HYDROGEN REFUELLING STATION CALIBRATION WITH A TRACEABLE GRAVIMETRIC STANDARD

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VSL, Delft
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HYDROGEN REFUELLING STATION CALIBRATION
Related European Programs

- This work has been realized within two European projects

MetroHyVe – EURAMET EMPIR call

FCH-JU : FCH / OP / 196 : “Development of a Metering Protocol for Hydrogen Refuelling Stations”

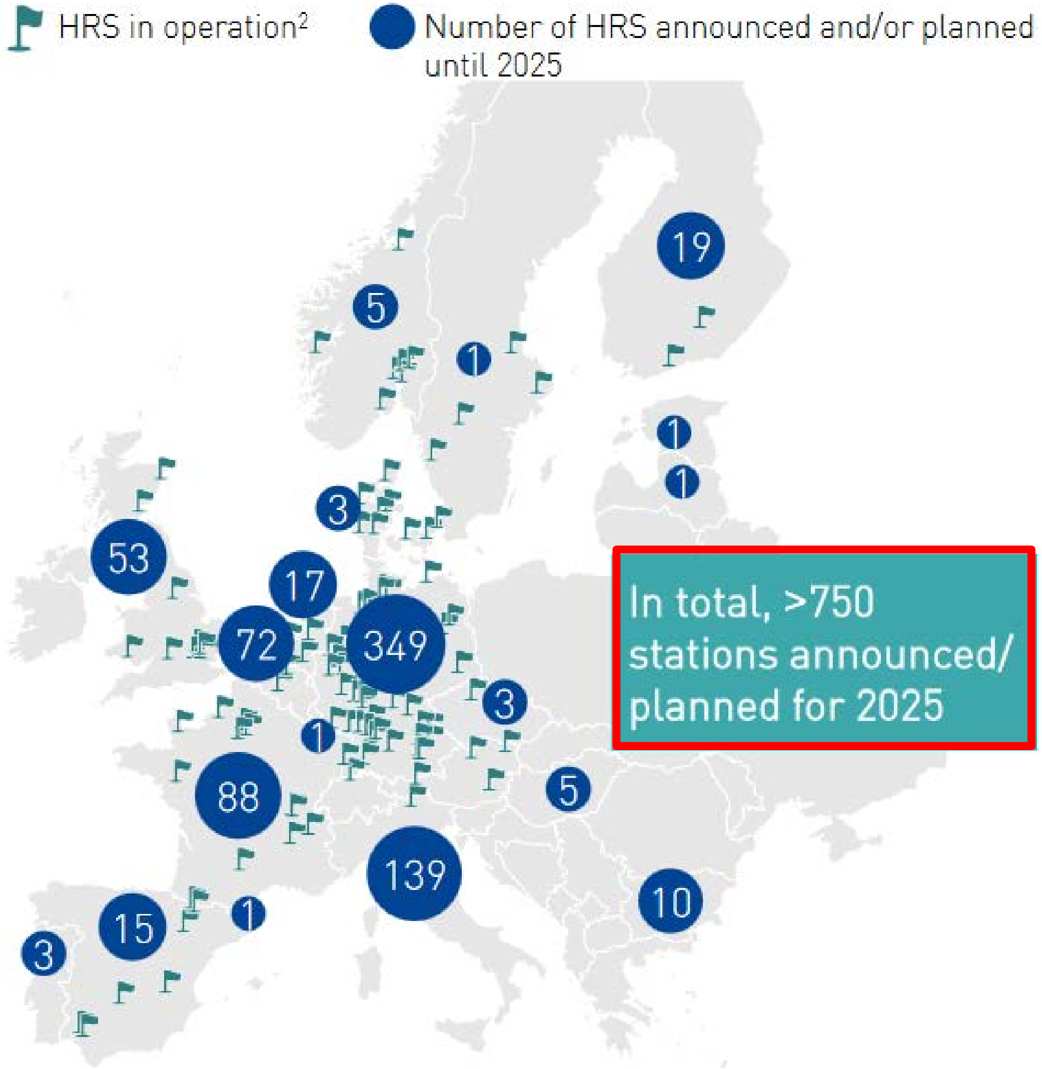
Road map of the presentation

- Background regarding HRS in Europe
- Basic operating principle of a HRS station
- Test protocol for HRS calibration (on-site) and primary gravimetric standard.
- Results from on-site measurements with the primary traceable gravimetric standard.
- Conclusions and perspectives

HYDROGEN REFUELLING STATION CALIBRATION
Background regarding HRS in Europe

- H2 HRS growth in Europe

Current and planned HRS in Europe



	FCEV share in respective segment 2030	2050
Small cars	2%	22%
Larger cars	5%	39%
Taxis	14%	61%
Vans/LCVs	8%	49%
Buses	6%	45%
Trucks	1%	35%
Small cars	0%	14%
Larger cars	2%	28%
Taxis	8%	57%
Vans/LCVs	3%	30%
Buses	2%	25%
Trucks	<1%	21%

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Background regarding HRS in Europe

- Why H_2 dispensers are not certified yet?

  - Flow meters are not approved according to OIML R139 due to the absence of testing facilities (H_2, 700 bar, ...)

  - OIML R139-2014 was not adapted for hydrogen dispensers

The standard has been revised in 2017-2018.
*New version issued on **Oct 2018**.*

→ **Therefore, short-term solution for the approval H2 dispensers is necessary for the ramp-up of the HRS network in Europe**

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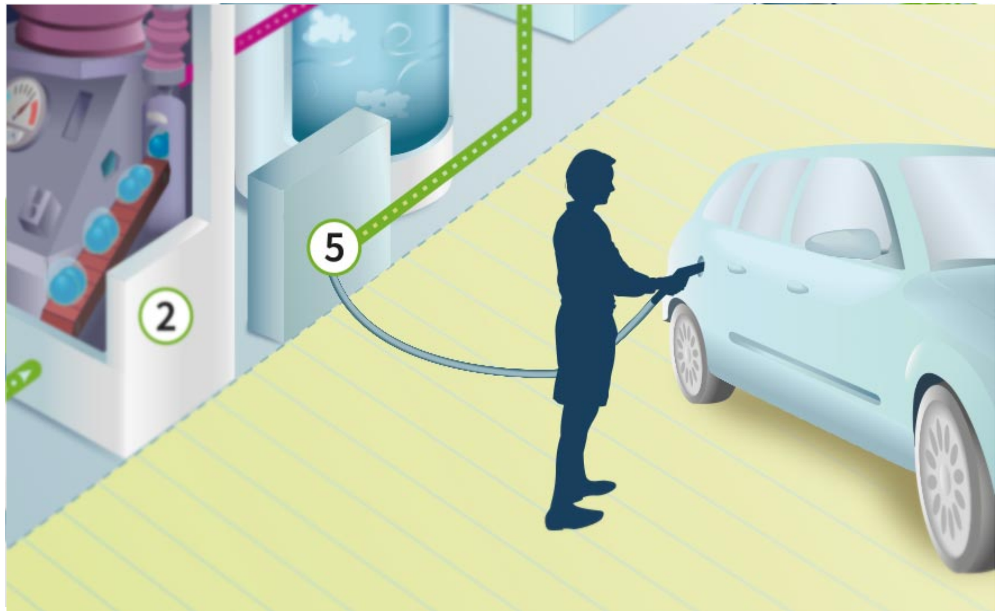
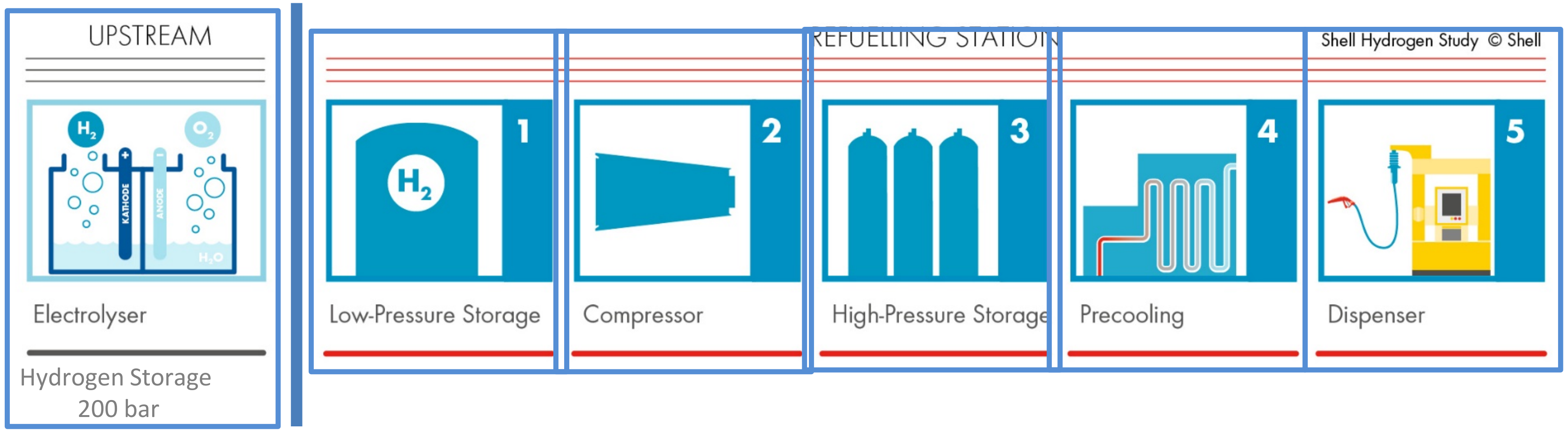
Basic operating principle of a HRS station

- Basic principle and listing of the component:

Photo courtesy of the California Fuel Cell Partnership





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Test protocol for HRS calibration (on-site)

- **Revision of the OIML R139 standard for gaseous dispensers**
  - OIML R139 revision initiated in **March 2017** to include specificities of Hydrogen dispensers
  - Accuracy classes have been largely discussed and revised in the new revision **October 2018**:
    - **Class 2** & **Class 4** have been created for hydrogen service

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

- In principle: **Class 2** is accepted for future stations, whereas **Class 4** is tolerated for existing stations

How to test a complete measuring system?

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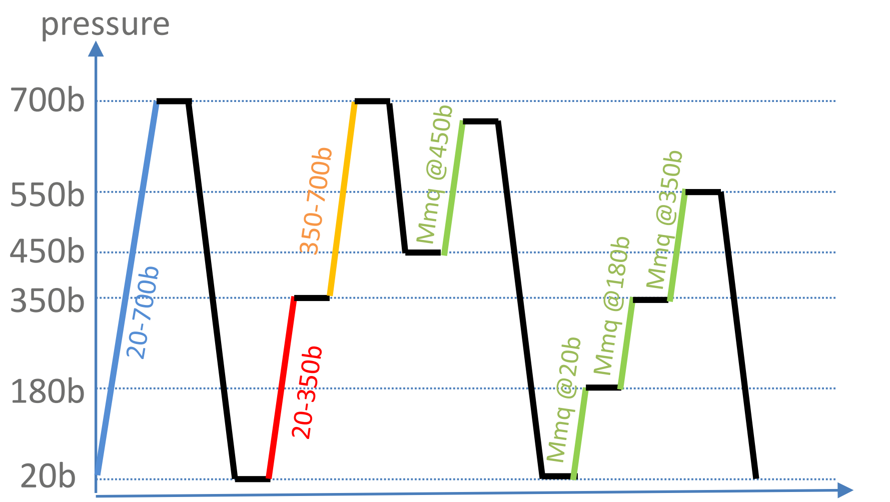
Test protocol for HRS calibration (on-site)

- **Accuracy tests based on *OIML R139-2018***

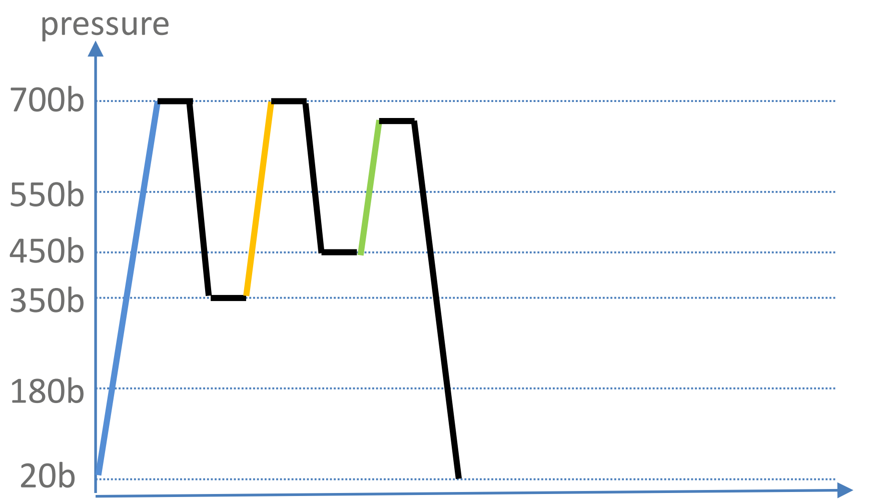
  – Full series of tests:

– 1 full fillings	20-700 bar	Automatic stop
– 1 partial fillings	20-350 bar	Manual stop
– 1 partial fillings	350-700 bar	Automatic stop
– 4 MMQ fillings	1Kg	
with different starting pressure	(450 bar - 20 bar - 180 bar - 350 bar)	Manual stop

  – This series of tests is performed **4 times**



Tests done in this study



Tests required by OIML R139

Which kind of technologies have been tested ?

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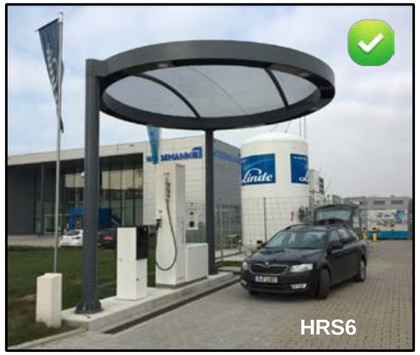
Test protocol for HRS calibration (on-site)

- **HRS technologies**
  - – compressed gas or liquid hydrogen (cryo pump) & compressed gas (ionic compressor)
  - – MFM located in the station, which can be far away from the dispenser / 3 different mass flow meters manufacturers

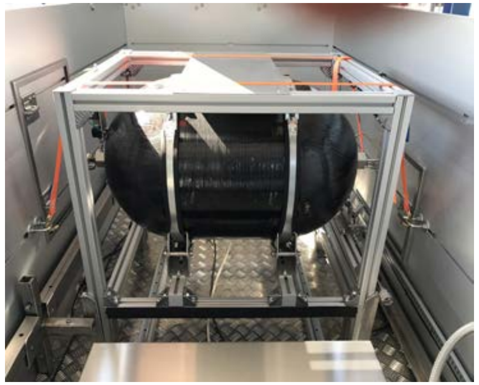
- **HRS location (France, Germany (mainly) and Netherland)**

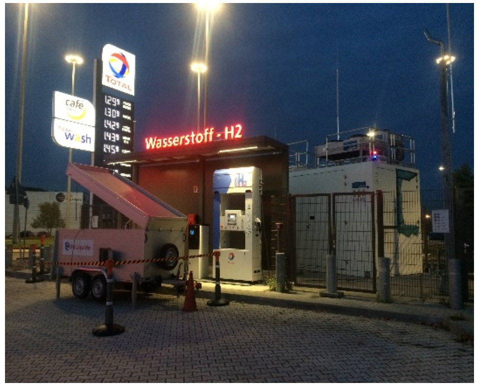


HYDROGEN REFUELLING STATION CALIBRATION
primary gravimetric standard (Air Liquide)

- **Main characteristics and design (Air Liquide + Cesame Exadebit)**

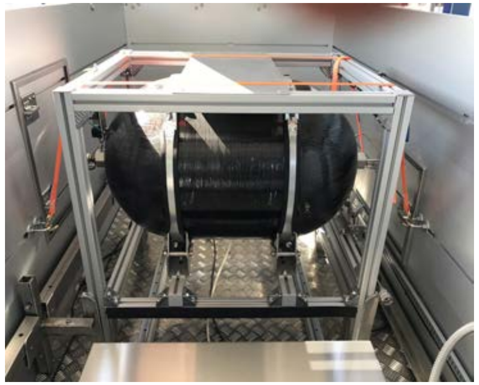
  - **High precision scale**: 150 kg resolution 0.2g, Ex-certified
  - **Composite tank type 4** of 104L (i.e. 4,0 Kg of Hydrogen at 700 bar, 15°C)
  - **Mobile** test bench (trailer) to be moved on each HRS
  - Trailer walls, doors and roof serve as **protection against wind**
  - Protection against fire (**TPRD**)
  - Possibility to remove the scale for transportation
  - Valve panel to **inert tank with N2** for transportation
  - Independent **vent stack** for depressurization of the tank

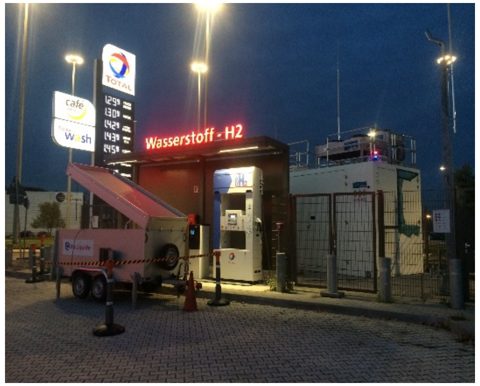




HYDROGEN REFUELLING STATION CALIBRATION
primary gravimetric standard (Air Liquide)

- **Testing device designed and manufactured by Air Liquide (with Cesame Exadebit)**
  - Certified by PTB (March 2018) as first reference standard for calibration, conformity assessment and verification of hydrogen refueling dispensers
    - Also accepted by LNE (France) and NMI Certin (Netherlands)
  - Fulfills metrological requirements as per OIML R139-2018
    - Uncertainty U < ⅕ MPE = 0,3%
    - Uncertainty budget defined in collaboration with PTB / LNE / Cesame Exadebit
- **CE approval**
  - Issue: tank is not designed as per PED, but **EC79** (on-board storage)
  - Long process with the Notified Body to get a Conformity Assessment according to PED
- **Testing equipment conform to Ex rules**





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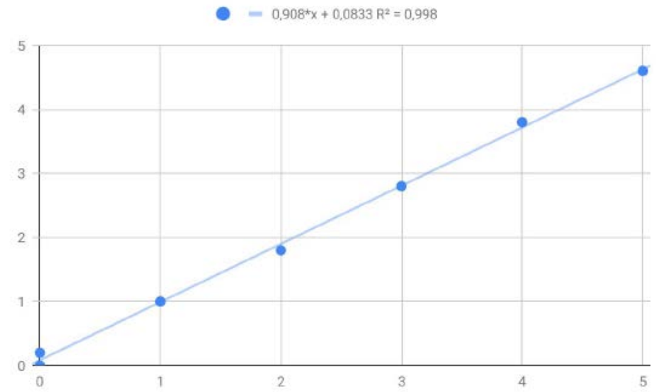
HYDROGEN REFUELLING STATION CALIBRATION
Results from on-site measurements with gravimetric standard

- **Typical planning of a testing week:**
  - Installation: 2-3h
  - Scale verification: 30 min
  - Accuracy test: 3 days
  - De-installation: 2-3h

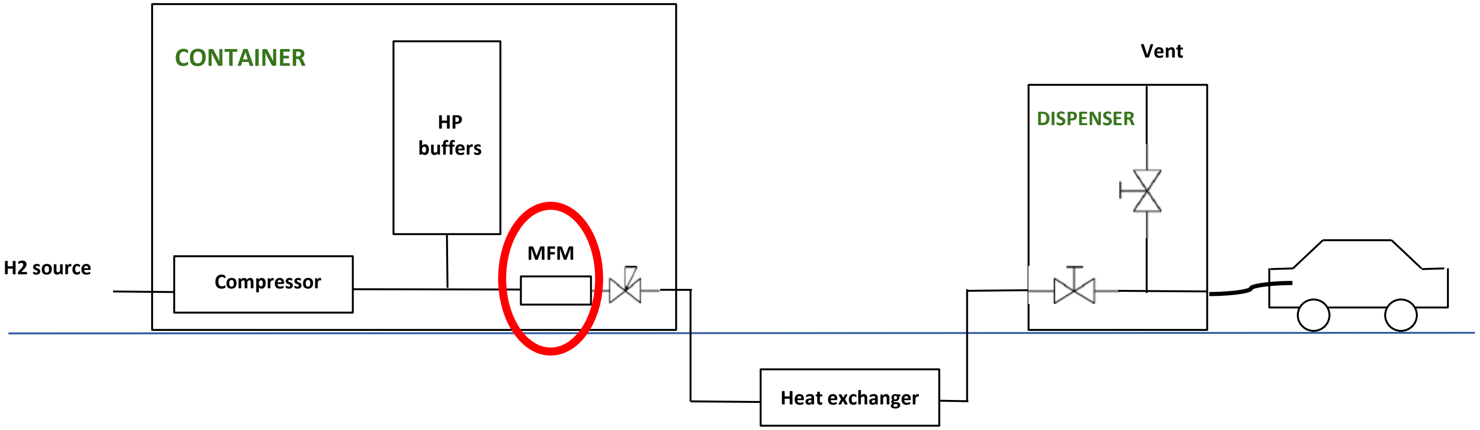
- **Scale verification**
  - Warm-up time required of about 1h30-2h
    - Scale must remain powered during nights to save time each morning
  - Verification using reference weights: 1 Kg / 2Kg / 4 Kg / 5 Kg:
    - One full verification on the 1st day
    - Then light verification each morning
  - Linear correction brought to mass measurements
    - Based on scale deviation measured each day



HYDROGEN REFUELLING STATION CALIBRATION

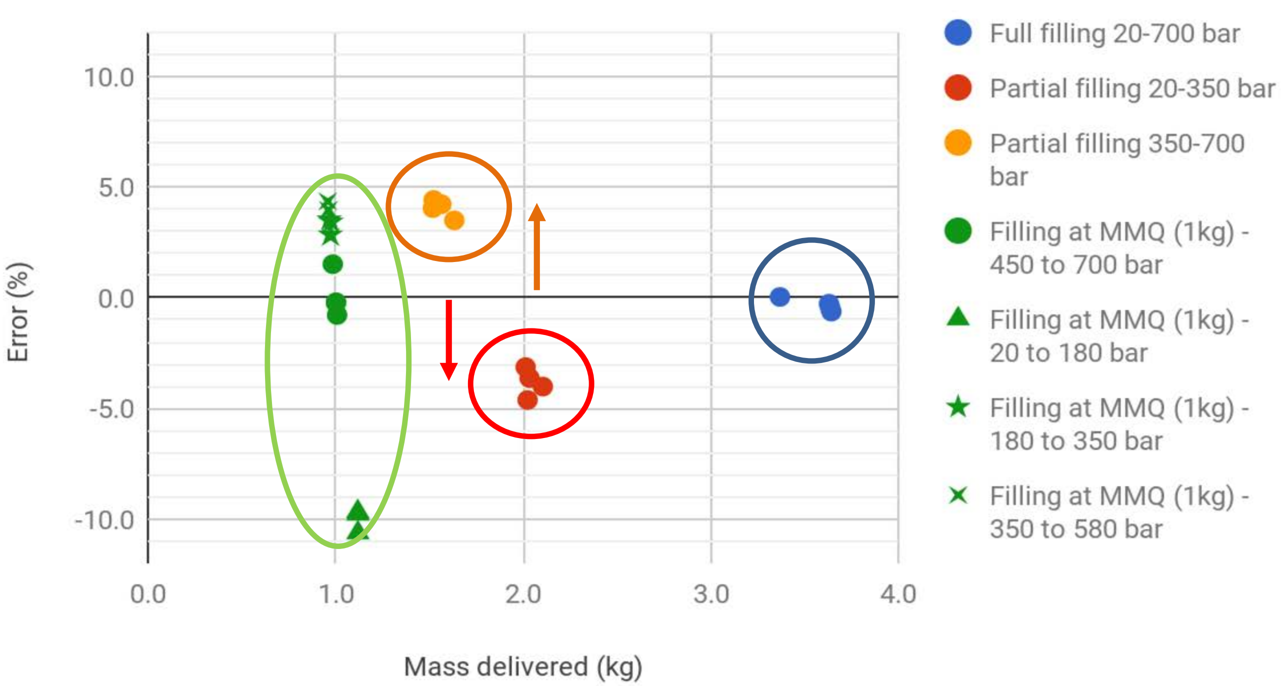
Results from on-site measurements with gravimetric standard

- same configuration (called 1) of the measuring system:



HYDROGEN REFUELLING STATION CALIBRATION
Results from on-site measurements with gravimetric standard

- **Configuration 1: HRS2 (compressed gas) – MFM in the container**

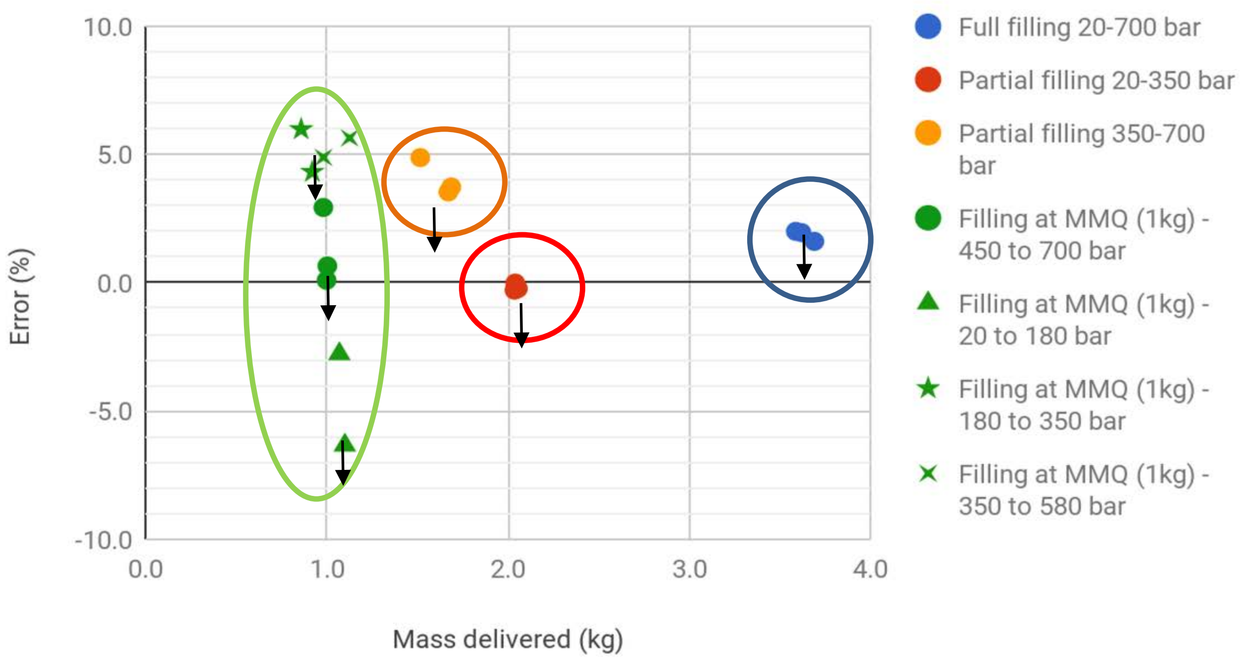


- Full filling : good repeatability – around 0
- Partial filling : negative offset (20-350bar)
- Partial filling : positive offset (350-700bar)
- Large scatter at MMQ depending on initial pressure

Is this tendency often seen with this configuration 1

HYDROGEN REFUELLING STATION CALIBRATION
Results from on-site measurements with gravimetric standard

- **Configuration 1: HRS1 (compressed gas) – MFM in the container**



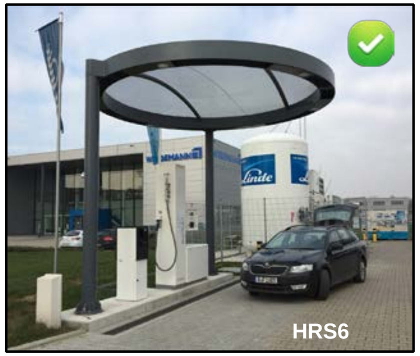
- The same trends are observed :
- For all fillings : good repeatability – ***but offset +2%***

This could be attributed to k factor in the MFM
Adjustment in Coriolis has not be realized during this test campaign
One adjustment is allowed by the OIML R139

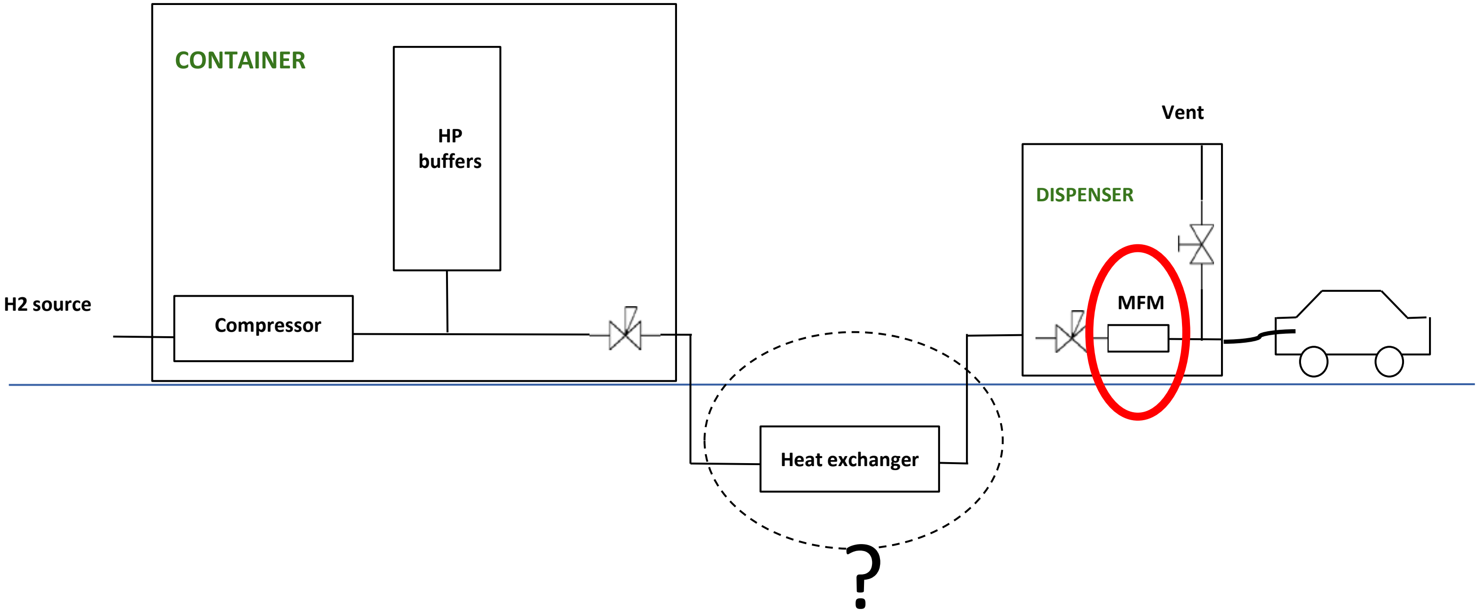
What about other HRS configuration ?

HYDROGEN REFUELLING STATION CALIBRATION

Results from on-site measurements with gravimetric standard



- same configuration (called 2) of the measuring system:



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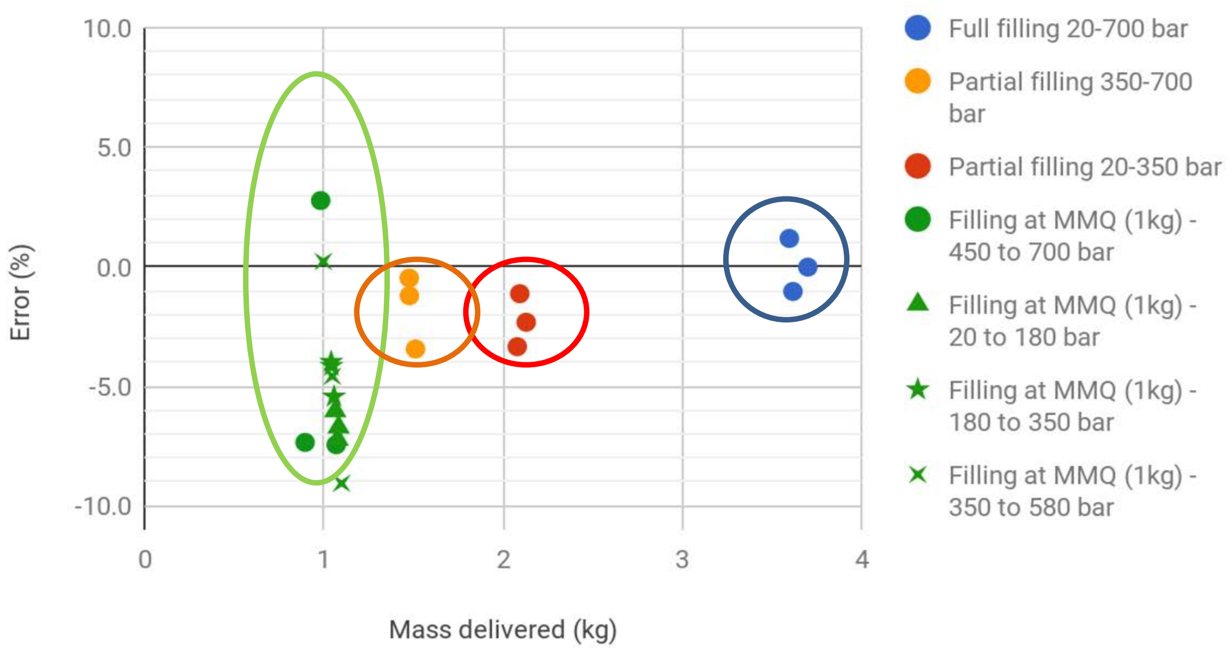
Results from on-site measurements with gravimetric standard

- **Configuration 2: HRS7 (compressed gas) – MFM in the dispenser**



- Different results than previous HRS
- More dispersion on the test results (other brand of MFM)
- ***Constant deviation seems observed → Icing issue***

Remark : weather was bad – high humidity / cold
Venting was taken into account – no indication how

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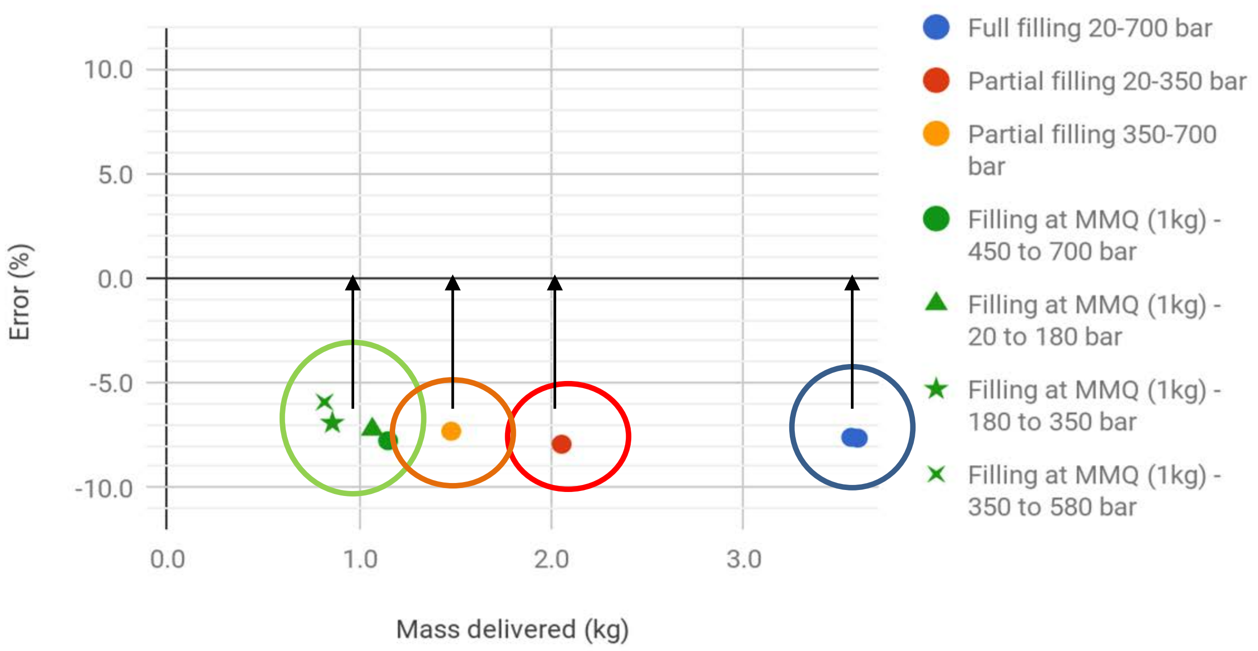
Results from on-site measurements with gravimetric standard

- **Configuration 2: HRS6 (Liquid H2) – MFM in the dispenser**



- Large negative offset
- Results are centered around -7%
- ***If a correction is applied to the CFM, this configuration could reach a class 1.5 in the OIML R139 classification***
- ***Only one set before HRS failure.***

Summary of all experiments and accuracy class for HRS

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Results from on-site measurements with gravimetric standard

MEAN VALUES	CONFIGURATION 1					CONFIGURATION 2	
	HRS1 *(based on adjusted values)*	**HRS2**	**HRS3**	**HRS4** *(based on adjusted values)*	**HRS5**	**HRS6** *(based on adjusted values)*	**HRS7**
Full fillings 20-700 bar	0,00%	-0,32%	0,52%	0,00%	0,50%	*0,00%*	0,04%
Partial fillings 20-350 bar *(*)*	-2,03%	-3,84%	-2,46%	-0,83%	-3,89%	*-0,31%* (*)	-2,26%
Partial fillings 350-700 bar	2,19%	4,05%	0,72%	1,00%	4,58%	*0,31%* (*)	-1,71%
Filling at MMQ 450 to 700 bar	-0,63%	0,08%	1,99%	0,50%	4,84%	*-0,14%* (*)	-4,01%
Filling at MMQ 20 to 180 bar *(*)*	-6,41%	-10,02%	-9,95%	-1,71%	-6,75%(*)	*0,40%* (*)	-6,65%
Filling at MMQ 180 to 350 bar *(*)*	3,29%	3,28%	-5,13%	0,94%	0,51%(*)	*0,71%* (*)	-4,51%
Filling at MMQ 350 to 580 bar *(*)*	3,41%	3,69%	-1,08%	0,71%	4,63%(*)	*1,70%* (*)	-4,47%
CLASS OIML R139	**4**	**4**	**2**	**2**	**4**	**2**	**4**

Legend:

Green = all values are within the limits (MPE)

Orange = mean value is within the limits (or very close to the limits), but some single values are out of the limits (MPE)

Red = all values are out of the limits (MPE)

(*) *single value*

(*) tests out of OIML R139:2018 scope

Explanations for the results

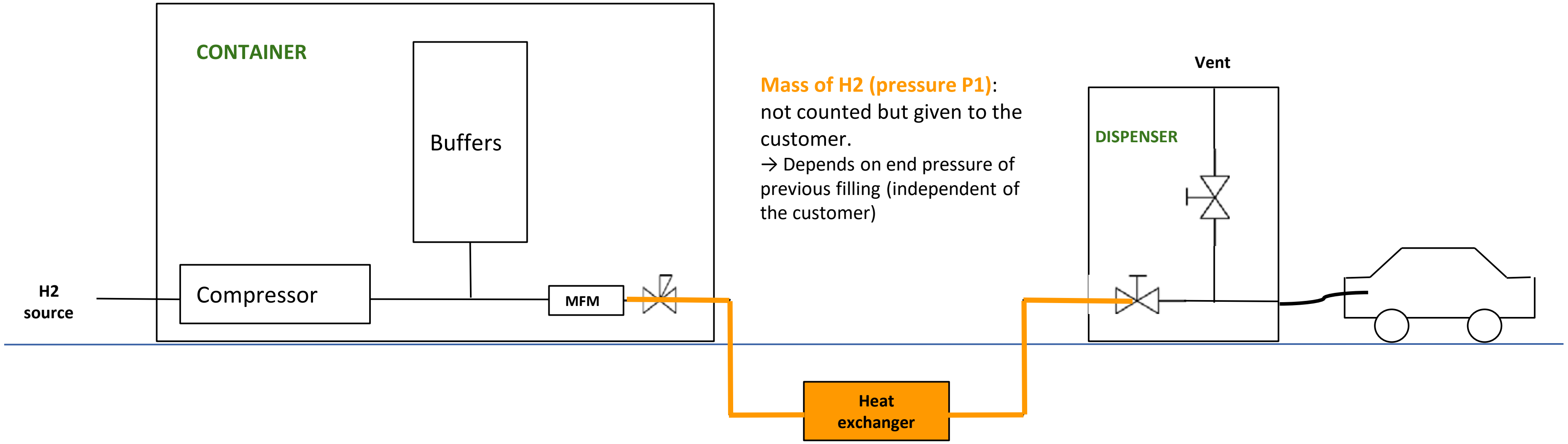
HYDROGEN REFUELLING STATION CALIBRATION
Results from on-site measurements with gravimetric standard

- **Good reliability of the testing device in ambient conditions** (hot temperatures, moderate wind, cold and humid conditions in winter)
  - Icing phenomenon to be **considered** and better quantified in the uncertainty budget
- **Influence of the type of MFM:**
  - Three models tested in different configurations
  - Good precision obtained with M1 & M2 MFM (cf. Full fillings) and good overall repeatability
  - Remark on the M3:
    - Dispersion seems more important
    - Further tests required to clearly conclude on the performance of this MFM
- **Influence of the measuring system configuration (distance between the MFM and the nozzle):**
  - **Configuration 2** show lower errors than configuration 1

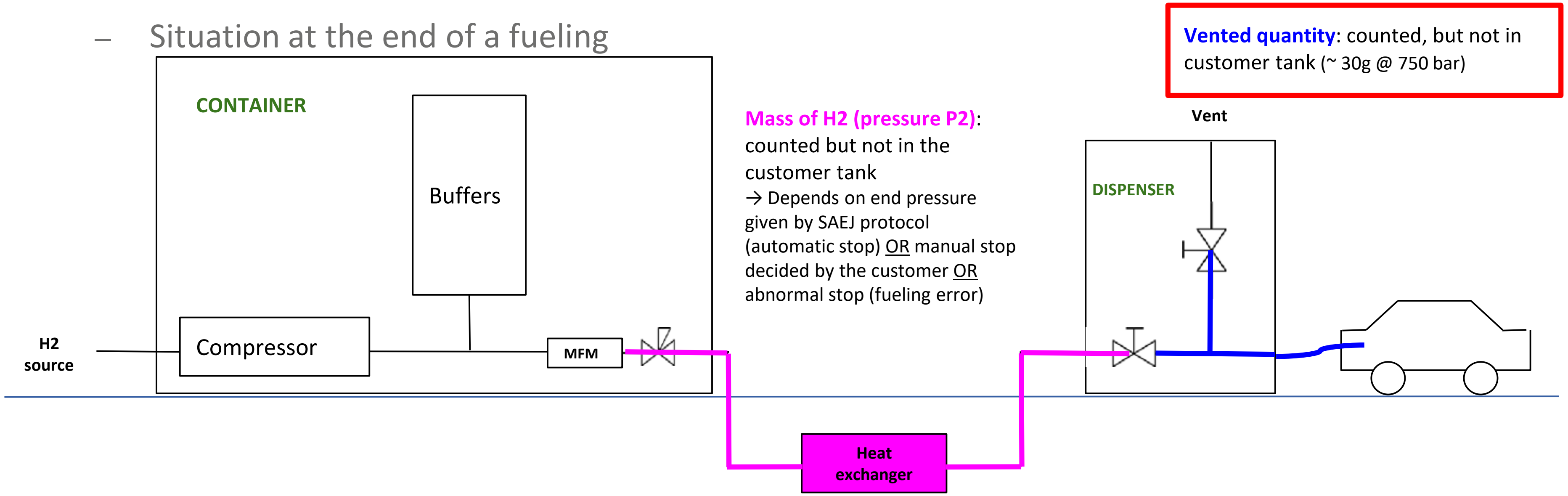
Why?

HYDROGEN REFUELLING STATION CALIBRATION
Results from on-site measurements with gravimetric standard

- **Influence of distance between MFM and dispenser: Configuration 1**
  - Situation at beginning of a fueling



  - Situation at the end of a fueling



HYDROGEN REFUELLING STATION CALIBRATION

Results from on-site measurements with gravimetric standard

- **Influence of distance between MFM and dispenser: Configuration 1**

  - If **P1** ~ **P2**: the customer pays ***exactly*** the quantity delivered in his tank
    - Initial mass of H_2 is replaced by the *same* quantity at end of fueling

m_delivered ~ m_invoiced

  - If **P1** > **P2**: the customer get ***more*** hydrogen than the quantity invoiced
    - Initial mass of H_2 is replaced by a *lower* quantity at end of fueling

m_delivered > m_invoiced ***(negative error)***

  - If **P1** < **P2**: the customer get ***less*** hydrogen than the quantity invoiced
    - Initial mass of H_2 is replaced by a *higher* quantity at end of fueling

m_delivered < m_invoiced ***(positive error)***

APPLICATION:

- ● Full fillings 20-700 bar
- ● MMG (1kg) 450-700 bar
- ● Partial fillings 20-350 bar
- ▲ MMG (1kg) 20-180 bar
- ● Partial fillings 350-700 bar
- ★ MMG (1kg) 180-350 bar
- □ MMG (1kg) 350-580 bar

- **Strong influence of the distance between the MFM and the dispenser**
  - **The longer is the distance (or volume), bigger is the error**
  - **Larger pressure difference in the pipe at beginning and end of fueling leads to a bigger error**
    - **Example: MMQ fueling at 450 bar and 20 bar initial pressure**
  - **If the volume of piping is known then errors can be calculated and corrected**

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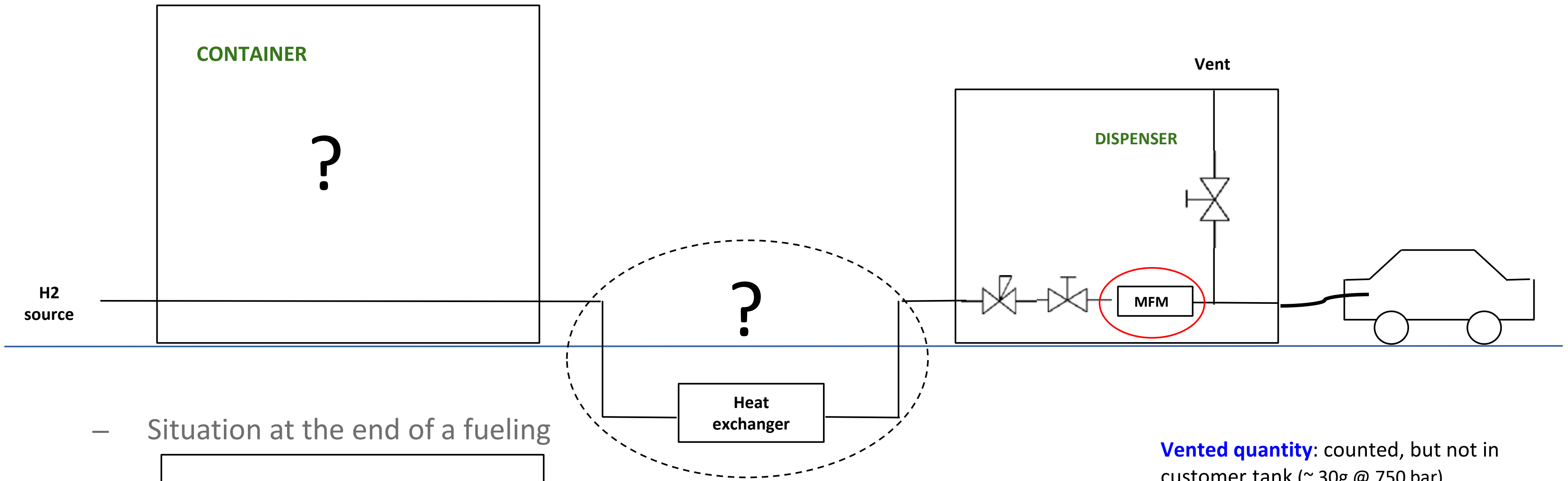
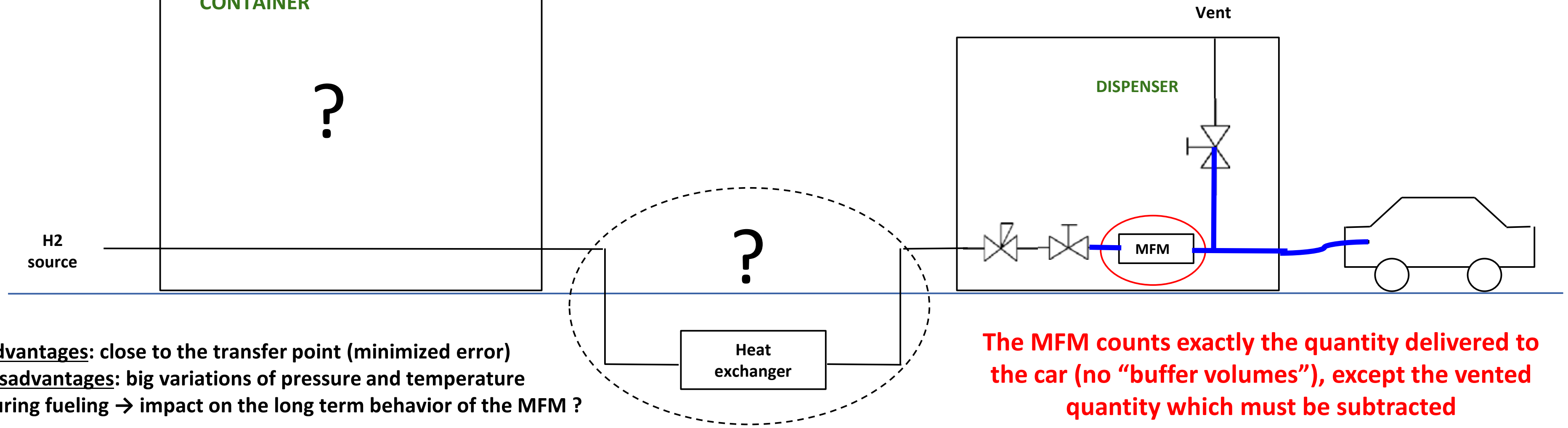
Results from on-site measurements with gravimetric standard

- **Influence of distance between MFM and dispenser: Configuration 2**

  – Situation at beginning of a fueling



  – Situation at the end of a fueling



Advantages: close to the transfer point (minimized error)
Disadvantages: big variations of pressure and temperature during fueling → impact on the long term behavior of the MFM ?

The MFM counts exactly the quantity delivered to the car (no "buffer volumes"), except the vented quantity which must be subtracted

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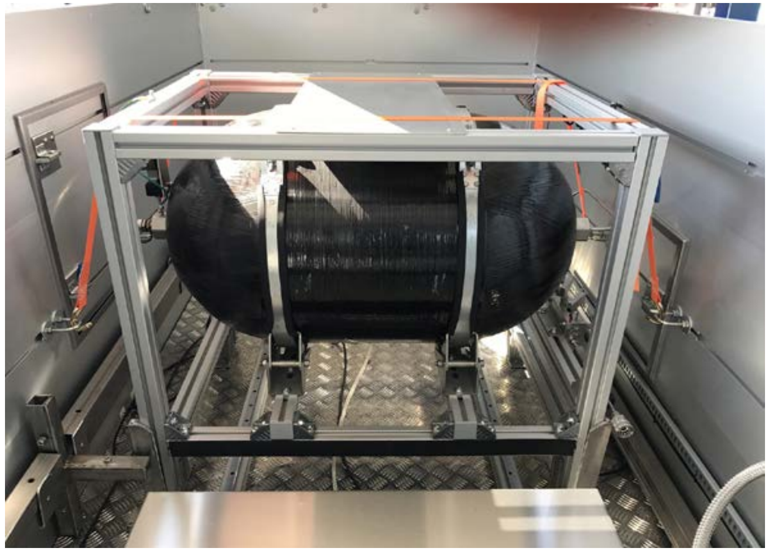
HYDROGEN REFUELLING STATION CALIBRATION

Conclusions and perspectives

- A primary test bench as been designed and developed for hydrogen refueling station calibration.
- An intensive test campaign has been realized in Europe (7 HRS).
- The accuracy classes has been found to mainly comply with Class 4 (for existing stations).
- The main errors have been measured and some hypothesis have been proposed to understand the difference between two main configurations – Configuration 2 seems more accurate but caution has to be taken regarding operating conditions.
- Need to make comparison between primary standard for hydrogen stations and develop new metrological framework for periodic verification to speed up the test campaign
- Need to consider other kind of technologies (bicycles, buses and train) and adapt our reference for these ranges of application.

HYDROGEN REFUELLING STATION CALIBRATION
Conclusions and perspectives

- Thank you !



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