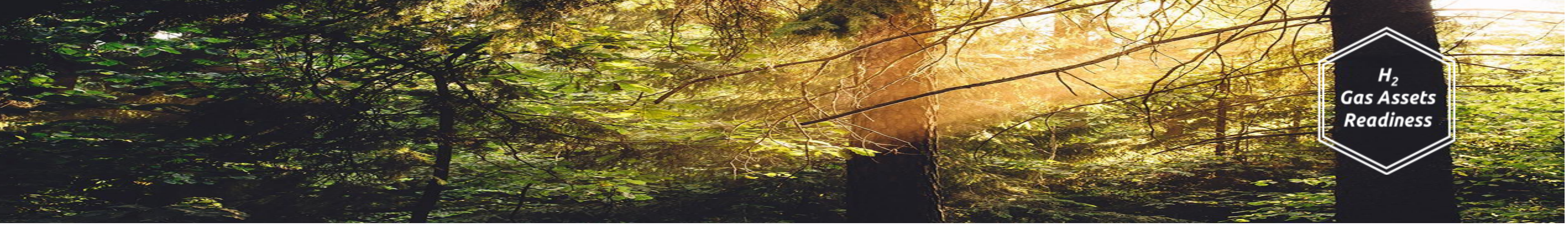
H_2 Gas Assets Readiness

Working Group 4: Metering

6th Activity Report:

Common proposal of minimum requirement for a H_2 metering station



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Working Group 4	02/07/2025	Public ☒	Confidential ☐

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1. EXECUTIVE SUMMARY

The purpose of this document is to serve as a guide for the design of large hydrogen energy metering stations connected to the transmission network.

First, a process is proposed to structure the design approach and ensure that certain key stages are not omitted.

In the next chapter, the legal and normative framework is analysed, and solutions are proposed when the framework is not directly applicable to the measurement of hydrogen. This chapter also emphasizes the importance of dialogue with NMIs to design solutions that comply with national and international regulations.

The metrological requirements are then determined, depending on the importance of the metering station. The challenges of a gas balance close to zero are illustrated.

The choice of measuring instruments, in particular gas meters and flow-computers, is also reviewed. Each technology is presented with its advantages and points of attention for hydrogen metering. The calibration of gas meters is also discussed as well as the equations of state to be preferred in the flow-computers.

Next, the notion of "documented provision" as introduced in OIML R140 is remembered here. This documentation will have to be built to ensure the traceability and fairness of trade and to argue the dialogue with the NMIs. Metrological maintenance is also addressed, to keep the station's metrological quality constant throughout its lifetime.

Finally, the conclusions and recommendations summarize the information made available in this document.

This document reflects the current knowledge and understanding of TSOs at this stage. As further developments and insights emerge, the document will be updated accordingly to ensure it remains aligned with the latest advancements and industry best practices.

2. INTRODUCTION

H_2 Gas Assets Readiness (H2GAR) is a collaboration among some European natural gas Transmission System Operators (TSOs). The initial aim was to share knowledge about the impact of the injection of a limited amount of H_2 into the assets within their high-pressure natural gas networks to understand the readiness of these assets for transporting H_2. This aim has evolved to include the transportation of pure H2 in repurposed or new built infrastructures.

This collaboration will expedite the process to identify the readiness of the different parts of the gas network for carrying H_2 blends with natural gas (up to 10% volume) or pure H_2.

The task has been divided into different Working Groups, according to the different topics identified as relevant:

1. Working Group 1 – Pipeline material and operation
2. Working Group 2 – Compressor Stations
3. Working Group 3 – Separation Systems
4. Working Group 4 – Metering/Other instrumentation
5. Working Group 5 – Safety
6. Working Group 6 – Underground Gas Storage

This report summarises the activities carried out in 2024 by the WG4, *Metering and Other Instrumentation*.

3. SCOPE OF THE DOCUMENT

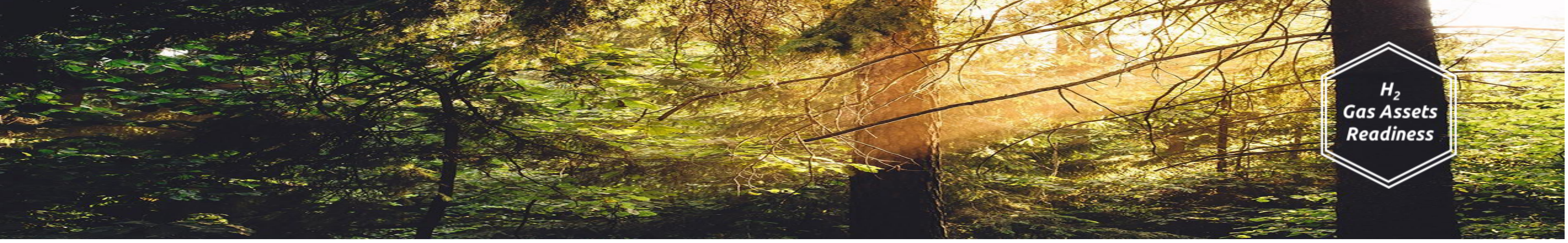
This document provides a process for designing a hydrogen metering system from a metrological point of view. Several aspects are covered: legal metrology, normative requirements and technological choices including for the initial and periodic verifications.

This document should enable a common approach to the design of a hydrogen metering station, particularly for interconnection points where two TSOs are involved. It should also enable a common interpretation of the texts referred to and propose examples of pragmatic solutions. These solutions may concern the choice of measurement technology, the application of a calculation method or the assessment of measurement uncertainties.

In addition, this document presents correlative methods for determining calorific value or other physical properties. These methods should enable to maintain an appropriate level of quality and reduce the construction and maintenance costs of measurement systems, to facilitate the development of hydrogen.

This document does not provide detailed information on other aspects of measurement system design, such as ATEX or installation safety.

This document reflects the current knowledge and understanding of TSOs at this stage. As further developments and insights emerge, the document will be updated accordingly to ensure it remains aligned with the latest advancements and industry best practices.



4. PROCESS TO DESIGN H_2 METERING STATION

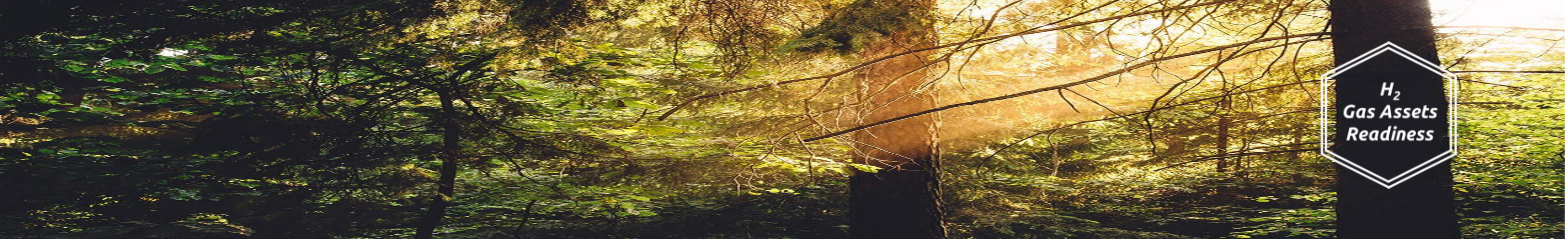
The following process is proposed to structure the approach:

Identify
- Legal and normative frameworks
- Metrological Requirements

Select
- Appropriate Standards
- Appropriate Measuring Devices

Design
- Metering line configuration & sizing
- Complete metering system for Energy Measurement

Document
- Quality management system
- Metrological maintenance



5. LEGAL AND NORMATIVE FRAMEWORK

5.1. LEGAL NATIONAL REQUIREMENT

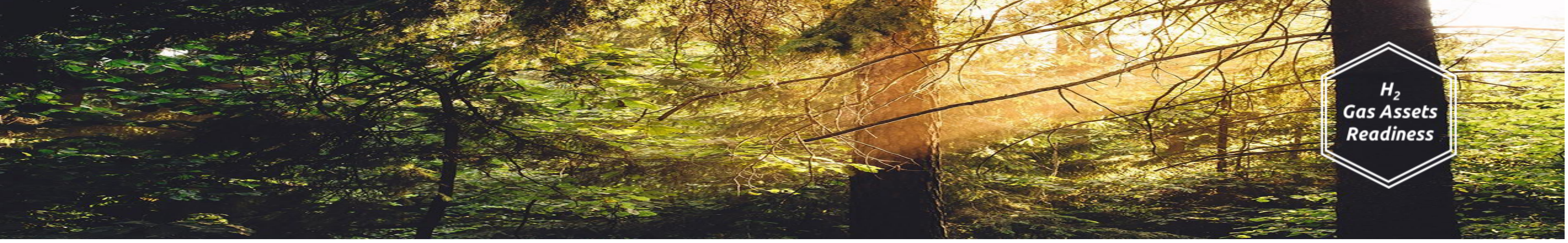
One of the first steps in designing a hydrogen metering station for fiscal purposes is to identify requirements to comply with the (national) legal framework. As hydrogen is not only a pure gas, but also a fuel gas, the authorities often accept the same legal framework as for natural gas.

Establishing a dialogue with the National Metrology Institute (NMI) or responsible Authority is important. In many countries, procedures already exist to enable technological developments by obtaining national (temporary) approval of a measuring system or an exemption. The notion of “documented provision” (OIML, OIML R140 - Measuring system for gaseous fuel, 2007) is important here. A technical file and traceable test results must be prepared by the applicant. This documented provision can be based on the recommendation cited above, as well as on the results of existing tests and model approvals. Additional tests specific to the measurement conditions envisaged may also be carried out by the TSO's and manufacturers, depending on each project (ex: MoSaHyc in France and Germany).

Figure 1: Test in Germany with UFM and TM in series on a 20 bar H2 pipeline (Source: OGE and Evonik)

Below, some examples of national regulations in development:

In Germany, the national authorities have already issued a number of guidelines, such as TR-G19 (Technische, 2023) concerning H_2 purity (quality), and the EoS allowed for Z calculation, such as AGA-8 (ISO, ISO 12213-2; Natural gas — Calculation of compression factor - Part 2: Calculation using molar-composition analysis, 2006) and the authorized gas meter technologies. PTB also is



working in close cooperation with the laboratories (ex: RMA) to ensure a fair and traceable measurement.

In France, the NMI decided to consider H_2 as a fuel gas. Consequently, the regulatory framework that applies to the measurement of natural gas also applies to the measurement of H_2: type approval according to MID (class 1) or OIML R137 (class 1 or class 0.5) is required for gas volume measuring devices. For new technologies, a specialized technical committee can also deliver (temporary) type approvals or exemption. This is a lengthy process and anticipation is needed (ex: approval by the LNE of a correlative method to determine the purity and GCV based on the Speed of Sound).

In Belgium, an Authorization of Use can be obtained for a metering system based on documented provision. An annual audit is performed to ensure that the requirements are respected regarding the design, initial calibration, periodic verifications, and metrological performance. This system enables the NMI to guarantee the control of these measurement systems used for transactional purposes. Under this approach, each measuring device involved in the fiscal process (energy determination) must have a valid model approval (ex: for natural gas) and be calibrated under the intended conditions of use.

In conclusion, the lack of maturity of the current legal framework should lead TSOs to take appropriate initiatives with the NMIs to design measurement systems that comply with current, interim, and future regulations. These discussions are often an opportunity to actively participate in regulatory monitoring and the development of a legal framework adapted to our activities.

5.2. DEALING WITH TYPE APPROVAL

Type approval of the currently available measurement devices suitable for H_2 is a specific concern for the TSO's. Type approvals are needed for gas meters, Volume Conversion Devices (VCD) and Calorific Value determination devices (CVDD). These three elements are used for energy conversion.

Type approval according to MID can be a legal requirement but from a metrological perspective, this directive is initially reserved for light industry and not for large metering station connected to the transmission network. A Maximum Permissible Error (MPE) of 1% or more could become an unacceptable financial risk for the operator as seen above. Each company must perform its own evaluation.

For the **gas meters**, an OIML certificate class 0.5 can be preferred or an optimized line configuration, to minimize errors, especially if the meter is not calibrated close to the field conditions, due to a lack of available test facilities. Additionally, the correction of the systematic error defined during the calibration can be implemented in the meter itself or in the VCD.

Regarding the gas meters, documented provision based on the following principle is a minimum:

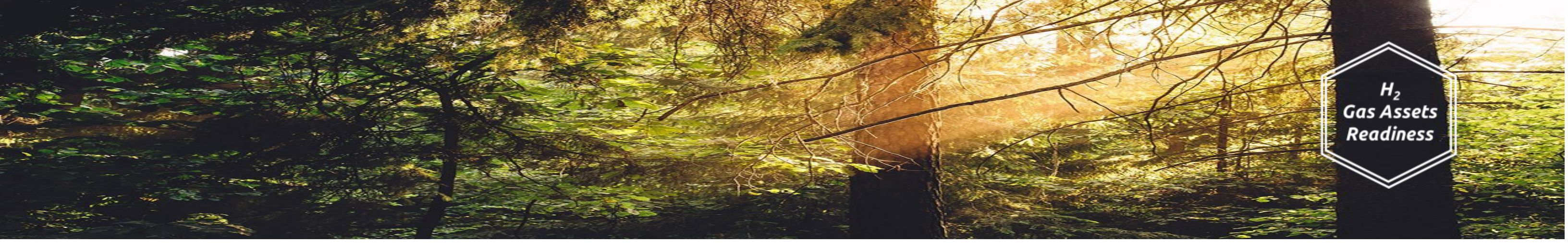
- The gas meter is approved for fuel gas (i.e. natural gas)
- The gas meter is technically adapted for H_2 (specific transducers or devices to avoid reflection)
- The gas meter is calibrated with H_2 and/or in the range of expected Reynolds number (transferability with other fluid must be documented)
- The error during the calibration is compatible with the accuracy class of the type of approval (legal requirements)

For the **conversion devices**, the following point of attention must be evaluated:

- The Z calculation is possible with (almost) pure H_2. Different possibilities exist:
  - ♦ GERG 2008 EoS is available and documented in the type of approval (preferred solution)
  - ♦ GERG 2008 EoS is available but not documented in the type of approval (regulatory evaluation is needed)
  - ♦ Only ISO 12213-1, -2 is available and documented in the type of approval (technical and regulatory evaluation is needed)
- The GCV calculation must be in accordance with (ISO-6976, 2016) and (ISO/TR-29922, 2017) if the GCV is calculated on volumetric basis.

For the **CVDD**, the legal framework is a national decision, but the following recommendations can be made as a minimum requirement:

- Metrological requirements of the OIML R140 must be respected (class A will be preferred)



- Technical evaluation of correlative devices will be made to decrease the cost and to facilitate the energy transition (if PGC can be avoided).

The table below give an overview regarding the type of approval, risks and opportunities:

	Gas Meter	**Conversion Device**	**CVDD**
reference for type approval	EN 12261, ISO 17089, EN 12480, MID, OIML R137	EN12405-1 OIML R140	OIML R140 EN 12405-2 National framework
Point of attention with H_2	Transferability between gases for calibration/approval Low density	Z and GCV calculationwith H_2 Behavior with AGA8(warnings or alarm)	GCV calculation (ISO/TR 19922) PGC is an expensive technology
Opportunity with H_2	High velocity possible (>40m/s)	Speed of sound calculation to monitor the purity	Correlative devices to consider (less expensive)

Today, a majority of measuring devices are technically usable for H_2, but only a minorityhave a valid type of approval for this fuel gas. Dialogue with NMIs is also necessary to implement certified solutions for fiscal purpose. This dialogue must be supported by documented provisions.

5.3. NORMATIVE FRAMEWORK

As a minimum requirement to design and build a metering station is to refer to a normative framework accepted by the stakeholders of the project. The main references applicable are listed and compared below.

5.3.1. OIML R140 or EN-1776 standards

Both OIML R140 and EN-1776 are valid approaches to design metering stations and provide documented provision for the stakeholders. Some differences in covered scope or approach can be highlighted:

	OIML R140	EN 1776	Remarks
For transmission network	✓	✓	OIML R140 is the recommended approach for large metering systems at interconnection points
For distribution network	✓	✓	EN 1776 is the recommended approach for PD interfaces or national connection points
For Energy determination	✓	✓	GCV determination also is described in EN12405-2
Metrological requirements	✓	✓	MPE are slightly different between the standards
Design of the meter run		✓	EN 1776 also give recommendations for valves and piping requirements
Operation and maintenance		✓	EN 1776 give more details about periodic verification on site
Safety and integrity details		✓	EN 1776 refer to European standards (ATEX, PED…)
Suitable for type approval	✓		A GCV determination device or a flow-computer can be OIML R140 approved
Reference for NMI and NB	✓		OIML stay the preferred recommendation for a dialog with NMI

In summary, ((CEN), prEN-1776, 2024) will be preferred to design a complete metering station, to define metrological maintenance and safety provisions. This standard can be the reference for contractual requirements of a metering station, especially if the station is located at the interface between two operators or connected to the transmission network.

OIML R140 will be preferred and/or complementary to EN-1776 for large international metering stations. Some clarifications regarding MPE, and the definition of a significant fault are also useful for documenting some technical choices. The notion of a documented provision is also particularly useful for arguing discussions with NMI's and to obtains temporary approval or exemption for fiscal purpose. This document also is an international recognized standard used by a notified body (NB) for type approval of the GCV determination devices (PGC or other technology).

6. METROLOGICAL REQUIREMENTS

Two situations can be considered for the TSO's:

- Connection point (national metering station connected to the transmission network)
- Interconnection point (fiscal metering station between two adjacent TSOs)

6.1. CONNECTION POINT

For a connection point, a minimal requirement is to design and build the station according to EN 1776 (Class A). This European standard is commonly accepted by the stakeholders and covers the main topics as the design, commissioning, metrological requirements and metrological maintenance.

Regarding the metrological maintenance, EN 1776 also refer to specific standards for measuring devices. In addition, and for large metering system, the following principle apply:

- The MPE of a new metering device also apply for periodic verification (ex: MPE for conversion devices and associates' transducers)
- Any known systematic error is corrected (ex: error curve of the meter)
- EoS used for volume and energy conversion are suitable for H_2 and documented (ex: Z calculation according to GERG 2008)

Also, some specific national requirements can by apply as specific base conditions for volume and combustion. The velocity in the pipe with H_2 can be higher than with natural gas but this possibility is only possible with electronic gas meters (ex: Coriolis or UFM).

6.2. INTERCONNECTION POINT

To design an interconnection point, both EN 1776 (Class A) and OIML R140 can be consider as complementary. In addition, specific requirements of the TSO's can be apply (ex: reduced MPE of the measuring devices) based on a risk assessment and uncertainty evaluation.

Some other considerations also are important to design a cross-border Metering Station:

- The importance of the pressure loss (ex: flow-conditioner may be avoided)
- The operational flexibility and reliability (ex: several metering lines in parallel)
- The gas quality monitoring (ex: determination of the impurities, refer to ((CEN), CEN/TS 17977:2023, 2023))

A CFD analysis is recommended to evaluate accurately the situation of the above-mentioned considerations. This analysis will be performed before to build a multiline metering station to facilitate an acceptable flow profile, to avoid swirl in the metering line and to ensure a symmetric flow distribution between the lines in parallel.

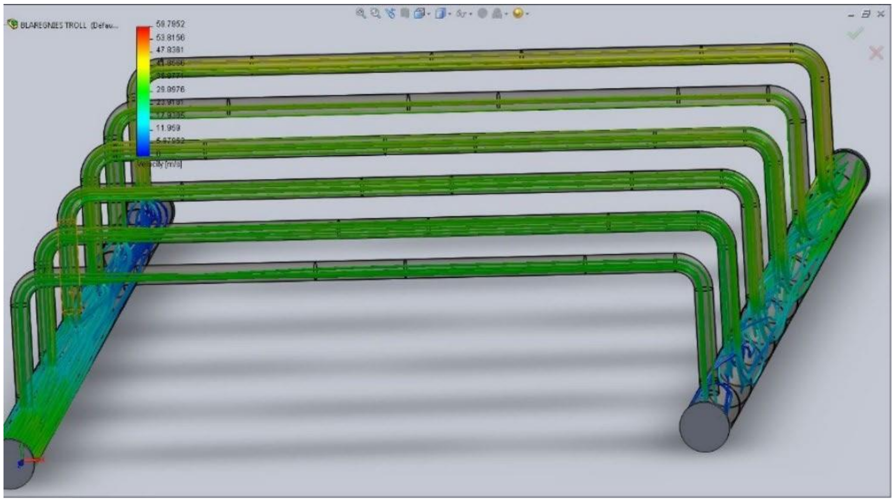


Figure 2: CFD evaluation to verify both flow profile and flow distribution (source: LC-engineering)

6.3. DETERMINATION OF THE MPE

The maximum permissible error (MPE) is one of the first concern for the TSO in order to keep the gas balance close to zero. To simplify the approach, MPE can be considered as a measurement uncertainty and this measurement uncertainty can be defined as a financial risk that will depend on two factors:

- The price of energy
- The economic impact of the gas balance

Since these two factors vary considerably from country to country, each TSO must carry out its own risk analysis. An example of the calculation is given below for information purposes:

	Quantities (MWh/y)	Uncertainty	Uncertainty (MWh)	Uncertainty (€)	Hypothesis
Hub 1 (IN)	621960	0.88%	5473.248	€ 1,609,135	(12h/day @ 40000m³/h)
Hub 2 (IN)	1305240	0.88%	11486.112	€ 3,376,917	(12h/day @ 84000m³/h)
Hub 3 (IN)	153300	0.88%	1349.04	€ 396,618	(12h/day @ 10000m³/h)
TOTAL	**2080500.00**	**0.61%**	**12794.81**	**3,761,673.66 €**	
Border (OUT)	2080500.00	0.88%	18308.4	€ 5,382,670	
TOTAL	**2080500.00**	**0.88%**	**18308.40**	**5,382,669.60 €**	
Delta max. (MWh)	22336.173				
Price/MWh H_2	€ 294.00	(source: European Hydrogen Observatory)			
Financial risk max.	€ 6,566,834.91				

Figure 3: Uncertainty and financial risk evaluation example for a H_2 network in France (Source: LC-Engineering)

In this example, the measurement uncertainty is determined on the network inputs and outputs with a 95% confidence interval (k=2). The delta max. (total uncertainty) represents the maximum statistically permissible deviation and is determined by:

$$Delta_{max} = \sqrt{U_{in}^2 + U_{out}^2}$$

If the potential lost (or gain) is potentially supported by the TSO or other market players, particular attention must be paid to measurement uncertainties. Several solutions can be implemented to reduce this risk and increase the reliability:

- The use of two meters in series.
- The use of the same traceability for both entry and exit points.
- The correction of the systematic errors identified during the calibration.

7. CHOICE OF APPROPRIATE MEASURING DEVICES

The next step is to **identify the appropriate and/or approved measuring devices** compatibles with the legal framework and technically suitable for H_2 measurement.

7.1. GENERAL

Based on the work of H2GAR and the experience of the participants, four types of gas meters have been selected to measure hydrogen under the conditions of a transmission network: the turbine meter, the Coriolis meter, the ultrasonic meter and the rotary piston meter. The graph below illustrates the measurement conditions that are suitable for each of the technologies:

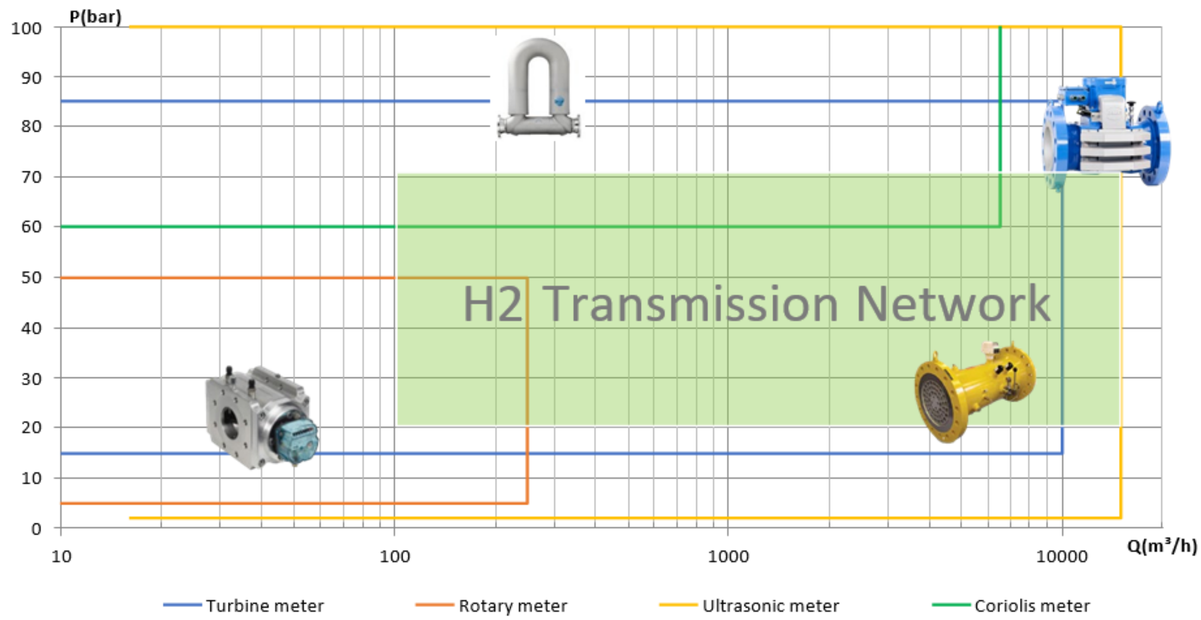


Figure 4: Position of the technology regarding the operating conditions (Source: LC-Engineering)

7.2. TURBINE GAS METERS

The turbine meters have a behaviour according to Reynolds number but a minimum density of 1.2 kg/m^3 (≈15 bars H_2) is recommended because this density is regularly tested during calibration with air at atmospheric pressure. Below this density, the error due to the mechanical friction is high and metrological performance can be rapidly affected. The calibration can be performed with

air or natural gas, but this theoretical transferability must be documented by the manufacturer or the network operator and approved by the NMI.
The validity of the type of approval, if the turbine meter is used with H_2, should be confirmed by the NMI or responsible Authority, since this is a country-specific situation.

+	−
Possible **velocity** is identical compare with natural gas due the mechanical limitations	**Minimum pressure is required** to ensure at least 1,2 kg/m³ and to minimize the error due to the mechanical frictions
The **rangeability** is identical, as with naturalgas (with min. 1,2 kg/m^3)	**No diagnostic** and no physical measurement available to determine the quality
Known, reliable and **inexpensive** technology	Possible **mechanical failure**
Transferability in terms of Reynolds number and calibration with natural gas or air is possible	**Scope of the type of approval** is to clarify withNMI for use with H_2

7.3. ULTRASONIC GAS METERS

The ultrasonic meters also are suitable for H_2 measurement to measure the highest flowrates, but because some technical modifications are needed (frequency of the transducers, devices to attenuate signal reflection…), the current OIML or MID type approval are not directly applicable for H_2. A minimal requirement is to calibrate the USM with H_2 in metering conditions close to the field conditions. Tests are currently possible, and manufacturers have already started to optimize the USM. However, the first infrastructures projects may be commissioned before all the metrological approvals have been obtained. This needs to be anticipated with NMI as well to design solutions that are accepted by the regulations.

+	−
High **velocity** is possible (>40m/s)	**Minimum pressure is required** to minimizethe error
Large **rangeability** (≥50)	**Calibration with H_2** is recommended (dryand flow calibrations)
No risk of **mechanical failure**	More **expensive** technology
Diagnostic and physical properties measurement available to determine the quality	**No type of approval** for H_2 available

7.4. ROTARY PISTONS METERS

Rotary pistons meters can be suitable to measure the smallest flowrates, but an extra uncertainty exists regarding the leakage between the pistons and the meter body. This leakage is a function of the viscosity and is only significant below the Q_{min} when the leakage rate is considered as laminar. A calibration with H_2 close to the field conditions (reg. density) is recommended or we can consider this very low flow as not significant. This must be evaluated for every situation.

+	−
Possible **velocity** is identical compare with natural gas due the mechanical limitations	**Calibration with H_2** is recommended dueto the possible internal leakages proportional to the viscosity
The **rangeability** is identical, as with naturalgas (with comparable dynamic viscosity)	**No diagnostic** and no physical measurement available to determine the quality
Known, reliable and **inexpensive** technology	Possible **mechanical failure**
Accurate measurement of very low flow	**Scope of the type of approval** is to clarify with NMI for use with H_2

7.5. CORIOLIS GAS METERS

Coriolis meters can also be considered for measuring hydrogen but under more specific conditions: (relatively) stable flow rates, high pressure or specific regulatory or contractual requirements.

+	−
High velocity is possible	The **rangeability** is limited with H_2 (low density)
Calibration with water is possible (with SoScorrection)	**Limited diagnostic** and no accurate physical measurement available to determine the quality
Type approval available and valid for H_2	**Expensive** technology for large metering stations
No risk of blocking or mechanical failure	**Heavy and Bulky** for Larger models

7.6. CALIBRATION OF THE GAS METERS

7.6.1. General

The calibration of the gas meter to measure H2 is ideally performed in conditions representative of the field conditions:

- Similar fluid
- Similar pressure and temperature
- Similar flowrates

Nonetheless, because the current lack of available facilities and economic reasons, the calibration with other metering conditions can be accepted if the transferability can be demonstrated (see chapter before).

7.6.2. Overview of the calibration facilities

Laboratory Name	Test Fluid	Accreditation
Pigsar (PTB, DE)	NG	ISO 17025
Euroloop (NMI, NL)	NG	ISO 17025
RMA (PTB, DE)	H_2 (100%) NG	In progress ISO 17025
DNV (NMI, NL)	NG - NG+H_2 (30%) - CO_2 - H_2 (100%)	ISO 17025
Cesame (LNE, FR)	Air	ISO 17025
Karlsruhe (PTB, DE)	Air	ISO 17025
FORCE (DK)	NG - NG+H_2 (20%)	ISO 17025
TCC (VSL, CA)	NG	ISO 17025
FortisBC (CA)	CO_2	ISO 17025
Enagás (PTB, ES)	NG – Air	ISO 17025
DNV (Unknown, UK)	NG	ISO 17025
NG = Natural Gas		

Figure 5: List of some available calibration facilities – Traceability and country (Source: LC-Engineering)

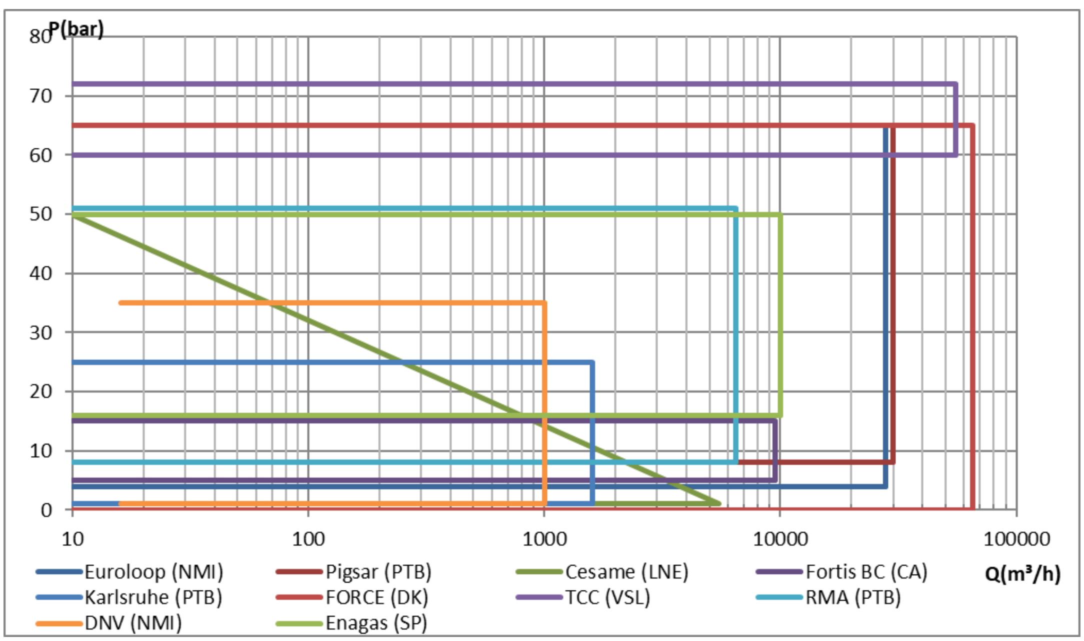


Figure 6: Capacities of the available facilities (Source: LC-Engineering)

7.6.3. Specifics for ultrasonic meters

The calibration of an ultrasonic device to measure H_2 requires at least two steps:

- A dry calibration with pure H_2/Zero flow calibration
- A flow calibration with H_2 or a representative mixture

During the first step, the velocity of sound measurement is verified with pure H_2. An adjustment is performed to minimize the error. This step also is important to minimize the error if the speed of sound is used for the determination of the GCV by correlative method.

Speed of sound adjustment

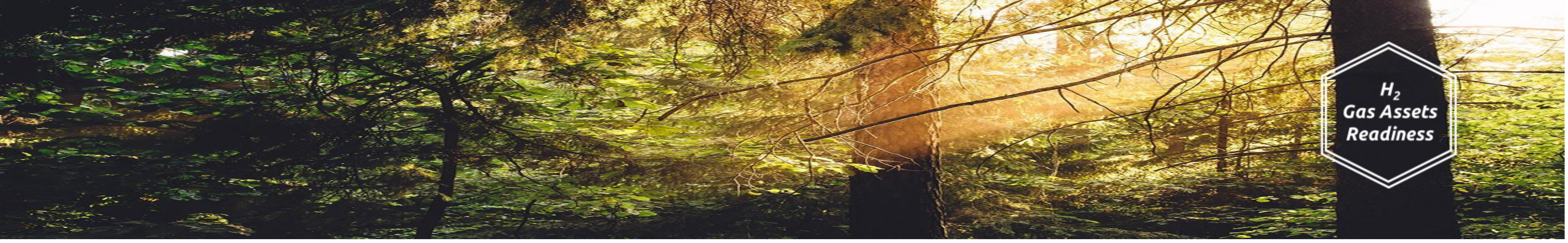
USM-GT-400	Path length (Adjust. with extended SoS mode)	Before adjustment			After adjustment		
-	[mm]	SoS [m/s]	Delay time tw [µs]	Deviation SoS [%]	SoS [m/s]	Delay time tw [µs]	Deviation SoS [%]
Path 1	194.039	1332.937	16.985	0.531%	1325.813	16.165	-0.006%
Path 2	194.074	1335.893	16.960	0.754%	1325.769	15.840	-0.009%
Path 3	251.417	1337.708	16.880	0.891%	1325.670	15.150	-0.017%
Path 4	251.407	1333.543	16.810	0.577%	1325.664	15.660	-0.017%
Path 5	194.082	1331.646	16.999	0.434%	1325.980	16.350	0.007%
Path 6	194.092	1333.023	17.245	0.538%	1325.792	16.420	-0.007%
Mean		1334.125		0.621%	1325.782		-0.008%
						limit AGA 9:	≤ 0,2%
						limit ISO 17089:	≤ 0,2%

Figure 7: Zero flow calibration and adjustment based on the SoS of H_2 as reference (Source: RMG)

During the second step, the ultrasonic meter package (USMP) is calibrated according to the requirements of the type of approval and following the recommendations of the ISO 17089.

Figure 8: Complete USM package including flow conditioner (Source: GRTgaz)

The calibration results will be used to minimize the error. The correction can be done in the meter itself (flow correction) or in the flow-computer (Reynolds correction). Compared with natural gas, the maximal velocity can be >40m/s due to the low density of H_2.



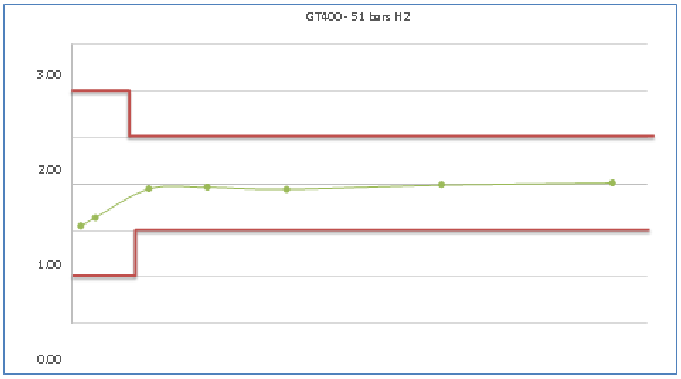


Figure 9: Flow calibration error curve with 99% H_2 (Source: GRTgaz)

In addition to the calibration, the metering line must be carefully designed to ensure that the flow profile during the calibration and in operation are comparable.[1] The use of a CFD analysis as a decision-making aid has a significant added value for assessing the level of disturbance in the metering line (Figure 10) and the associated flow profile and swirl expected in the gas meter (Figure 11).

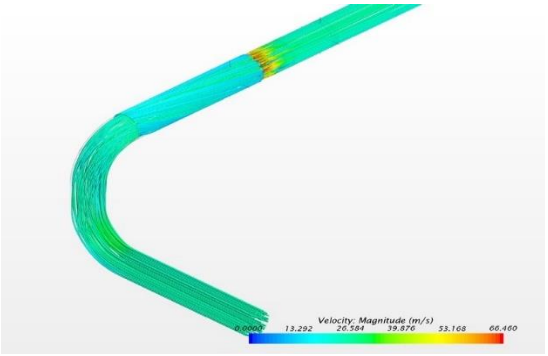


Figure 10: CFD analysis with H_2 (Source: CPA)

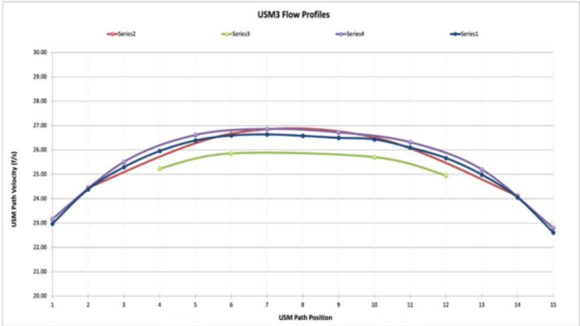
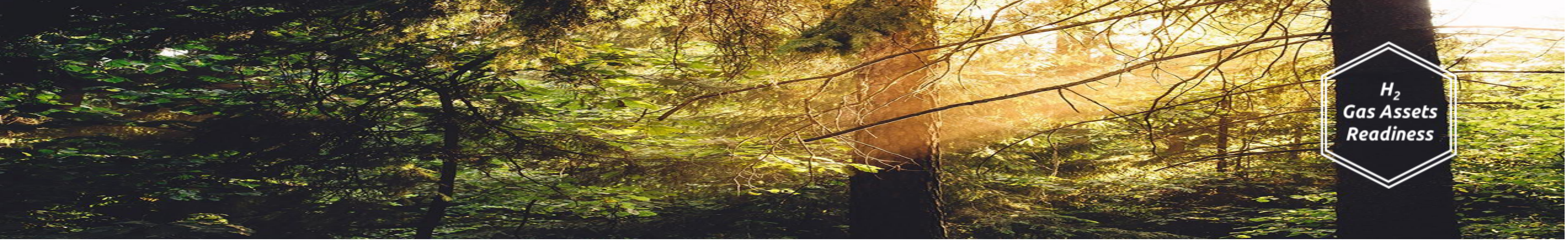


Figure 11: Flow profile evaluation based on CFD analysis (Source: CPA)

[1] Pressure loss must not be limited to the detriment of the flow profile. The two considerations are complementary.



7.7. CONVERSION DEVICES

7.7.1. General

Type 1 and type 2 conversion devices are suitable to measure H_2. However, certain provisions are necessary to ensure hydrogen compatibility: the correct application of equations of state (EoS), pressure sensor compatibility, correct GCV calculation, and the scope of the type of approval.

7.7.2. Equations of State

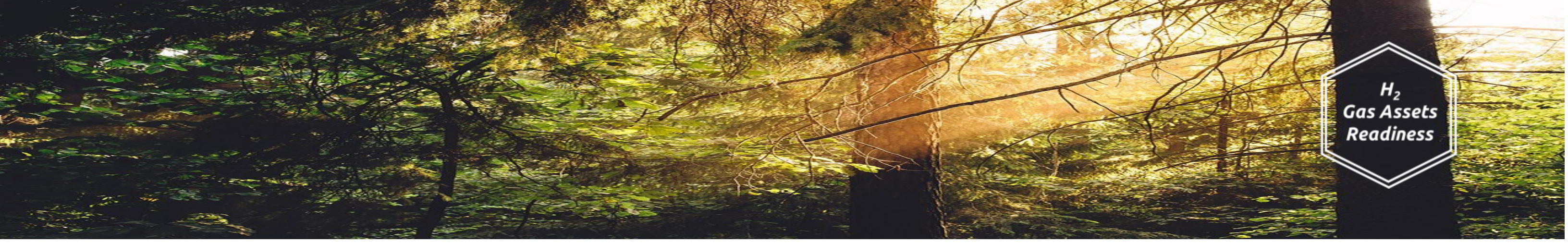
The calculation of the Z (compressibility) must be the subject of particular attention.

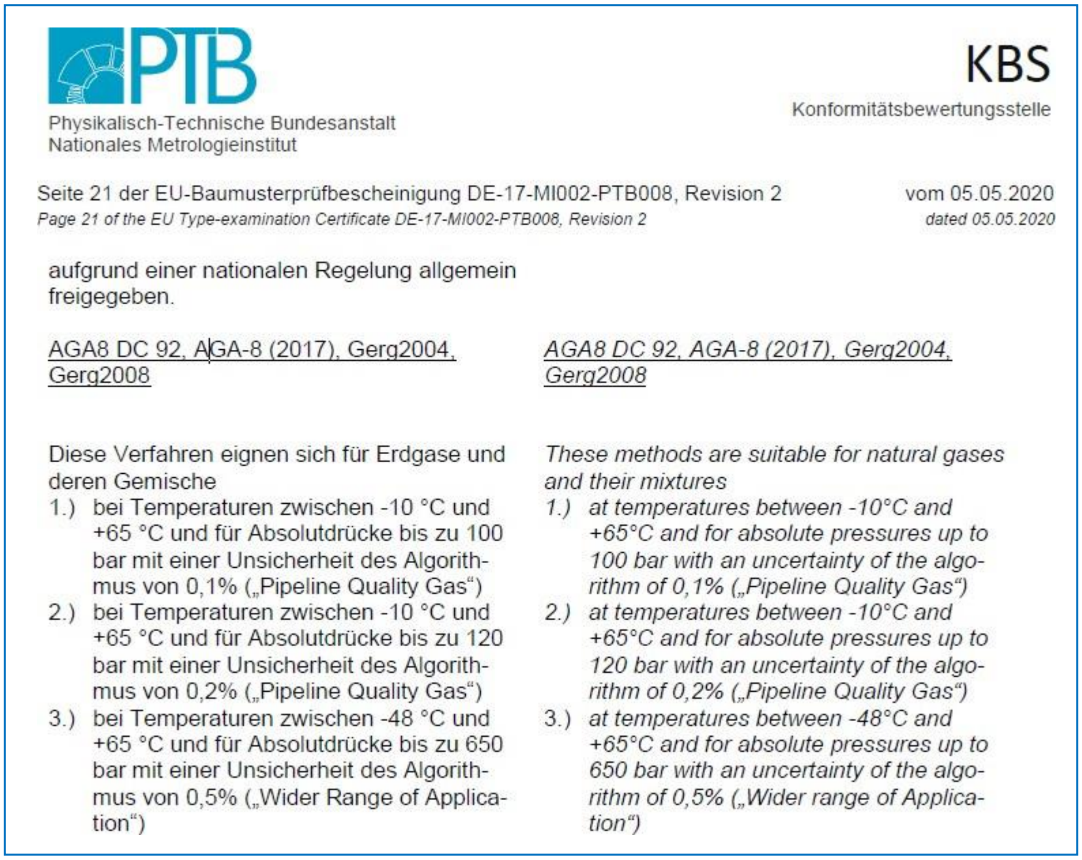
For pure H_2, a two-dimensional table (P, T) can be used. The reference can be the data from Air Liquide Gas Encyclopaedia or another accepted table. The Beattie Bridgeman equation also is a possible approach for pure gases. Some Conversion Devices on the market are available and approved to calculate the compressibility with pure gases.

For H_2 with possible impurities (N_2, O_2, CH_4…), the situation is more complex. The usual standards used for natural gas (ISO 12213) are valid up to 10% H_2. However, studies have demonstrated an acceptable uncertainty (<0.15%) with concentrations up to 100% H_2. However, several criteria must be met:

- Ideally, the type of approval should indicate this compatibility.
- The converter must be set up to allow the molar concentrations provided for by the standard to be exceeded.
- The use of these standards for H_2 must be approved by NMIs and stakeholders.

The use of GERG2008 EoS (ISO 20765-2) is therefore recommended because this standard is initially intended also for pure gases or mixtures without limitation of molar concentration. In addition, the measurement uncertainties are the lowest.





PTB

Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

KBS
Konformitätsbewertungsstelle

Seite 21 der EU-Baumusterprüfbescheinigung DE-17-MI002-PTB008, Revision 2 vom 05.05.2020
Page 21 of the EU Type-examination Certificate DE-17-MI002-PTB008, Revision 2 dated 05.05.2020

aufgrund einer nationalen Regelung allgemein freigegeben.

AGA8 DC 92, AGA-8 (2017), Gerg2004, Gerg2008	*AGA8 DC 92, AGA-8 (2017), Gerg2004, Gerg2008*
Diese Verfahren eignen sich für Erdgase und deren Gemische	*These methods are suitable for natural gases and their mixtures*
1.) bei Temperaturen zwischen -10 °C und +65 °C und für Absolutdrücke bis zu 100 bar mit einer Unsicherheit des Algorithmus von 0,1% („Pipeline Quality Gas“)	*1.) at temperatures between -10°C and +65°C and for absolute pressures up to 100 bar with an uncertainty of the algorithm of 0,1% („Pipeline Quality Gas“)*
2.) bei Temperaturen zwischen -10 °C und +65 °C und für Absolutdrücke bis zu 120 bar mit einer Unsicherheit des Algorithmus von 0,2% („Pipeline Quality Gas“)	*2.) at temperatures between -10°C and +65°C and for absolute pressures up to 120 bar with an uncertainty of the algorithm of 0,2% („Pipeline Quality Gas“)*
3.) bei Temperaturen zwischen -48 °C und +65 °C und für Absolutdrücke bis zu 650 bar mit einer Unsicherheit des Algorithmus von 0,5% („Wider Range of Application“)	*3.) at temperatures between -48°C and +65°C and for absolute pressures up to 650 bar with an uncertainty of the algorithm of 0,5% („Wider range of Application“)*

Figure 12: Example of type approval for VCD calculating the compressibility with GERG2008 (Source: RMG)

7.7.3. Energy conversion

The conversion into energy involves the determination of the GCV of H_2. This can be achieved using several methods:

- The use of a fixed GCV (value from ISO 6976).
- Analysis of the gas by an analytical method (e.g. gas chromatograph).
- Determination of the GCV by a correlative method (e.g. based on the speed of sound).

Several scenarios can also be considered:

- The GCV is determined on a volume or mass basis.
- The GCV considers the presence of methane or other hydrocarbons.
- The GCV is calculated by the ECD or by the external device.

The choice of the envisaged scenario must be determined with the stakeholders and its correct application verified by the operator or accredited body (parameterization of the ECD). In all cases, the criteria of OIML R140 should be complied with, and the calculation of the GCV carried out according to ISO 6976 and ISO/TR 29922.

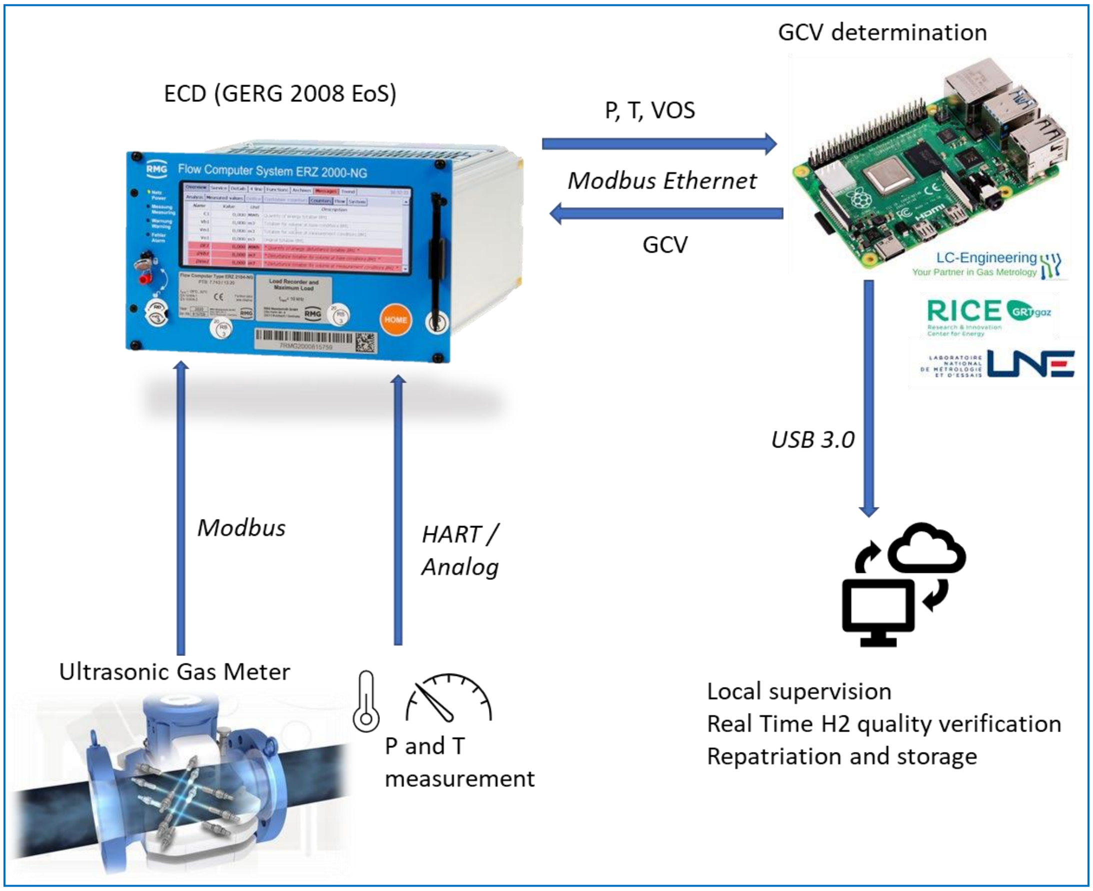


Figure 13: Example of architecture for energy conversion with correlative GCV determination (Source: LC-Engineering)

7.7.4. Pressure and Temperature transducers

There are no specific recommendations for temperature transducers (except for ATEX aspects which need to be checked). The transducers used for natural gas can also be used for hydrogen.

Pressure transducers should be given special attention when used at high pressure (>40 bars). Some special executions (e.g. golden membrane) may be recommended to avoid the migration of H2 molecules into the material and the degradation of metrological performance in the long term. It is necessary to consult with the manufacturers to select the appropriate sensors that are compatible with the ECD model approval.

<table>
<tr><th>Device type</th><th>H_2 compatibility</th><th>Remarks</th></tr>
<tr><td>ERZ 2000-NG</td><td>100%</td><td>100% possible with Beattie Bridgeman method - only pure gases - admixture of up to 10% with: AGA 8, GERG 88S</td></tr>
<tr><td>ERZ 2000-DI</td><td>100%</td><td>GERG2004 or GERG2008 are compatible up to 100%;
full analysis required. -
Admixture of up to 10% with: AGA 8, GERG 88S</td></tr>
<tr><td>Pressure transmitter Rosemount</td><td>100%</td><td>
<table>
<tr><th>Item</th><th>Process medium / conditions</th><th>Stainless steel separating membrane</th><th>gold coated stainless steel separating membrane</th><th>Transmitter / diaphragm seal decision</th></tr>
<tr><td>1</td><td>Hydrogen gas (< 69 bar)</td><td>ja</td><td>ja</td><td>2088, 2051, 3051, 3051S, 1199</td></tr>
<tr><td>2</td><td>Hydrogen gas (> 69 bar)</td><td>not recommended</td><td>ja</td><td>3051C, 3051S_C, 1199</td></tr>
<tr><td>3</td><td>Hydrogen gas (< 176°C)</td><td>ja</td><td>ja</td><td>2088, 2051, 3051, 3051S, 1199</td></tr>
<tr><td>4</td><td>Hydrogen gas (> 176°C)</td><td>not recommended</td><td>ja</td><td>3051C, 3051S_C, 1199</td></tr>
<tr><td>5</td><td>Hydrogen gas with H2S (NACE MR01-75)</td><td>not recommended</td><td>ja</td><td>3051C, 3051S_C, 1199</td></tr>
</table>
</td></tr>
<tr><td>Pressure transmitter E+H</td><td>100%</td><td>100% H_2 up to 10 bar, 20% H_2 up to 60 bar, 10% H_2 without restriction</td></tr>
<tr><td>Thermowells for the T. transmitter</td><td>100%</td><td>Thermowells are made of stainless steel, material: 1.4571 Material is mentioned in the final report_DVGW_240714 on page 12.</td></tr>
</table>

Figure 14: Example of recommended transmitters compatible with H_2 measurement (Source: RMG)

7.7.5. GCV Determination

The determination of the GCV used for transactional data will have to be approved by the NMI as this remains a national competence (not yet a part of the MID).

To facilitate the energy transition (e.g. cost reduction), correlative methods may be preferred over gas chromatographs. These correlative methods can be easily implemented when physical measurements are available on site: pressure, temperature, speed of sound, etc.

OIML R140 briefly describes the correlative methods (inferential determination), i.e. a method that makes it possible to determine a physical property (e.g. calorific value) based on other properties that are already available or more easily measurable.

Two approaches are possible to develop correlative methods:

- The creation of a physic mathematical model
- The implementation of AI in the form of artificial neural networks

The first method, based on mathematical regressions, materialized by a multi-variable polynomial that can be easily implemented in a local or remote device or system.
The second method is based on the analysis of experimental data and materialized by a computer file that contains more complex mathematical functions.

	Polynomial model	**Neural Network**
Complexity	Medium	High
Accuracy class (OIML R140)	Class A (MPE < 0.5%)	Class A (MPE < 0.5%)
Needed measurement on site	Pressure (U≤0.15%), temperature (U≤0.2K), Speed of Sound (U≤0.15%)	Pressure (U≤0.15%),temperature (U≤0.2K), Speed ofSound (U≤0.15%)
Risks to assess	Behavior of the model with extrapolation	over-trained network causing outliers when interpolated
Opportunities to develop	Less expansive solution and possible implementation in the flow-computer	Other information available as output and more efficient model
Approval for fiscalpurpose	Need NMI approval and verification procedures	Need NMI approval and verification procedures

In both cases, the MPEs prescribed in OIML R140 (class A) can be met. However, any known systematic errors should be corrected, for example by revalidating the methodology based on data observed in the field.

The Figure 15 shows an example of correlative device to determine the GCV of the H2 based on the SoS measurement. This device, a separate electronic board, can be consider as an additional functionality of the conversion device. The communication with the flow-computer is similar to that with a gas chromatograph (Modbus/TCP) and no modification of the flow-computer is required. The Figure 16 shows the displayed values by the flow-computer and the configuration optimized for H2 (i.e. GERG 2008 for Z calculation). (OIML, OIML R140 - Measuring system for gaseous fuel, 2007).

Figure 15: Example of correlative device communicating with the GCV to the flow-computer (Source: LC-Engineering)

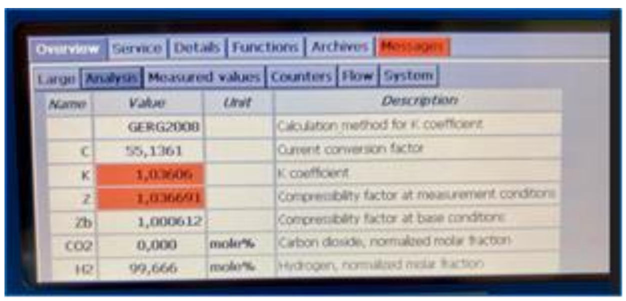
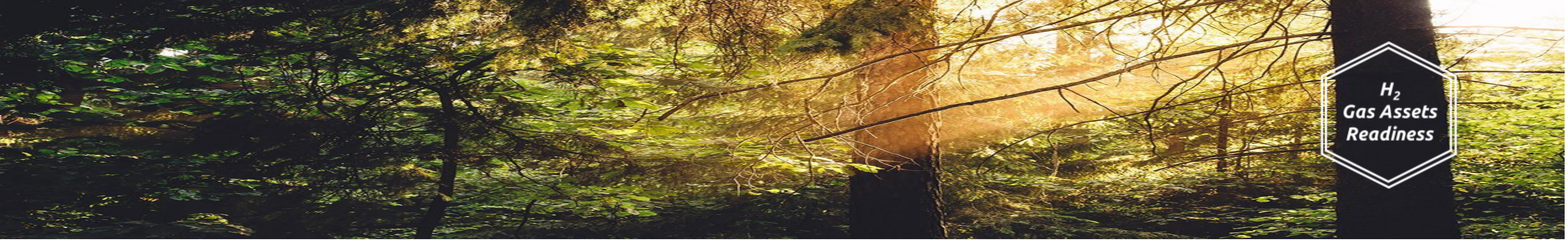


Figure 16: Example of typical configuration of the ECD for H_2 measurement (Source: LC-Engineering)

The documented provision to prove the reliability of this method must be established, for example:

- By comparison of the algorithm with theoretical value calculated with recognized standards and validated software
- By testing in laboratory with USM device and reference gases
- By testing of the long-term reliability of the hardware hosting the software and the software itself (the WELMEC guide 7.2 can be a reference)



8. DOCUMENTED PROVISIONS

8.1. GENERAL

The notion of "documented provisions", as described in the latest version of OIML R140, takes on its full meaning here for several reasons:

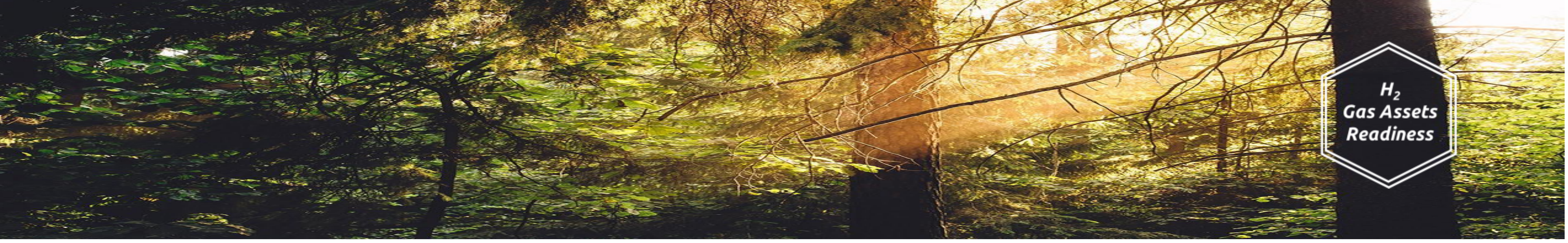
- Type approvals for H_2 are not always available and dialogue with NMIs will need to be based on this notion to obtain derogation or authorization of use.
- The H_2 metering station will be equipped with new technologies, for example, to determine the purity and the GCV. The traceability and the uncertainty of the measurement must be documented for fiscal purpose.
- The metrological maintenance (initial and periodic verifications…) of measurement devices must be documented, as well as the data validation process, to guarantee consistent metrological quality throughout the life of the measurement system.

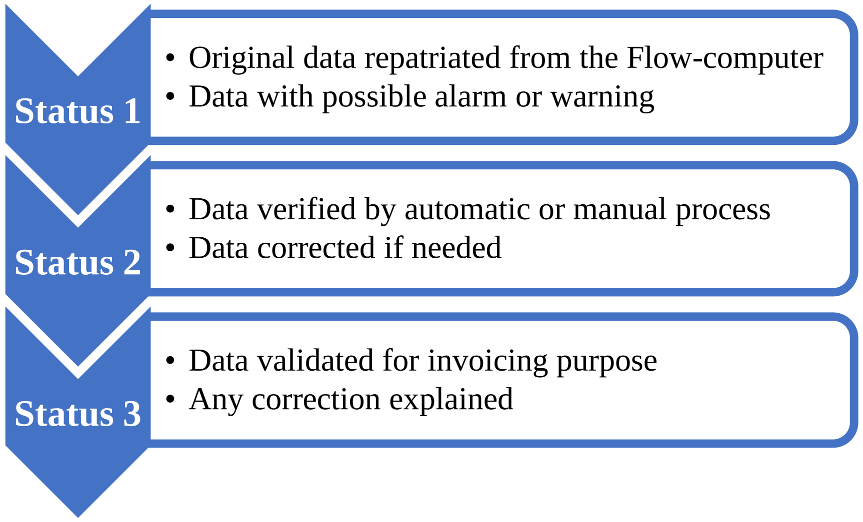
8.2. METROLOGICAL MAINTENANCE AND VALIDATION PROCESS

The initial and periodic calibration/verifications must be documented, especially if:

- The gas used for calibration of the gas volume meter is not H_2. In this case, the transferability must be proven, and the uncertainty evaluated.
- The calibration is performed by a laboratory without ISO 17025 accreditation.
- The measuring device is equipped with a specific function or devices to be compatible with H_2.

A validation process must be documented to ensure that the final figures for invoicing purpose are traceable and reliable:





This process (or similar one) can be implemented with contractual timing to provide validated data in due time for invoicing purposes.

For interconnection points, the above requirements also apply. In addition, contractual agreements must be concluded between adjacent TSOs. These agreements must cover the following points:

- **Calculating** gas and energy quantities: EoS used, base conditions, calorific value determination, purity of H_2 determination, traces components, etc.
- **Design** of the metering station: single metering or gas meters in series (and the use of the average for fiscal purpose), number of meter-run in parallel to ensure operational flexibility, etc.
- **QMS** (Quality Management System) applied to document uncertainty measurement, ensure traceability and long-term stability of metrological performance.
- **Auxiliary measurements** for determining other physical properties needed for process purpose (ex: purity of H_2, water content…).

9. CONCLUSIONS AND RECOMMENDATIONS

In Europe, the legal and normative framework is not yet mature for the metering of hydrogen as energy. To facilitate the energy transition and not slow down the development of hydrogen, we have seen that dialogue with NMIs is important. In some countries (e.g. France), hydrogen is now considered a fuel gas and the existing regulations for natural gas apply.

Another difficulty concerns the type of approval of gas meters or other measuring devices. Often, a type of approval made with natural gas is not directly applicable for hydrogen:

- Some technologies need to be optimized for H_2 measurement (e.g., ultrasonic meters);
- The availability of test facilities is limited, especially for the calibration of gas meters;
- Some technologies may have limitations due to the very low density of H_2 (e.g. turbine meters);
- The equations of state or calculation of the GCV must be adapted to avoid systematic error.

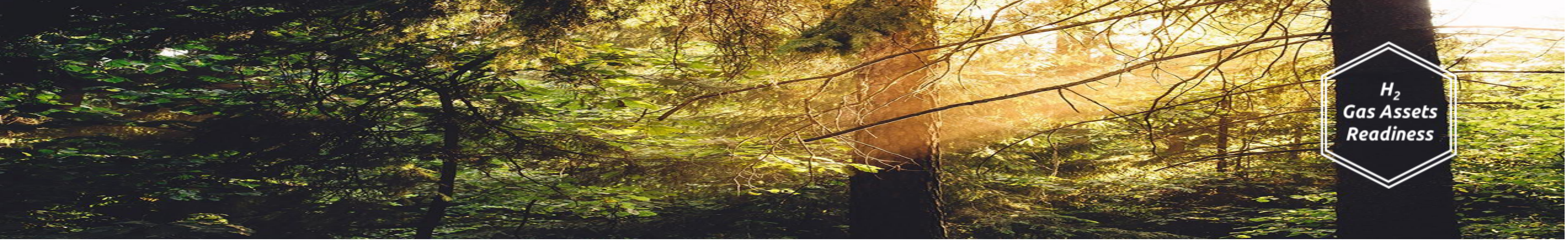
Here, also, the dialogue with the NMI will be important because technical solutions are available and national regulations have often provided for the possibility of approving measurement systems based on a "documented provision", even when certain regulatory requirements cannot be applied due to new technologies.

Regarding the choice of gas meters, several technologies can be used for hydrogen. For large metering stations, however, ultrasonic meters have an advantage, as the measurement of the speed of sound allows the development of correlative methods to, for example, determine the purity of H_2.

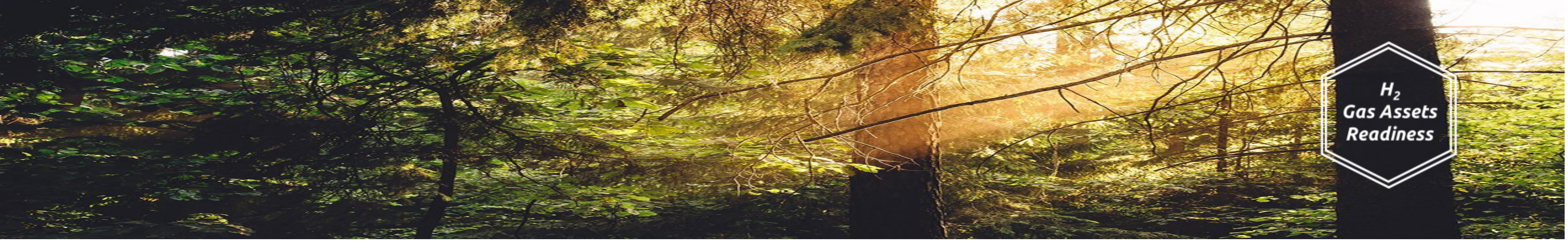
Concerning flow-computers, the main point of attention concerns the calculation of the Z and the GCV. A technical and regulatory analysis will have to be carried out. The use of ISO 20765-2 (GERG 2008) is recommended for the calculation of Z.

Finally, appropriate metrological maintenance will have to be implemented as well as gas quality monitoring to ensure compliance with international requirements regarding hydrogen purity.

This document will be updated by H2GAR on an ongoing basis.



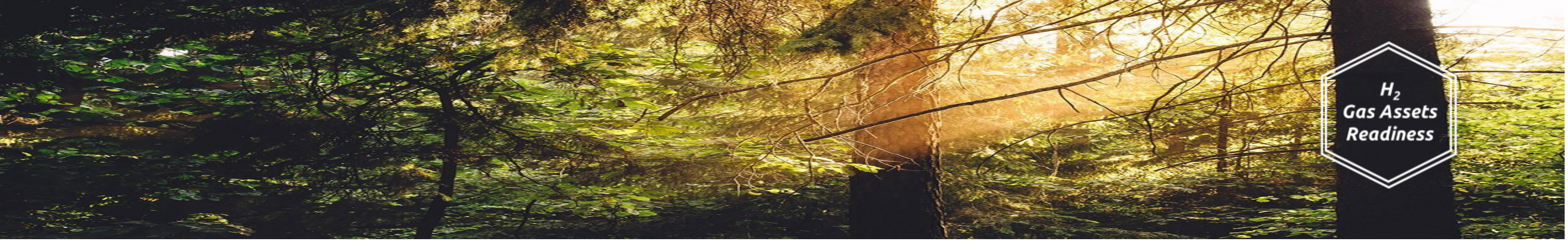
10. LIST OF FIGURES



11. DEFINITIONS AND ABBREVIATIONS

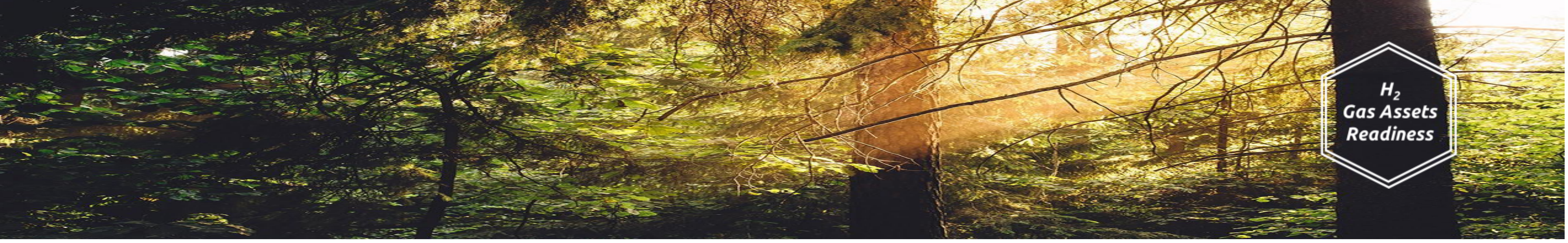
Definitions

Correlative device	A type of calorific value measurement device that determines the value indirectly by inferring it from other measurable properties available on-site, such as speed of sound, pressure, temperature, or other physical properties.
Zero flow calibration	Calibration performed with a pure gas and stable pressure and temperature, to verify and adjust the transit time measurement system of each ultrasonic meter, based on a reference speed of sound value. This calibration is performed with blind flanges attached to the ends of the meter body.
Flow Calibration	Calibration performed in metering conditions close to the expected field conditions. This calibration is preferably made by an accredited laboratory. *"The flow calibration delivers a set of systematic errors, as a function of flow rate or Reynolds number. This set is usually presented as a "calibration curve" and shall be used to correct the meter output"* (ISO 17089-1, 2019)
Interconnection point	Metering station between two main Operators. Main Operators can be a TSO, a LNG terminal or a storage facility. A border metering station always is considered as an interconnection point.
Connection point	Metering station connected to the transmission network and intended to measure quantities delivered to an industrial customer, the public distribution network or a power plant.



Abbreviations

CFD	Computational Fluid Dynamics
CVDD	Calorific Value Determination Device
EoS	Equation of State
PD	Public Distribution
GCV	Gross Calorific Value
NMI	National Metrology Institute
SoS	Speed of Sound
TSO	Transport (or Transmission) System Operator
VCD	Volume Conversion Device
ECD	Energy Conversion Device
Z	Compressibility factor
ATEX	Explosive Atmosphere regulations
OIML	Organisation Internationale de Métrologie Légale (International Organization of Legal Metrology)
PTB	Physikalisch-Technische Bundesanstalt, Germany (National Metrology Institute of Germany)
MID	European Measuring Instrument Directive
LNE	Laboratoire national de métrologie et d'essais (National Metrology Laboratory, France)
MPE	Minimum Permissible Error
PGC	Process Gas Chromatograph
NB	Notified Body
UFM	Ultrasonic Flow Meter
WELMEC	European Cooperation in Legal Metrology
QMS	Quality Management System



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