Cignus: An ancient roman measuring spoon

Creating next generation high-accuracy Coriolis flow meters – breaking through current technology barriers

By Martin Nese, CEO Cignus Instruments AS

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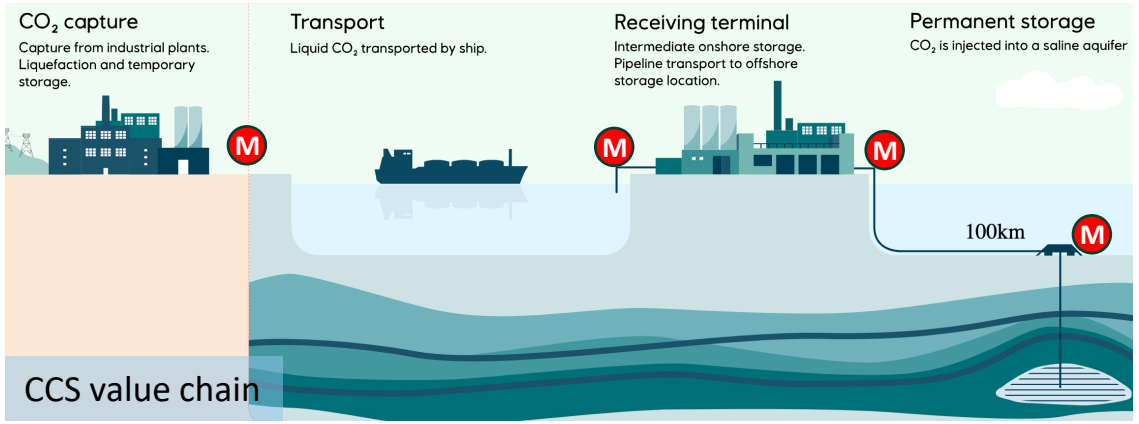
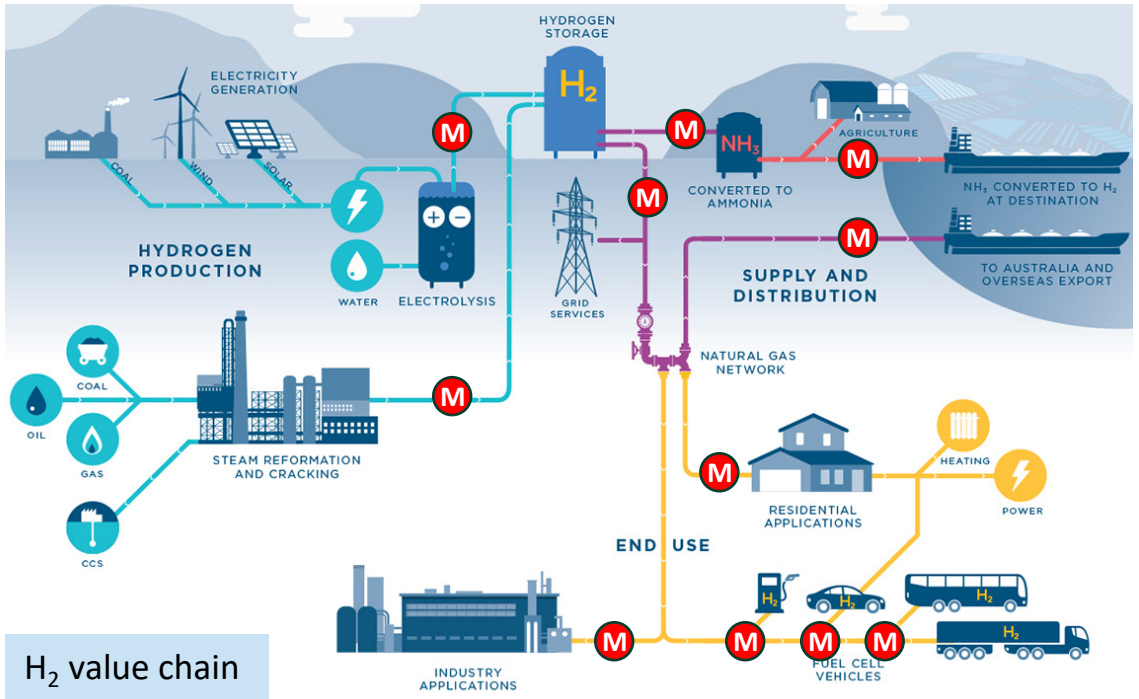
Cignus will be an enabler for efficient H_2 and CCS value chains

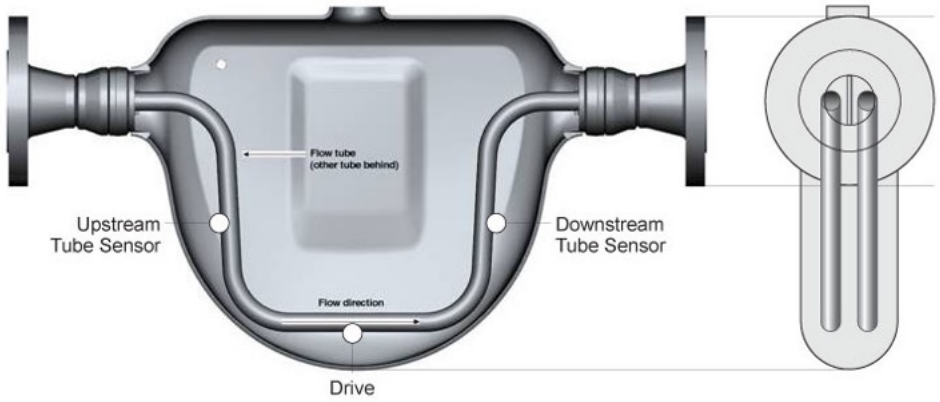
- Industrializing novel and patented technology for direct mass-flow metering of liquids and gases
- Solving technology gaps for large-scale CCS and H_2-metering
- Competitive advantages throughout emerging H_2 and CCS value chains
- Cignus is an enabler for more efficient value chains
- Development is supported by Research Council of Norway and Gassnova - Climit in partnership with Equinor, TotalEnergies, TechnipFMC, NEL Hydrogen and Gassco

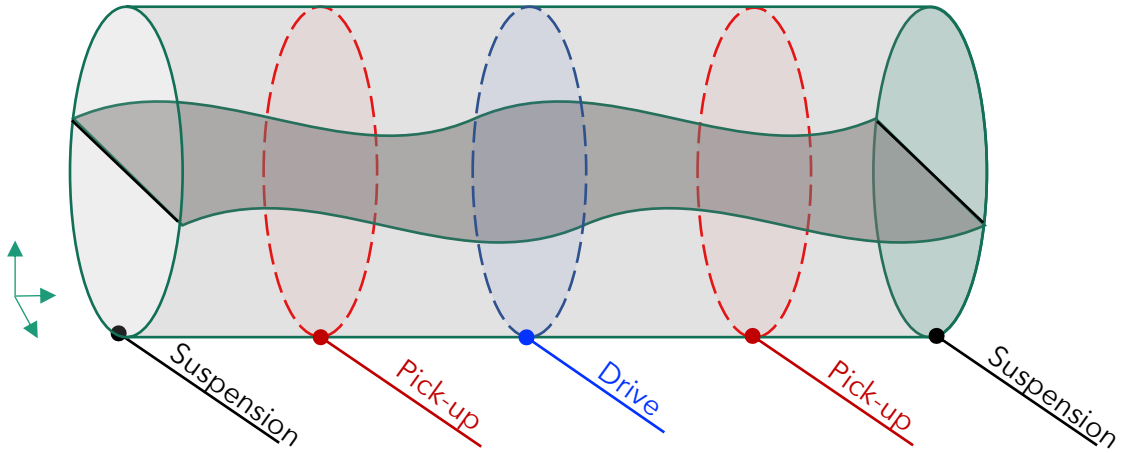




SOURCE: Illustration and picture from Northern Lights

Solving technology gaps when scaling H_2 and CCS





Traditional Coriolis Flowmeters

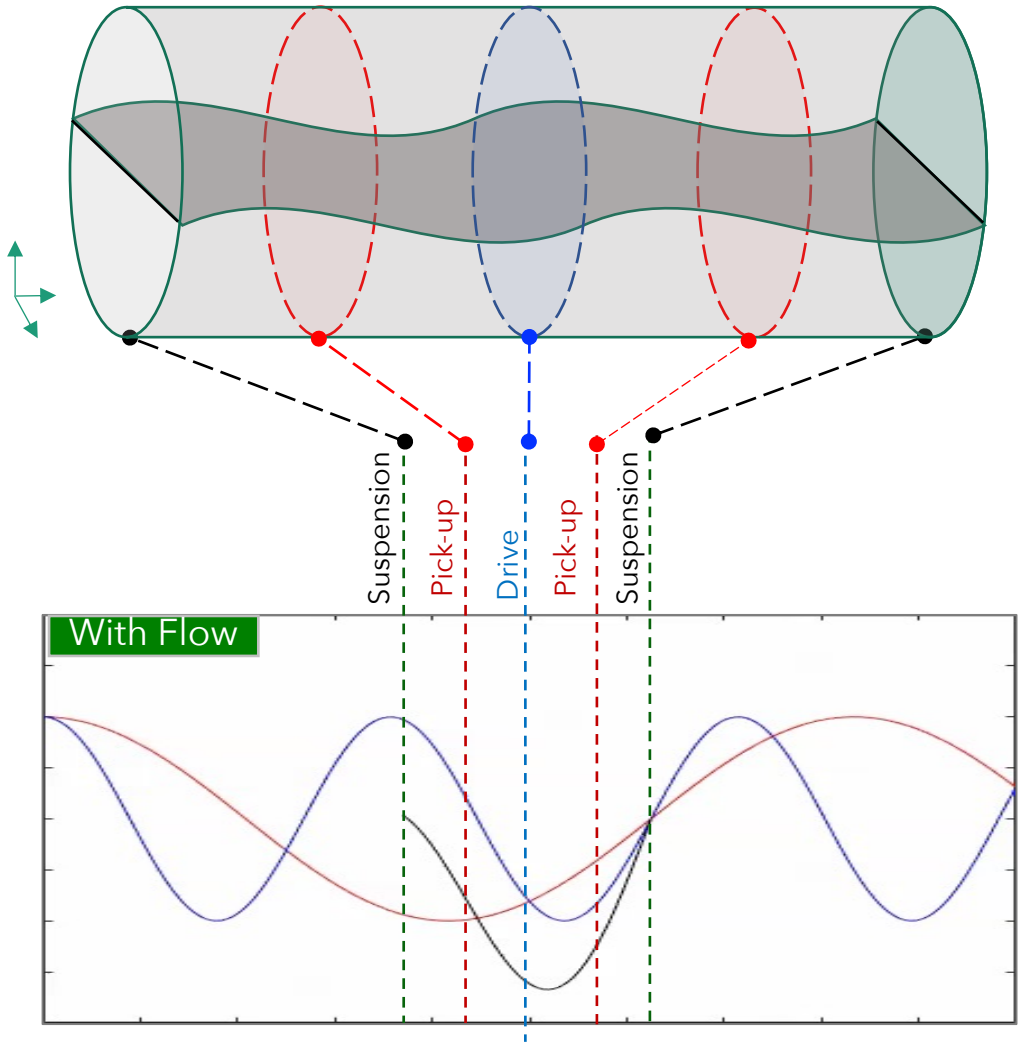
- Pipe is both sensor structure and pressure containment
- High accuracy, regarded as current state of art
- Measure direct mass flow and fluid density
- Challenging for large diameter pipes and thick walls
- High operational pressure limits the sensitivity
- Significant internal pressure loss
- Sensitive to line-pressure
- Not qualified for submerged installations
- Compromise between sensor and containment function

Cignus Flowmeters

- Sensing structure independent of pressure bearing pipe
- High accuracy, same as for traditional Coriolis
- Measure direct mass flow and fluid density
- Suited for large diameter pipes and thick walls
- High operational pressure
- Very low internal pressure loss
- Insensitive to line-pressure
- Well suited for submerged installations
- No compromise between sensor and containment function

Technology principle – rigid pipe with flexible plate inside

- Flexible plate stiffness adapted to applications independent of rigid pipe pressure capability
- Flexible plate suspended to pipe in end-points
- Flexible plate motion actuated wireless by electromagnetic system in centre position
- Flexible plate motion recorded wireless by electromagnetic system in pick-up locations
- Same basic physics as for coriolis mass flow meter
- Mass-flow proportional with time delay between upstream and downstream pick-up signals
- Density inversely proportional with eigenfrequency[2*)] of flexible plate with fluid



*) Natural frequency, also known as eigenfrequency, is the frequency at which a system tends to oscillate in the absence of any driving or damping force.

Significant limitations in existing technologies for liquid CO_2

- Screening study for Northern Lights CCS-project
  - Significant limitations for all shortlisted technologies
  - Ultrasound limited as a volumetric measurement, and additional issues with sound attenuation, bubbles and particles causing increased uncertainty
  - Coriolis limited by internal pressure drop, pipeline size, operational pressure and not qualified for subsea
- Cignus technology will meet all requirements for CCS

Table 2 - Applicability for CO2 metering for shortlisted technologies.

	Ultrasonic	Coriolis	Venturi	Turbine
Pure Gas	OK	OK	OK	OK
Pure Liquid	OK	OK	OK	OK
Pure Supercritical	OK	OK	OK	OK
Meter output	Volume	Mass	Mass*	Volume
Gas + some liq.	Potential issues	Can be handled	High uncertainty	May damage meter
Liquid + some gas	Potential issues	Can be handled	Increased uncertainty	May damage meter
Gas + Impurities	Potential issues	Can be handled	Potential issues	Potential issues
Liquid + Impurities	Potential issues	Can be handled	Potential issues	Potential issues
Pressure drop	Low	Permanent + Dynamic	Permanent + Dynamic	Permanent + Dynamic
Installation req.	Flow conditioning	No	Flow conditioning	Flow conditioning
Pipeline size	Fluid OK, gas limited	Max 16 inch (or less)	All OK	Max 24 inch
Subsea	Gas	Potential	OK	No

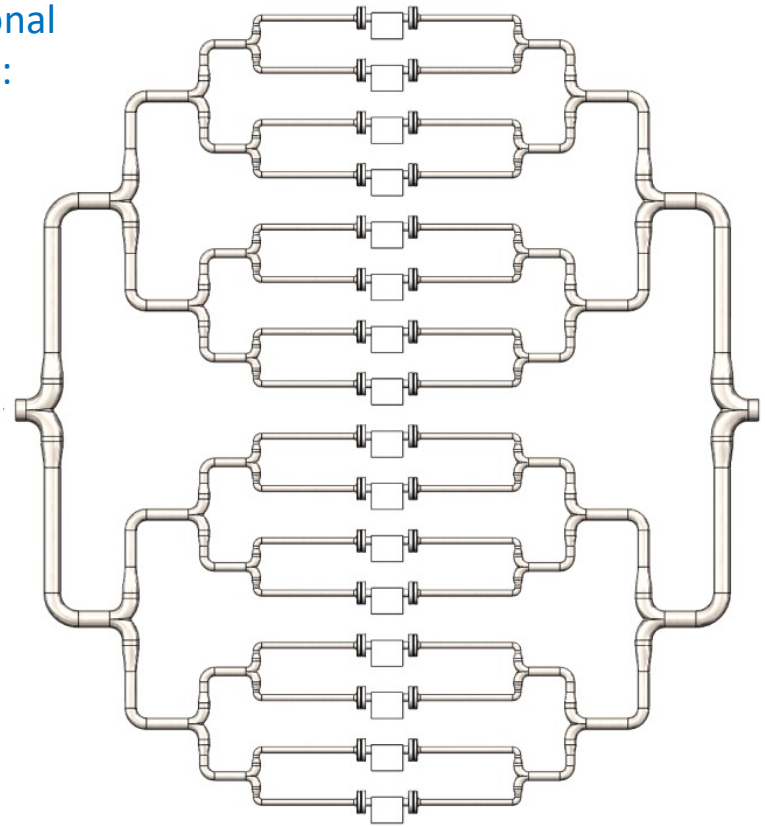
** Requires input of density to calculate mass or volume flow rate. May be considered as volume measurement.*

SOURCE: Where do we stand on flow metering for CO_2 handling and storage?, Kocbach et al, published at 38th International North Sea Flow Measurement Workshop October 2020.

CCS projects outside traditional Coriolis rating

- Woodside Browse: CO_2 separated from NG in FPSO
  - CO_2 injection to subsea in 8″ pipeline at 240 bar
  - Splitting into 16 parallel 2″ pipes to comply with current tech.
- Northern Lights Phase 2: Full scale CCS
  - CO_2 export to subsea in 12″ pipeline at 290 bar and 1000 tons/h
- Aramis CCS (NL): > 5 Mt/yr by 2030
  - Export to subsea in 10″ pipeline at ~ 200 bar
  - Material requirements at -78 °C additional challenge
- Equinor Smeaheia CCS
  - 25 – 35 Mt/yr CO_2 offshore pipeline at ~ 200 bar from Europe
  - Injection into 20–30 wells likely to require subsea metering
- East Coast Cluster (Uk)
  - 23 - 27 Mt/yr CO_2 offshore pipeline at ~ 130 bar
- Aramco Jubail CCS hub
  - 44 Mt/yr CO_2 capture and pipeline transport by 2035
- CCS ship transport and off-loading to subsea
  - Flow rate ~ 1000 tons/hr up to 300 bar
- DNV: Commercial calibration facility
  - Main test section 10 inch at 200 bar up to 1000 tons/hr
  - 3 parallel 6″ meters and piston prover as primary reference

Traditional Coriolis:

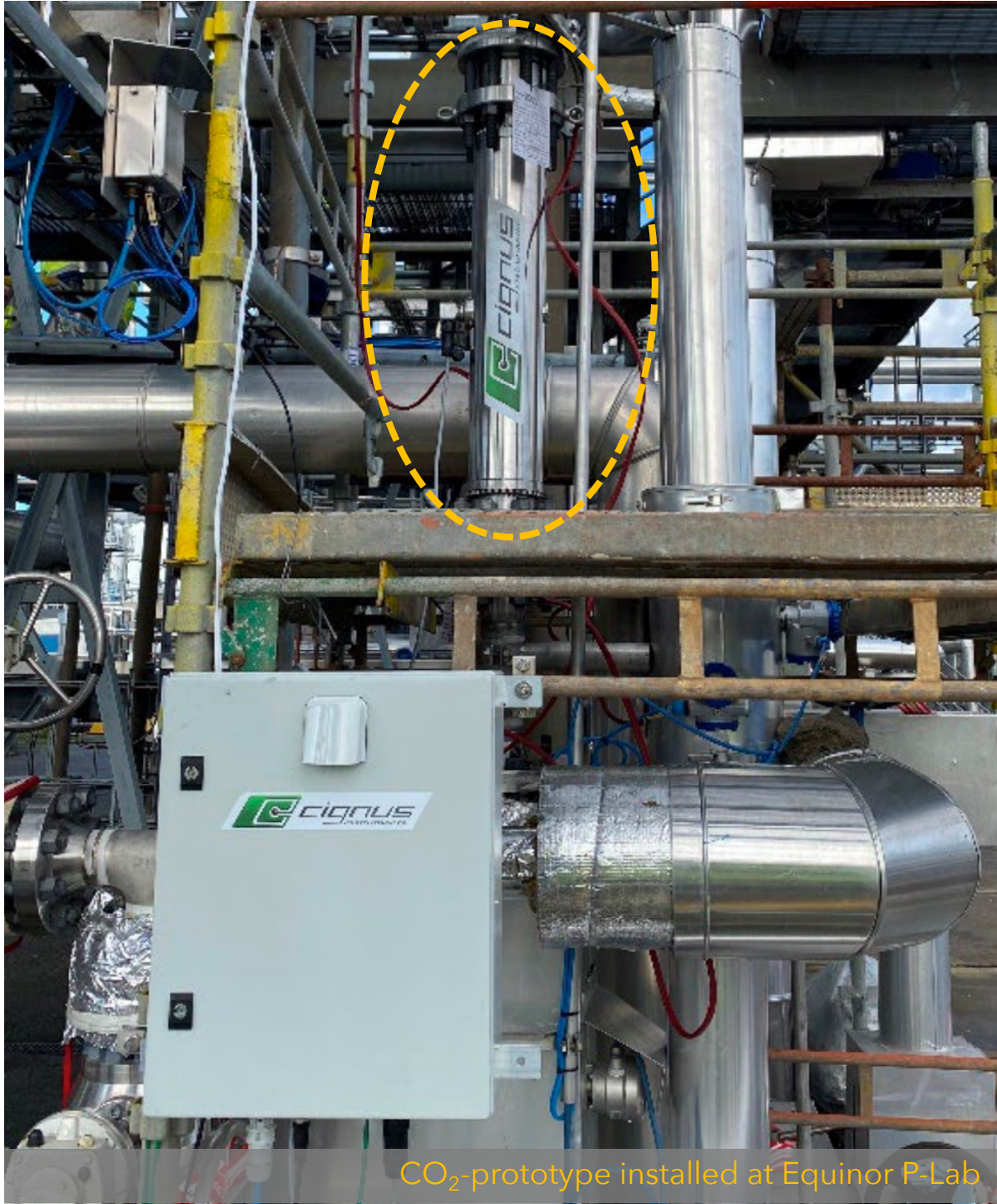


Cignus:

Woodside Browse field development
Northern Lights is a JV owned by Equinor, TotalEnergies and Shell

Testing confirms TRL6 for CCS

- Prototype designed for 50 tons/hr and 120 bar
  - Internal diameter ≈ 3″ and length ≈ 960 mm
  - Prototype design can easily be adapted to subsea
  - Robust full range signal 300 µs
- 3rd party testing and calibration confirming high accuracy potential
  - Excellent water-flow calibration error < 0.1%
  - N_2- and water-testing supports a wide range CO_2 metering applications
  - Mass-flow measurement not sensitive to pressure
  - Mass flow compensation with temperature and density measured internally
- CO_2-test campaign @ Equinor P-Lab (→ TRL6[2])
  - Performance comparable to traditional Coriolis meters
  - Pressure loss confirmed < 1/10 of Coriolis meters



CO_2-prototype installed at Equinor P-Lab

1) Falcon is a CO_2-test loop at Institute for Energy Technology (IFE)
2) EU Technology Readiness Level scale to TRL9

Water-flow calibration at 21°C

- Linearization
  - From Bilfinger (No) test up to 835 kg/min
  - No temperature compensation implemented
- Calibration @ Force Technologies (DK)
  - Similar temperature as linearisation
  - Flow rate from 100 to 1000 kg/min
  - Gravimetric reference uncertainty < 0.05%
  - Flying start and stop
  - Calibration error
    - 0.5 % of reading at 12% flow
      - Zeroing error
    - < 0.1 % of reading at 24% to 84% flow
    - 0.22 % at 120% flow
      - This is higher than linearized max flow

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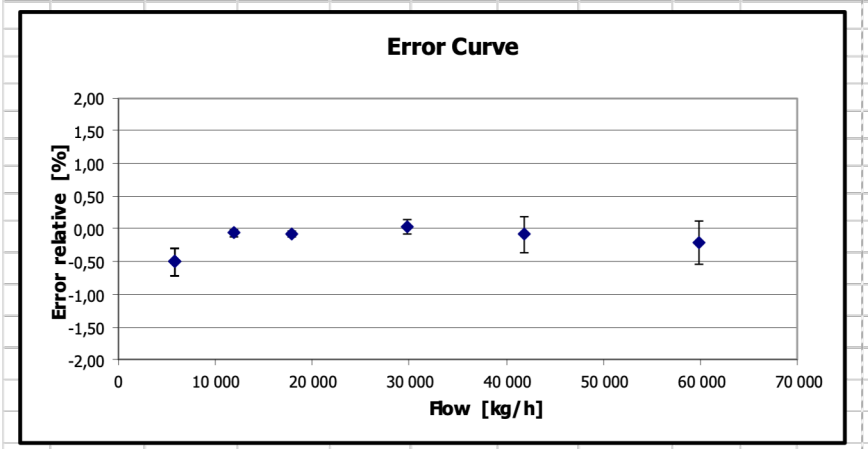
Calibration Results - Mass against weight

Serial No.: -

Customer ID: -

Flow nr	Actual flow [kg/h]	Indicated mass [kg]	True mass [kg]	Error absolute *** [kg]	Error relative [%]	u_{cmc} (k=1) [kg]	Uncertainty contribution DUT* (k=1) [kg]	U_{cal} ** (k=2) [%]	Count (n)
1	59.787,0	690,43	691,92	-1,49	-0,22	0,1730	1,151	0,33	3
2	41.886,0	691,27	691,86	-0,59	-0,09	0,1730	0,949	0,28	3
3	29.792,3	692,53	692,34	0,19	0,03	0,1731	0,362	0,11	3
4	17.844,4	692,13	692,66	-0,53	-0,08	0,1732	0,067	0,05	3
5	11.935,0	692,10	692,51	-0,41	-0,06	0,1731	0,166	0,05	3
6	5.770,9	688,90	692,39	-3,49	-0,50	0,1731	0,700	0,20	3



* The uncertainty contribution from the DUT includes contribution from reading and the standard deviation of the results.

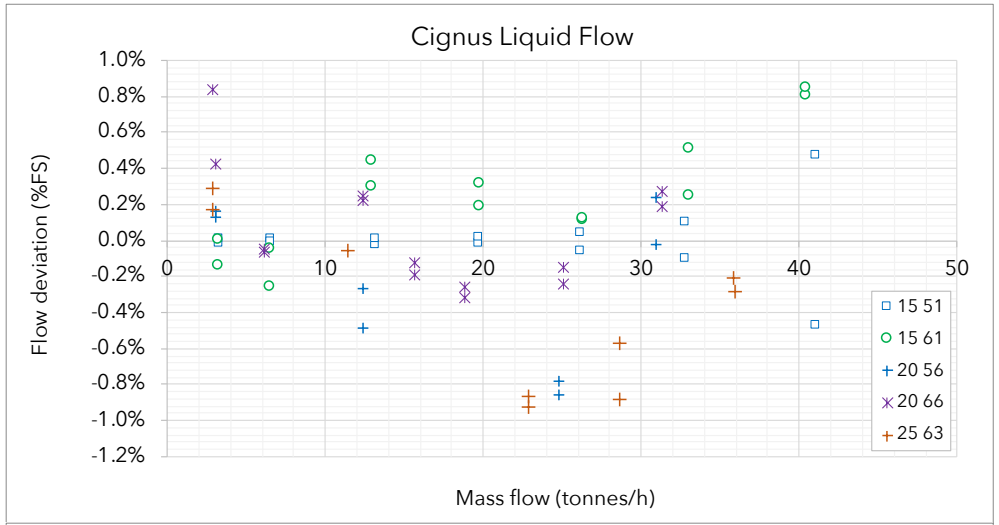
** U_{cal} includes the accredited uncertainty (u_{cmc}) and the contribution from the DUT.

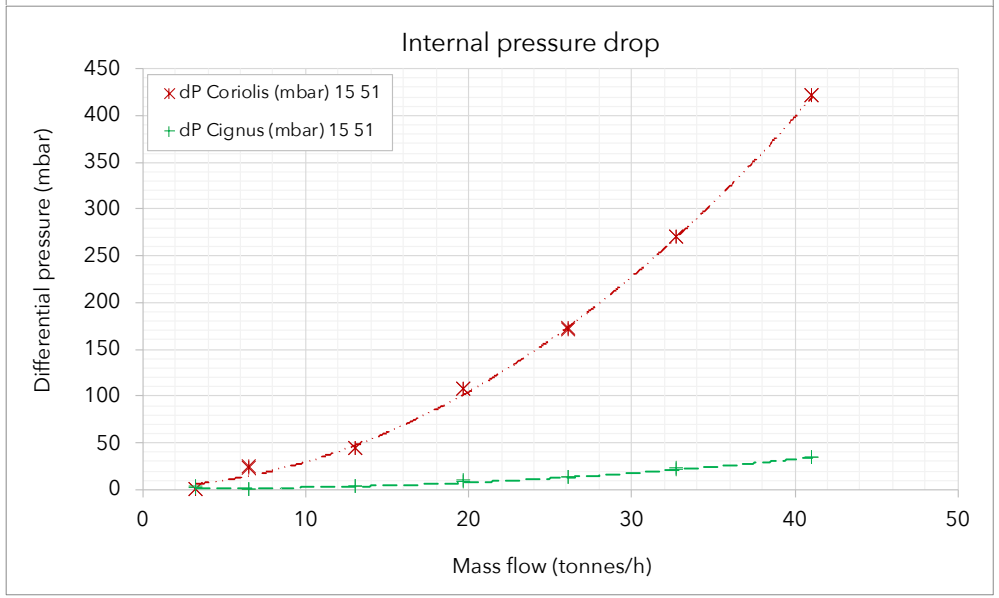
*** The results is based on repeated measurements, so the values in the columns "Indicated mass/volume" and "True mass/volume" is shown as rounded values. All calculation is done with full resolution.

Cignus mass-flow and density deviation in CO_2 similar to traditional Coriolis-meter

- Semi-industrial test facility
  - Facility adapted and commissioned to CO_2 for test campaign
  - Wide range test facility with uncertainty in the range 1 to 2 %
- Mass-flow deviation ≈ 1 %FS
  - Liquid CO_2 flow-rate from 3 to 41 tonnes/h
  - Compensated based on internal density and temperature
  - Algorithms still under development
  - Deviation similar to Coriolis located shortly upstream
- Density deviation from reference < 1.5 %
  - Gamma densiometer reference located ≈ 10 m upstream
- Pressure loss < 1/10 of same size Coriolis
  - Pressure drop measured across Cignus-meter and Coriolis-meter with direct dp-cells
  - Important to avoid risk for boiling and increased uncertainty
  - Pressure loss = energy loss

➢ Test results confirms TRL6[1] for CCS

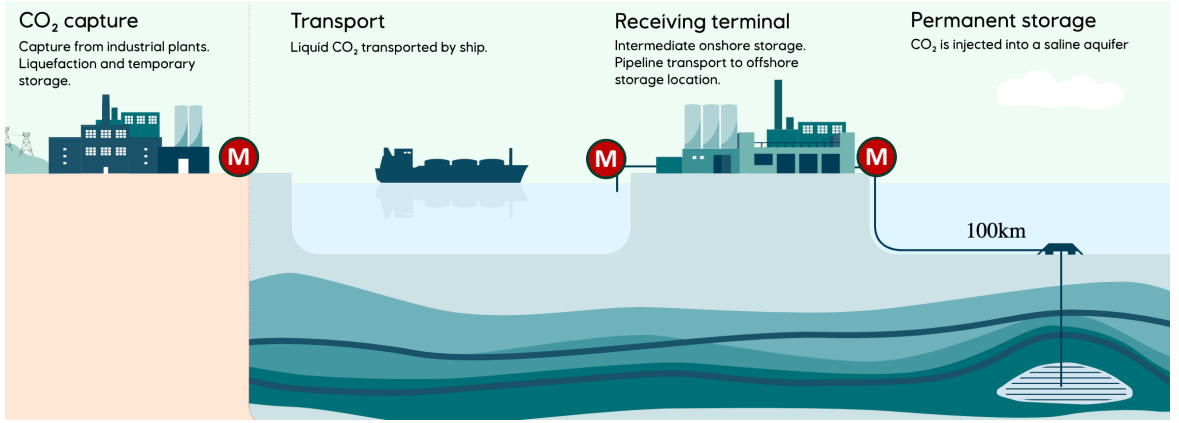




1) EU Technology Readiness Level scale to TRL9

Launching project to qualify CO_2-meter for large scale CCS

- Climit-grant awarded
  - Customer co-funding
  - Project start Q3/2024
  - Qualification to complete by H1/2026
  - Targeting to install in full-scale CCS-facility
- Full-size CO_2-meter design
  - Inner diameter 12"
  - Design pressure ≈ 300 bar
  - Full-range 1000 tons/hr
- Target applications
  - Large-scale pipeline transport
  - CO_2 ship carrier off-loading to subsea

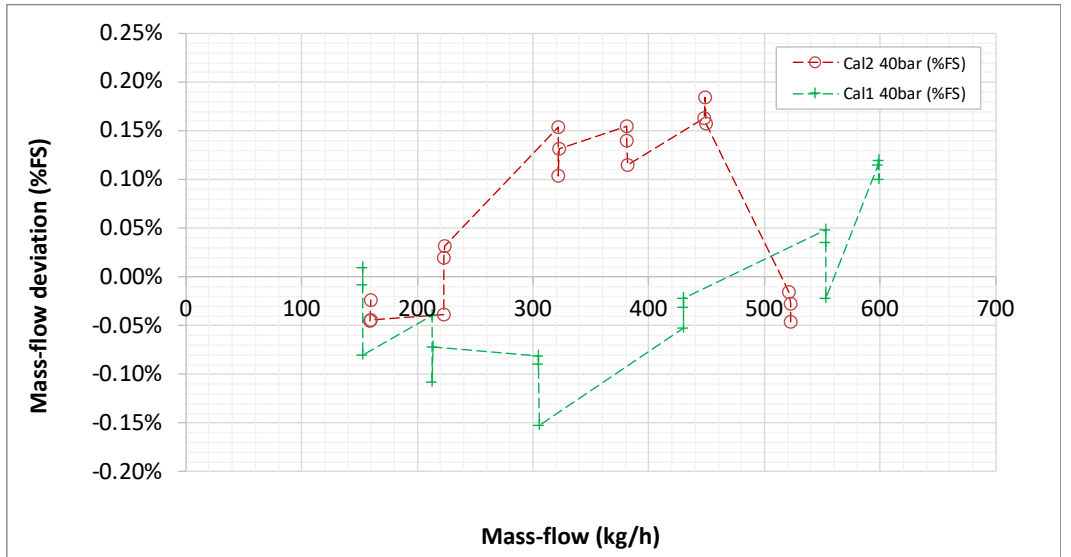


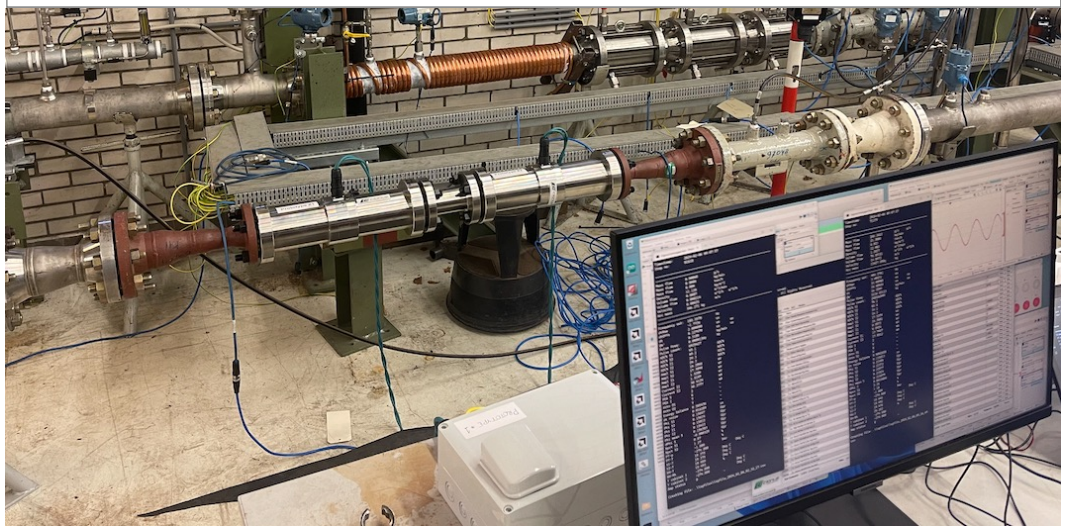
SOURCE: Illustration from Northern Lights

H_2-prototypes tested in pure H_2 at DNV Groningen

Pure H_2–test at DNV confirms high-accuracy performance

- Prototype to demonstrate H_2 feasibility
  - ID44 mm and length ≈ 430 mm
  - Designed for 120 bar operating pressure
  - Targeting next generation H_2 electrolysers at 15 – 30 MW operating between 5 and 60 bar
  - Concept can be adapted to wide range of H_2-applications
- Mass-flow deviation limited to 0.2 %FS
  - H_2-flow up to 10 kg/min at 40 bara
  - Significant variation in facility density and temperature during test is not yet compensated
  - Total accuracy can be improved with optimised density and temperature compensation
  - Pressure loss limited to few mbar
- ➢ Good results confirms Cignus technology is applicable for high accuracy metering of any gas

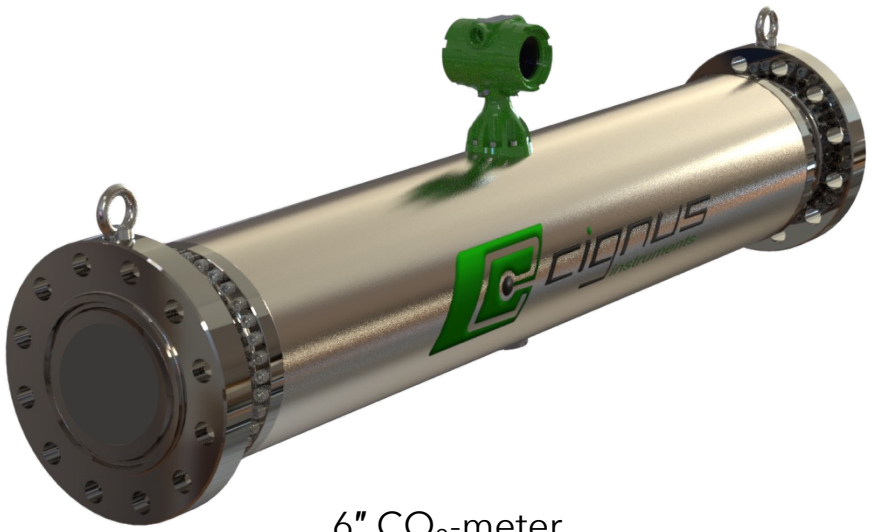




Cignus in comparison with UltraSound Meters

- Cignus measure both mass flow and density
  - The fiscal measurand is mass
- Ultrasound measures volume flow
  - Natural gas has approximately 4 times higher calorific value than hydrogen per volume (varies with pressure)
  - Hydrogen has approx. 2.4 times higher calorific value than natural gas per mass
  - Errors in pressure, temperature, composition and volume flow contributes to mass uncertainty
  - Composition error for H_2-NG blend will give half error in calorific value when measured as mass versus volume
  - In natural gas an error in composition for CH_4, C_2H_6 blend will give only 1/5 of the error when measured as mass versus volume
  - Challenging to meet regulatory requirements for density uncertainty
- Increasing Coriolis sensitivity for gas is compromised by increased pressure drop
  - Pressure drop ⇒ energy ⇒ cost
  - Sensitivity challenge increase with operating pressure
  - Coriolis even less suited for H_2 – NG mixture transport due to increased uncertainty on density and composition
  - Worse for less dense gas like pure hydrogen.

Cignus summary



6″ CO_2-meter

- Novel mass-flow metering technology solving gaps with traditional Coriolis technology
- Direct mass-flow metering;
  - for very large diameters and/or high operating pressure
    - no practical limitation
  - any fluid density,
    - even very low-densities like natural gas and hydrogen,
  - very low pressure drop,
    - reduced energy loss and reduced risk for cavitation.
- Solving technology gaps when scaling CCS and H_2 value chains by more accurate and simplified fiscal metering
- CO_2-testing confirms TRL6 for CCS
- H_2–test confirms high-accuracy performance for any gas
- Concept well suited for submerged installations

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Contact

Martin Nese, CEO & co-founder

c: +47 917 35 232

e: Martin.Nese@cignus.com