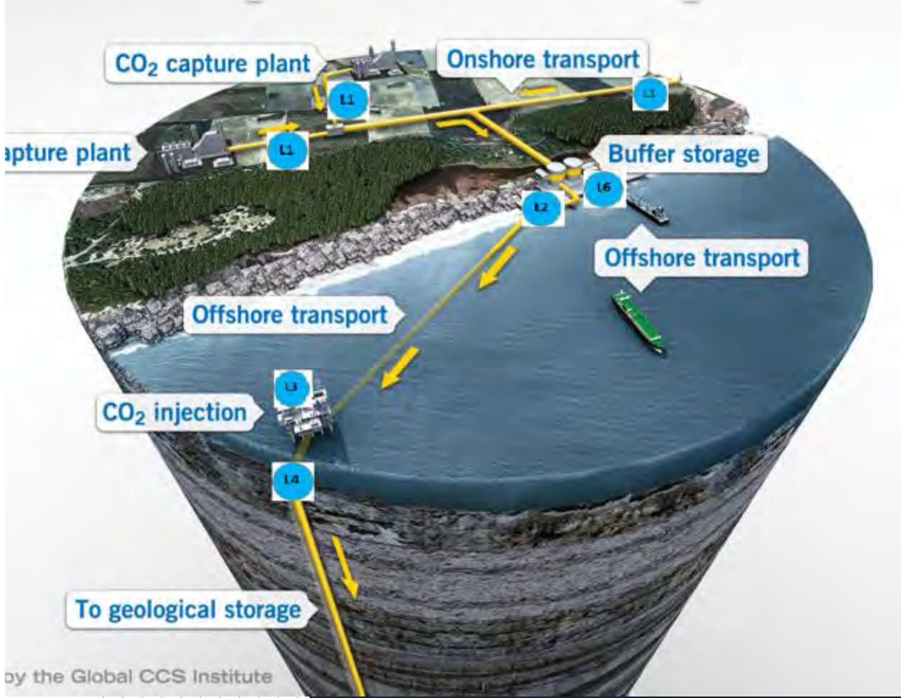
CCUS Network and Measurement



- IPCC states that CCUS is critical to reducing CO2 emissions and reaching net-zero emissions
- CCUS demand is increasing globally, with a near doubling in capture capacity in development since 2021
- CO2 will be captured in the gas phase, then compressed and transported in gaseous or dense phase to a geological storage
- It may be further cooled for shipping transport
- It is a requirement of UK and EU Emission Trading Schemes to measure CO2 flow for reporting purposes. It is also a requirement for commercial contracts (e.g. subsidy payment in the UK)

CO2 flow is now required for custody transfer, therefore needs robust flow measurement

Challenges Facing CCUS Deployment

- For the regulatory and contractual framework underpinning CCUS to be successful, robust flow measurement of liquid and dense phase CO2 is required

- This is achieved through calibration of flow meters in accredited traceable calibration facilities.

- However, there are currently no traceable flow facilities for liquid and dense phase CO2

- A possible strategy is to calibrate in water or oil and transfer the calibration

- There is currently no data available in literature to prove this is possible

Can a flow meter be calibrated in water for use in Liquid or Dense Phase CO2?

Experimental Process

Build Transfer Package

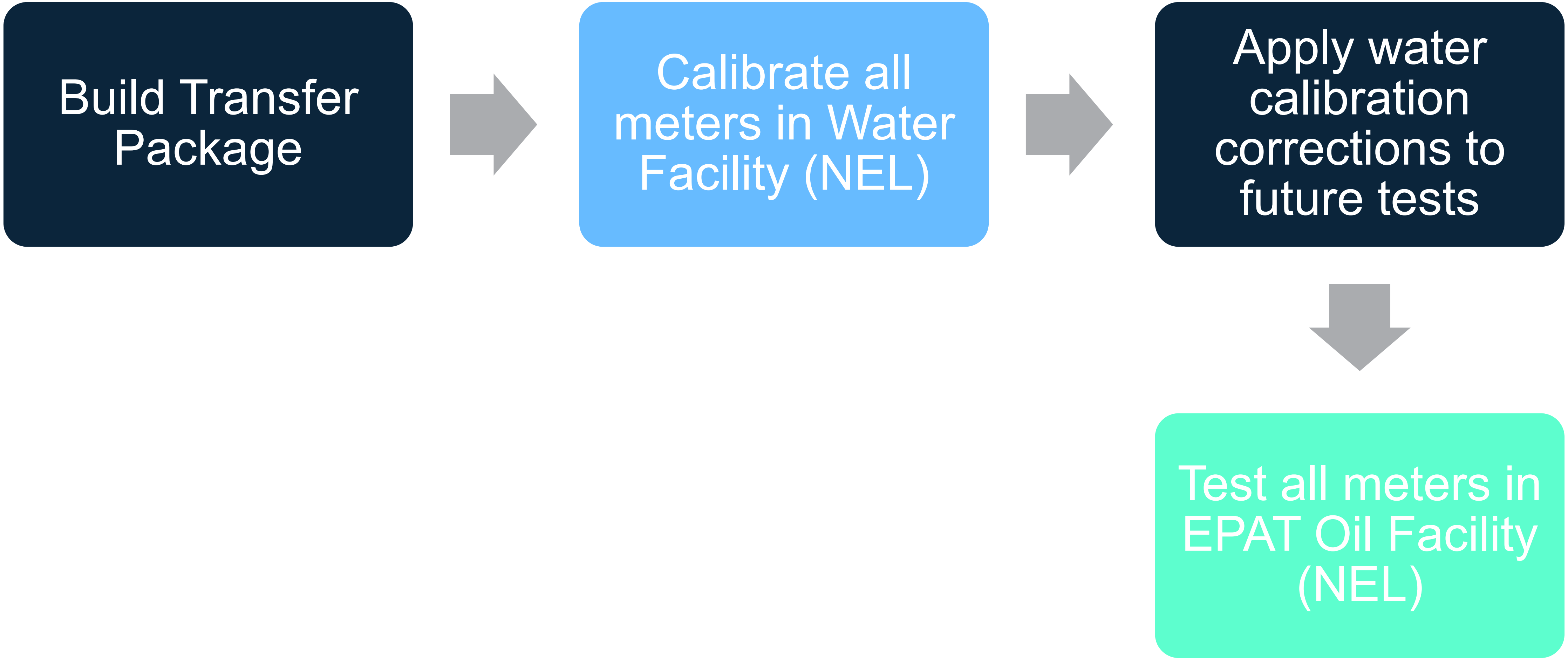
Experimental Process

Build Transfer Package → Calibrate all meters in Water Facility (NEL)

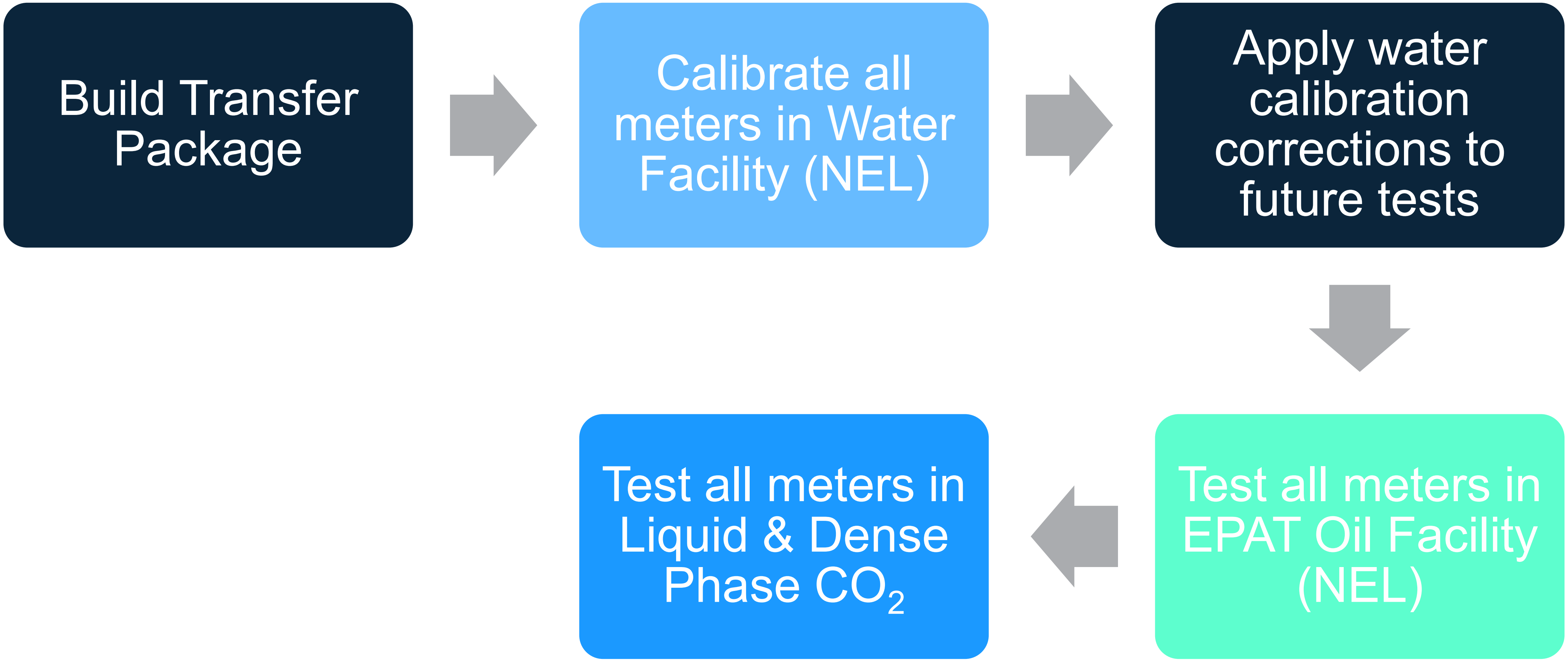
Experimental Process

Build Transfer Package → Calibrate all meters in Water Facility (NEL) → Apply water calibration corrections to future tests

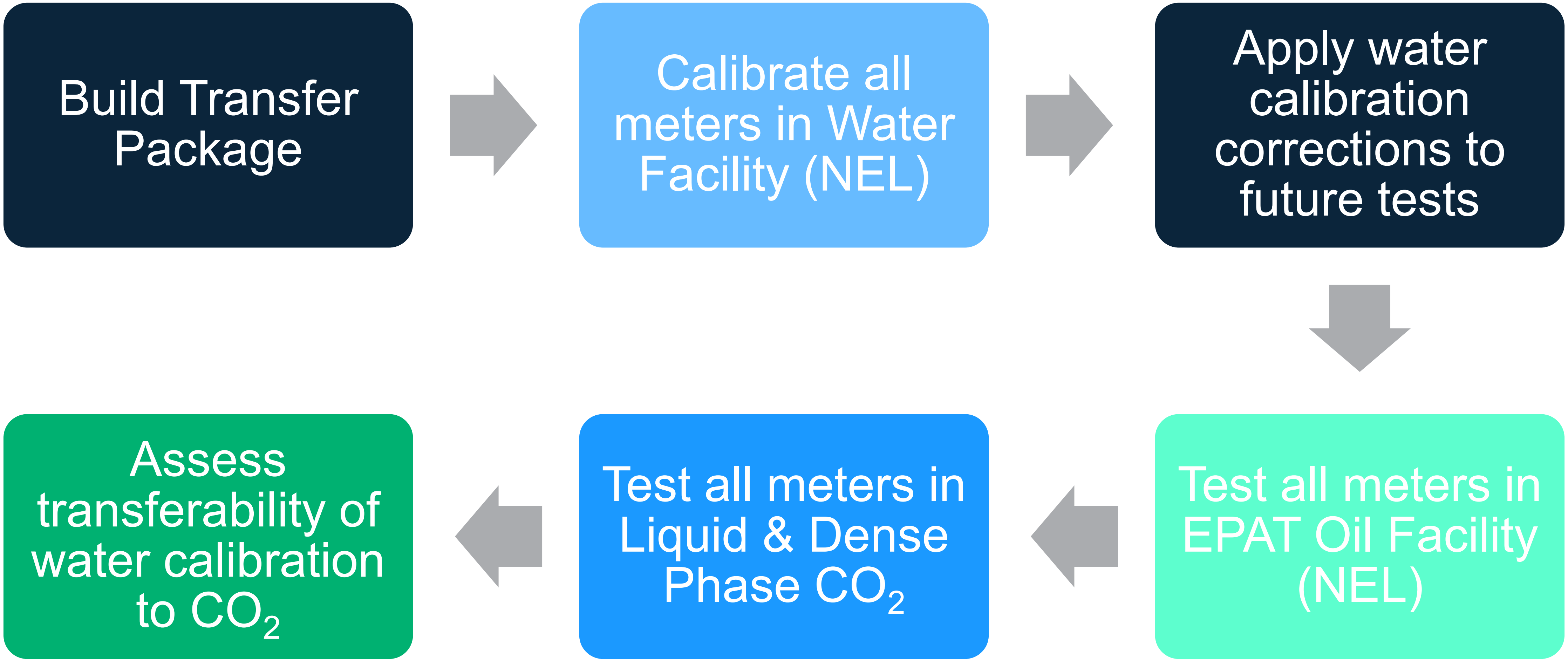
Experimental Process



Experimental Process

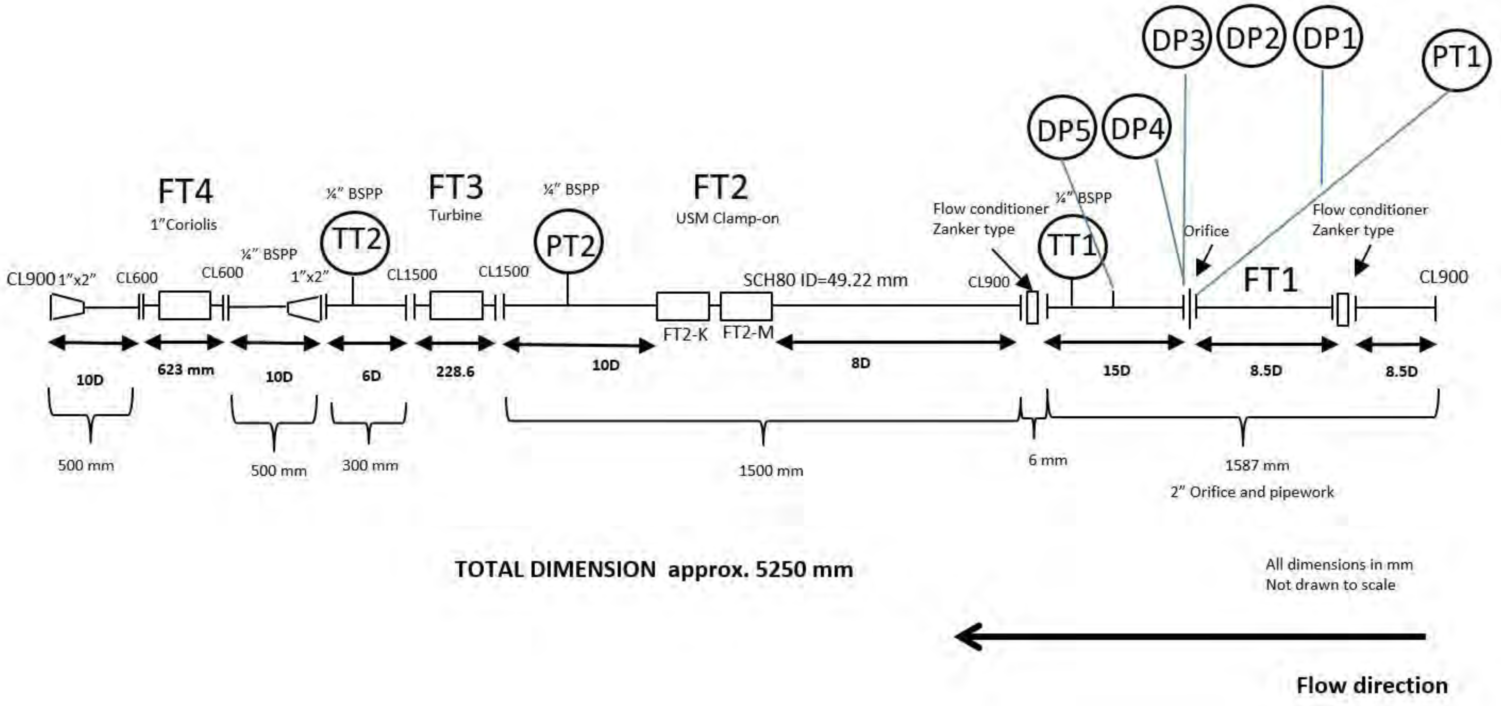


Experimental Process



Flow Meter Transfer Package

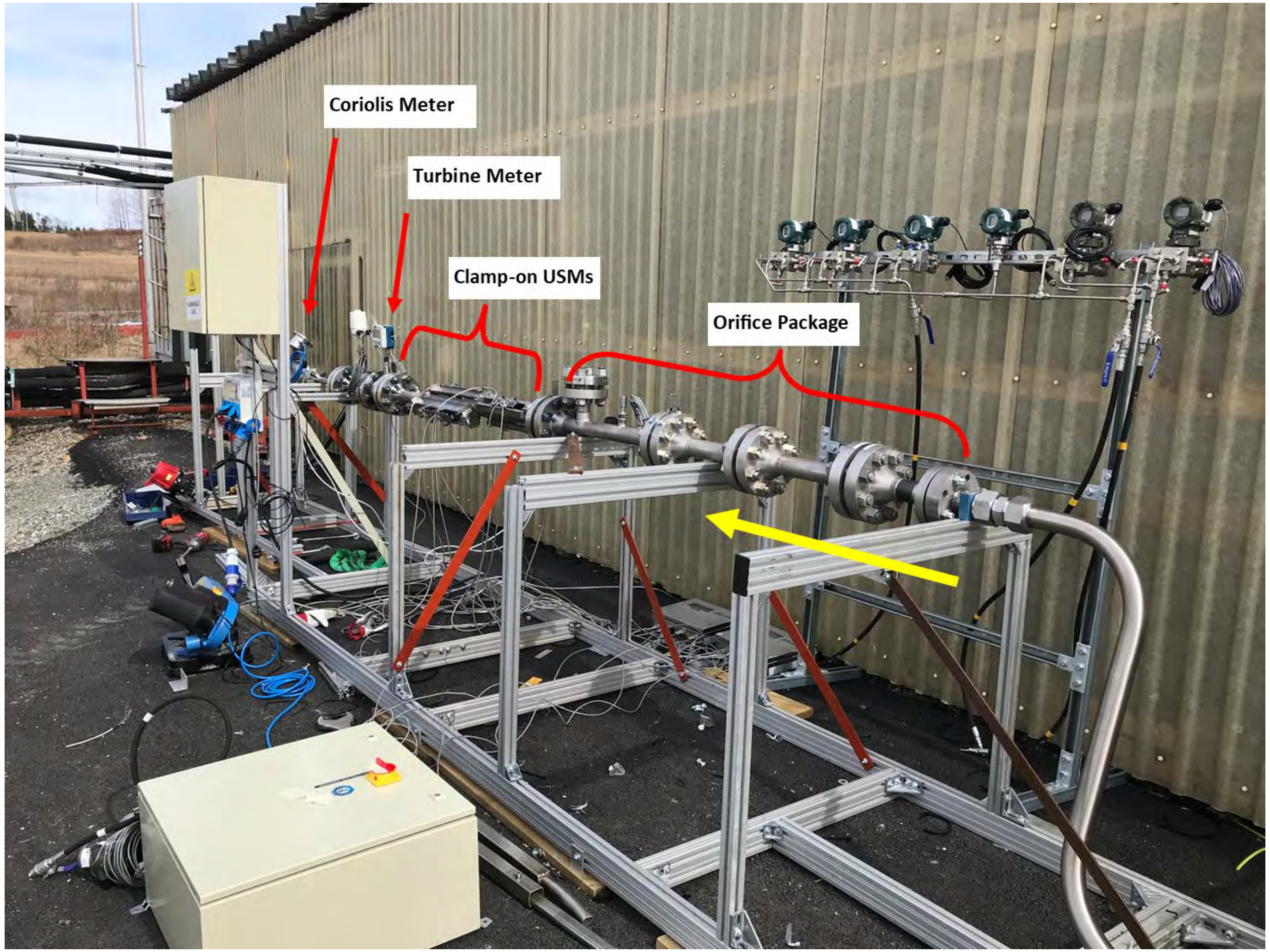
- Five flow meters from four different metering technologies built in series
- Two of these will be reported on today.
- Nominal diameter, 2 inch (DN50) with sch80, CL900 pipe and flanges



Tag Number	Meter Type	Size	Manufacturer	Model
FT1	Orifice 0.6 Beta	2 inch	McMennon	Compliant with ISO 5167
FT4	Coriolis	1 inch	Emerson	CMF100M

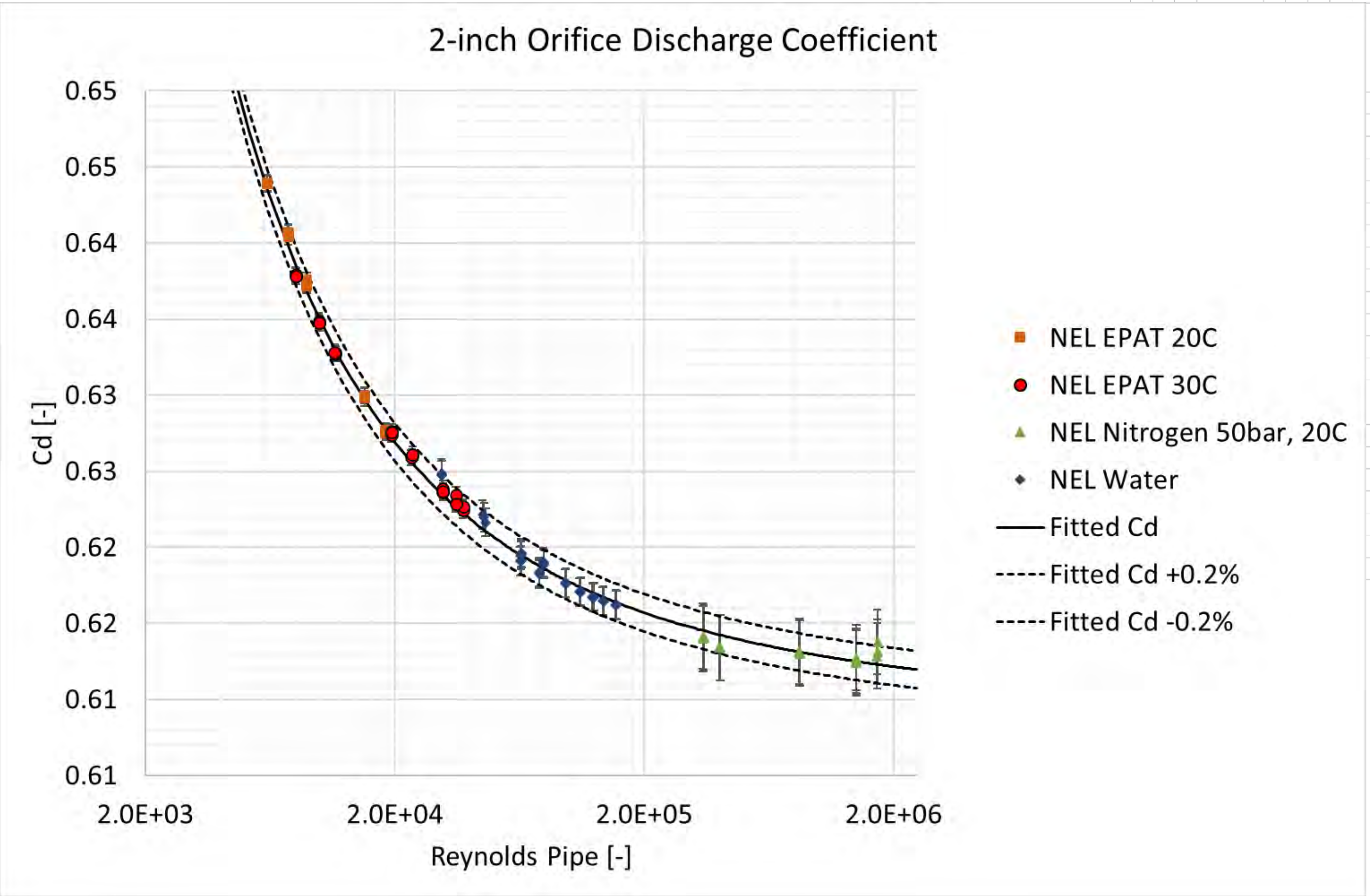
Flow Meter Transfer Package

- Package set-up, orientation and pipework remained the same between the test at NEL and IFE
- No traceable reference or primary standard available, therefore, Orifice Meter used as reference for CO_2 testing



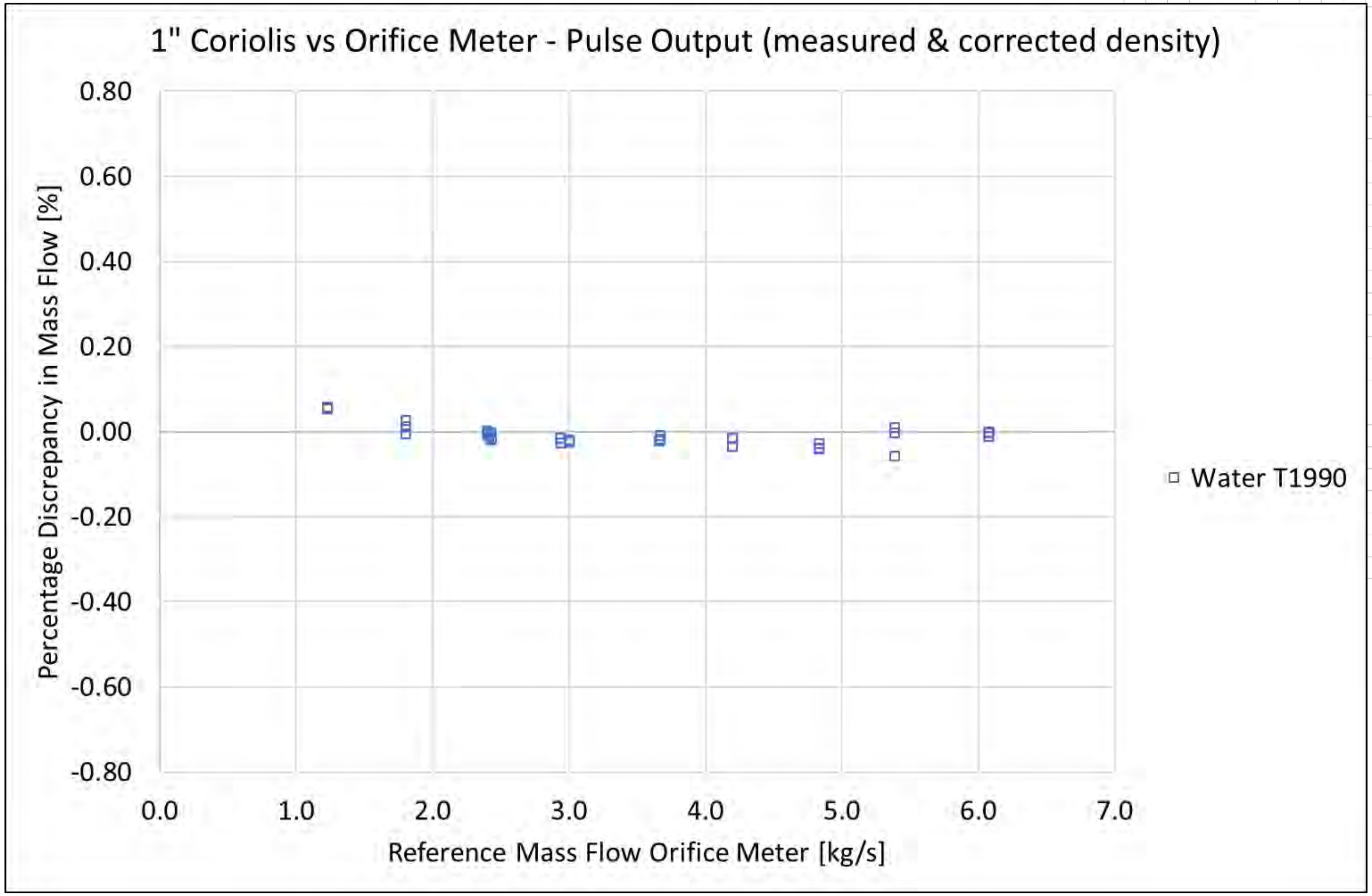

Water
Calibration

2-inch Orifice Calibration



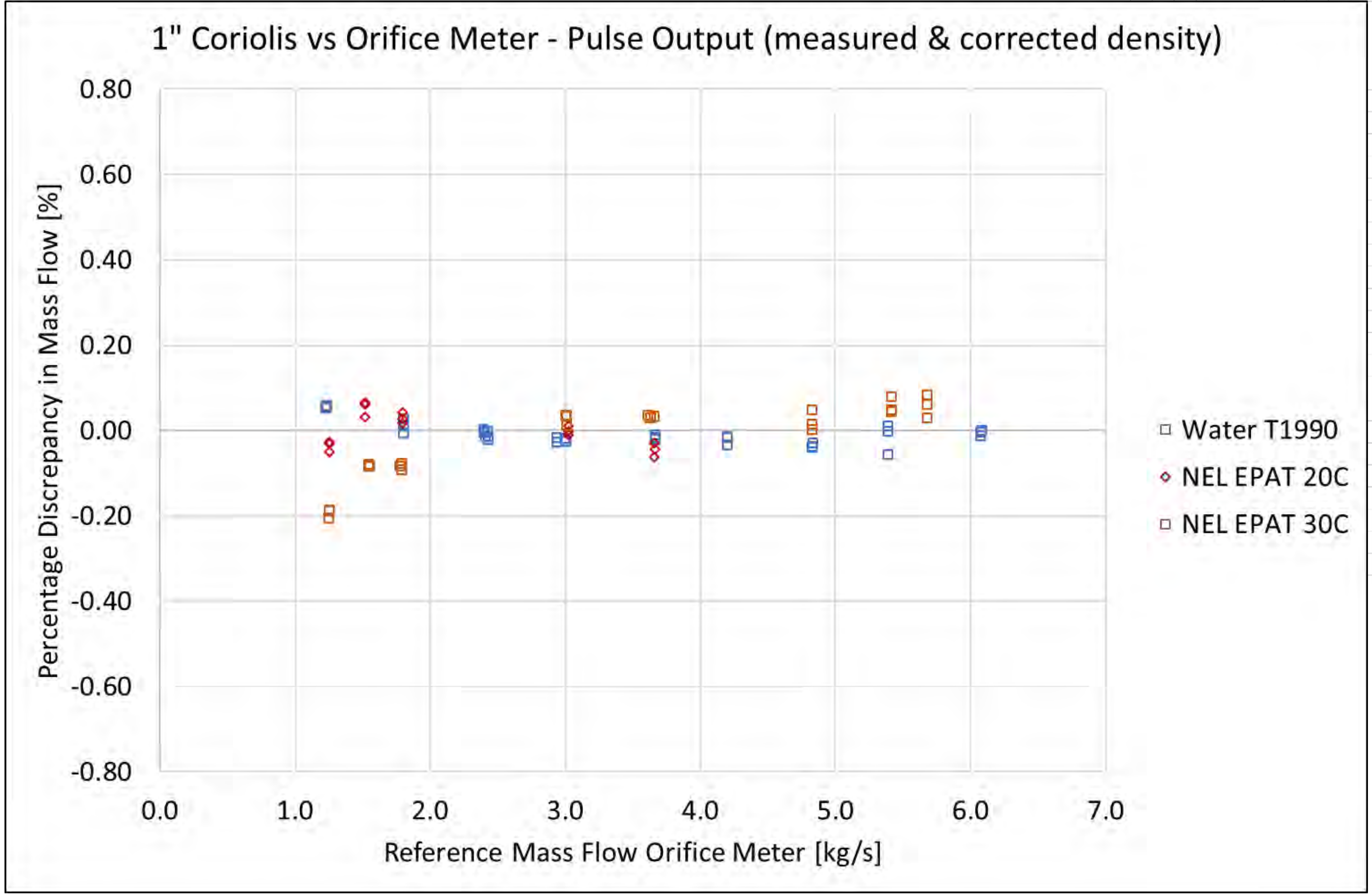
- Calibrated discharge coefficient fitted to NEL Water, EPAT Oil & High Pressure Gas test results
- Calibrated over Re. range: $6.15x10^3$ – $1.72x10^6$
- Resulting measured Cd was within ±0.2% of fitted Cd Curve
- The orifice was used as reference for CO_2 tests

1-inch Coriolis Flow Calibration



- Calibrated K-factor developed from NEL Water facility tests
- Calibrated over range: 1.23 – 6.1 kg/s
- Resulting discrepancy between orifice meter and Coriolis after calibration applied was within ±0.06%

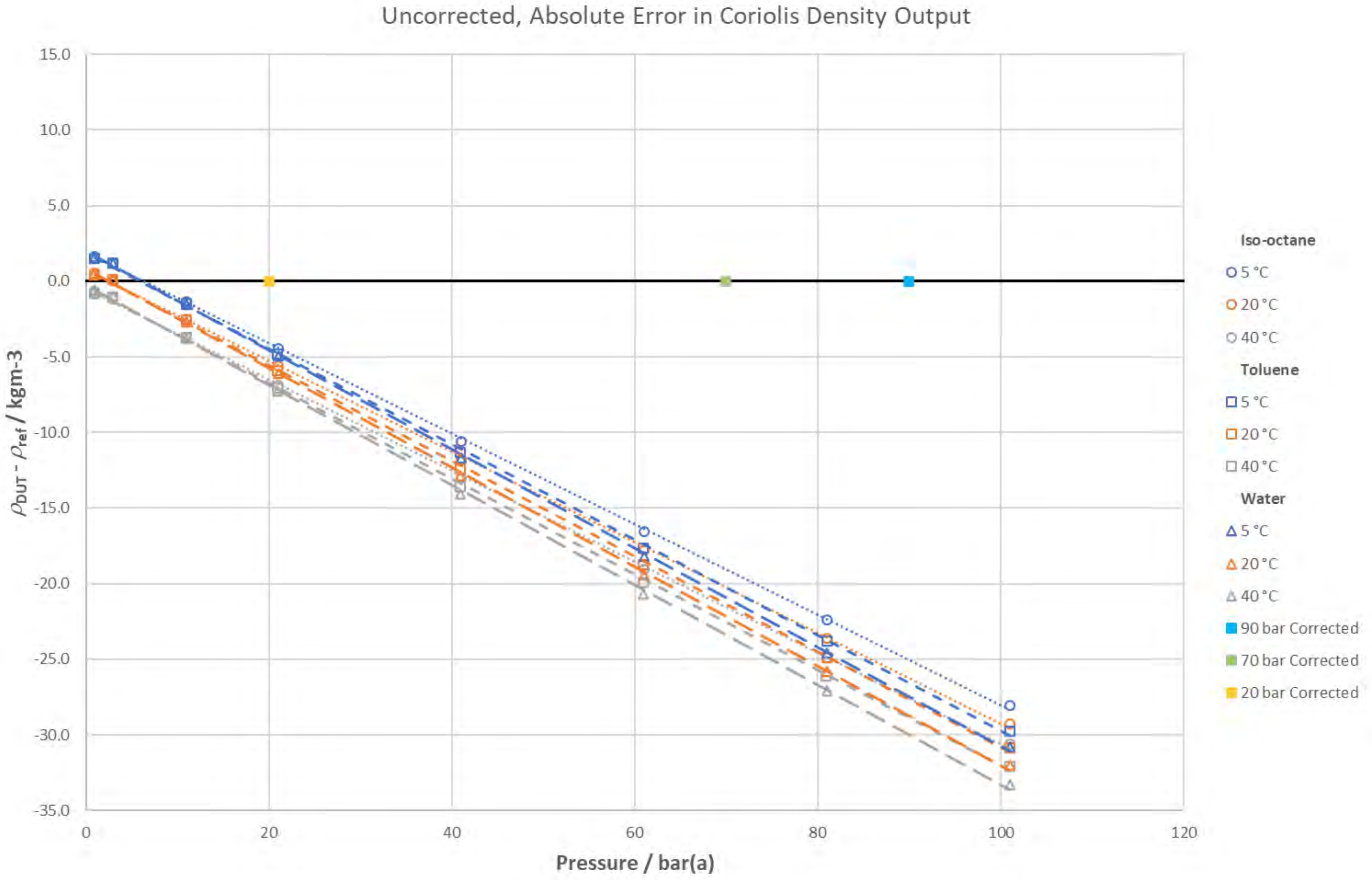
1-inch Coriolis Flow Calibration



- Meter was then tested in oil at elevated pressure and temperature (EPAT) to determine a pressure correction
- Pressure correction was applied to all results

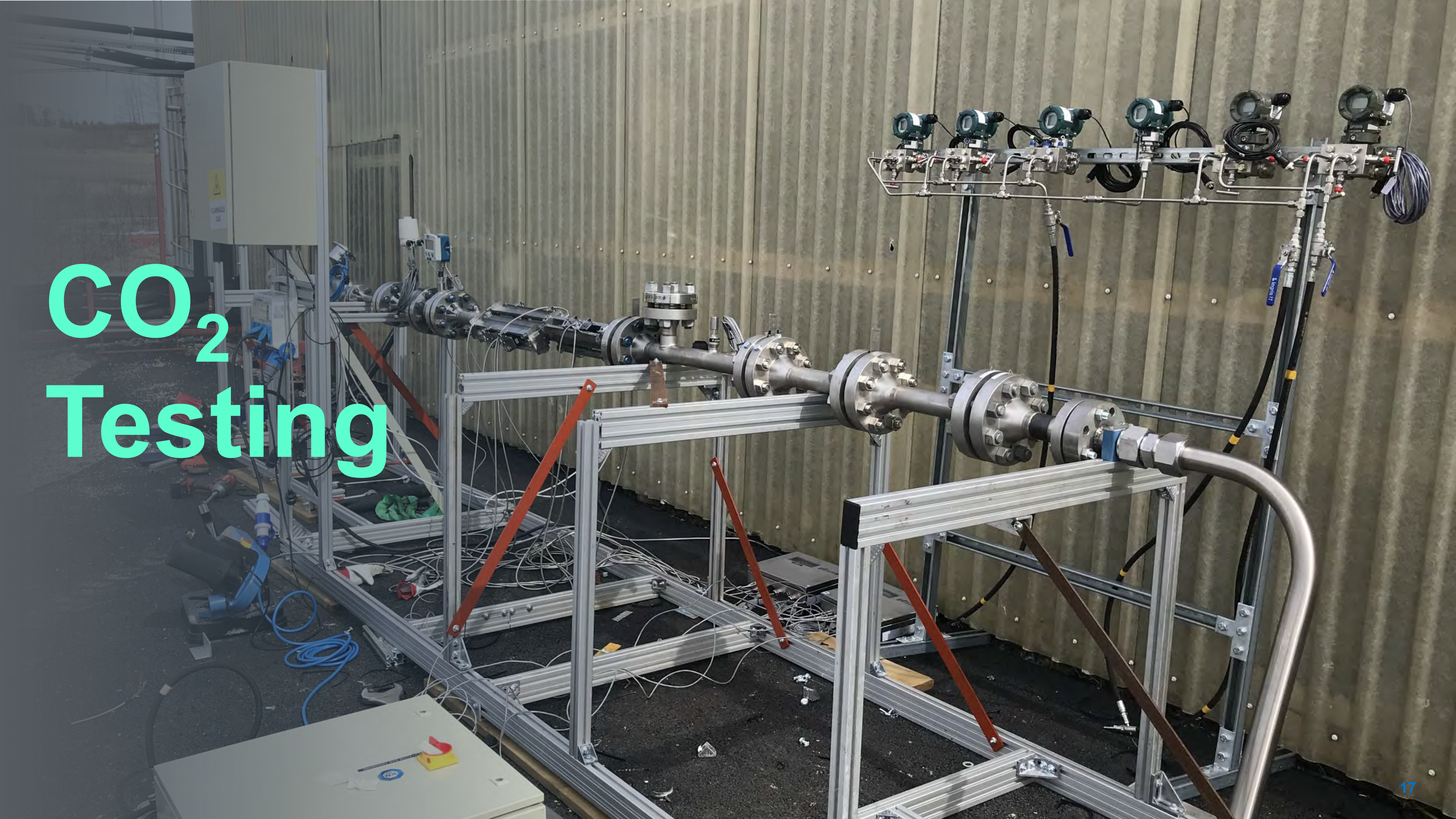
- Tested in Oil at 20°C & 30°C, error within ±0.08% except for lowest flow at 20°C.

1-inch Coriolis Density Calibration



- Uncorrected error from Coriolis density was up to -30 kg/m^3 at 100 bar. Equating to approximately a 3% error at the highest density CO_2
- This error was corrected with an offset for pressure and temperature at the CO_2 test conditions
- Resulting corrected error was within ±0.01% for liquid at -20°C, ±0.006% for dense phase at +20°C and within ±0.0004% for dense phase at 40°C

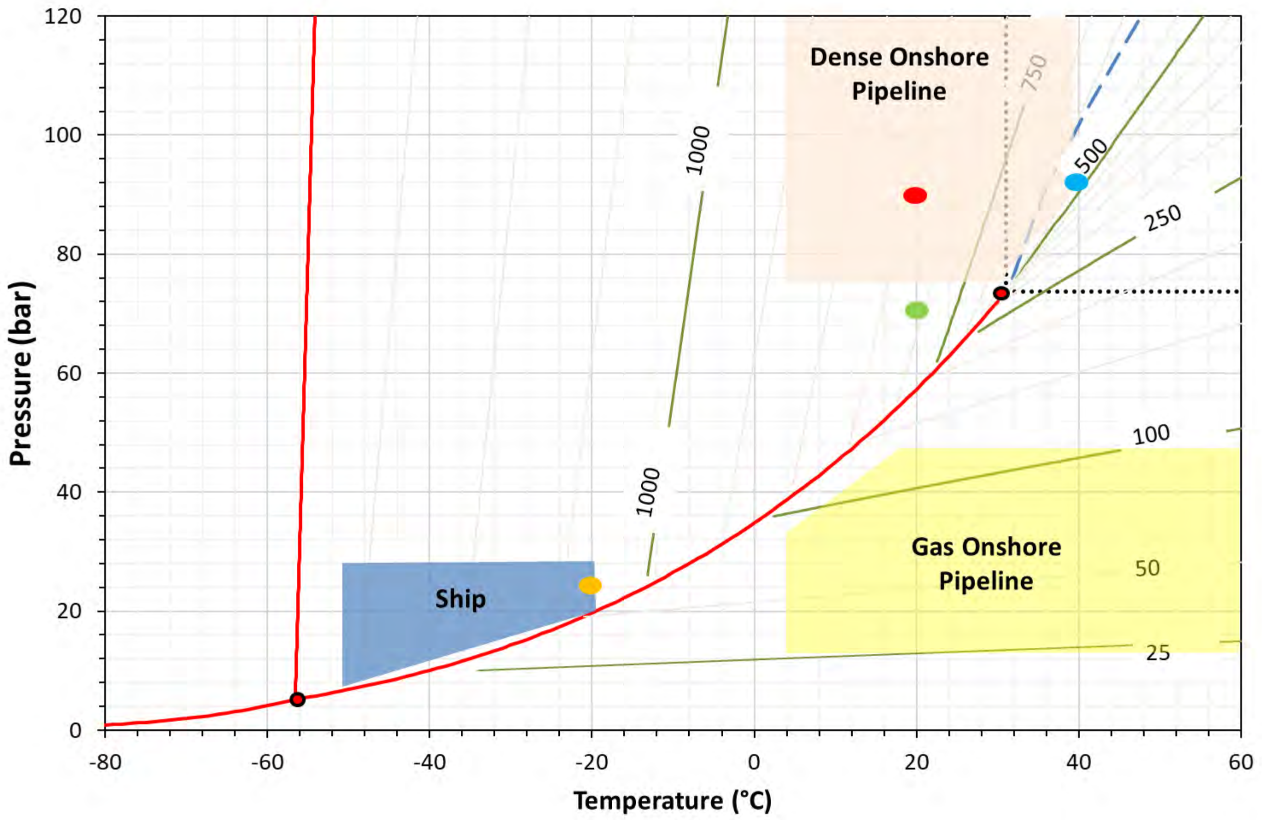
CO_2 Testing



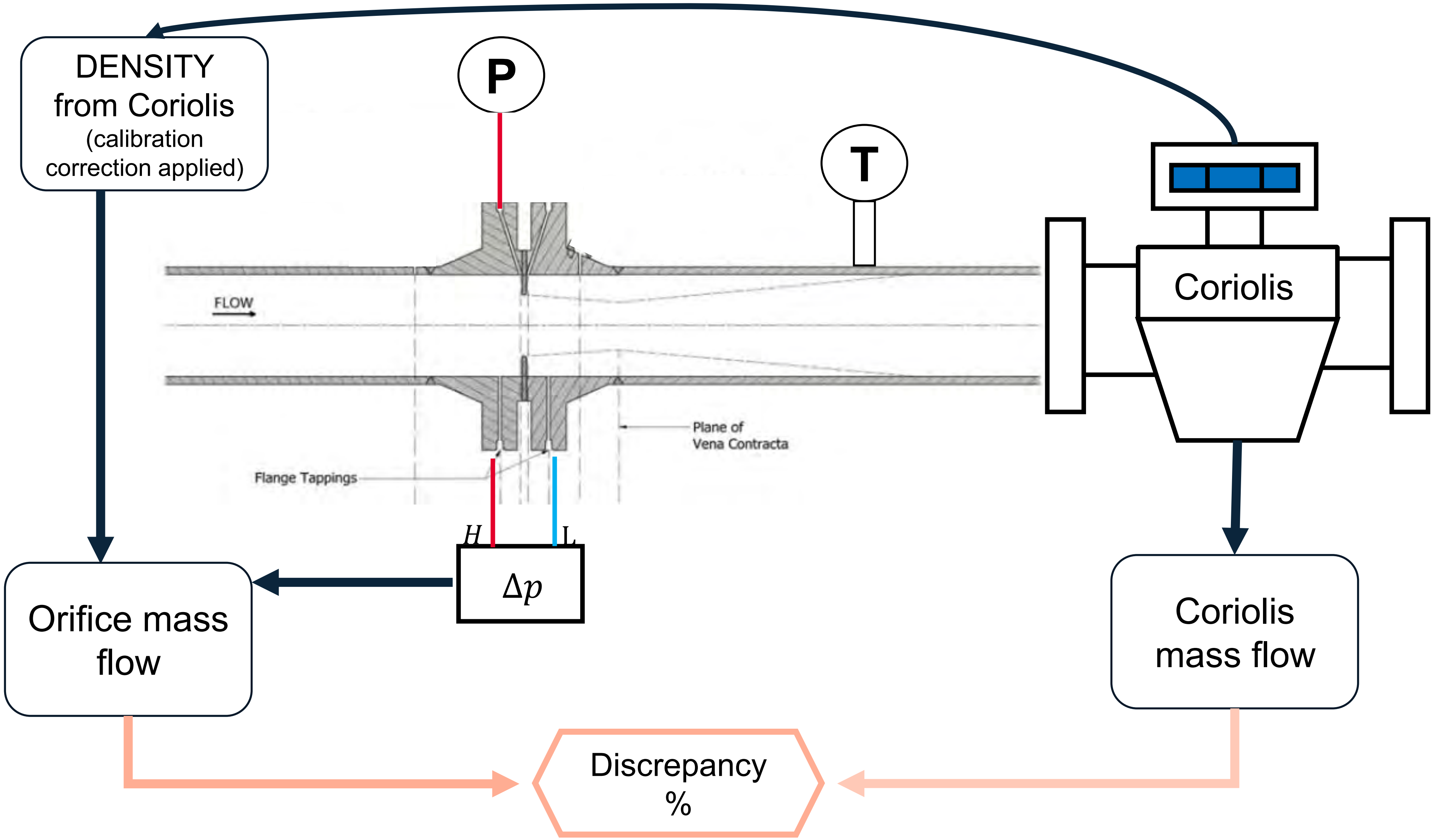
Testing in Liquid & Dense Phase CO_2

- Transfer package tested in CO_2 across four distinct fluid conditions at the Institute for Energy Technology (IFE) in Kjeller, Norway
- No traceable master meters or primary standard were available at IFE for CO_2. Therefore, the Orifice meter, calibrated at NEL, was used as the reference for the CO_2 tests.

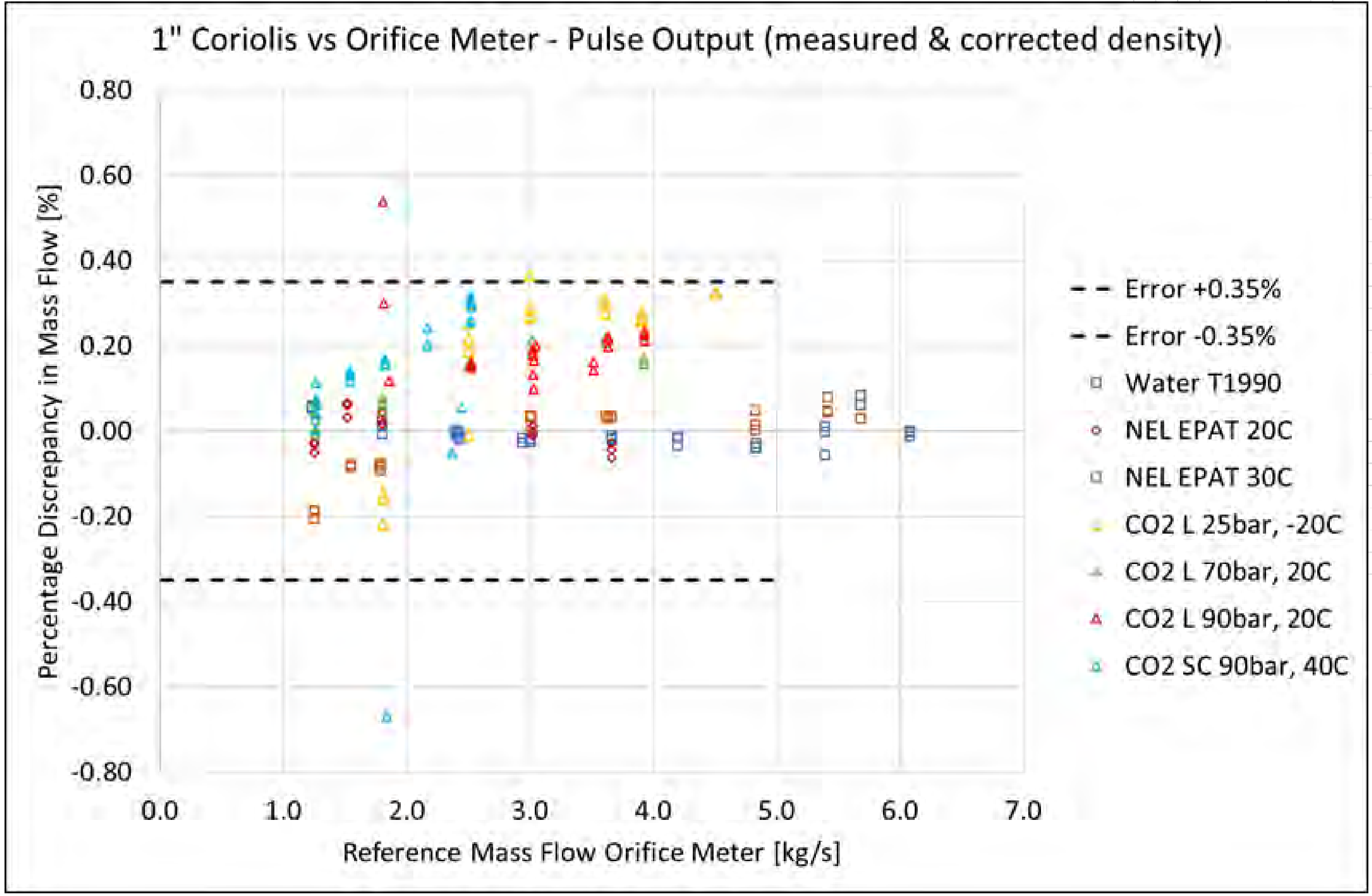
Phase Diagram Colour	Phase / Condition	Pressure (Bar.g)	Temperature (°C)	Flow Rate Range (kg/s)
(blue)	Dense /Supercritical	90	40	1.27 – 2.5
(green)	Liquid	70	20	1.25 – 3.9
(red)	Liquid / Dense	90	20	1.8 – 3.9
(yellow)	Liquid	25	-20	1.24 – 4.5



Flow and Density Reference – Measured Density

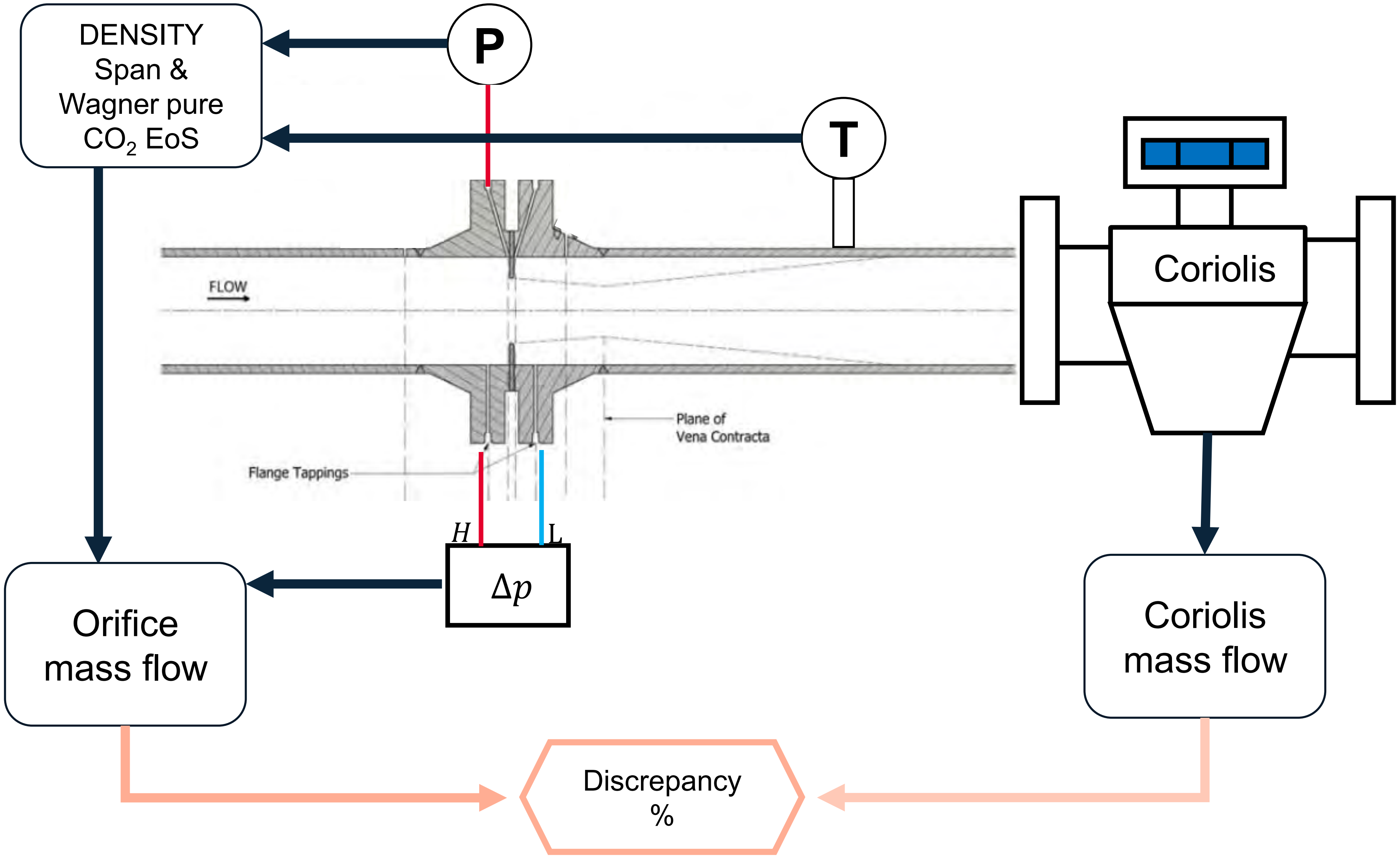


1-inch Coriolis CO_2 Results

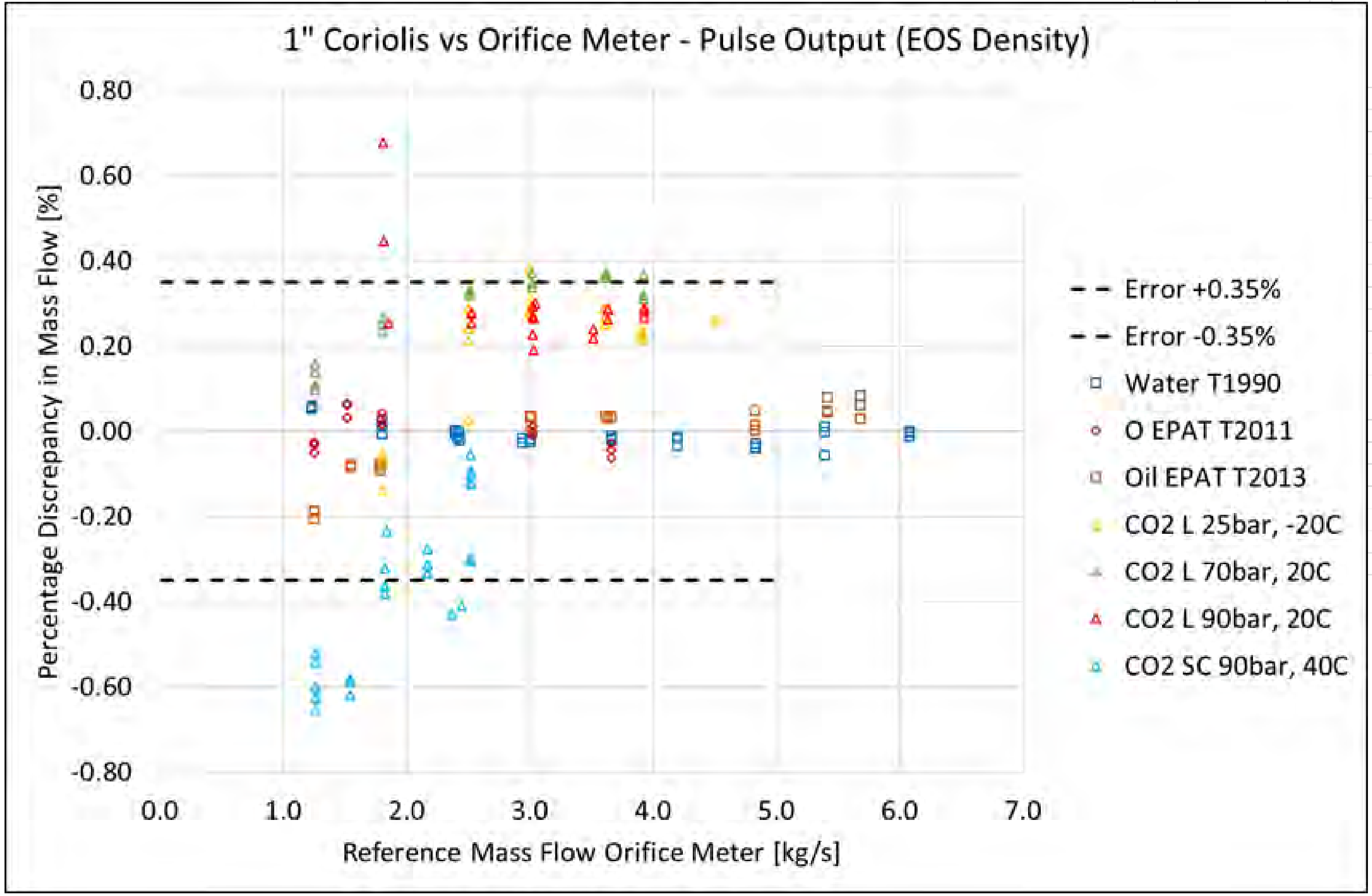


- When Density is measured directly
- Coriolis shows a positive bias
- Overall agreement between Coriolis and orifice is within ±0.35%
- Within expected uncertainty of Orifice Meter

Flow and Density Reference – EOS Density

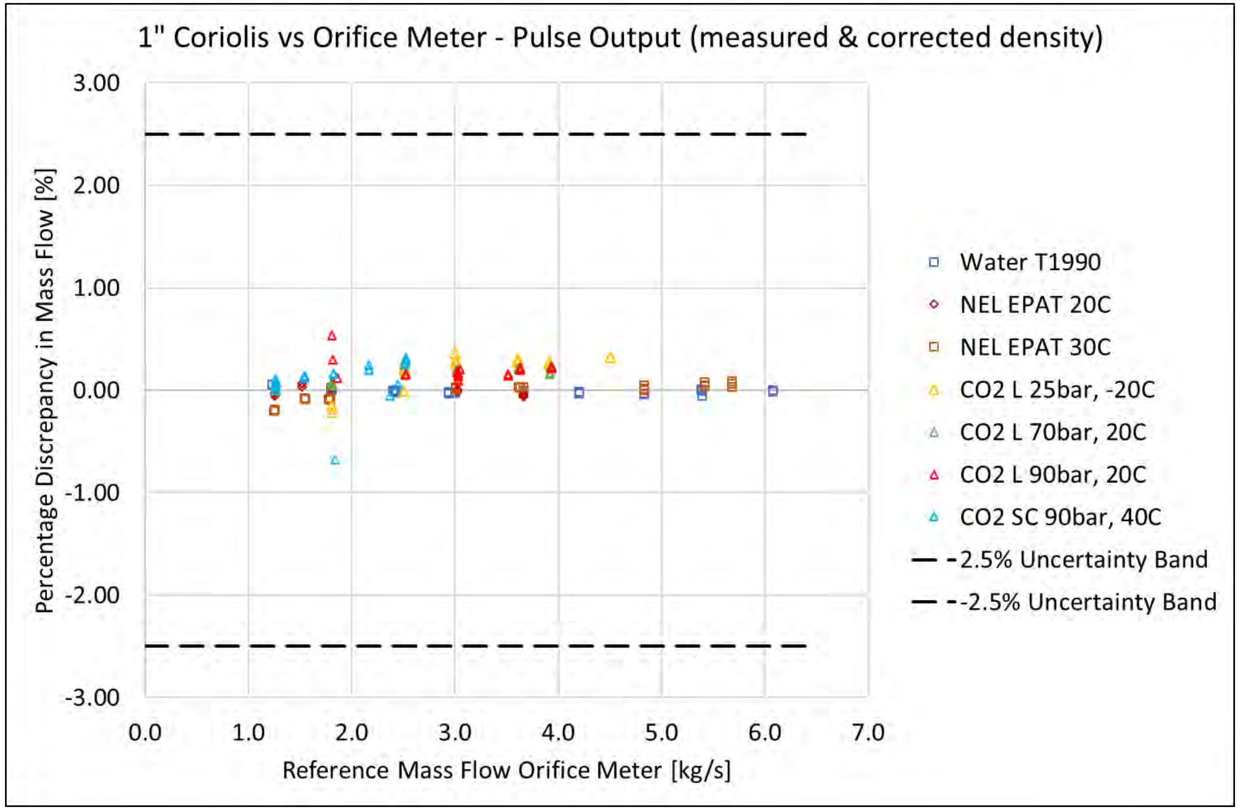


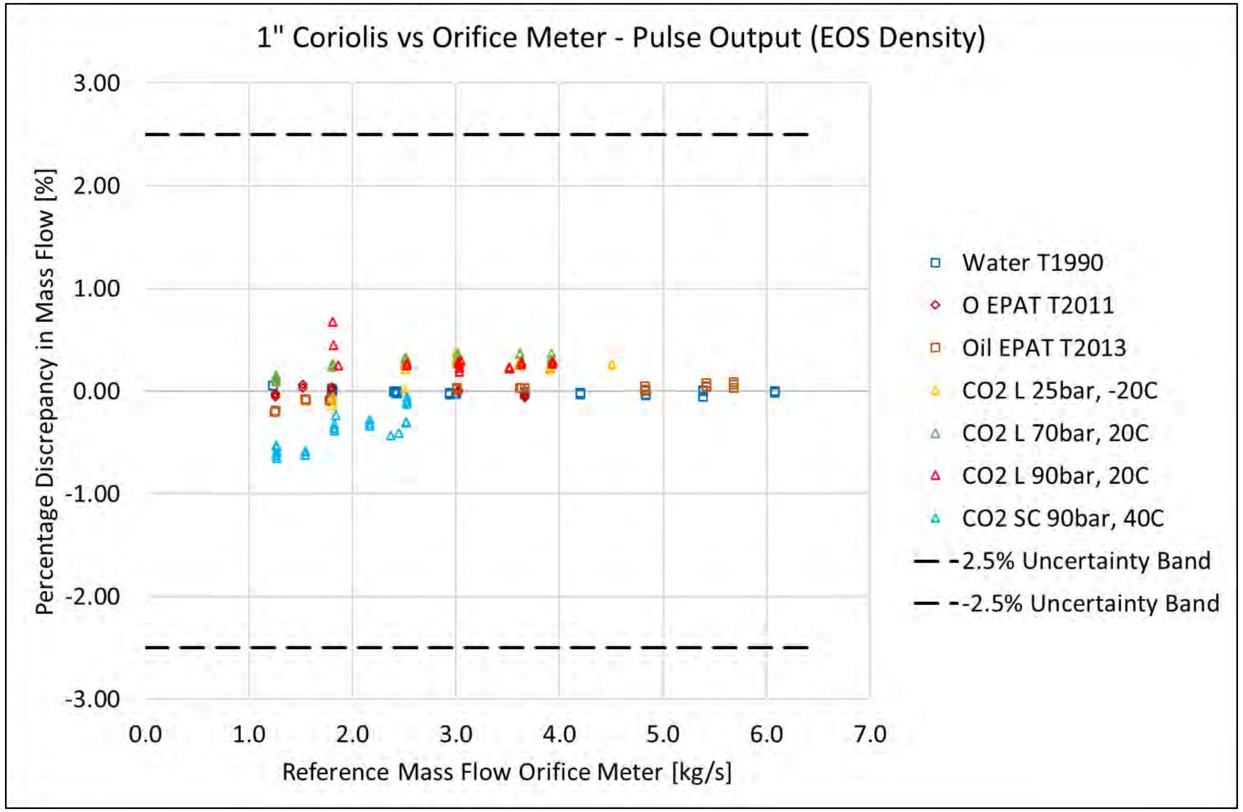
1-inch Coriolis CO_2 Results



- When Span & Wagner EOS is used for Density:
- Coriolis shows a positive bias for Liquid Phase
- Substantial shift in results for dense phase at 40°C
- Error between Coriolis and orifice gets worse, with mass flow error reaching ±0.4%

Coriolis Discrepancy in Perspective of the UK ETS





Conclusions

- This work presents a relative comparison between an orifice and Coriolis meter with water, oil, liquid and dense phase CO_2
- Discrepancy between orifice and Coriolis in water and oil is within ±0.08%
- Results with CO_2 suggest that the calibration of a Coriolis meter with water can be effectively extended to liquid and dense-phase CO_2, with an associated uncertainty of approximately ±0.35 % (k = 2).
- It should be noted that 0.35% is approximately within the expected uncertainty of the orifice meter

This is a hugely significant initial result

Future Work

- To draw final conclusions further testing required:

- Primary standard
- Additional meter sizes
- Multiple manufacturers
- Additional flow rates and test conditions
- Impurities

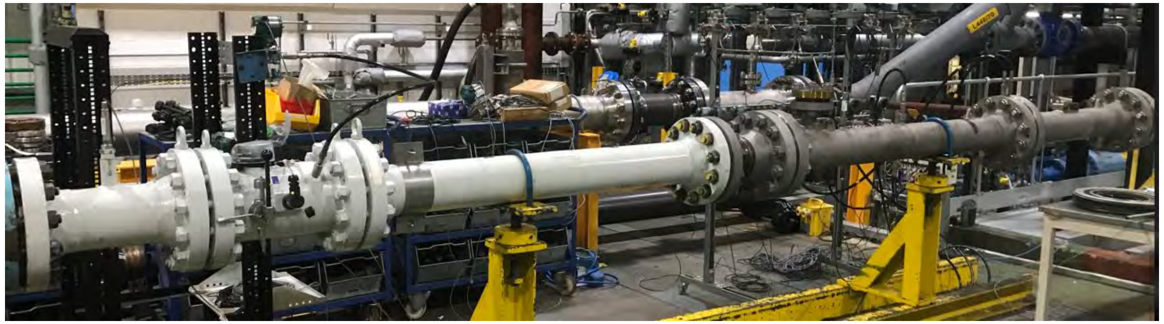
- NEL is currently building a primary standard liquid/dense phase CO2 facility and is planning test work with CO2 mixtures as part of an EU funded project called ENCASE

Test Results in Gas Phase

Test Results in Gas Phase - NEL

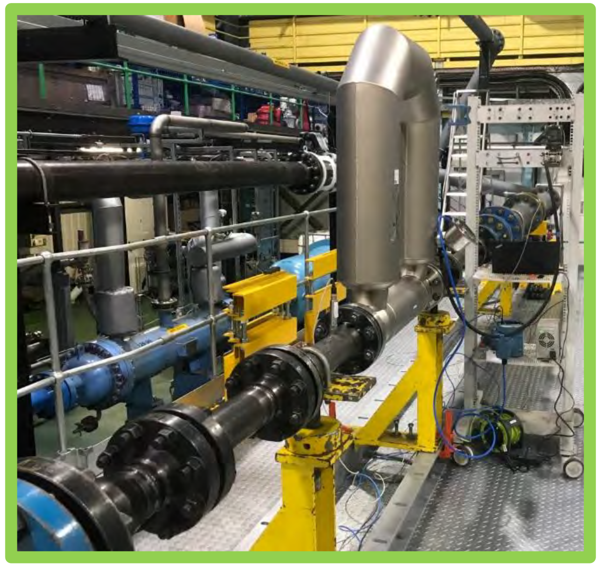
Department for Science, Innovation & Technology

Metrology for decarbonising the gas grid

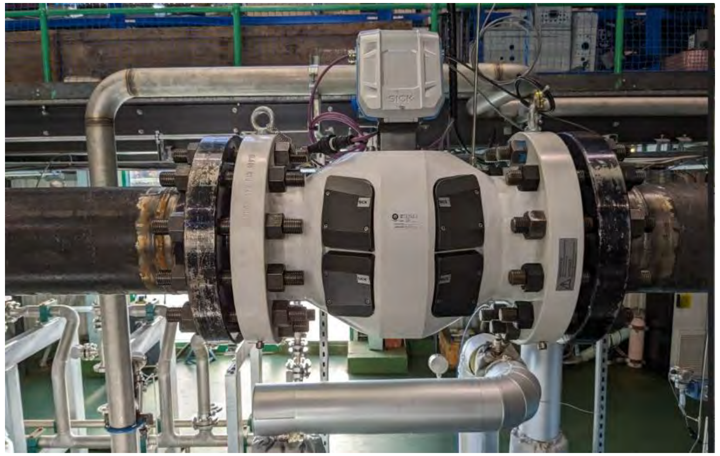


6” Turbine

6” Orifice

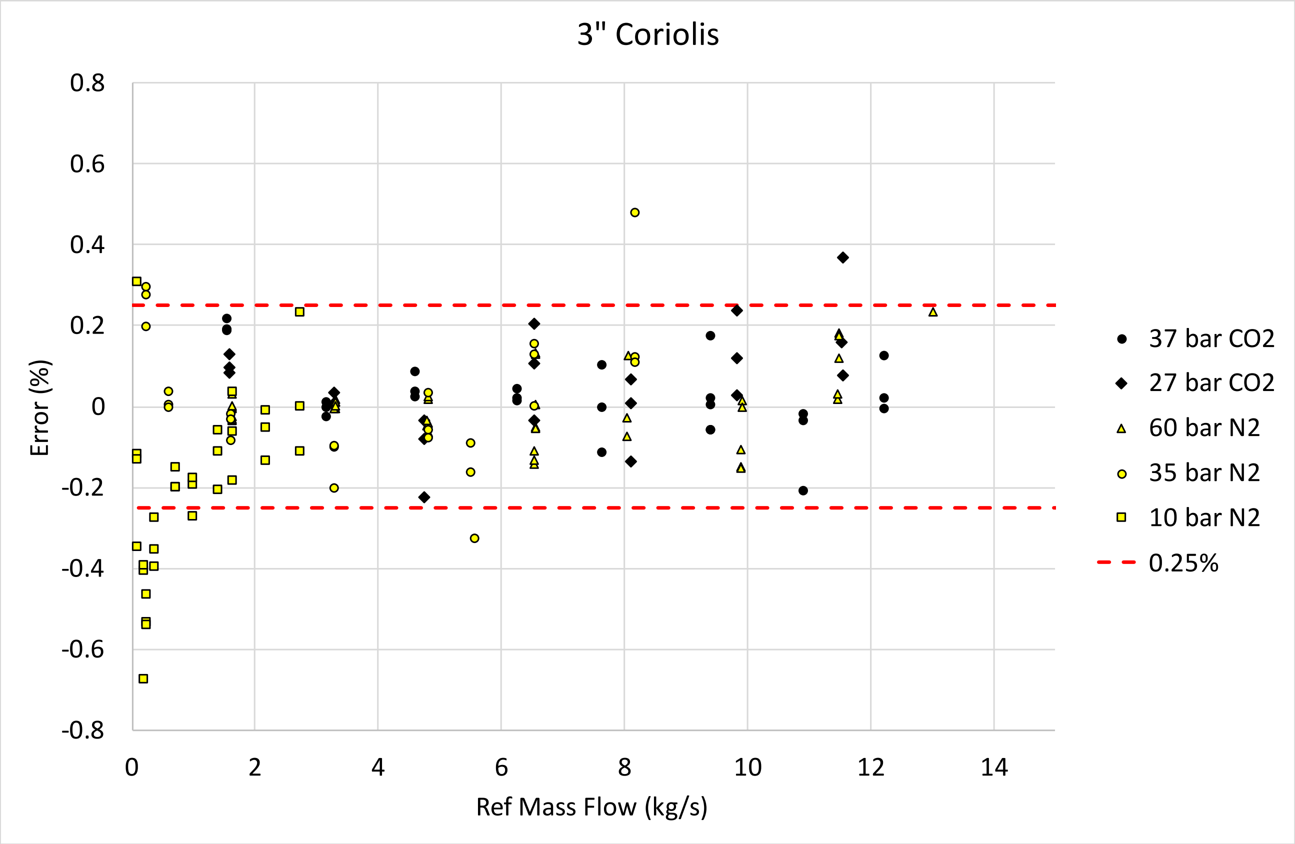


3” Coriolis



8” USM

Test Results in Gas Phase - NEL



- Pressure correction applied as per manufacturer specifications
- Coriolis calibrated with nitrogen at 60 bar
- Calibration at 60 bar with N_2 applied at the other pressures and with CO_2
- Density of N_2 at 60 bar is like CO_2 at 27 bar

Test Results in Gas Phase - NEL

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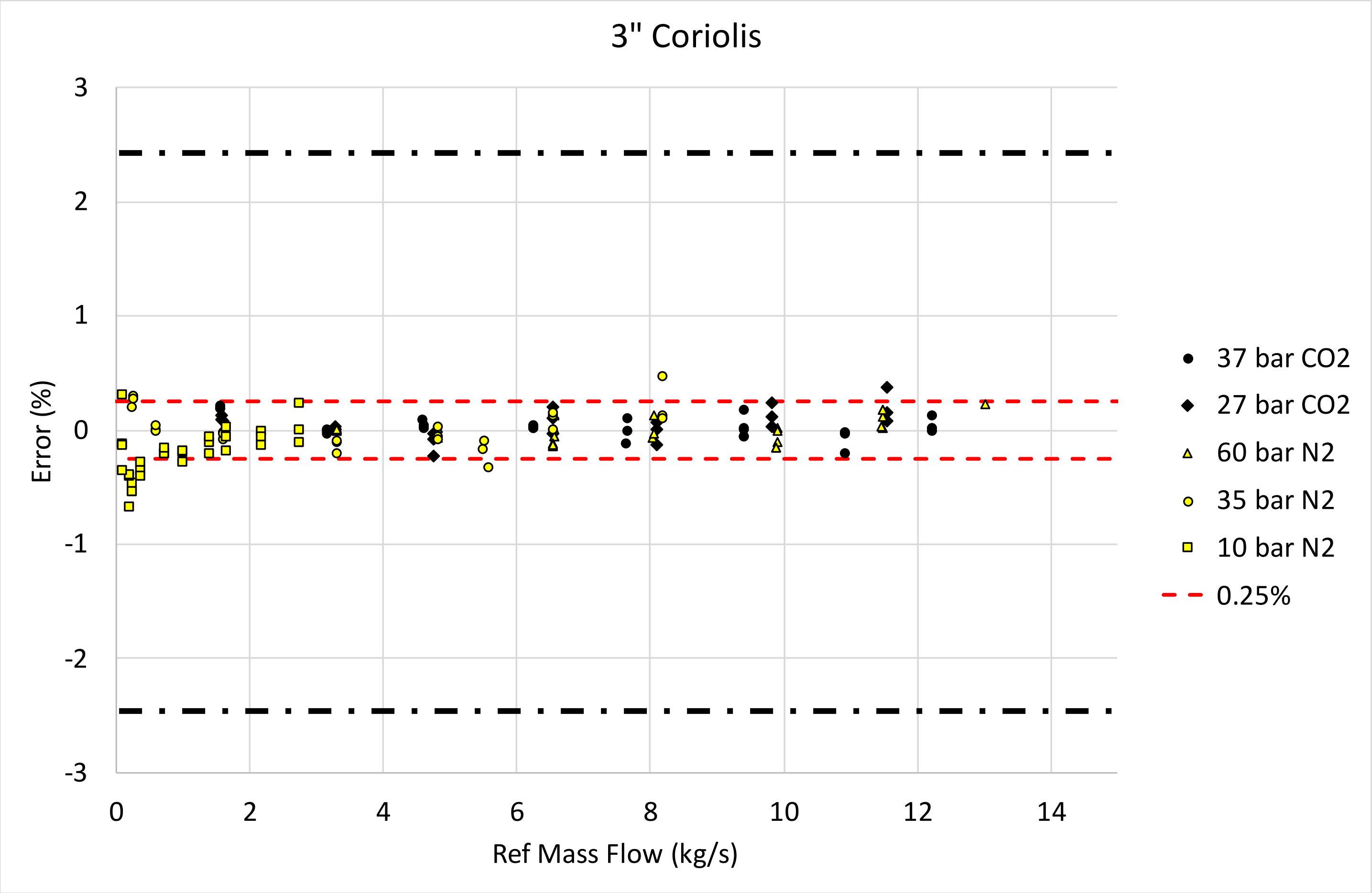
Metrology for decarbonising the gas grid



Test Results in Gas Phase – HWU/NEL

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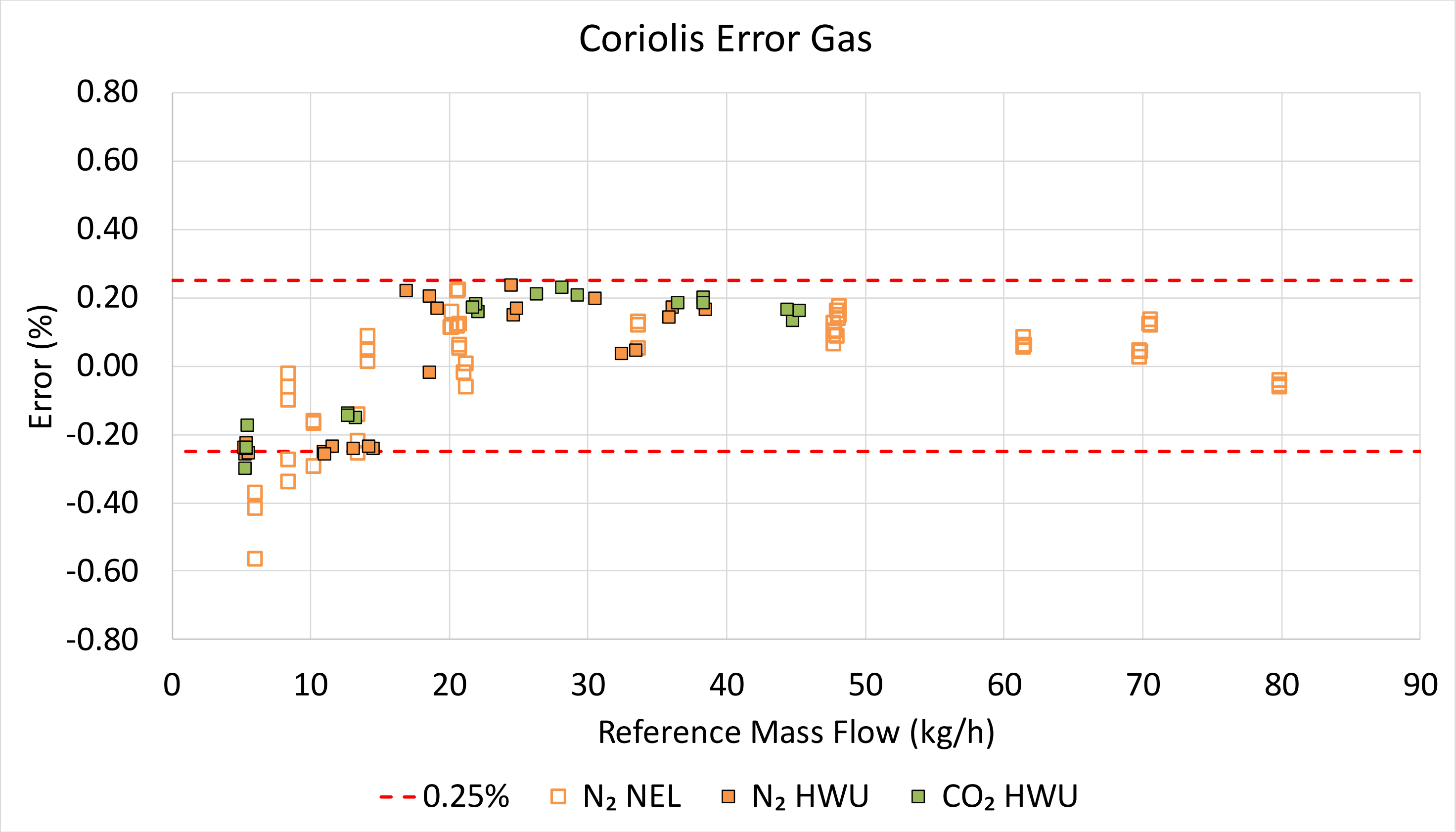
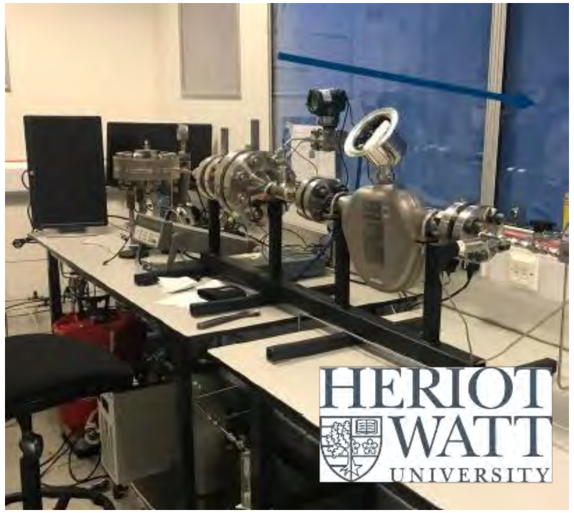




Test Results in Gas Phase - DNV

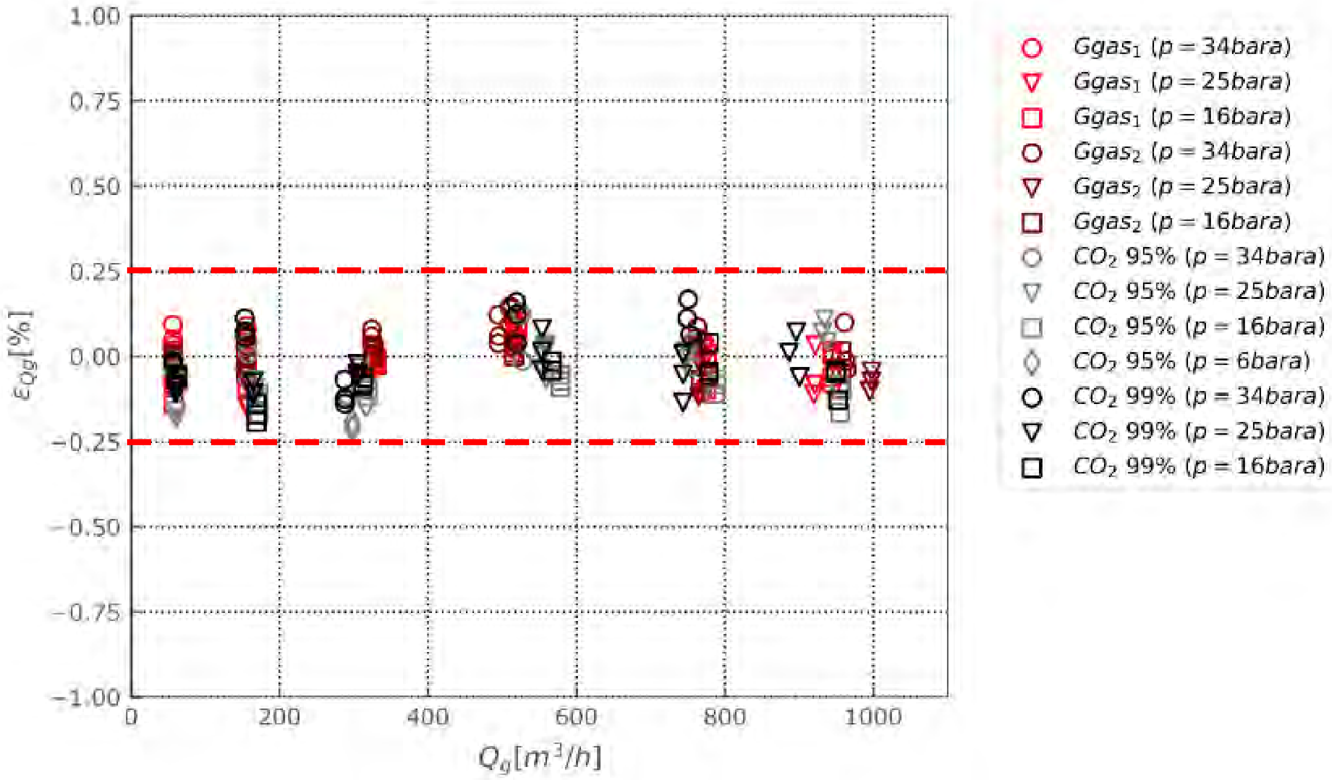


Fig. 17 – Deviation of Coriolis meter as function of volume flow rate for different gases and pressures

NORTH SEA FLOW MEASUREMENT WORKSHOP

Flow meter performance under CO_2 gaseous conditions

Dennis van Putten, DNV Netherlands BV

Robert Kruithof, NV Nederlandse Gasunie

1 INTRODUCTION

The transport and energy measurement and billing of natural gas in pipeline systems is well understood in the gas industry. ISO standards and best practice specifications and procedures to facilitate transport and custody transfer are widely available and under constant improvement and review.

With decarbonization ambitions moving forward, the transport of CO_2 is becoming increasingly important to facilitate carbon capture, utilization, and storage (CCUS). As well as for natural gas systems, accurate measurement and subsequent billing for CCUS is required to show compliance with national and international emissions-reduction regulations, like the EU Emission Trading System (ETS). The ETS is based on the principle of cap and trade, meaning that the "capped" emission rights can be traded between parties. The ETS states that all CO_2 reported amounts above 500 kilotons/year should be within an uncertainty of 2.5% (k=2) independent of the thermodynamic state of the CO_2, *i.e.* gas, liquid or dense phase.

There are many ongoing CCUS projects especially in northwestern part of Europe, e.g. Northern Lights (Norway), Porthos & Aramis (Netherlands), Net Zero Teesside & Zero Carbon Humber (UK). Due to the complexity of the CO_2 value chain, accurate flow measurements are required in a variety of thermodynamic conditions ranging from low-pressure, low-temperature gas/liquid measurements to high-pressure liquid and dense phase measurements.

1.1 Porthos CCUS project

Porthos is developing a CCUS project in the Rotterdam harbour with storage offshore in the P18 gas fields, operated by TAQA. The project is a collaboration between Port of Rotterdam Authority, EBN and Gasunie. An important part of the transportation network of Porthos is the medium-pressure (<35 bar) onshore CO_2 gas transport, in a joint venture with Gasunie. This part of the network connects the different emitters (customers) before compression and offshore dense phase transportation towards the P18 fields. A schematic overview of the CCUS transportation system is given in Fig. 1.

North Sea Flow Measurement Workshop, 26-29 October 2021 page 1 / 18

Test Results in Gas Phase – Fortis BC

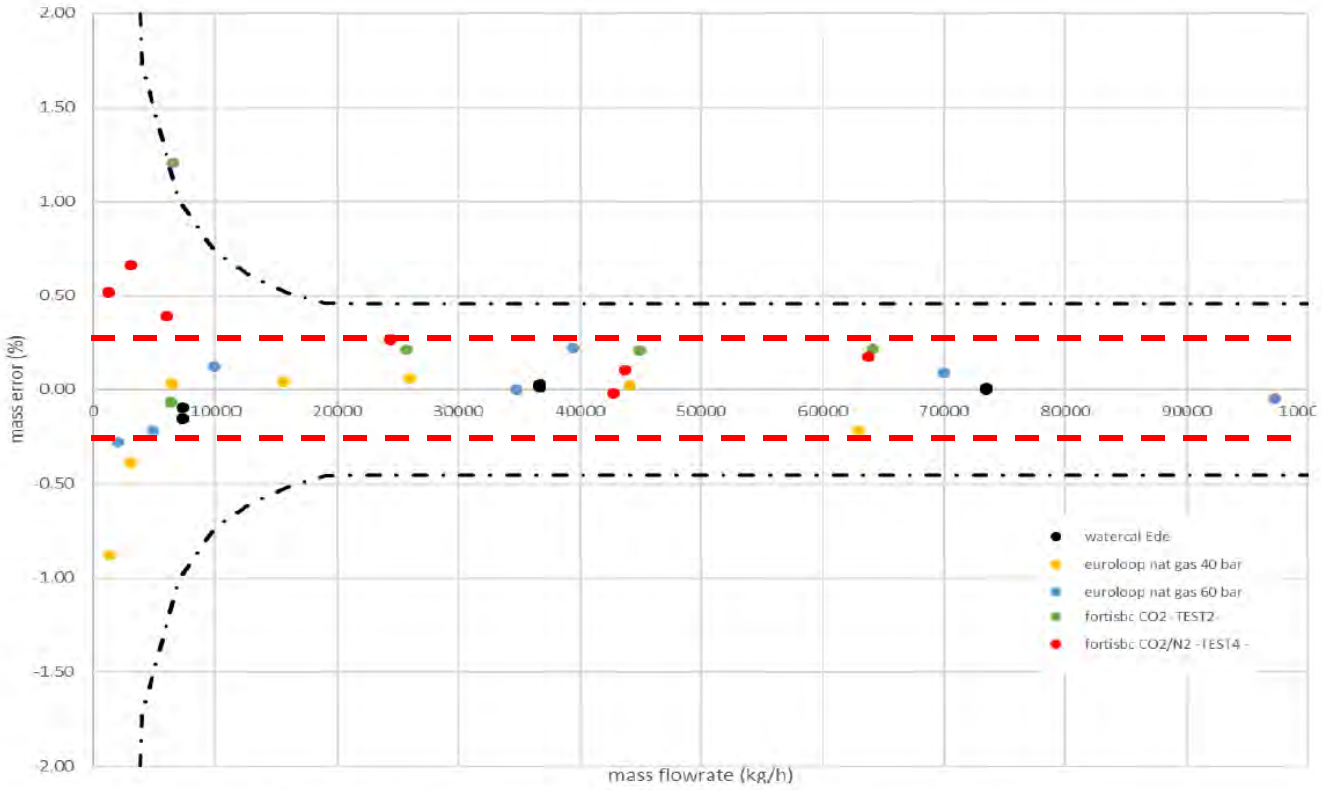


Fig. 6 - Calibration on CO2, Natural Gas and Water (ISO 17025)

Global Flow Measurement Workshop
25 - 27 October 2022

Technical Paper

Flow Meter Performance for The New Hydrogen and Carbon Capture Economy

Yaser Alghanmi, Emerson Automation Solutions
Maarten Brugman, Emerson Automation Solutions
Aleksandr Druzhkov, Emerson Automation Solutions
Salvatore Pitti, Emerson Automation Solutions
Thomas Sautier, Emerson Automation Solutions
Marc Buttler, Emerson Automation Solutions

1 INTRODUCTION

World policy makers and energy sector leaders are ramping up efforts to establish the infrastructure that will support the energy transition and lead the way to Net Zero Energy which is promised to offset the carbon footprint and mitigate rising climate temperature. To achieve Net Zero Energy, policies and large scale investments need to produce and put into operation the technology that facilitates a balance between the energy produced and the Green House Gas (GHG) emissions released into the atmosphere.

As the Energy Transition value chain, Fig. 1, grows enabling Net Zero Energy, both the Hydrogen (H_2) in all its forms and the captured Carbon Dioxide (CO_2) will be subject to transportation tariffs, storage fees, fiscal hand-overs, and carbon tax rebate. This will necessitate a unified approach of quantity/quality measurement and thus the necessity for the means/infrastructure for traceability of measuring instruments to a reference standard. Until such time dedicated traceability platforms are built, tested, and recognized for Net Zero Energy enablers, it is technically feasible to employ the existing calibration facilities for measurement accuracy transferability from other fluids similar to what have been adopted for the Oil and Gas industry.

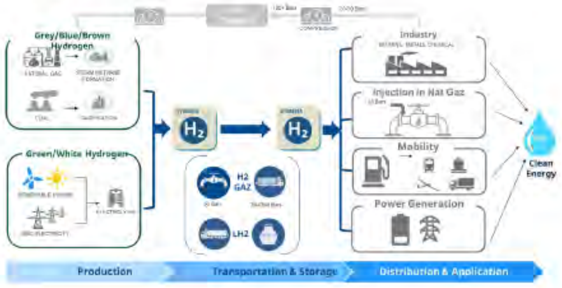


Fig. 1 - Energy Transition Value Chain

1

4 different labs,
3 meter sizes,
similar results,
suggesting that a Coriolis meter can be calibrated with alternative fluid and used with gaseous CO_2

Thank you

Contact us:

Russell Brown
CCUS Flow Measurement Consultant

Email: russell.brown@tuvsud.com

Gabriele Chinello
Head of CCUS

Email: gabriele.chinello@tuvsud.com

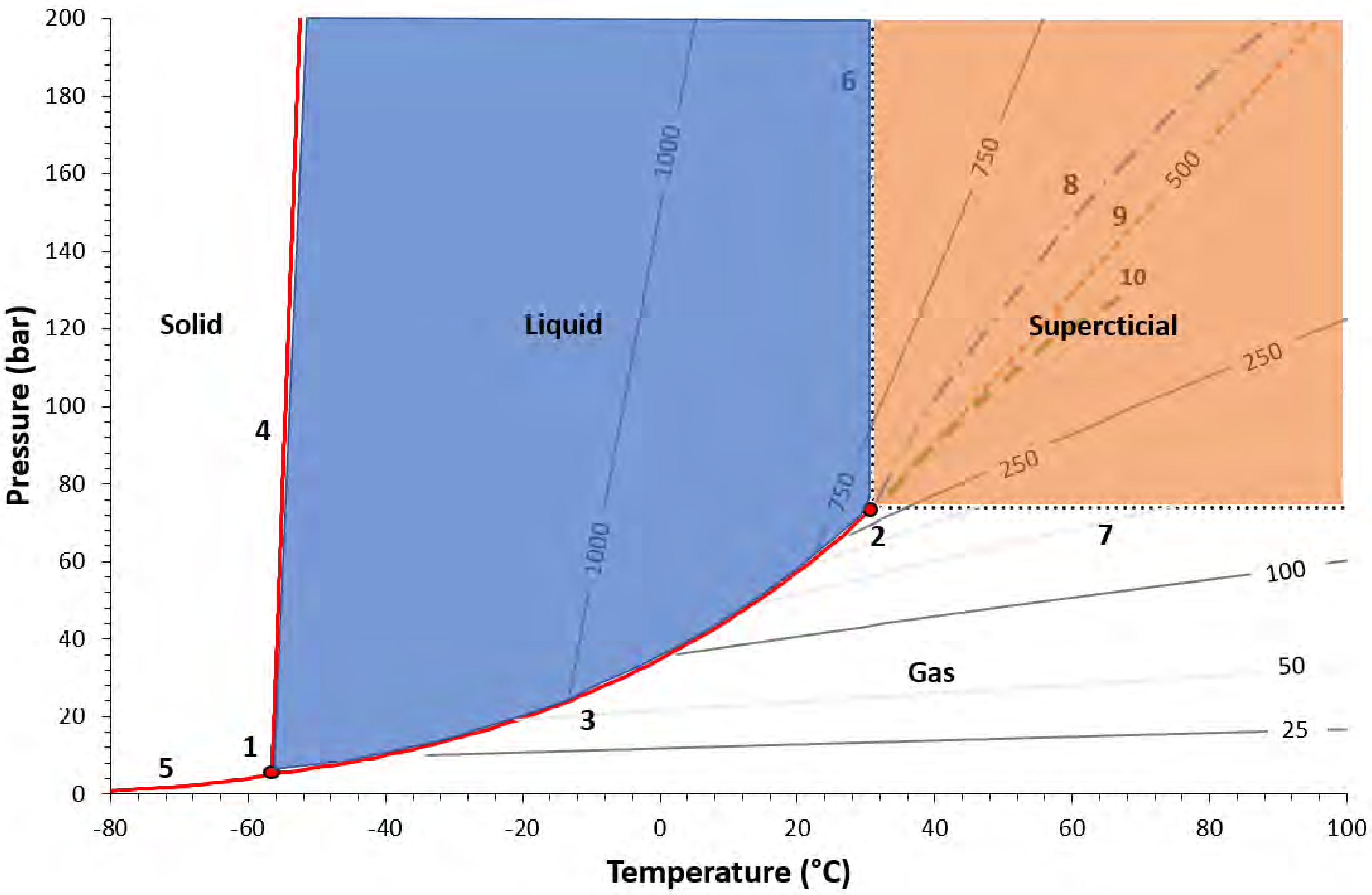
Research Funded by:

Department for Science, Innovation & Technology

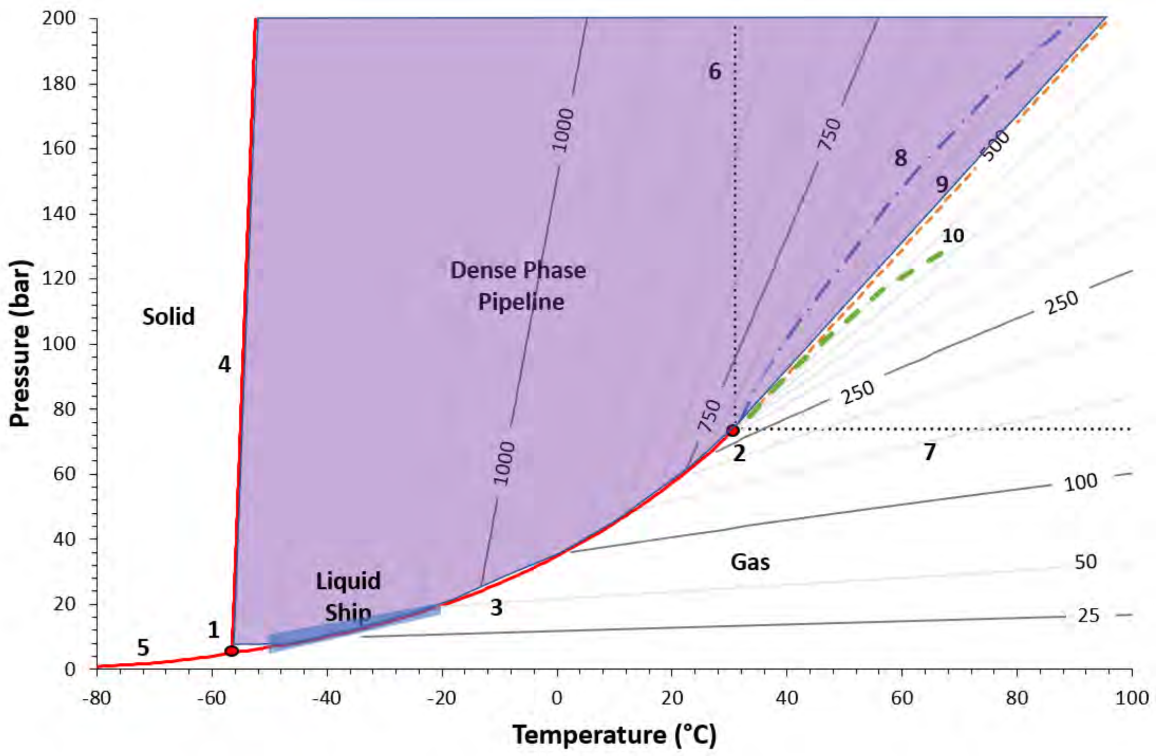
Metrology for decarbonising the gas grid

www.decarbgrid.eu

Dense phase: a note on terminology

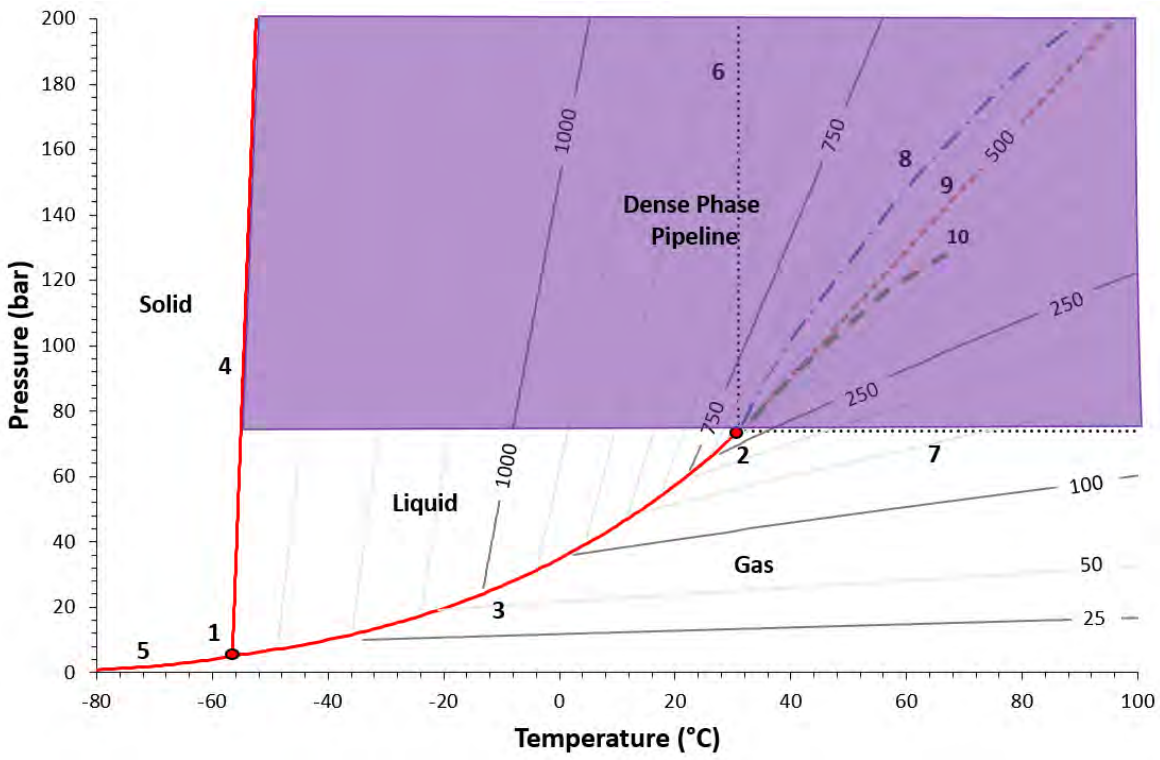


Dense phase: a note on terminology



CO_2 or CO_2 stream in the single-phase fluid state above a density of 500 kg/m^3

This definition is aligned with: CCUS Forum Expert Group on CO2 Specifications, "An Interoperable CO2 Transport Network-Towards Specifications for the Transport of Impure CO2," 2023



CO_2 or CO_2 stream in its liquid or supercritical phases above the critical pressure (pure CO_2 stream) or cricondenbar (CO_2 rich stream)