HRS Field Testing Methods

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Workshop on the harmonisation of verification periods for HRS in Europe,
October 11th, 2023

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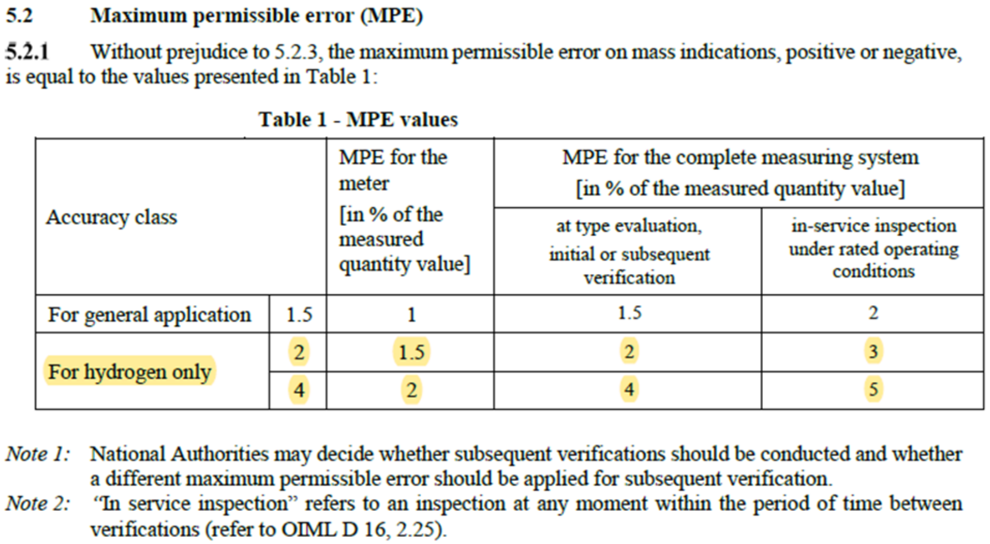
Background

- Hydrogen vehicles are a potential alternative to battery electric vehicles for decarbonisation of transport
- The accuracy requirements for hydrogen refuelling station (HRS) dispensers are set out in the international recommendation OIML R139
- Challenging to achieve due to operating conditions at hydrogen refuelling stations, which are specified in the worldwide accepted standard SAE J2601
- OIML R139 does not say which testing equipment should be used, but flow standards have been developed by measurement institutes



5.2 Maximum permissible error (MPE)

5.2.1 Without prejudice to 5.2.3, the maximum permissible error on mass indications, positive or negative, is equal to the values presented in Table 1:

Table 1 - MPE values

Accuracy class		MPE for the meter [in % of the measured quantity value]	MPE for the complete measuring system [in % of the measured quantity value]	
			at type evaluation, initial or subsequent verification	in-service inspection under rated operating conditions
For general application	1.5	1	1.5	2
For hydrogen only	2	1.5	2	3
	4	2	4	5

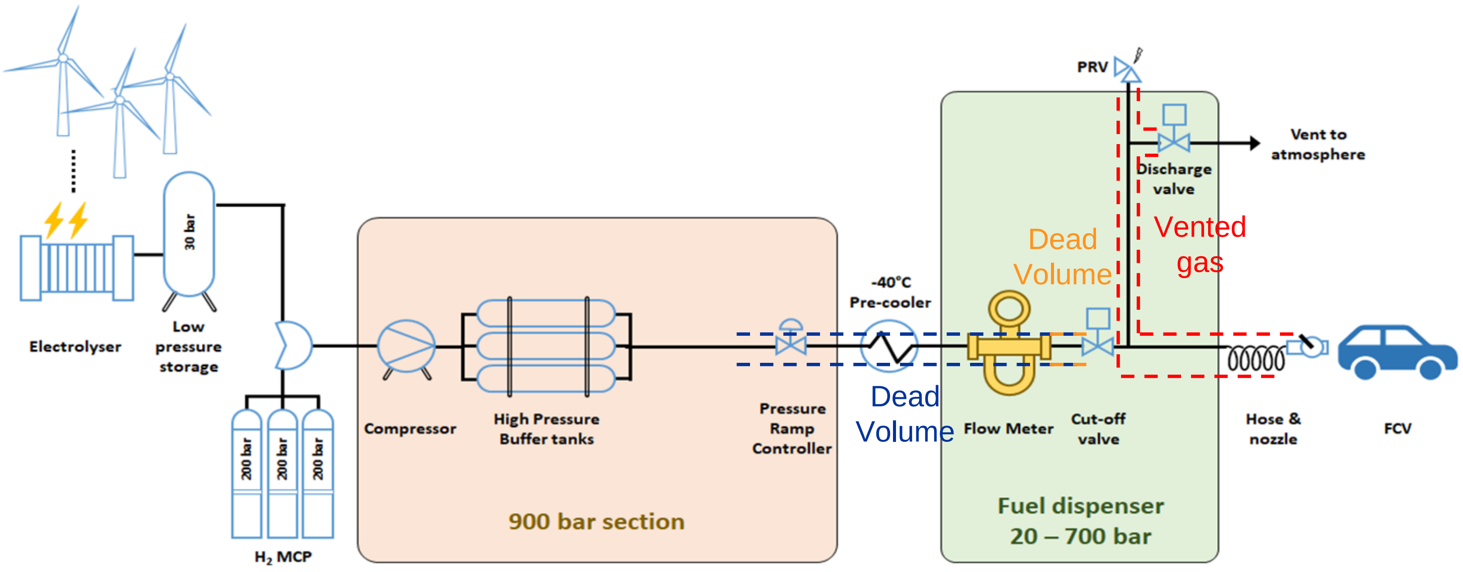
Note 1: National Authorities may decide whether subsequent verifications should be conducted and whether a different maximum permissible error should be applied for subsequent verification.

Note 2: "In service inspection" refers to an inspection at any moment within the period of time between verifications (refer to OIML D 16, 2.25).

Background

Considering the typical HRS, the main sources of measurement error/uncertainty are:

1. Accuracy of the flow meter
2. Gas vented at end of refuelling
3. Density changes in “dead volumes”



The various influences on the flow meter accuracy (incl. flow rate, temperature, pressure, density) were studied in detail in the first project. The other two influences can be calculated from PVT data.

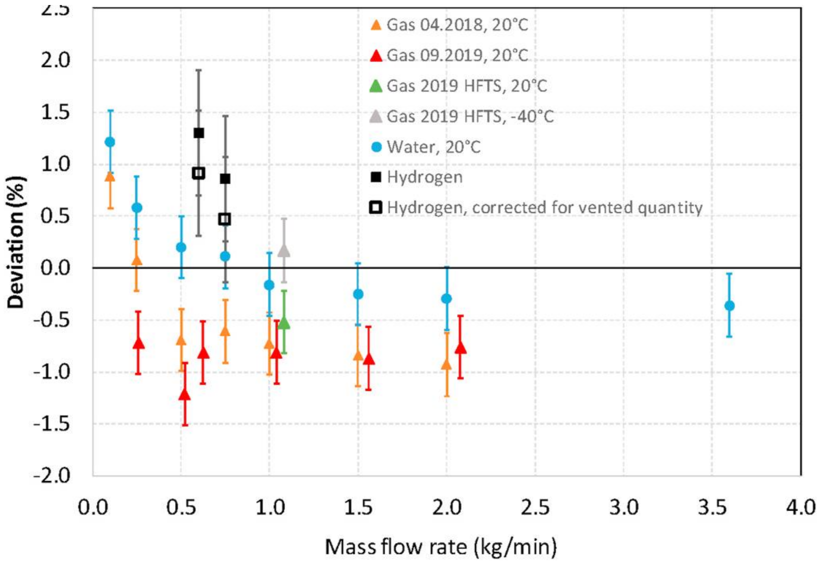
Background

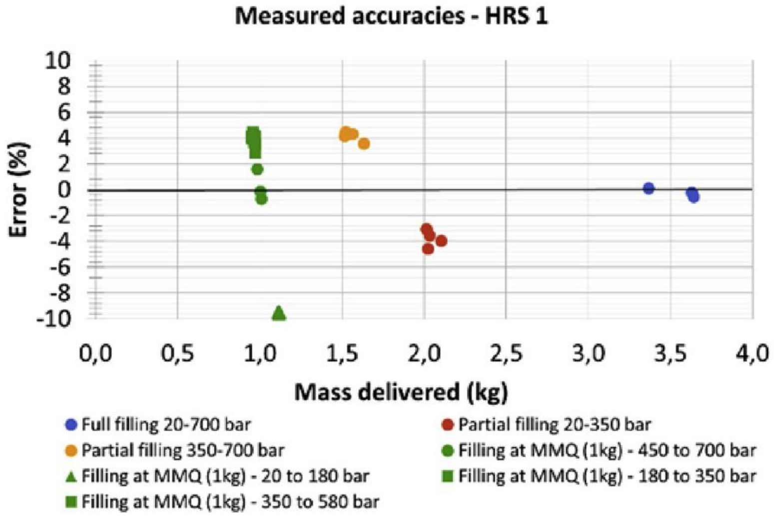
HRS dispensers are required to meet the OIML R139 accuracy requirements

- Accuracy Class 2 or Class 4 (2% or 4% MPE)

From the previous project we know:

- The available flow meters are capable of meeting the accuracy requirement
- Regardless, larger errors are observed at many stations
- This is largely a result of the station design e.g. when dead volume is large and no corrections are applied





Background

What are the implications for testing methods?

- Cannot simply remove the flow meter and send to a lab for calibration, no calibration labs available for 875 bar H_2
- Even if the calibration labs existed, this approach won’t account for important influences on billing accuracy:
    - Transient temperature effects on the meter (downstream of heat exchanger)
    - Dead volumes and vented gas compensated for correctly?
    - Meter zeroed correctly when installed in the station?

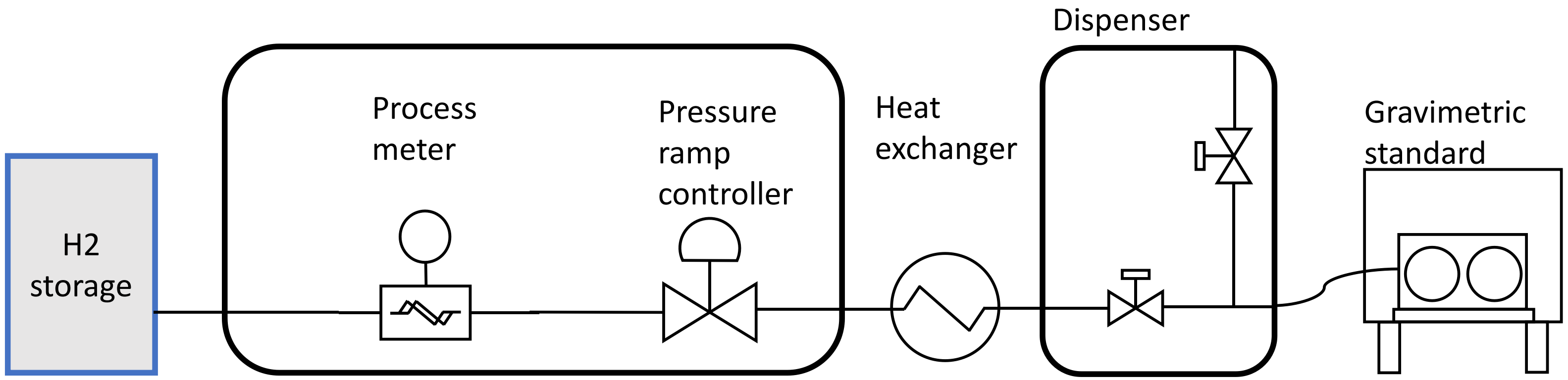
Therefore, field verifications at the HRS are required. Two approaches are presented:

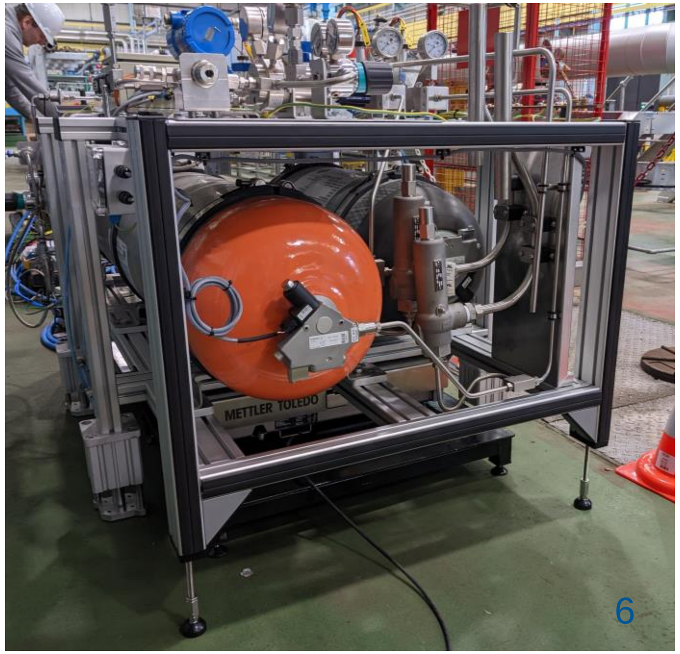
- Mobile primary standard
- Mobile secondary standard (or “master meter”)

Primary standards (light-duty)

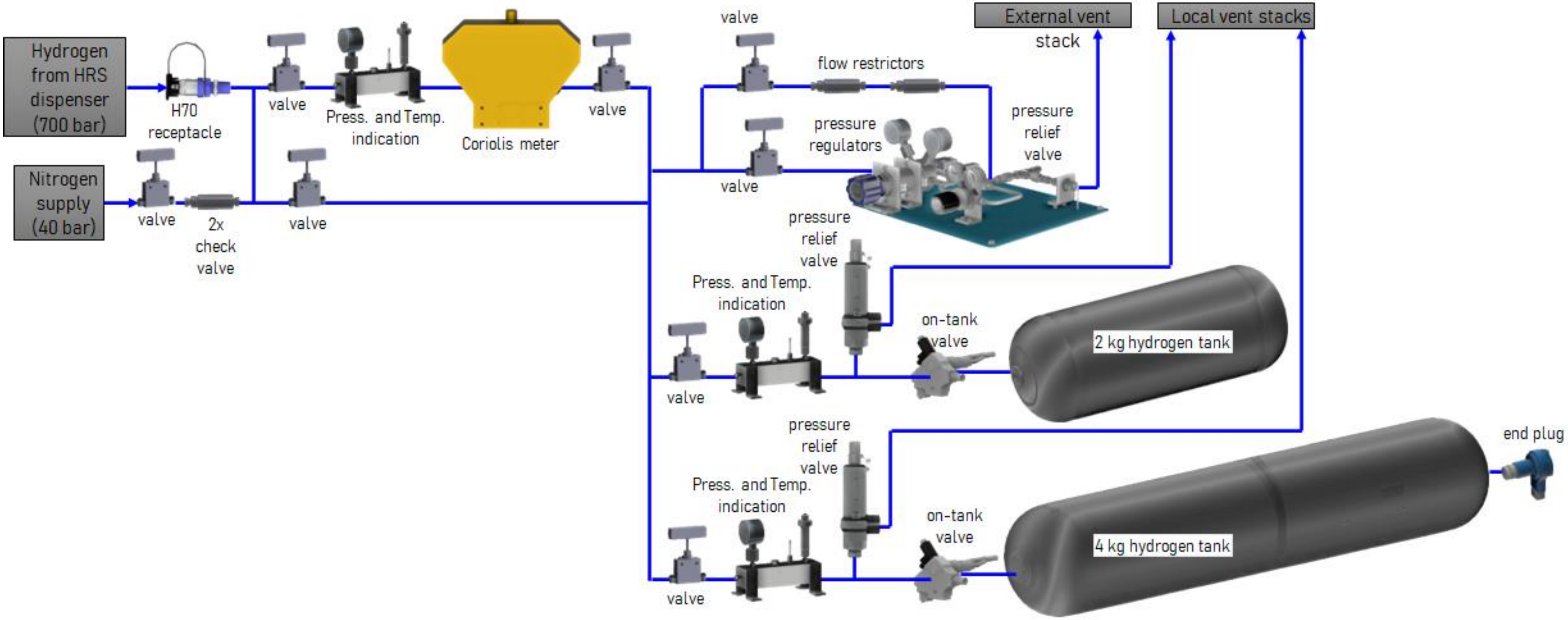
- Mobile primary standard takes the place of a vehicle, filled by dispenser
- Mass of H_2 collected compared with amount billed by dispenser
- Existing primary standards all based on gravimetric method. Weight of system measured before and after filling, using high-precision weigh scales

- Simple in principle, but more complicated in execution





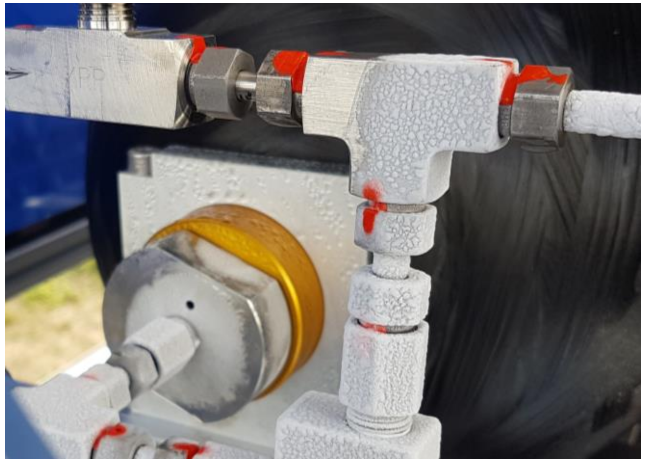
Primary standards (light-duty)



Practical considerations

Operational challenges to achieving the required measurement uncertainty:

- Venting: H_2 must be taken to safe vent location. Vent rate must be limited to minimise icing and avoid lower temperature limit of tanks
- Condensation and icing: accumulate when tanks are vented, source of measurement uncertainty, must be carefully removed



Practical considerations

- Outdoor environment: wind, rain, air currents, low ambient temperature

- Buoyancy corrections

$$m_{H2} = (W_2 - W_1).\left(1 - \frac{\rho_o}{\rho_N}\right) + V_o[\rho_{air2}.(1 + \lambda\Delta P_2) - \rho_{air1}.(1 + \lambda\Delta P_1)] + V_{frame}.(\rho_{air2} - \rho_{air1})$$

Where:
W_1, W_2 : initial and final mass readings from the balance readings
λ : pressure coefficient for the tank
V_{frame} : volume of HFTS frame, instrumentation, tubing and fittings

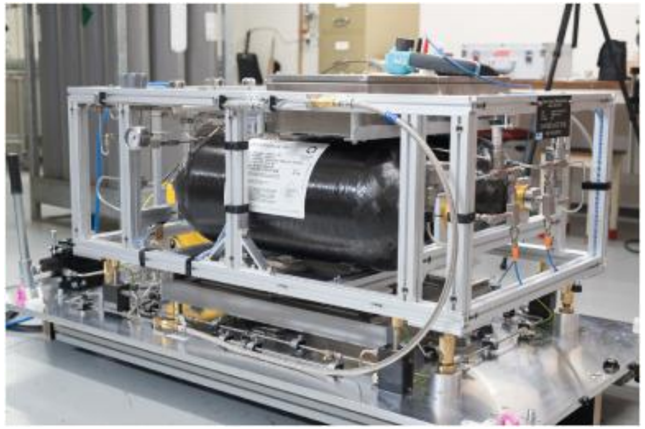
ρ_{air1}, ρ_{air2} : air density calculations based on environmental sensor
P_1, P_2 : tank initial and final pressures

Primary Standards (light-duty)

Several standards with the required uncertainty 0.3% (k=2)

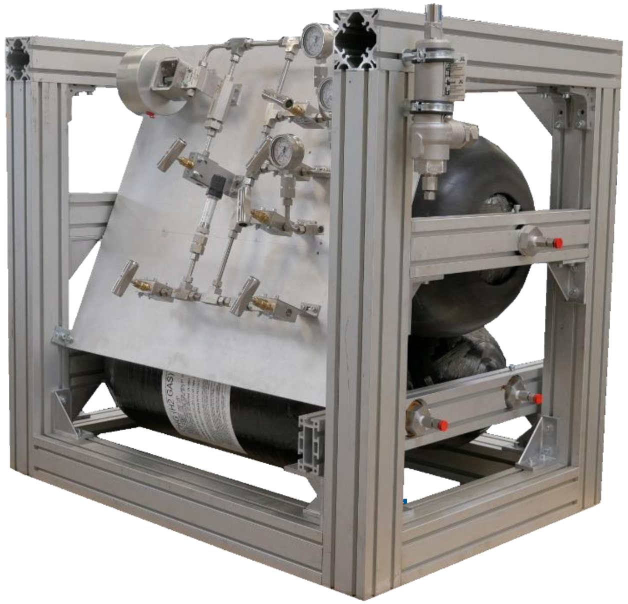
MetroHyVe 1

Institute	Tank volume
METAS	2 x 36 L
Justervesenet	3 x 36 L
VSL	3 x 52 L



MetroHyVe 2

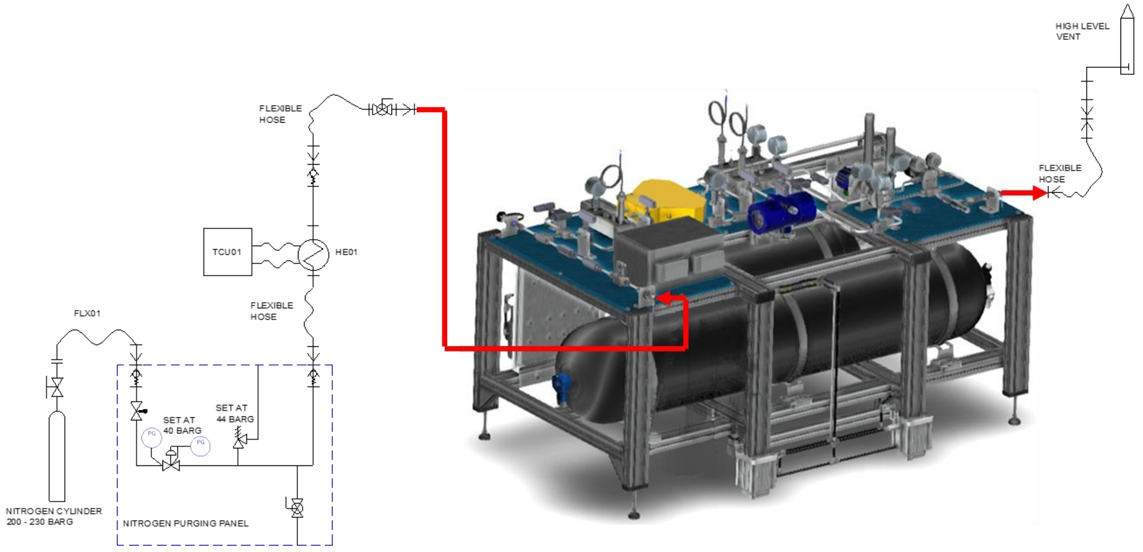
Institute	Tank volume
BEV-PTP	1 x 76 L, 2 x 36 L
CESAME	2 x 104 L
NEL	1 x 51 L, 1 x 103 L

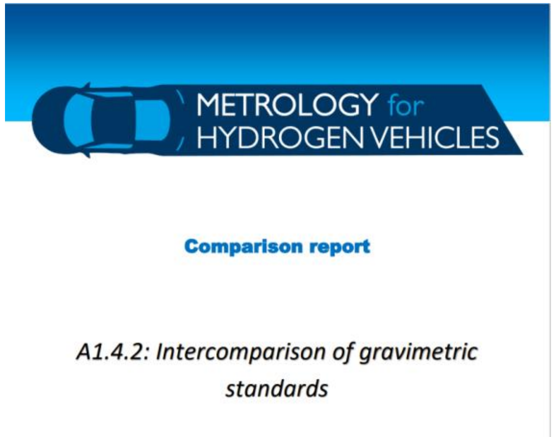


Primary Standards (light-duty)

Laboratory comparison using nitrogen

- Intercomparisons organised to validate the new flow standards, with some existing: METAS, JV, CESAME, NEL, BEV-PTP
- Intercomparisons carried out the same way as in MetroHyVe 1:
  - Fill the tanks with nitrogen to approx. 40 bar
  - Compare weigh-scale measurements with transfer standard flow meter

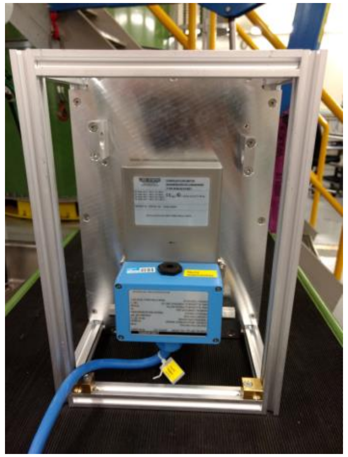




METROLOGY for HYDROGEN VEHICLES

Comparison report

A1.4.2: Intercomparison of gravimetric standards



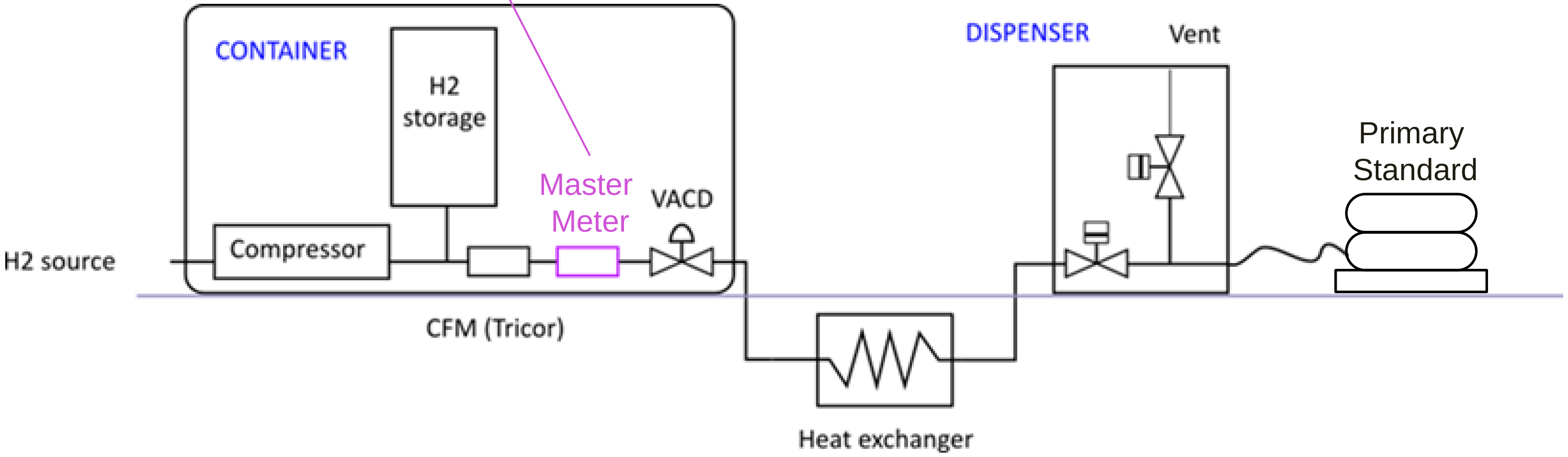
Primary Standards (light-duty)

The laboratory comparison is useful but has limitations

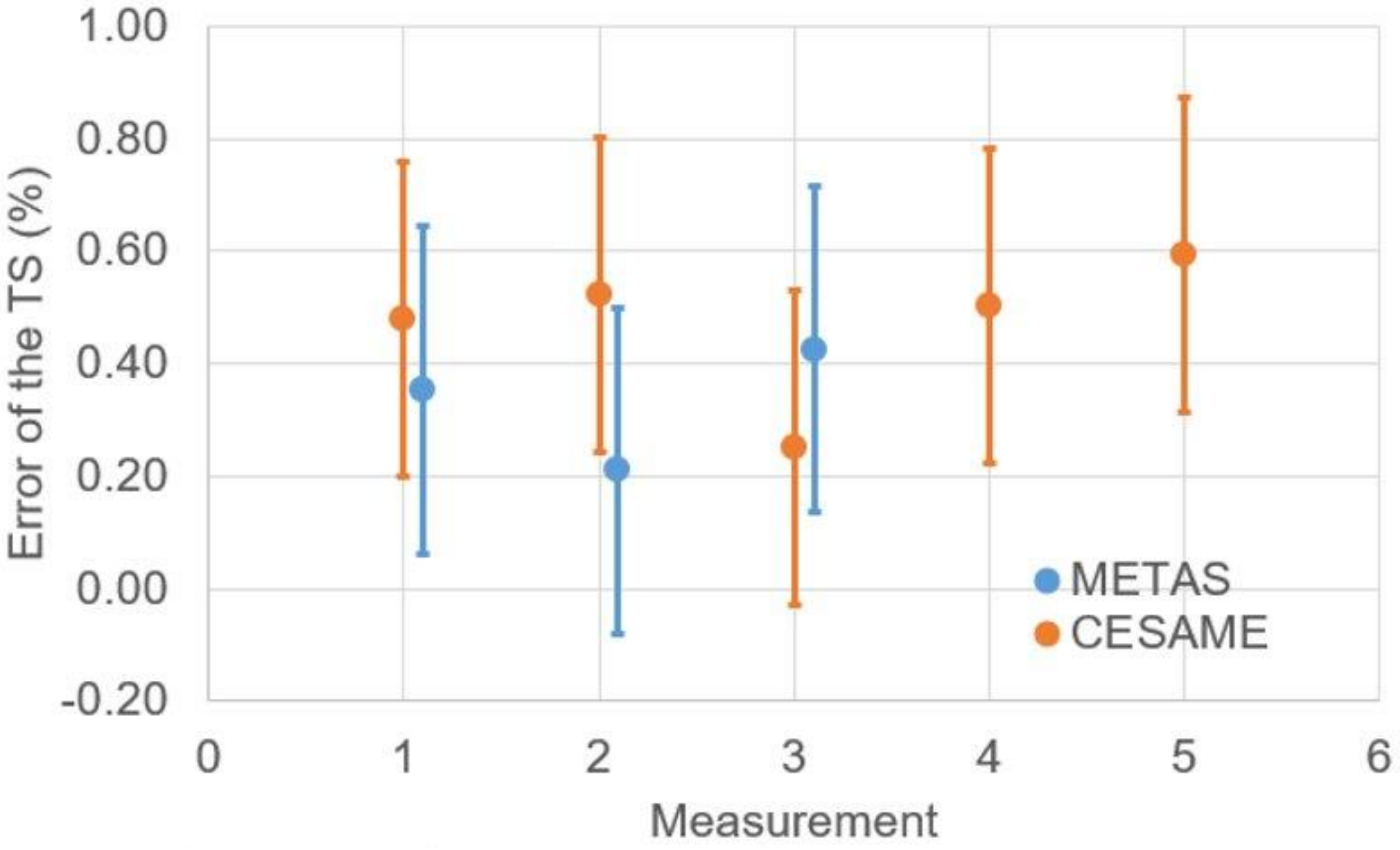
- Nitrogen less prone to leaks than hydrogen
- Pressure range limited to 40 bar, instead of 700 bar
- Does not account for outdoor environment (low ambient temperature, wind, rain, condensation/icing on tanks, vibration etc)

Field comparisons also organised at HRS

- Experimental HRS of project partner ZBT, Duisburg
- Transfer standard mounted in HRS, upstream of pre-cooler
- First measurements by CESAME and METAS in March



Primary Standards (light-duty)



Uncertainty Budget

Uncertainty source	Nominal value	Sensitivity coefficient, c	Absolute uncertainty (k=1), u	Relative uncertainty ui	Output uncertainty squared $(u.c)^2$	Contribution
Initial mass (kg)	150	-149.978	0.0007	4.67E-06	4.90E-07	31.67%
Final mass (kg)	151	150.9774	0.0007	4.64E-06	4.90E-07	31.67%
Tank volume (m^3)	0.12	2.54E-03	0.005	4.167%	1.12E-08	0.72%
Initial air density (kg/m^3)	1.178	-0.20026	0.0029	0.250%	2.51E-07	16.21%
Final air density (kg/m^3)	1.181	0.2030	0.0030	0.250%	2.57E-07	16.64%
Frame volume	0.05	0.00015	0.005	10.00%	2.52E-10	0.01%
Initial tank pressure (MPa)	0.1	-3.11E-06	0.2	200.00%	3.87E-11	0.003%
Final tank pressure (MPa)	0.1	2.18E-03	0.2	0.286%	3.89E-11	0.003%
Pressure coefficient (1/Pa)	70	2.18E-03	2.20E-11	10.00%	4.75E-08	3.07%
				SUM	1.547E-06	100%
				U (k=1)	0.12%	1.24 g
				u (k=2)	0.25%	2.49 g

Ref: Design of gravimetric primary standards for field-testing of hydrogen refuelling stations, M. de Huu et al., Flow Measurement and Instrumentation Vol. 73

Uncertainty Budget

Uncertainty source	Nominal value	Sensitivity coefficient, c	Absolute uncertainty (k=1), u	Relative uncertainty ui	Output uncertainty squared $(u.c)^2$	Contribution
Initial mass (kg)	150	-149.978	0.0007	4.67E-06	4.90E-07	13.79%
Final mass (kg)	151	150.9774	0.0007	4.64E-06	4.90E-07	13.79%
Tank volume (m^3)	0.12	2.54E-03	0.005	4.167%	1.12E-08	0.32%
Initial air density (kg/m^3)	1.178	-0.20026	0.0029	0.250%	2.51E-07	6.99%
Final air density (kg/m^3)	1.181	0.2030	0.0030	0.250%	2.57E-07	7.48%
Frame volume	0.05	0.00015	0.005	10.00%	2.52E-10	0.01%
Initial tank pressure (MPa)	0.1	-3.11E-06	0.2	200.00%	3.87E-11	0.00%
Final tank pressure (MPa)	0.1	2.18E-03	0.2	0.286%	3.89E-11	0.00%
Pressure coefficient (1/Pa)	70	2.18E-03	2.20E-11	10.00%	4.75E-08	1.34%
Icing, cleaning (kg)	1	1	0.001	0.1%	1.00E-06	28.15%
Repeatability (kg)	1	1	0.001	0.1%	1.00E-06	28.15%
				SUM	3.553E-06	100%
				U (k=1)	0.188%	1.88 g
				u (k=2)	0.38%	3.77 g

Primary Standards (heavy-duty)

- Existing primary standards have similar hydrogen capacity as light-duty vehicles (cars)
- Approx 4-6 kg H_2 at 700 bar
- When refilled at the HRS, filling times and flow rates same as for a car

This is not the case for heavy-duty vehicles (trucks)

- These vehicles typically store 30 kg+ hydrogen at 350 bar, with collection volumes ≥ 1000 L
- Light duty primary standards have 100 – 200 L collection vessels
- This leads to much lower flow rates when filling the primary standards compared to the vehicle ⇒ not a representative test of the station.

- METAS and NEL are building new primary standards for heavy-duty refuelling:

			H_2 Capacity		Average flow rate	
Institute	Pressure Class	Tanks	@ 350 bar	@ 700 bar	3 Mpa/min, no pre-cooling	20 Mpa/min
NEL	350 bar	3 x 350 L	25.2 kg	-	1.8 kg/min	-
METAS	700 bar	6 x 100 L	14.4 kg	24.5 kg	1.02 kg/min	6.8 kg/min

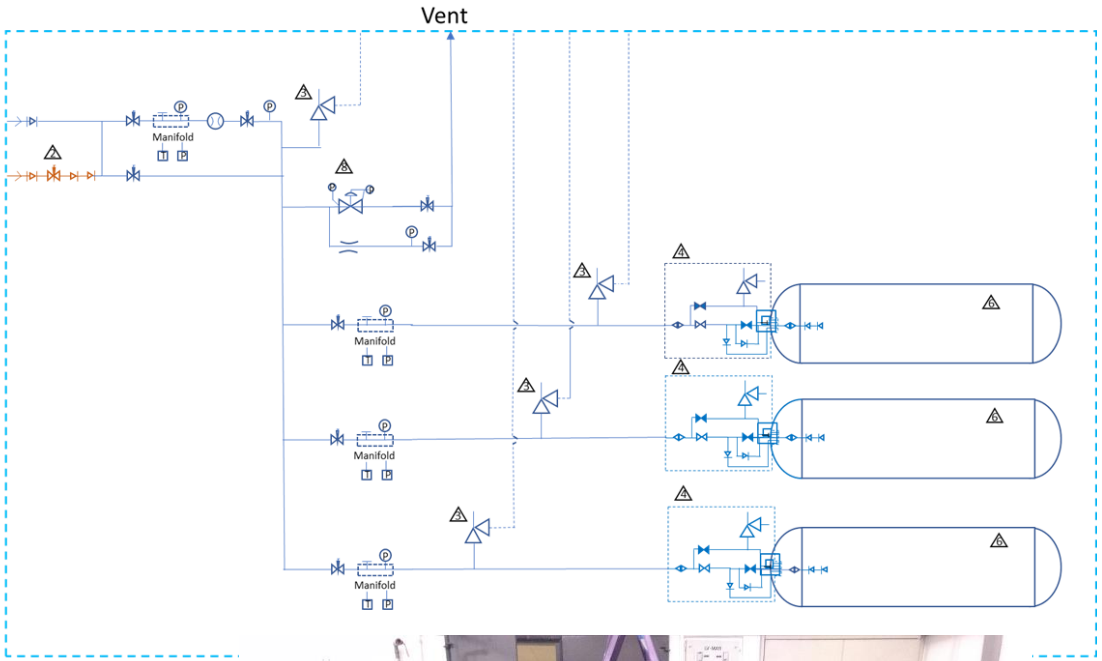
- Both systems are gravimetric, target measurement uncertainty is 0.5% (k=2) for 1 kg fill.

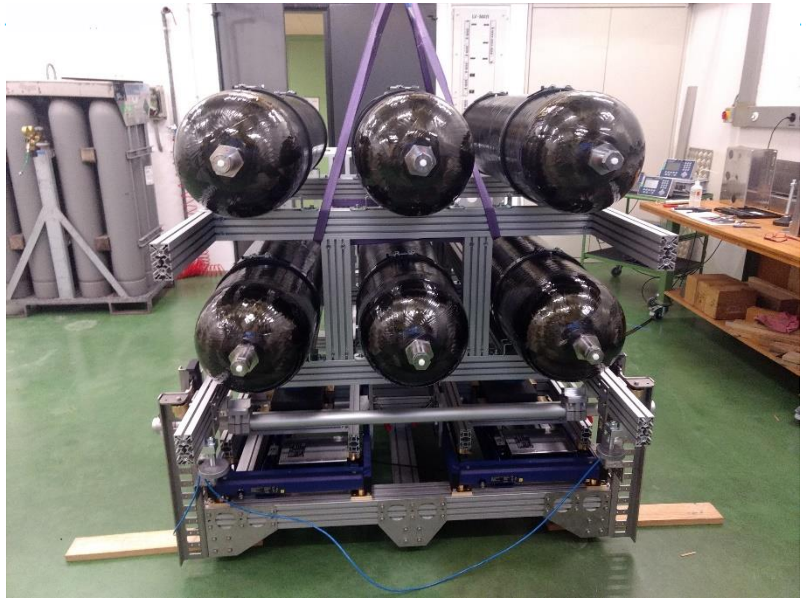
Primary Standards (heavy-duty)

- NEL design using 3 × 350 L tanks, total 24 kg H_2 capacity at 350 bar
  - Each tank will be weighed independently, 1 weigh scale for each tank
  - Small dead volumes must be vented before tanks are weighed, PVT corrections must be applied.

- METAS also using 3 weigh-scales, but the loads will be spread across all 3 scales simultaneously

- METAS primary standard is built, NEL will be done in Q4 2023





Primary Standards (heavy-duty)

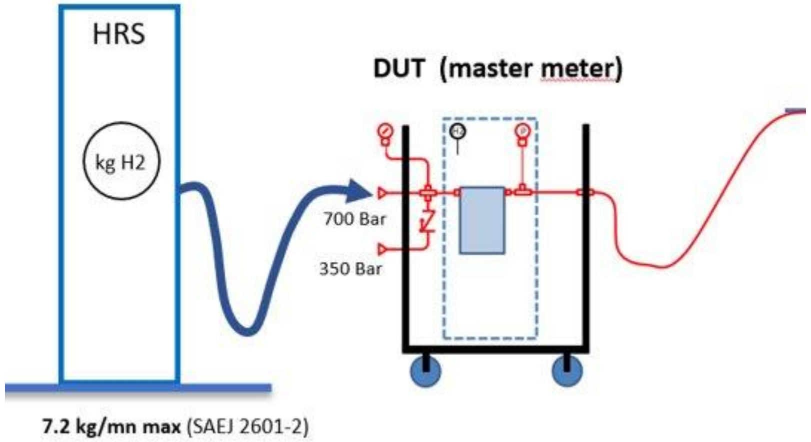
Secondary standard

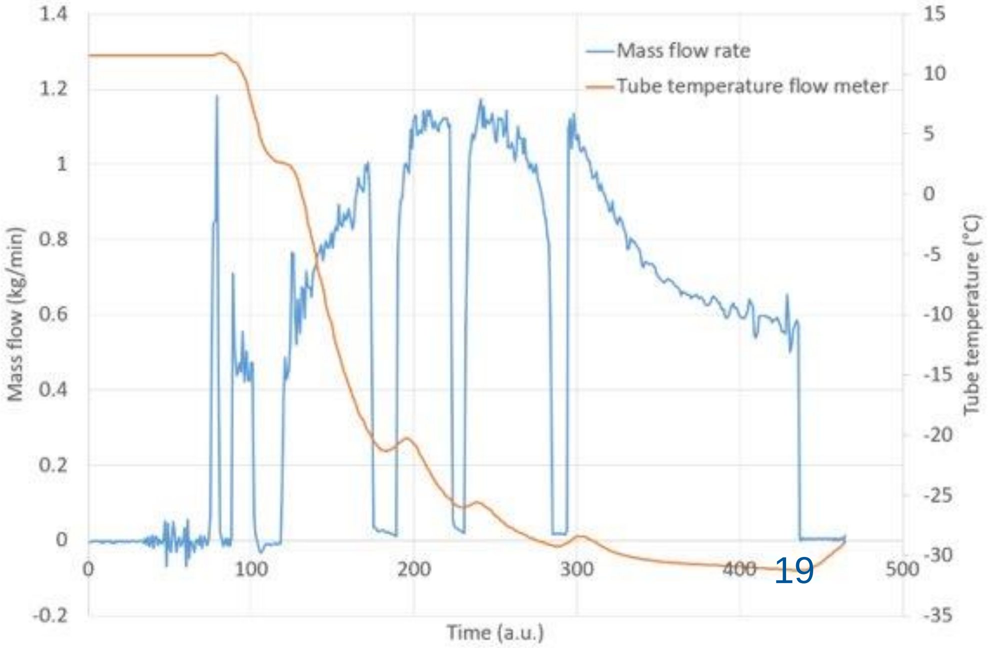
Although crucial, the portable primary standards have limitations:

- HRS verifications are time consuming
- Problems scaling up, practical limits are already reached for trucks

MetroHyVe 2 is investigating the use of secondary standards for HRS verifications

- Use of a flow meter calibrate against a primary standard
- Enables faster calibrations, although with higher uncertainty
- Easier to scale up to very large vehicles
- Meter will be downstream of pre-cooler, so temperature effect still needs to be addressed





Secondary standard

MetroHyVe 2 is investigating the use of secondary standards for HRS verifications

- CESAME developed HRSmsr: Hydrogen Refuelling Station mobile secondary reference

- SI traceability via CESAME primary standard, first ISO 17025 accredited primary reference (regarding OIML R-139) in Europe

- Claimed uncertainty < 0.6% (k=2)
- Compliant with subs. Verification R139

- Initial and subsequent verifications (legal metrology) will be faster, cheaper, easier!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Sorigny (37, France) - With CCTVI authorization

Uncertainty Budget

Uncertainty source	Nominal value	Sensitivity coefficient, c	Absolute uncertainty (k=1), u	Relative uncertainty ui	Output uncertainty squared $(u.c)^2$	Contribution
Primary standard	3.5 kg	1	0.0025	0.072%	6.25E-06	6.73%
Dead volume	3.5 kg	1	0.002	0.057%	4.00E-06	4.31%
Zero-point stability	0.26 kg/min	13.461	0.0005	0.193%	4.53E-05	48.81%
Repeatability	3.5 kg	1	0.0035	0.100%	1.225E-05	13.20%
Reproducibility	3.5 kg	1	0.005	0.150%	3.675E-05	26.94%
				SUM	9.28E-05	100%
				U (k=1)	0.29%	10 g
				U (k=2)	0.57%	20 g

Summary

- Field testing at the HRS is needed to demonstrate OIML R139 accuracy requirements are achieved

Mobile primary standards provide the lowest measurement uncertainty but have some operational challenges

- Time consuming, sensitive to environmental conditions, expensive, bulky, impractical to continue scale up for larger vehicles

Secondary options have a higher measurement uncertainty, but allow faster verifications and a more practical method to scale up

- Need to mitigate the transient temperature effect on the flow meter: pre-cool the meter body
- Still need a vessel to receive the hydrogen: vehicle or dummy tank

METROLOGY for HYDROGEN VEHICLES 2

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THANK YOU

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