Where do we stand on flow metering for CO2 handling and storage?

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[1] NORCE Norwegian Research Centre AS [2] Equinor [3] Gassco [4] Total

Overview

- Background
  - Many CCS projects with demands to measure total mass (or volume) of CO_2
- Scope
  - Focus on Northern lights CO_2 transport chain
  - Review of CO_2 metering technologies for pipe flow
  - Mass balance calculations
  - Screening of calibration sites for CO_2 flow measurement systems

Content

- Introduction: Regulations & overview of CO2 transport chain
- Measurement technology for CO2 metering
- Mapping of measurement technology to cases & uncertainty analysis
- Mass balance calculations
- CO2 calibration facilities

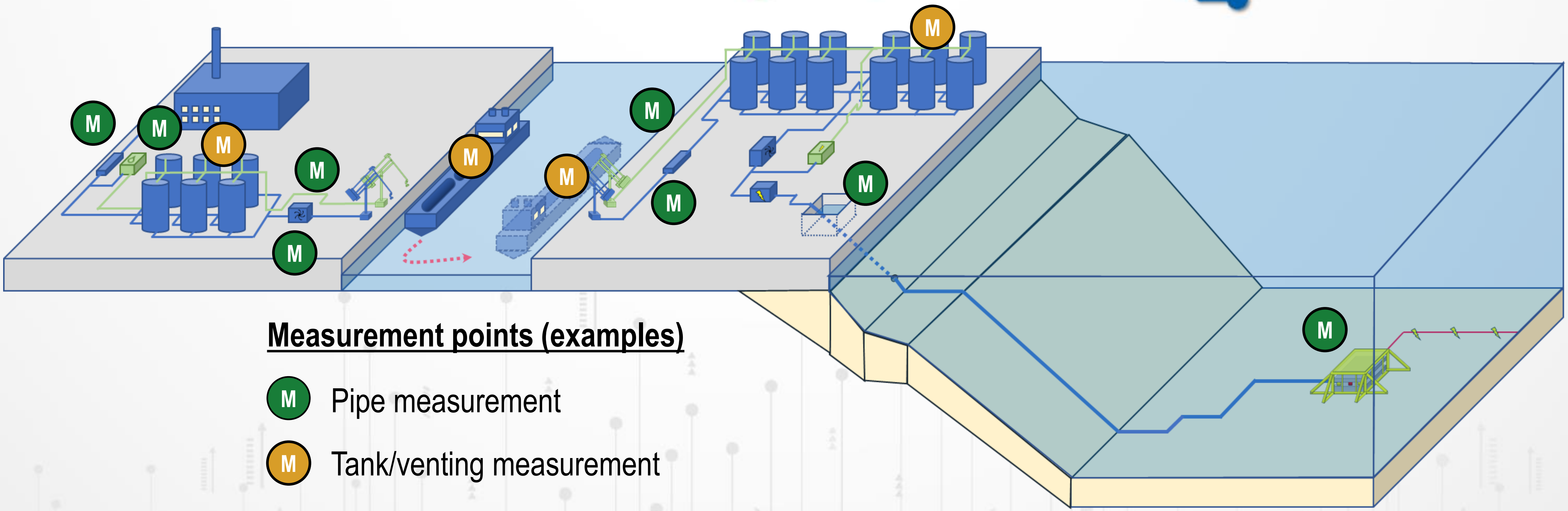
Regulations

- The COMMISSION REGULATION (EU) No 601/2012 of 21 June 2012:
  - From paragraph 49, section 4: For determining the quantity of CO2 transferred from one installation to another, the operator shall apply tier 4 as defined in section 1 of Annex VIII: ±2.5%, mass based.
- Company specific requirements or future national regulations may be stronger

Tiers for CEMS (maximum permissible uncertainty for each tier)

	Tier 1	Tier 2	Tier 3	Tier 4
CO_2 emission sources	± 10 %	± 7,5 %	± 5 %	± 2,5 %
N_2O emission sources	± 10 %	± 7,5 %	± 5 %	N.A.
CO_2 transfer	± 10 %	± 7,5 %	± 5 %	± 2,5 %

Schematic overview CO2 transport chain



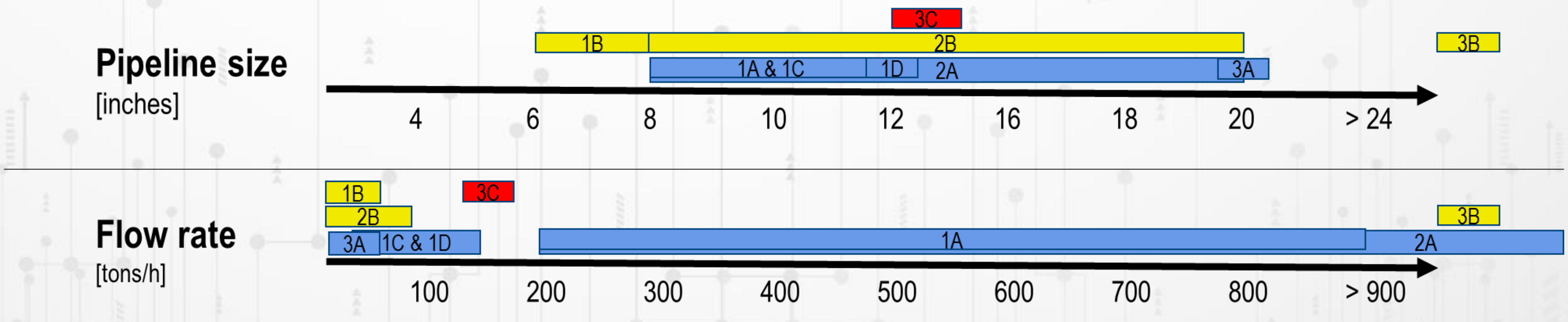
Measurement points (examples)

- M — Pipe measurement
- M — Tank/venting measurement

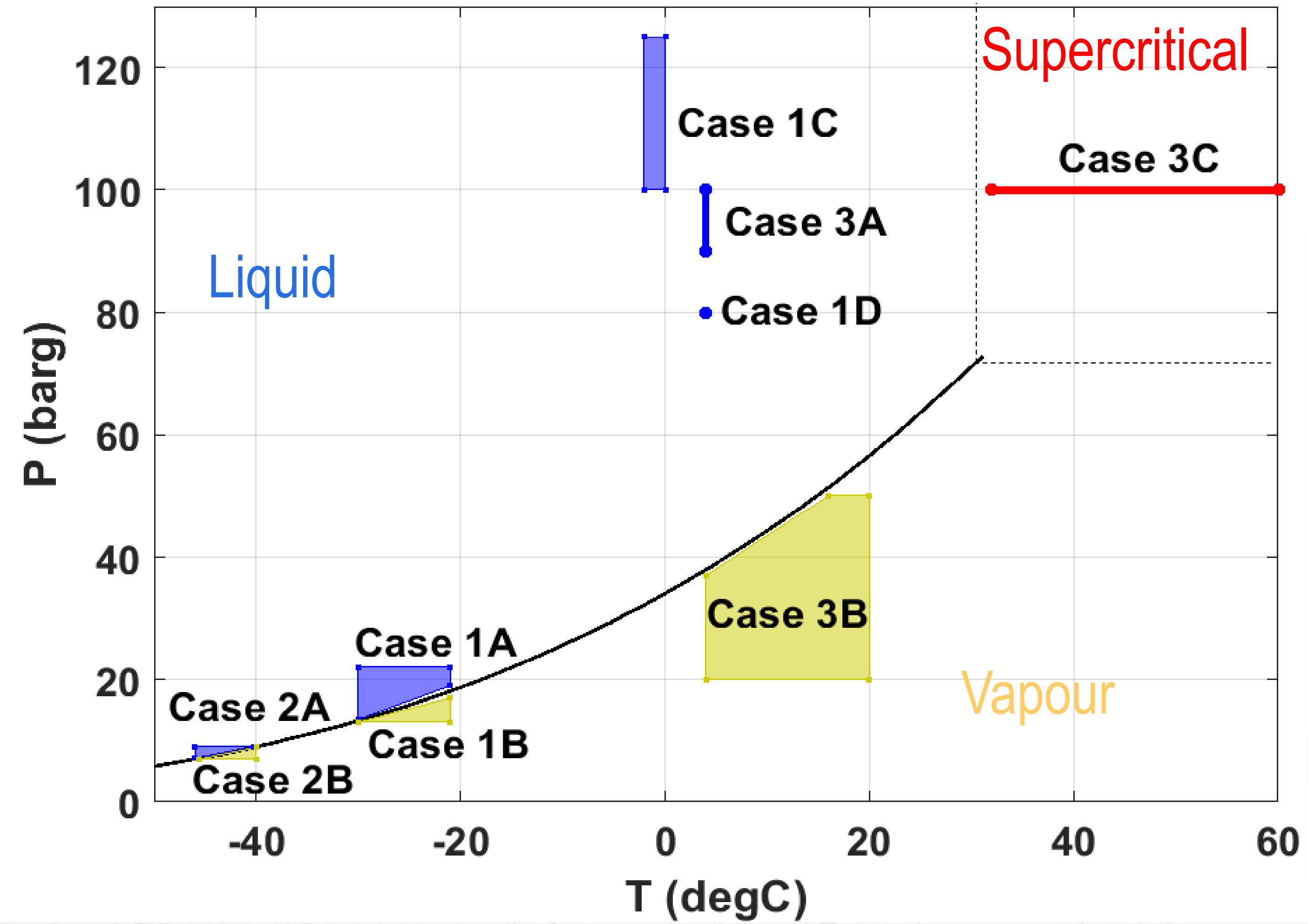
Required measurement points: Ownership transfer and injection

9 measurement cases considered

	Liquid				Vapour		Supercritical
	Ship load/off-load	Injection	Wellhead	Pipeline reuse	Ship load/off-load	Pipeline reuse	
1. Northern Lights medium pressure	1A	1C	1D		1B		
2. Northern Lights low pressure	2A				2B		
3. Offshore pipeline (re-use)				3A		3B	
4. Onshore pipeline							3C



Cases placed in PT-diagram



	Liquid				Vapour		S
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1. Northern Lights medium pressure	1A	1C	1D		1B		
2. Northern Lights low pressure	2A				2B		
3. Offshore pipeline (re-use)				3A		3B	
4. Onshore pipeline							3C

Content

Screening of technologies

- Screening of CO_2 metering technologies for pipe flow
- Goal: Prepare a shortlist of technologies for further review
- Main focus on metering of pure, single phase CO_2
- Sensitivity to other phases and/or impurities also considered

Considered technologies
Coriolis
DP technologies (focus on Venturi)
Turbine
Ultrasonic
Calorific
Gamma technology
Geared impeller
Heat transfer/Hastings
Pitot tubes
Positive displacement
Radiation attenuation
Rotary vane
Vortex

Shortlisted technologies

- Four shortlisted technologies
  - Coriolis
  - DP technologies (focus on Venturi)
  - Turbine
  - Ultrasonic
- All applicable to pure single-phase gas, liquid and supercritical CO2
- All used for custody transfer for oil/natural gas

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Turbine
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Vortex

Evaluation of shortlisted technologies

- Detailed evaluation based on
  - Literature review
  - Application of technology for other fluids
  - Communication and discussions with multiple vendors for each technology
  - Project partners' extensive experience (NORCE, Equinor, Total, Gassco)
  - Calculations and considerations

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	Ultrasonic	Coriolis	Venturi	Turbine
Pure Gas	OK	OK	OK	OK
Pure Liquid	OK	OK	OK	OK
Pure Supercritical	OK	OK	OK	OK
Meter output				
Gas + some liq.				
Liquid + some gas				
Gas + Impurities				
Liquid + Impurities				
Pressure drop				
Installation req.				
Pipeline size				
Subsea				
Comments				

Evaluation of shortlisted technologies

- Meter output
  - Coriolis measures CO_2 mass directly
  - Other technologies get density via
    - Equation of State (EoS) via measured P/T
    - Densitometer

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Pressure drop	Low	Perm. + Dynamic	Perm. + Dynamic	Perm. + Dynamic
Installation req.	Flow cond.	No	Flow cond.	Flow cond.
Pipeline size	Liquid OK, gas limited	Max 16 inch (or less)	All OK	Max 24 inch
Subsea	Gas	Potential	OK	No
Comments	- Volume based - Two-phase flow challenging - No known installations + Multiple vendors positive	- Large meter size & high cost - Max ~16 inch - Pressure drop. + Used for ship load/offload & in CO2 flow rigs	- Two-phase flow challenging - No known installations + Large pipelines + Lower density to sensitivity	- Least versatile - Maintenance + Not sensitive to density var. + Large pipelines + One vendor possible for liq.

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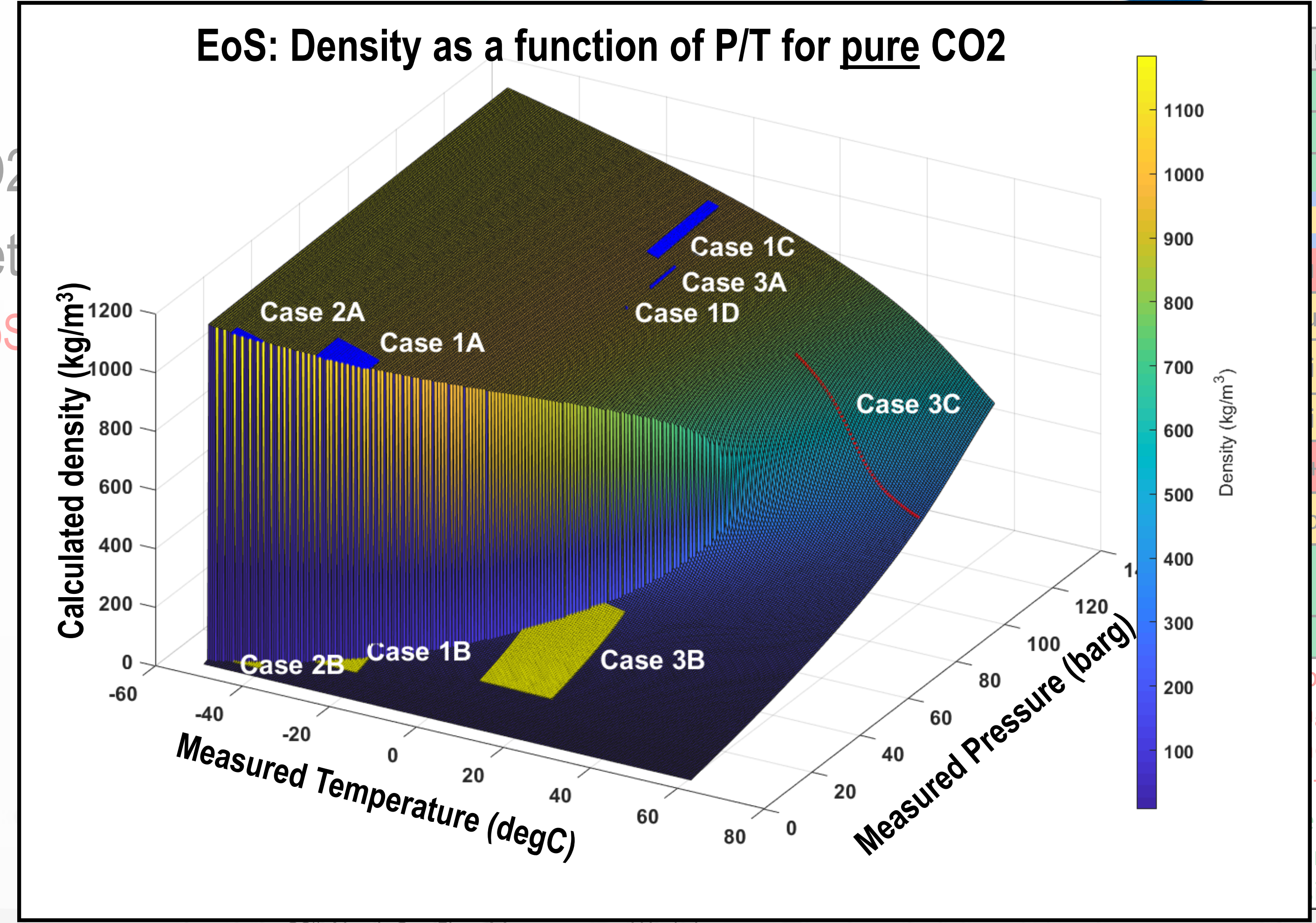

ri	Turbine
	OK
	OK
	OK
	Volume
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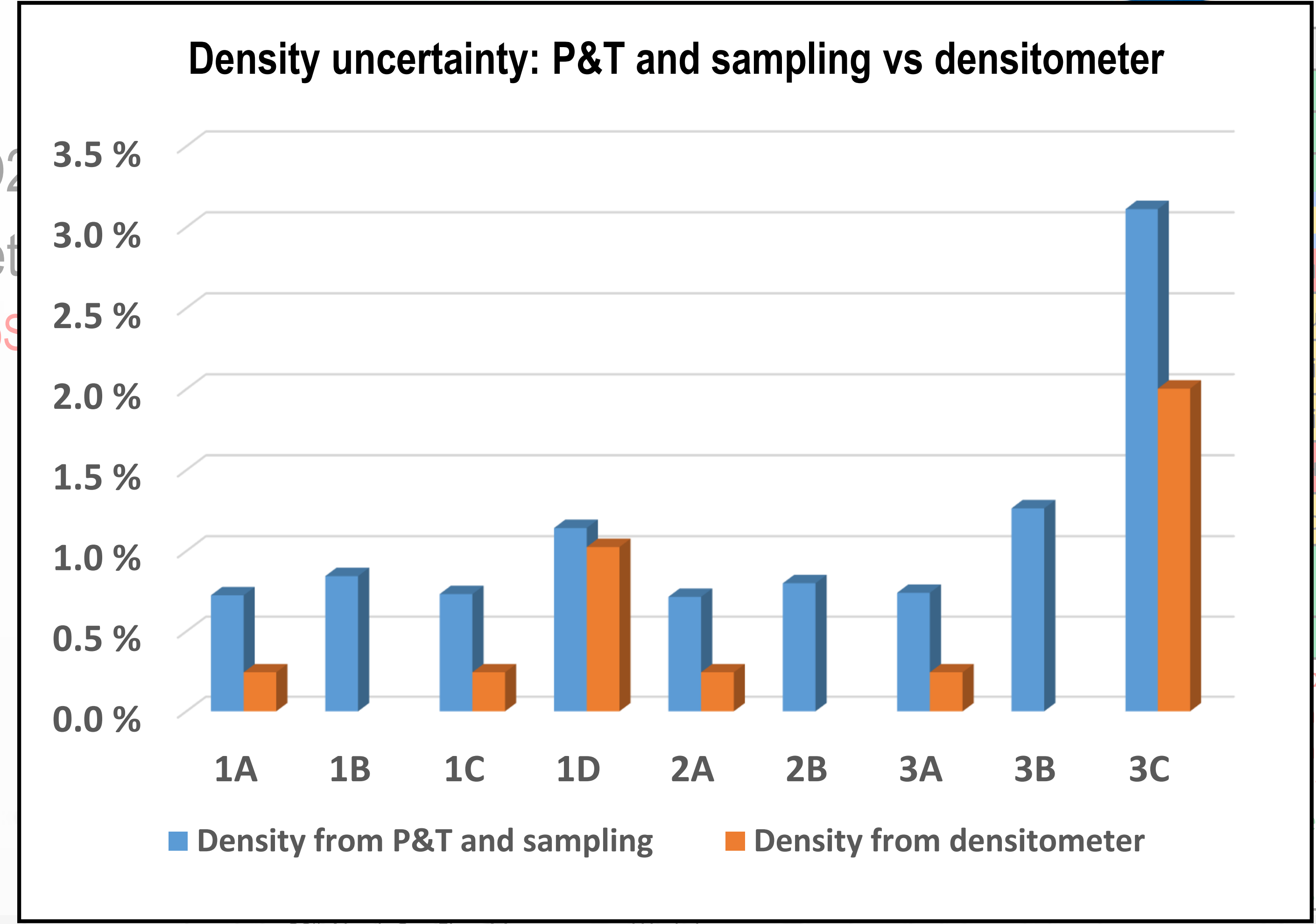

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Evaluation of shortlisted technologies

- Presence of other phases
  - Coriolis best suited, Turbine worst
  - Density EoS evaluation gives increased uncertainty

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Evaluation of shortlisted technologies

- Impurities
  - Coriolis best suited – all technologies may handle small amounts
  - Density EoS evaluation gives increased uncertainty

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Pure Liquid	OK	OK	OK	OK
Pure Supercritical	OK	OK	OK	OK
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Evaluation of shortlisted technologies

- Pressure drop
  - Important due to phase transitions
  - Ultrasonic lowest pressure drop

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Evaluation of shortlisted technologies

- Installation requirements
  - All except Coriolis need flow conditioning

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Evaluation of shortlisted technologies

- Pipeline size restrictions
  - Max ~16 inch pipeline for Coriolis - very large & high cost for large pipelines
  - Limited meter size for Ultrasound gas

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Evaluation of shortlisted technologies

- Subsea usage
  - Venturi best suited

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Evaluation of shortlisted technologies

- Summary
  - All technologies feasible & low uncertainty (well below 1% for pure single-phase CO2)
  - Two-phase flow & impurities increase uncertainty more for some technologies
  - Installation effects & calibration/verification approach are key uncertainty contributions

Detailed evaluation & uncertainty analysis should be made for each measurement case/scenario

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Content

Mapping: Case vs technology

- Each case mapped to the four shortlisted technologies

	Ship load/off-load		Injection	Wellhead	Ship load/off-load		Pipeline re-use				Supercr.
	1A - liquid	1B - vapour	1C - liquid	1D - liquid	2A - liquid	2B - vapour	3A - liquid Topside	3A - liquid Subsea	3B - vapour Topside	3B - vapour Subsea	3C - supercritical
USM	suitable	suitable	suitable	possible	suitable	suitable	suitable	possible	suitable	possible	unsuitable
Venturi	possible	suitable	possible	possible	possible	suitable	possible	possible	suitable	possible	possible
Coriolis	suitable	suitable	suitable	possible	suitable	suitable	suitable	possible	unsuitable	unsuitable	suitable
Turbine	unsuitable	unsuitable	suitable	unsuitable	unsuitable	unsuitable	suitable	unsuitable	unsuitable	unsuitable	unsuitable
	Northern lights medium pressure				Northern lights low pressure		Offshore pipeline re-use				Onshore pipeline

suitable	possible	unsuitable

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Venturi											
Coriolis											
Turbine											
	Northern lights medium pressure				Northern lights low pressure		Offshore pipeline re-use				

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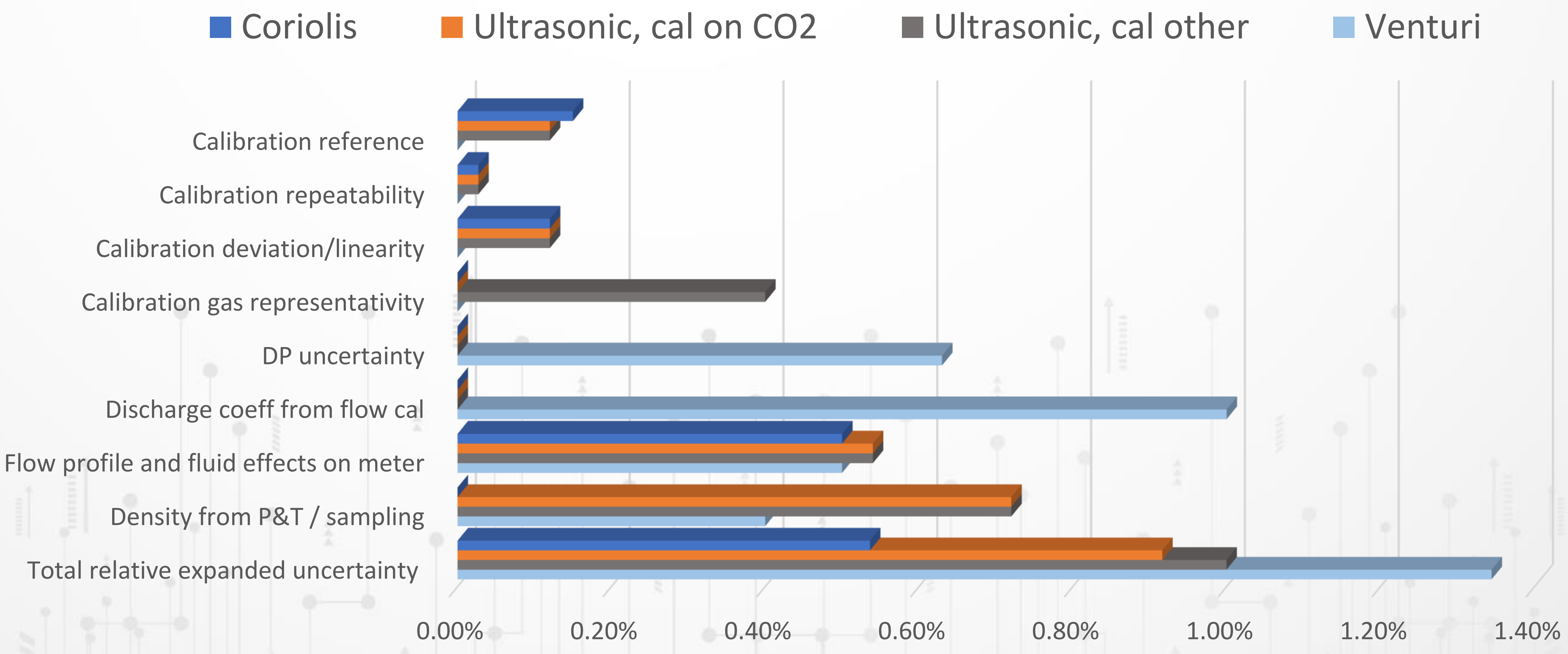
Uncertainty budget example: Case 1A



Mapping 1A – for low uncertainty requirement

For lowest CO_2 mass uncertainty (e.g. commercial agreements) – Example:

- Ultrasonic or Coriolis meter as duty meter
  - Turbine meter as master meter, regularly calibrated against a small volume prover.
  - Density from online densitometer.
  - Off- and on-loading process carefully regulated and monitored

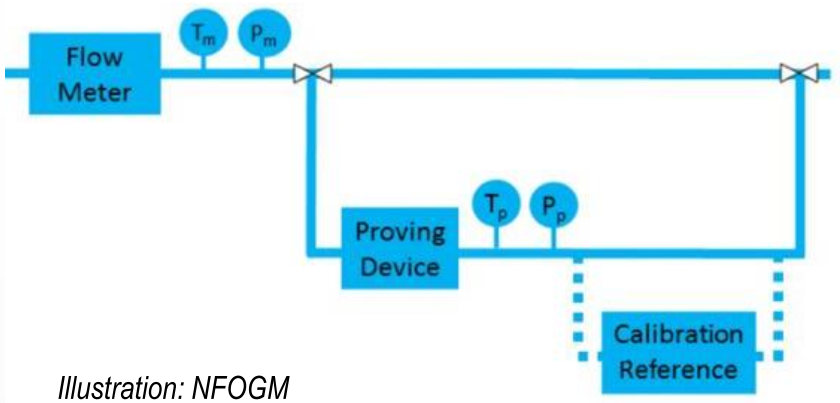


Illustration: NFOGM

- Two coriolis meters in rotation with regular calibration at flow loop
  - Would not minimize installation/flow profile effects

Mapping: Case vs technology

- Rough uncertainty estimate for each of the four shortlisted technologies

	Ship load/off-load		Injection	Wellhead	Ship load/off-load		Pipeline re-use		Supercr.
	1A - liquid	1B - vapour	1C - liquid	1D - liquid	2A - liquid	2B - vapour	3A - liquid Topside	3B - vapour Topside	3C - supercritical
USM	0.90%	1.20%	0.90%	1.50%	0.90%	1.20%	0.90%	1.50%	
Venturi	1.30%	1.80%	1.30%	2.00%	1.30%	1.70%	1.30%	1.80%	1.80%
Coriolis	0.50%	0.90%	0.50%	1.50%	0.50%	0.90%	0.50%		0.50%
Turbine			1.00%				1.10%		
	Northern lights medium pressure				Northern lights low pressure		Offshore pipeline re-use		Onshore pipeline

suitable	possible	unsuitable

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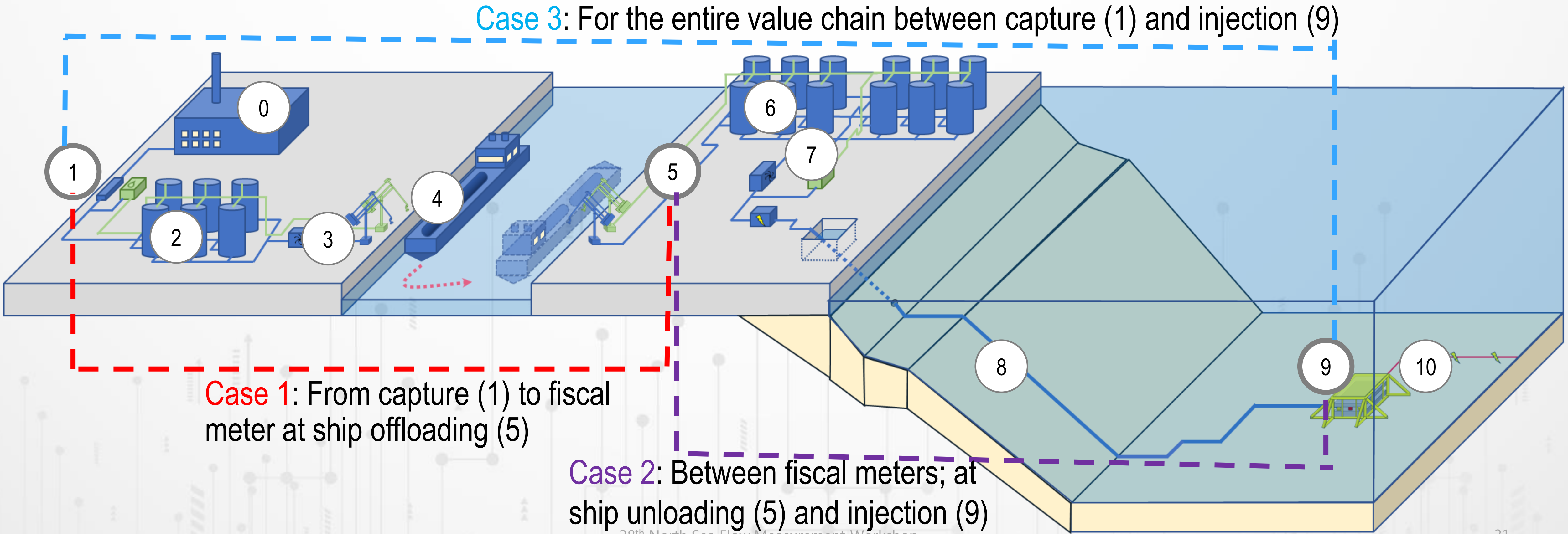
Schematic overview for mass balance calculations

- Mass balance equations and uncertainty models set up for 3 cases:

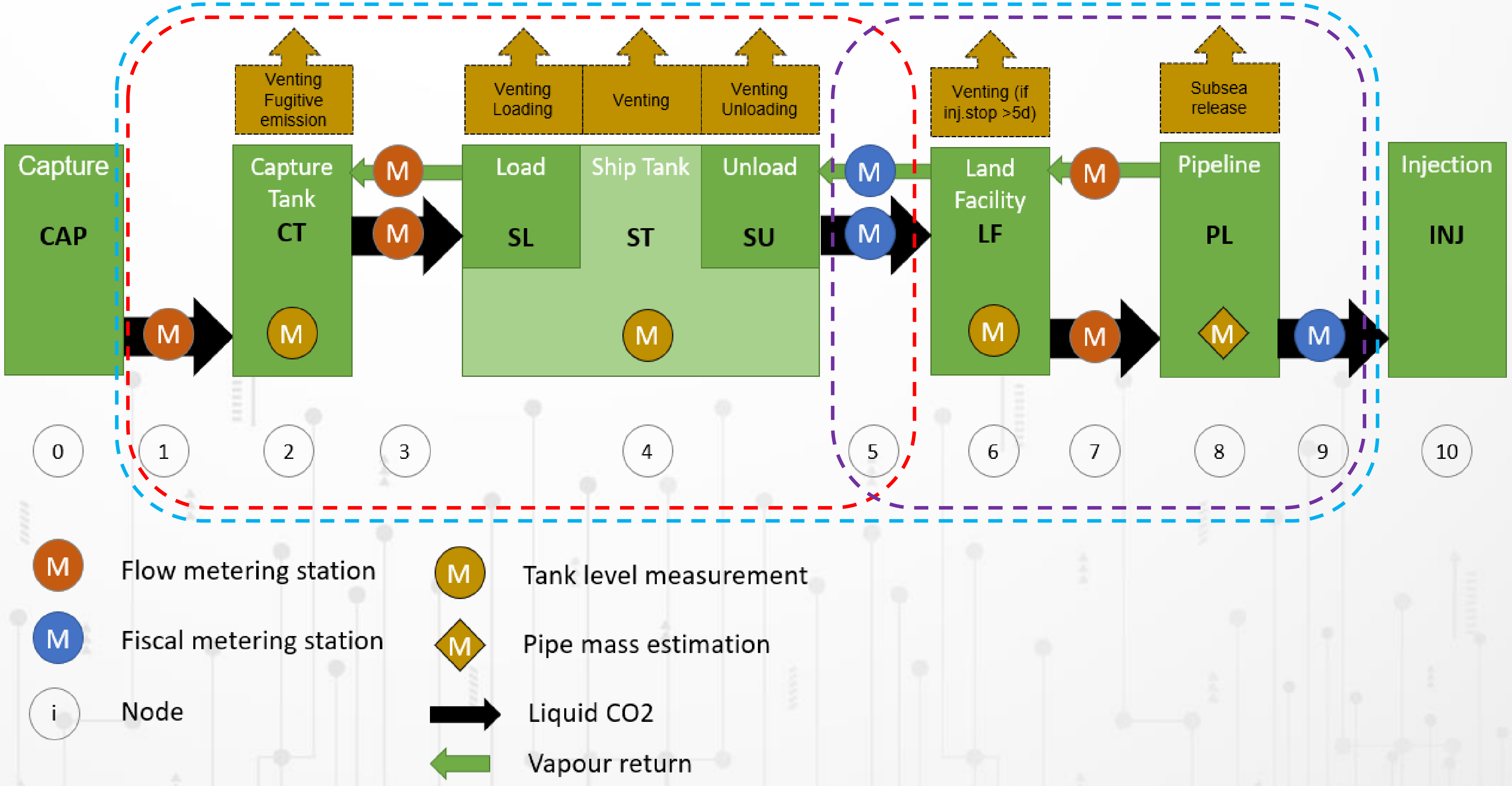


Mass balances between different measurement points

Evaluation for each case:

If mass balance is higher or lower than associated *mass balance uncertainty*, this indicates either:

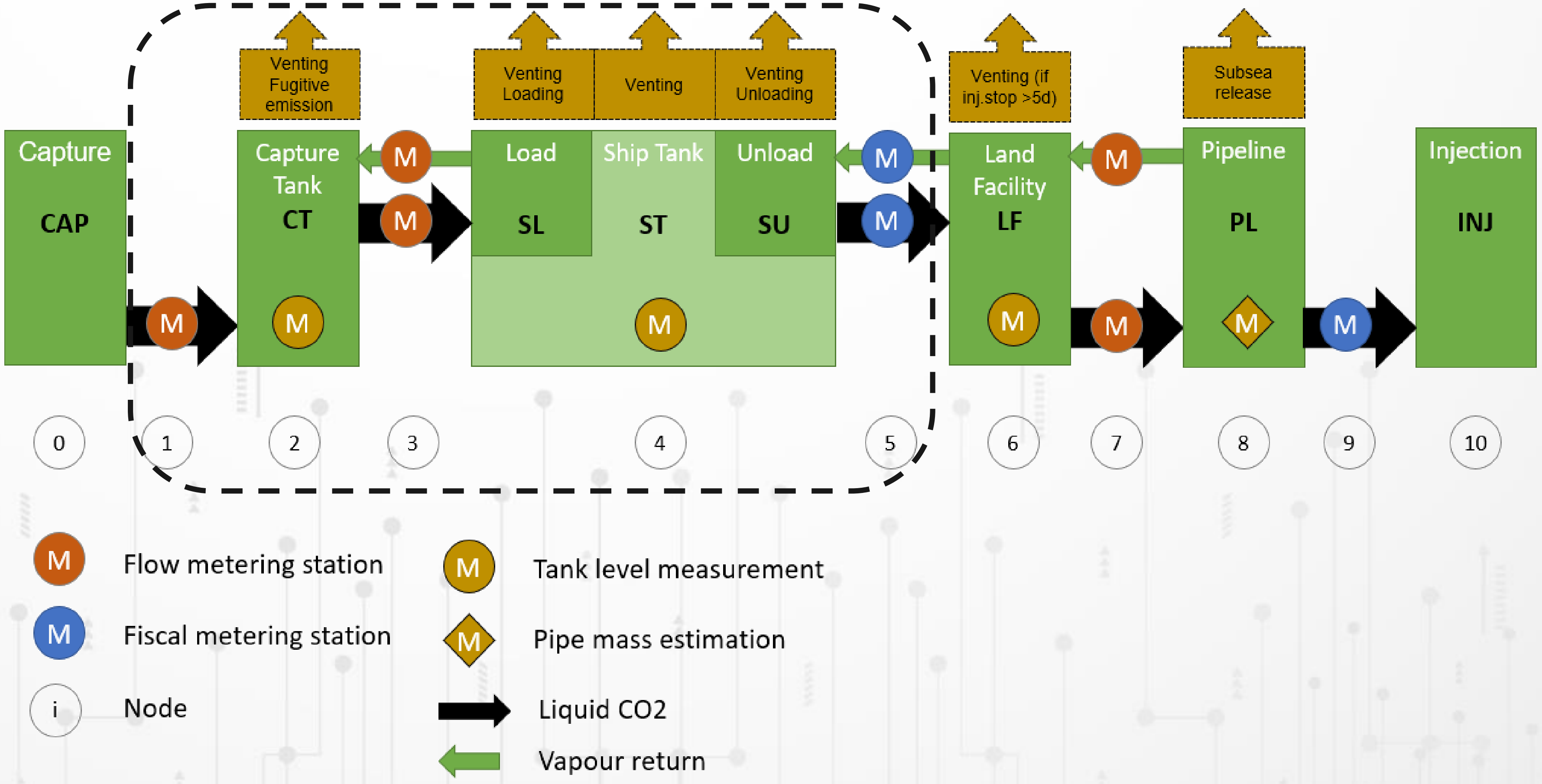
- one or more systematic measurement errors in the system or
- leakage to the atmosphere (for mass balance <0)



Case 1: Mass balance from capture to fiscal meter at ship offloading

CASE 1: Mass balance from capture to fiscal meter at ship offloading	
Mass (mass/period)	-10,9
Mass balance inside uncertainty limit	
U (mass/period)	15,1
U* relative to inflow	1,5 %

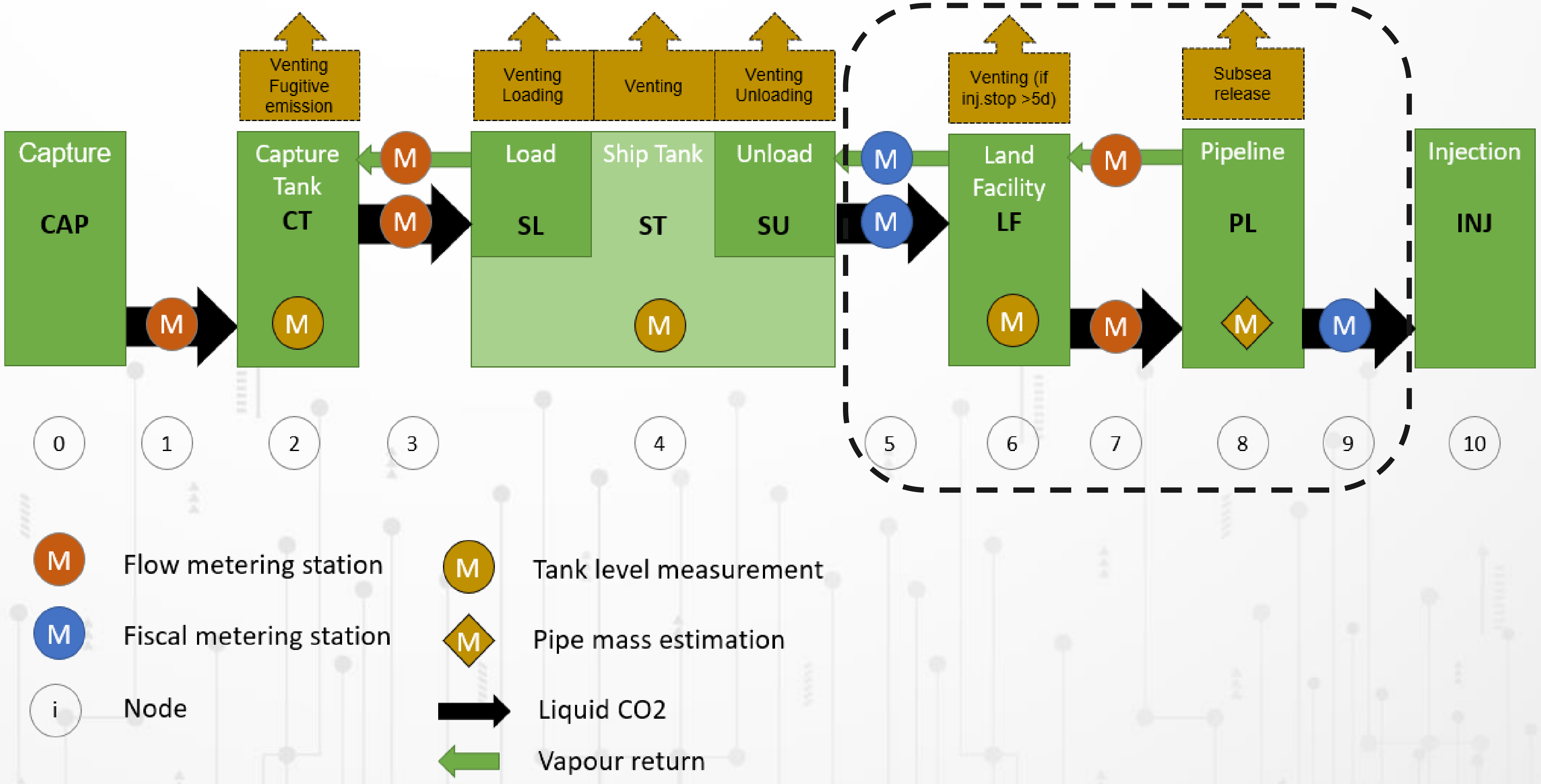
(example)



Case 2: Mass balance between fiscal meters (ship unloading and injection)

CASE 2: Mass balance between fiscal meters (ship unl. - injection)	
Mass (mass/period)	-17,5
Mass balance outside uncertainty limit. Possible undetected leakage.	
U (mass/period)	13,9
U* relative to inflow	1,3 %

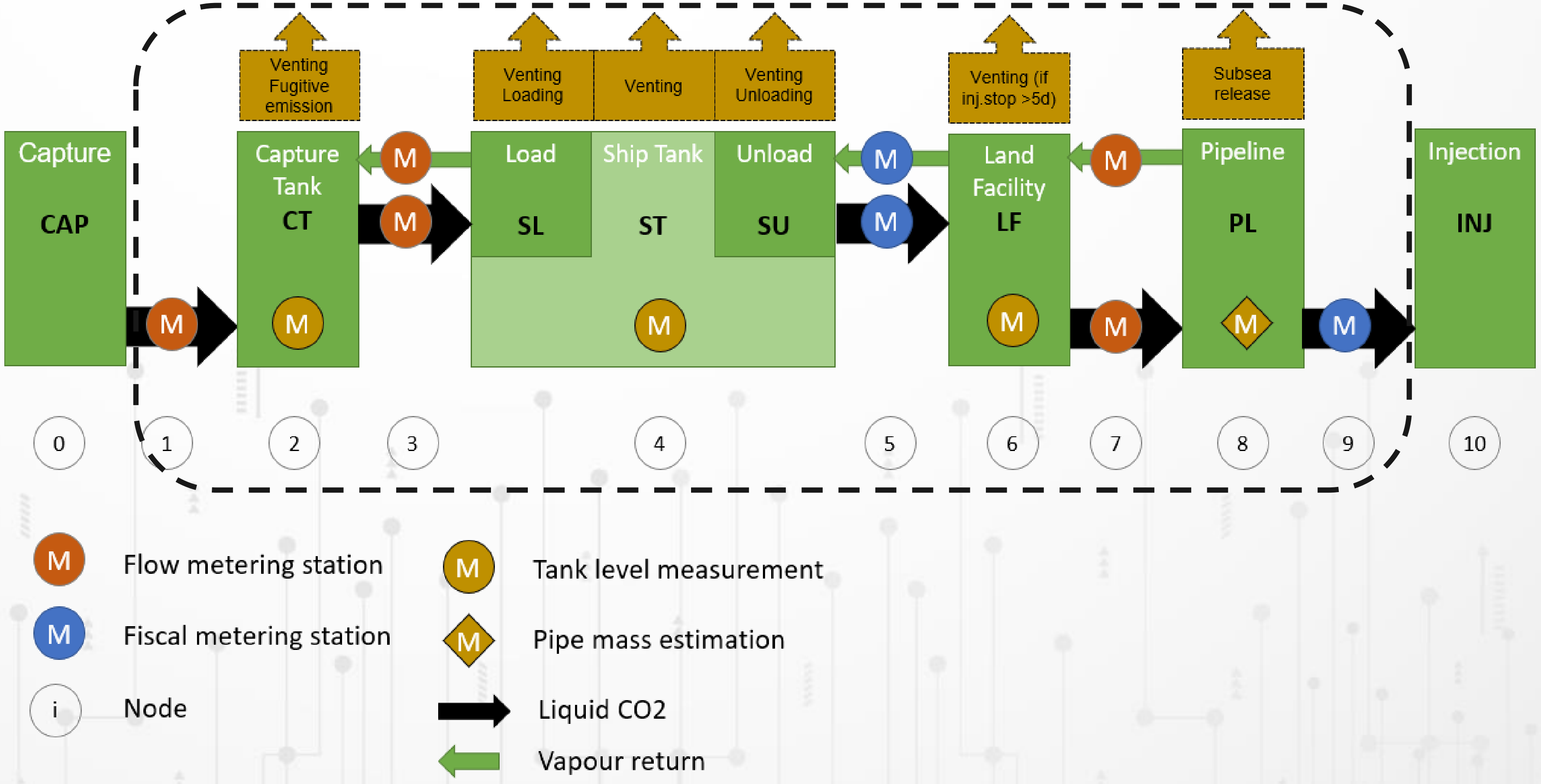
(example)



Case 3: Mass balance for the entire transport chain between capture and injection

CASE 3: Mass balance for the entire value chain between capture and injection	
Mass (mass/period)	-28,4
Mass balance outside uncertainty limit. Possible undetected leakage.	
U (mass/period)	13,8
U* relative to inflow	1,4 %

(example)



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- **CO_2 calibration facilities**

Test sites for testing of CO2 flow meters

- Calibration/testing of CO2 flow meters necessary for traceable uncertainties
- Scope: Identify test sites for testing of CO2 flow meters
  - Sites which are already prepared for calibration of CO2 flow metering
  - Laboratories interested in extending their business to cover CO2 metering
  - World market
- Approach
  - First stage e-mail / phone conversations
    - Current capabilities, plans, possibilities, requirements for establishment
    - Functionality testing or calibration?
  - Second stage
    - Level of certification, reference instrumentation, calibration range, fluid phase

Test sites for testing of CO_2 flow meters

- FortisBC Energy
  - Current full-scale certified calibration facilities for CO_2 gas flow turbine meters.
  - Working towards accreditation also for Ultrasonic and Coriolis meters.
- DNV GL in the Netherlands
  - Adding to their multiphase flow loop to be able to calibrate CO_2 gas flow meters
  - Aiming for Calibration and Measurement Capability (CMC) $< 0.25\%$
- Several smaller scale facilities exist
- Several other organizations are interested in, or have plans for, CO_2 test facilities, depending on funding and/or market increase

Summary

- Four measurement technologies have been identified as feasible for CO2 mass measurements for Northern Lights and other CCS applications
- Optimal technology and achievable measurement uncertainty strongly dependent on conditions at measurement point
- Mass balance uncertainty evaluations can be used for detecting leakages to atmosphere
- Some sites propose calibration of CO2 gas flow meters, and several others are interested depending on funding and market increase

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