



Department for
Science, Innovation
& Technology



Hydrogen Refuelling Station Intercomparison Testing with the TÜV SÜD LD HFTS

The Measurement Focus Group Meeting,
3rd December 2025

**Add value.
Inspire trust.**





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Shift towards zero-emission vehicles



- UK and the European Union are committed to net zero by 2050
- Transport remains the highest carbon emitting sector in the UK and EU
 - 29% of GHG emissions in the EU (2022) and UK (2023)
- UK's Zero Emission Vehicle (ZEV) mandate with 100% ZEV by 2035

Annual target for ZEV sales shares from 2024 to 2035

| Year | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|--------|------|------|------|------|------|------|------|
| Target | 22% | 28% | 33% | 38% | 52% | 66% | 80% |

- EU Fit for 55 package
 - Reduce GHG emissions from vehicles by at least 55% by 2030
- Two options for ZEVs: battery electric vehicles and hydrogen-powered vehicles
- Advantages when using hydrogen-powered vehicles
 - Shorter refuelling times (under 5 minutes for cars)
 - Longer range (ideal for heavy duty vehicles)
 - Higher energy density (lightweight powertrain)

2023 Net UK GHG Emissions by TES Sector



Source: <https://assets.publishing.service.gov.uk/media/6604460f91a320001a82b0fd/uk-greenhouse-gas-emissions-provisional-figures-statistical-release-2023.pdf>



Source: S Mathison- FirstElement Fuel Inc. , "How to Deploy H2 Trucks", in 2024 Mission - Hydrogen Online conference, 2024

Regulatory requirements for refuelling stations



- Accurate refuelling at the station affects customer confidence and the UK government (fuel duty & VAT)
- **OIML R 117:** For liquid fuels (petrol, diesel, etc.) - error at the dispensing nozzle must be -0.5% to 1.0% at minimum measured quantity (MMQ) of 5 L
- **OIML R 139:** For gaseous fuels - 2018 version sets out accuracy requirements for hydrogen refuelling station (HRS) dispensers
- Two accuracy classes for hydrogen gas



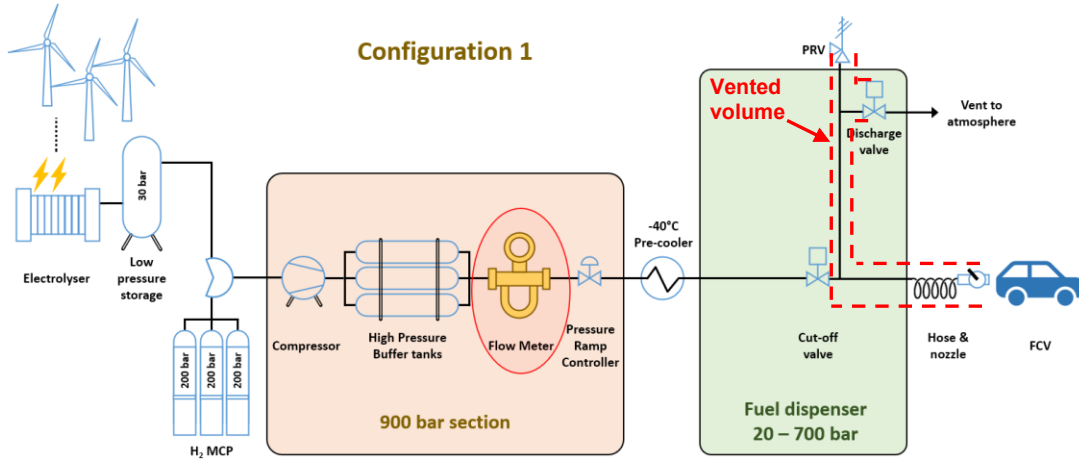
| Accuracy class | | MPE for the meter [in % of the measured quantity value] | MPE for the complete measuring system [in % of the measured quantity value] | |
|-------------------------|-----|--|--|--|
| | | | at type evaluation, initial or subsequent verification | in-service inspection under rated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

Requirement to verify performance of the HRS flow meter and the dispenser as a complete measuring system

- Minimum Measured Quantity (MMQ) for hydrogen = 1 kg
- Maximum Permissible Error (MPE) is doubled at MMQ:
- Challenging due to the HRS operating conditions specified in SAE J2601

OIML R 139 provides no specification for the testing equipment, but NMIs favour a gravimetric approach

Measurement challenges when fuelling hydrogen vehicles

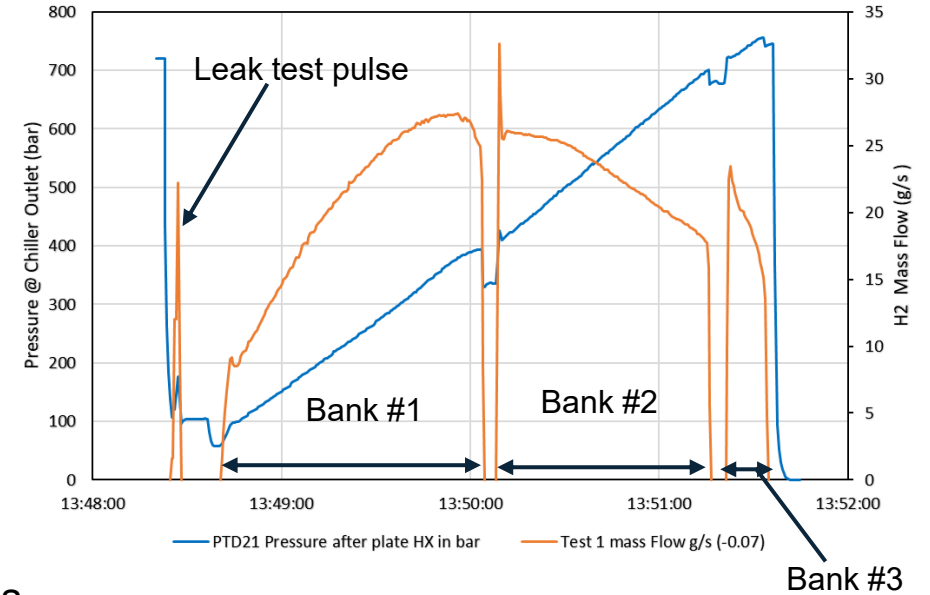


- Hydrogen refuelling process

- Leak test pulse - also checks initial vehicle pressure and tank capacity
- Bank switching at some HRS dispensers as the vehicle pressure increases
- Venting of hydrogen in the hose after refuelling is completed before the nozzle can be disconnected

- Measurement challenges

- Hydrogen supplied can vary up to 875 bar in pressure
- Dead volume (up to 200 g)
- Fast refuelling flow rates requires precooling of hydrogen to -40 °C
- Vented gas (ca. 10 g)



$$\text{Depressurisation quantity (kg)} = M \sum \left(\frac{PV}{RfT} \right)$$

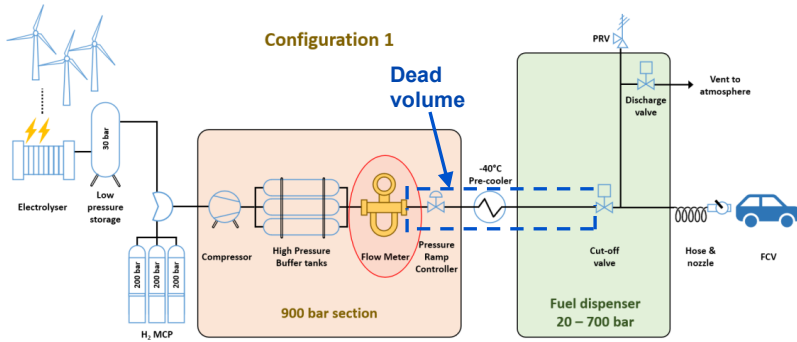
Where:

M : H₂ molecular mass
 T : Temperature

P : Pressure
 R : Gas constant

V : Volume of depressurisation area
 f : Compressibility factor

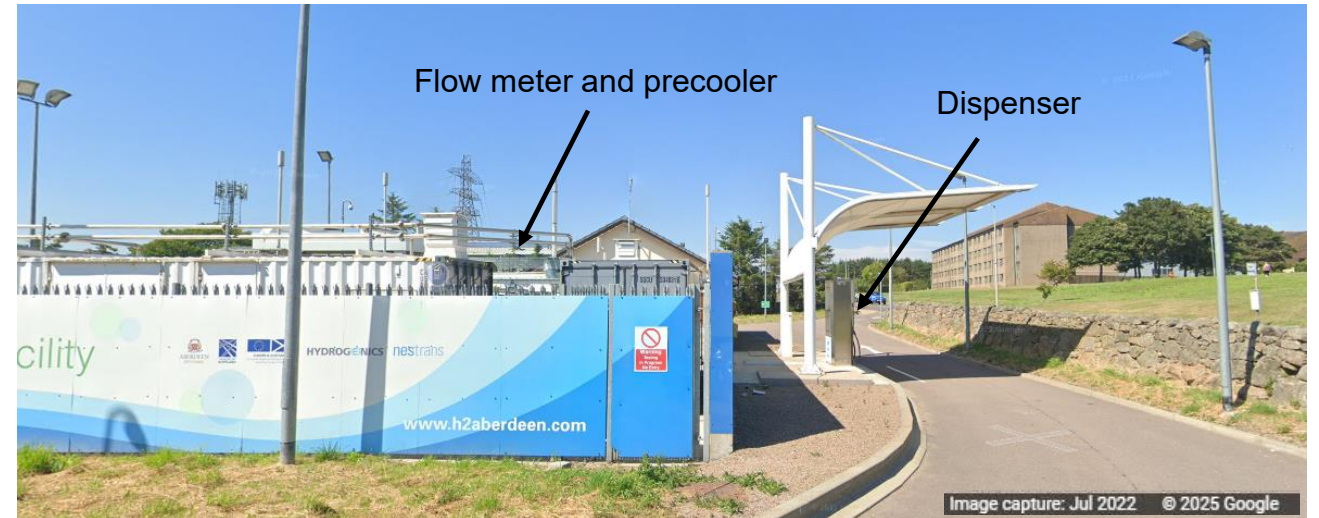
HRS configurations and effect on flow measurement



Meter at 900 bar section before pre-cooler

- Pro: relatively constant near ambient temperature
- Con: significant 'dead volume' containing gas measured by flow meter but not delivered to the FCEV

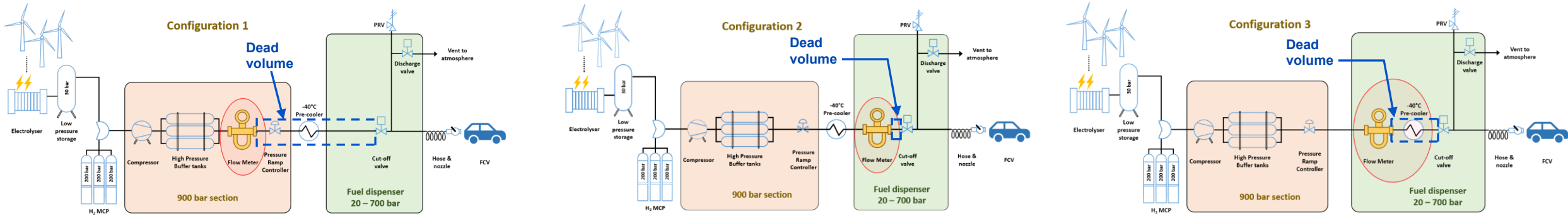
Aberdeen Cove Bay HRS



Source: <https://www.google.com/maps/place/Aberdeen+Hydrogen+Centre>

'dead volume' effect is significant when successive customers do not refuel to the same pressure (e.g. 100 bar fill versus 700 bar fill).

HRS configurations and effect on flow measurement



Meter at 900 bar section before pre-cooler

- Pro: relatively constant near ambient temperature
- Con: significant 'dead volume' containing gas measured by flow meter but not delivered to the FCEV

Meter at dispenser after pre-cooler

- Pro: 'dead volume' minimised
- Con: large change hydrogen gas temperature from initial ambient to -40 °C

Meter at dispenser but before pre-cooler

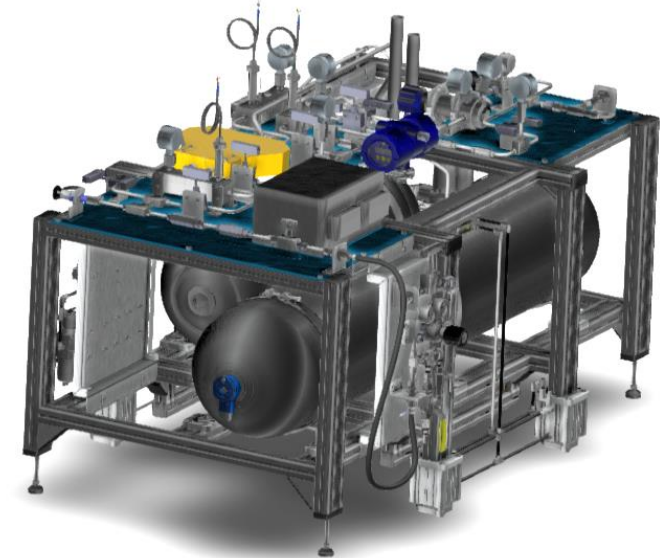
- Pro: relatively constant near ambient temperature whilst reducing the 'dead volume'
- Con: could be expensive for large stations with multiple dispensers

Requirement to verify performance of the HRS flow meter and the dispenser as a complete measuring system

TÜV SÜD Light Duty Hydrogen Field Test Standard

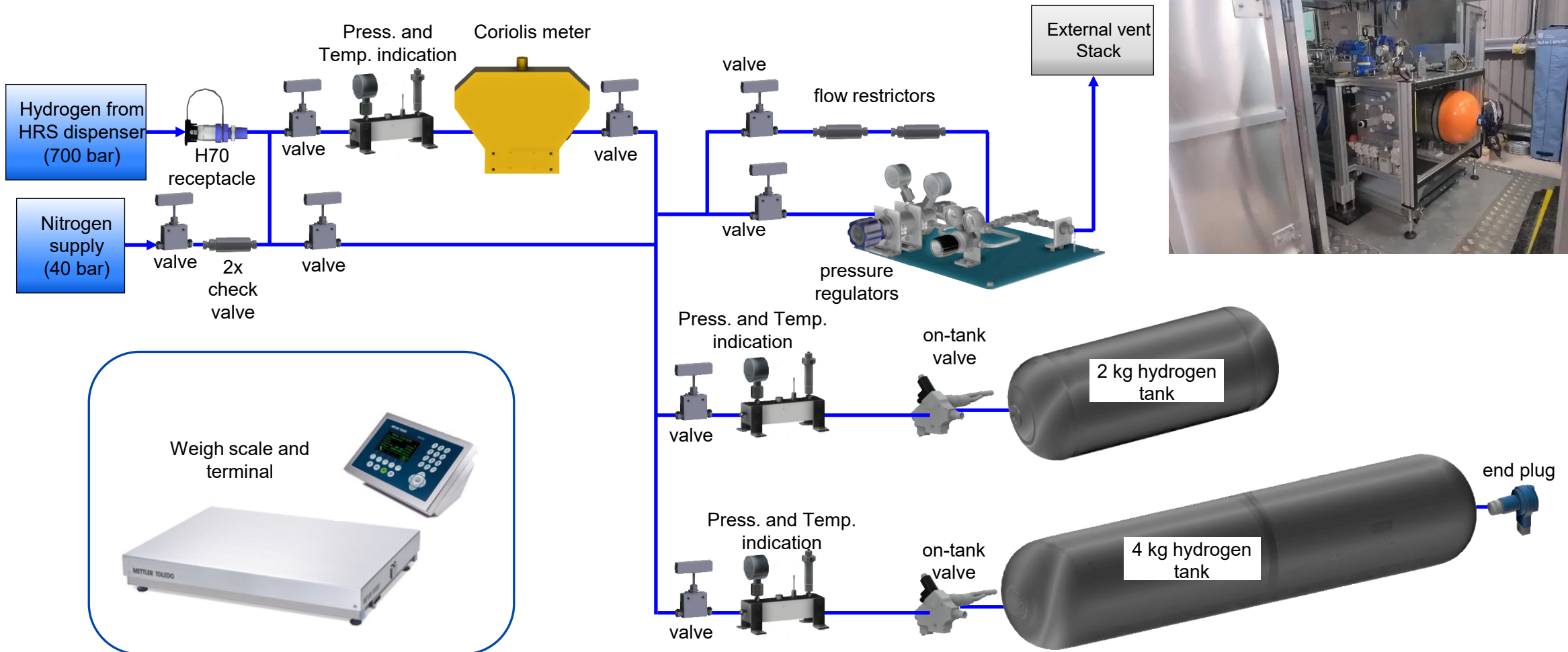


- Requirement: Evaluate accuracy of hydrogen dispensed from light duty HRSs with respect to OIML R139
- Expanded uncertainty of the associated test method as per Part 2 of OIML R139
 - For type evaluation: < 1/5th of the applicable MPE
 - For verifications: < 1/3rd of the applicable MPE
- Target uncertainty in collected mass of hydrogen $\approx 0.3\%$ @ 95 % confidence
(Based on Accuracy Class 2)
- Based on experience from FTSs designed and operated by other measurement institutes
- Gravimetric system with a hydrogen capacity similar to light duty FCEVs
- Mass of hydrogen collected = 1 kg to 6 kg
- Capability to verify H70 dispensers filling hydrogen to 700 bar
- Safety Studies include HAZOP and Hazardous Area Classification study
- Needs to conform to UK regulations
 - Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)
 - ATEX/ UK EX – Zone 2
 - Pressure Systems Safety Regulations 2000 and Carriage of Dangerous Goods Regulations



TÜV SÜD Light Duty Hydrogen Field Test Standard
(LD HFTS)

TÜV SÜD LD HFTS: Key components



Quantification of the amount of hydrogen dispensed

- Amount of hydrogen dispensed by the HRS: Quantified by measuring the mass of the LD HFTS before and after refuelling
- Buoyancy corrections: Measure initial and final tank pressures and ambient conditions
- Expression for calculating the mass of hydrogen gas dispensed by the HRS

$$m_{H_2} = (W_2 - W_1) \cdot \left(1 - \frac{\rho_o}{\rho_N}\right) + V_o [\rho_{air2} \cdot (1 + \lambda \Delta P_2) - \rho_{air1} \cdot (1 + \lambda \Delta P_1)] + V_{frame} \cdot (\rho_{air2} - \rho_{air1})$$

Where:

W_1, W_2 : initial and final mass readings from the balance

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 readings

P_1, P_2 : tank initial and final pressures

- Consider ice forming during refueling and venting
- OIML R139 specifies the performance tests that need to be completed
 - Test sequence includes full fills, half fills and MMQ
 - Three repeats (two repeats for MMQ)
- Several days to complete a HRS verification
 - Can take up to two hours to vent a full tank



MetroHyVe 2: Intercomparison test



- EMPIR MetroHyVe 2 project: Comparison of performance of test standards for light duty HRS
 - CESAME (France)
 - METAS (Switzerland)
 - TÜV SÜD (UK)
 - JV (Norway)
- All tests undertaken at a HRS in Duisburg, Germany operated by ZBT, October 2023
 - HRS dispenser's flow meter used as the transfer standard
 - Flow meter installed upstream of the heat exchanger, before the pressure ramp controller
- Test protocol: Full fills to 700 bar with tank capacity of 100 litres (if possible)
 - CESAME, NEL and JV ca. 100 litres
 - METAS ca. 72 litres
- Average mass flow rate above 0.8 kg/min
- Mass balance for each test point is given by: $m_{ref} = m_{meter} - m_{deadvol} - m_{vented} - \varepsilon_{meter}$ (eq. 1)

Where:

m_{ref} : mass collected by HFTS

m_{meter} : flow meter's totaliser reading

$m_{deadvol}$: mass difference due to dead volume

- Mass difference due to the dead volume was calculated by: $m_{deadvol} = V_{deadvol} \times (\rho_{H_2,end} - \rho_{H_2,start})$ (eq. 2)

Where:

$\rho_{H_2,start}$ and $\rho_{H_2,end}$ are the average densities of hydrogen in the dead volume section



MetroHyVe 2: Intercomparison test results



- Pressure at the end of each refuelling was almost identical ➡ Variations due to vented volume are negligible
 - Error due to vented gas was therefore merged with the error of the meter

• Thus, error when using meter expressed as: $\varepsilon_{meter} = m_{meter} - m_{deadvol} - m_{ref}$ (eq. 3)

- Test data from each mobile facility

CESAME results.

| Run | m_{ref} (g) | m_{PM} (g) | $m_{deadvol}$ (g) | ε_{PM} (%) |
|-----|---------------|--------------|-------------------|------------------------|
| 1 | 3641.1 | 3765 | 72.1 | 1.42 |
| 2 | 3553.2 | 3605 | 0.5 | 1.44 |
| 3 | 3557.1 | 3604 | -1.7 | 1.37 |
| 4 | 3548.8 | 3601 | 1.5 | 1.43 |
| 5 | 3561 | 3614 | -1.8 | 1.54 |

METAS results.

| Run | m_{ref} (g) | m_{PM} (g) | $m_{deadvol}$ (g) | ε_{PM} (%) |
|-----|---------------|--------------|-------------------|------------------------|
| 1 | 2093 | 2123 | 8.8 | 1.03 |
| 2 | 2426 | 2459 | 8.9 | 1.00 |
| 3 | 2494 | 2719 | 197.8 | 1.07 |
| 4 | 2488 | 2542 | 1.8 | 2.10 |
| 5 | 2427 | 2606 | 142.7 | 1.52 |
| 6 | 2440 | 2504 | 5.1 | 2.41 |

TÜV SÜD results

| Run | m_{ref} (g) | m_{PM} (g) | $m_{deadvol}$ (g) | ε_{PM} (%) |
|-----|---------------|--------------|-------------------|------------------------|
| 1 | 3476 | - | 2.6 | - |
| 2 | 3377 | 3499 | 74.3 | 1.43 |
| 3 | 3387 | 3512 | 75.1 | 1.46 |
| 4 | 3387 | 3435 | -0.4 | 1.44 |
| 5 | 3234 | 3293 | 3.2 | 1.73 |

- Dead volume corrections – important for some test points which depended on initial condition of HRS
- Good repeatability between CESAME test points - provides an indication that dead volume correction was applied correctly
- METAS – leak in the HRS heat exchanger during the last four test points
- TÜV SÜD – HRS dispenser reading not recorded for the first test point

Source: M. de Huu, R. Maury, M. MacDonald and E. Venslovas, "Comparison of gravimetric standards for hydrogen refuelling stations," in XXIV IMEKO World Congress "Think Metrology", Hamburg, 2024

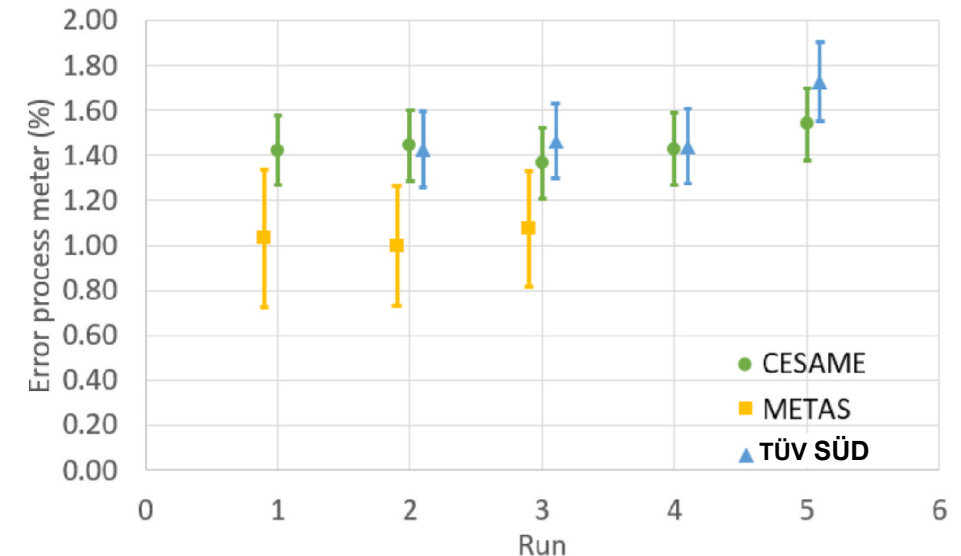
MetroHyVe 2: Analysis of test results



- Degree of Equivalence (En) and Comparison Reference Value (CRV) calculated according to Cox (2007)
 - $|En| < 1$: Laboratory's result is consistent with CRV
 - $1.0 < |En| < 1.2$: Laboratory's result might indicate a possible warning in the measurement process
 - $|En| > 1.2$: Laboratory's result is not consistent with CRV
- Input sources for uncertainty budget ($k = 2$)
 - Primary standards: 5 g for METAS and 4 g for CESAME and TÜV SÜD
 - Dead volume correction: 4 g (error in pressure and temperature measurements)
 - Repeatability: Estimated by standard deviation of measurements
- MetroHyVe 2 intercomparison test results for CRV and Equivalence

| Lab | $\varepsilon_{PM}(\%)$ | $U_{lab}(\%)$ | $CRV(\%)$ | $U_{CRV}(\%)$ | $ En $ |
|---------|------------------------|---------------|-----------|---------------|--------|
| CESAME | 1.44 | 0.17 | | | 0.45 |
| METAS | 1.03 | 0.34 | 1.40 | 0.14 | 1.17 |
| TÜV SÜD | 1.52 | 0.27 | | | 0.51 |

- CESAME and TÜV SÜD test results are consistent and thus confirm the declared uncertainties for these two test standards
- No clear explanation for discrepancy in METAS results
 - Some evidence to suggest a temporary effect on the HRS flow meter



Source: M. de Huu, R. Maury, M. MacDonald and E. Venslovas, "Comparison of gravimetric standards for hydrogen refuelling stations," in XXIV IMEKO World Congress "Think Metrology", Hamburg, 2024

Regulations and HRS requirements for hydrogen refuelling



- LD HFTS transported with 20 bar nitrogen gas inside the tanks
 - Needs to conform to UK Carriage of Dangerous Goods regulations
 - Tanks do not have TPED certification → Special dispensation authorisation from UK Department of Transport
- Operating with hydrogen gas when verifying the HRS
 - Mobile test facility needs to be UK EX / ATEX certified (DSEAR regulations)
 - No UK EX / ATEX certification for the on-tank valve and IR transmitter used for hydrogen refuelling with IR communication
 - LD HFTS was certified by disabling the on-tank valve and for hydrogen refuelling with the table-based approach
- Some UK HRS require IR communication for the station to refuel at the its “normal” condition
 - No IR communication → HRS stops refuelling at a lower pressure or refuels at a lower flow rate
 - Thus, unable to verify the HRS at its normal condition
- SAE J2601/5 protocol (2024) for high flow refuelling of heavy-duty hydrogen powered vehicles
 - Flow rates up to 300 g/s (18 kg/min) [vs. 60 g/s (3.6 kg/min) currently at light duty vehicle HRS]
 - Heavy duty vehicle with 120 kg capacity refuelled within 10 minutes
 - Requires IR communication to achieve the 18 kg/min refuelling flow rates



TÜV SÜD plans for future verification of UK HRS



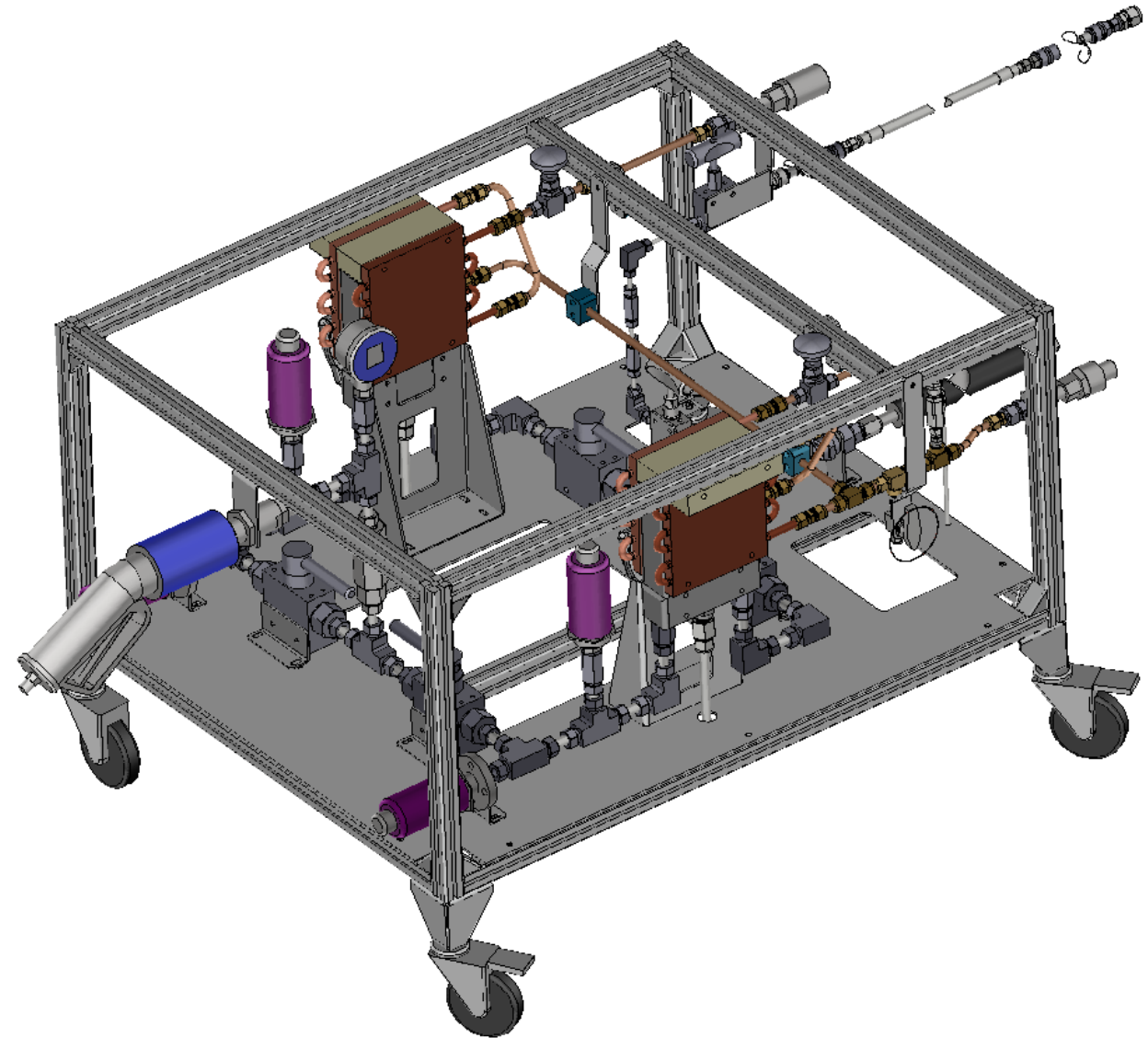
- Upgrading the LD HFTS to allow hydrogen refuelling with IR communication
 - Designing a system that can be UK EX / ATEX certified
- Complete the build of the HD HFTS designed for 350 bar heavy-duty vehicle HRS
 - Includes hydrogen refuelling with IR communication
 - Suitable for verifying heavy duty vehicle HRS operating in the UK



TÜV SÜD plans for future verification of UK HRS



- TÜV SÜD currently building a Master Meter System (MMS) that allows faster verification of HRS and is not affected by environmental effects (wind, low temperature)
- The MMS will be traceable to the mobile primary standards (LD HFTS, HD HFTS) and stationary standards (nitrogen, water or kerosene)
- Includes flow meters within a temperature-controlled enclosure (needs to be UK EX / ATEX certified), designed to keep the flow meters close $-40\text{ }^{\circ}\text{C}$ to minimise flow measurement uncertainty due to rapid temperature change during fuelling
- Sized for fast flow hydrogen refuelling up to 18 kg/min (SAE J2601/5)
- Participate in the EMPIR MetroHyVe 3 project (started in September 2025)
- Provides UK the capability to verify current and future HRS with respect to the requirements in OIML R 139



Thank you

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