NOVEL METHODS OF TESTING FOR MEASUREMENT OF NATURAL GAS AND HYDROGEN MIXTURES

D1.3

Normative Gaps towards H2NG Gas Grid

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EXECUTIVE SUMMARY

Chapter 1 is the introduction, where the urgency for a revision of normative regarding the metrology of the gas grid, both transport and distribution ones, is highlighted. Chapter 2 illustrates how the report has been prepared, detailing the work steps and interactions among partners and with experts involved in the European Technical Committee on the subject. Chapter 3 focuses on the current State of Art of normative regulations for gas grid metering. The actual Standard regulating the used gas meter typologies, gas properties measurements, composition measurements, leak detection, calculation and conversion are listed; for each of them the aspects that should be revised to account for H2 injection into the actual natural gas grid are evidenced. Chapter 4 collects the results from analysis in Chapter 3, including the answers to the survey distributed among partners on the subject, the conclusions drawn from similar projects and the information from the deputed committees to individuate the gaps that need to be covered by standards revision. The goal is to support the definition of a comprehensive European normative framework that regulates hydrogen injection into the natural gas grid. Finally, Chapter 5 summarizes the Report's conclusions.

Acronyms and Symbols

CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLC	CENELEC National Committees
CNG	Compressed Natural Gas
CV	Calorific Value
d	Relative density
DSO	Distribution System Operator
DIAL	Differential, Infrared Laser, Absorption Spectroscopy
DVGW	German Technical and Scientific Association for Gas and Water
f	Friction factor
FCEV	Fuel Cell Electric Vehicle
FID	Flame Ionization Detection
GCV	Gross Calorific Value
GIE	Gas Infrastructure Europe
HHV	Higher Heating Value
H2NG	Hydrogen added natural gas (hydrogen content in natural gas from 0 to 100%)
ISO	International Organization for Standardization
I_W	Wobbe Index
JTC	Joint Technical Committee
k	Thermal conductivity
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MID	Measuring Instruments Directive
MOx	Semiconducting metal oxide
MPE	Maximum Permissible Error

OIML	International Organization of Legal Metrology
P	Pressure
P_s	Standard Pressure
PCS	Net Calorific Value
PGC	Process Gas Chromatograph
RTD	Resistance Thermometer Detector
Q_{min}	Minimum Flow Rate
Q_{max}	Maximum Flow Rate
Q_r	Overload Flow Rate
SoA	State of Art
T	Absolute Temperature
T_s	Standard Temperature
TC	Technical Committee
TR	Technical Report
TSO	Transmission System Operator
Z	Compression factor
WG	Working Group
ρ_{op}	Density at operating conditions
ρ_n	Density at standard conditions
ρ_{ref}	Density at reference conditions

1. INTRODUCTION

Hydrogen injection into the existing natural gas grid is recognized as a suitable "first step" towards the development of dedicated hydrogen infrastructures. The Gas Infrastructure Europe (GIE) in 2021 stated: "For some European regions, promoting hydrogen mixtures in the existing natural gas networks is the most effective and affordable stepwise way to quickly trigger the deployment of the hydrogen economy, while using the existing gas infrastructure and ensuring access for hydrogen to an integrated EU gas market. Blending acts therefore as a tool to stimulate hydrogen production and consumption in the short and medium term until hydrogen transport in dedicated pipelines becomes more economically attractive in those regions. Blending has numerous advantages as well as a number of challenges which can be overcome with the right policy, regulatory and technical decisions" [1].

Outside Europe NREL, the National Laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, already in 2013 stated [2] "blending hydrogen into natural gas pipeline networks at low concentrations has the potential to increase output from renewable energy production facilities in the near term. In the longer term, blending may provide an economic means of hydrogen delivery when the hydrogen is injected upstream and then extracted downstream for use in fuel cell electric vehicles (FCEVs) or stationary fuel cells".

The feasibility of the actual gas grid for hydrogen injection into the natural gas flow implies to face several technological issues. These technological issues are linked to hydrogen compatibility, material selection, leakage and safety, storage, purity and quality control, gas flow management, monitoring and maintenance, cost and infrastructure upgrades, and regulatory and policy frameworks. Addressing these technological issues is essential to ensure safe, efficient, and effective hydrogen integration into the gas grid's natural gas flow [3-8]. To ensure a safe and uniformly regulated energy distribution across European countries, it is crucial to simultaneously review the standards governing gas grid instrumentation and metering, addressing and filling any existing gaps [5]. The need for a complete revision of the European regulatory framework on gas grid metering was evidenced by several European and national projects [9-16]. Due to the impressive acceleration towards hydrogen deployment and exploitation impressed by the EU Hydrogen strategy in 2020, it can be considered an urgency.

The EU co-funded THOTH2 Project [17] aims to fulfil the normative and standards gaps in the actual EU regulating framework on natural gas grid metering, to be able to be adapted for the measuring devices on the foreseen hydrogen/natural gas (H2NG) mixture, from 0 to 100% hydrogen content, in transport and distribution grids. The Project goals are: assessing the State of the Art (SoA) of the measuring devices typologies installed in the European transport and distribution gas grid, individuating within the related normative, namely the standards on instrumentation devices, physical quantities conversion and leak detection, what needs to be implemented for H2NG grids measurements, developing test benches, methodologies and protocols for evaluating the devices performances, identifying the limits and the tolerance devices when measuring H2NG mixtures or pure H2; finally, new measurement protocols and a revised normative framework will be proposed.

Within THOTH2, the WP1 (lead by UNIBO) deals with “SoA, Barriers and bias on metering devices for NG blend”; in particular, Task 1.3 (Task Leader: ENEA, Participants: Enagás, GRTGaz, GS, CESAME EXADEBIT, INRETE, INRIM, METAS, SNAM, UNIBO) is focused on “Actual standards and main Regulation, Codes and Standards”. The present Report, constituting Deliverable D1.3, contains the outcomes of that activity.

2. METHODOLOGY

The present Report written as a summary of the Task 1.3 was redacted following the steps listed below:

1. Assessing the normative state of art governing the actual regulation of metering instrumentation by listing the set of Directives/Standards/Recommendations from the European Commission, Normative Bodies and their deputed Technical Committees (TCs) regarding the measuring devices that are installed on the gas grid and that have been identified in Task 1.1.
2. Circulating among the Project partners a survey to collect their suggestions on which item included in the list of point 1 needed to be modified/rejected/enlarged to be compliant with H2NG blending.
3. Widening the set of experts by proposing the same questions to different gas measuring equipment manufacturers, Distribution System Operators & Transmission System Operators (DSOs & TSOs) and members of national standardization committees on gas grid instrumentation
4. Reviewing the gaps on normative fixed by the results from literature papers and reports on experimental activities by comparing metrological equipment measurements performed with H2NG mixtures.
5. Checking the ongoing processes within the dedicated European normative Technical Committees (TCs) to fill the identified gaps.
6. List for each item of point 1 the gaps individuated with regard to points 2-5.

3. THE EUROPEAN NORMATIVE FRAMEWORK: State-of-Art and analysis

The European Commission with the Directive 2014/32/EU [18] established the essential rules for measuring equipment to be commercialized in the EU. The technical requirements for each type of measuring device, the testing procedures, the limits in operating conditions, the algorithms to be used for conversion from a physical characteristic to another, and several other issues related to metrology are detailed in the technical standards. The standards are prepared, proposed and periodically revised within the different European Committee for Standardization Technical Committees (CEN TCs), formed by experts from the national standardization body members. Each European nation must subsequently adopt the European standards within the national standard sets, agreed within the national standardization bodies.

Every standard is requested to accomplish the Essential Requirements of Directive 2014/32/EU.

Moreover, Directive 2014/34/EU [19] on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres needs to be accomplished when dealing with hydrogen containing mixtures.

The TCs are delegated to define the standards to regulate the metrology of the transport and distribution in the natural gas grid [20]. The following TCs are relevant for the present conclusions: European Committee for Standardization/European Committee for Electrotechnical Standardization (CEN/CENELEC) Technical Committee CEN/CLC/JTC 6 is in charge of “Hydrogen in Energy Systems”, CEN/TC 237 is in charge of “Gas meters”; CEN/TC 238 is in charge of “Test gases, test pressures, appliance categories and gas appliance types”. The injection of hydrogen and H2NG mixture in the gas infrastructure and the metrology of the grid is covered in the scope of CEN/TC 234, and for this reason is out of the scope of CEN/CLC/JTC 6, even if the two committees work in close cooperation. The standardization work is supported by the CEN Sector Forum Gas [14].

CEN/TC 234 decided to create a new working group, CEN TC/234 WG9 “Injection of non-conventional gases into the natural gas network”, to adapt or develop standard also considering H2NG mixtures. It covers the state of the art in the treatment, injection, transportation, distribution, and utilization of gases from non-conventional sources, including hydrogen, in the natural gas system.

The aim of Task 1.3 of the THOTH2 Project is to individuate the normative gaps on the gas grid (both transmission and distribution grid) metering when using H2NG blend. The standards under analysis are those regulating the measuring devices installed in gas grids, including gas meters (such as, for example, diaphragm, turbine, rotary, ultrasonic, Coriolis and thermal mass fiscal flowmeter), and also those devices for the conversion from one physical quantity to another, the calculation of gas properties, the measurement of gas composition by gas chromatography, and the use of leak detectors.

The requirements on safety, namely the ATEX Directive, are out of the scope of the Report; each metering device must be compliant with the ATEX Directive 2014/34/UE, depending on the environmental operating conditions.

Table 1 summarizes the selection of European standards currently in use for the above listed instruments regulation [20], the Technical Committee/Working Group by which it was elaborated, published and revised, the last revision. The status column indicates if the standard is under revision to account for H2 injection into the gas grid, or if the standardization topic is addressed by the designated CEN TC and ISO TC and the standard is under discussion/preparation, or if the standardization topic is still to be defined by the TC, as reported in [16]. Among the standards listed in Table 1, those that experts agree that could be affected by the presence of H2NG in the gas transmission and distribution infrastructure or pure hydrogen are marked with a red star (last column on the right) and will be analyzed in the following paragraphs. Further discussion is suggested for the other standards.

Normative	Title	Published by Technical Committee	Working Group	Last revision	Status	Affected by H2NG replacing NG
EN 12480	Gas meters - Rotary displacement gas meters	CEN/TC 237	WG2	2018	In preparation By CEN/TC 237 ISO/TC30	★
EN 12261	Gas meters - turbine gas meters	CEN/TC 237	WG3	2018	In preparation By CEN/TC 237 ISO/TC30	★
EN 12405-1	Gas meters - Conversion devices - Part 1: Volume conversion	CEN/TC 237	WG4	2021	In preparation By CEN/TC 237 ISO/TC30	★
EN 12405-2	Gas meters - Conversion devices - Part 2: Energy conversion	CEN/TC 237	WG4	2021		★
EN 12405-3	Gas meters - Conversion devices - Part 3: Flow computer	CEN/TC 237	WG4	2015		
TR 16061	Gas meters - Smart gas meters	CEN/TC 237	WG5	2010		
EN 16314	Gas meters Additional functionalities	CEN/TC 237	WG5	2013		
EN 1359	Gas meters - Diaphragm meters	CEN/TC 237	WG8	2017	In preparation By CEN/TC 237 ISO/TC30	★
EN 14236	Gas meters – Ultrasonic domestic gas meters	CEN/TC 237	WG9	2018	In preparation By CEN/TC 237 ISO/TC30	★
EN 17526	Gas meters – Thermal mass flow meter based gas meters	CEN/TC 237	WG10	2022	In preparation By CEN/TC 237 ISO/TC30	★

EN 437	Test gases - Test pressures - Appliance categories	CEN/TC 238	WG1	2021	Under revision by CEN TC 238	★
EN ISO 13443	Natural gas - Standard reference conditions	CEN/TC 238	WG1	1997	To be identified by CEN TC 238 and ISO TC 193	★
EN ISO 13686	Natural gas - Quality designation	CEN/TC 238	WG1	2013		
EN ISO 12213-1	Natural gas - Calculation of compression factor - Part 1: Introduction and guidelines	CEN/TC 238	WG1	2006	In preparation by CEN/TC 238	★
EN ISO 12213-2	Natural gas - Calculation of compression factor - Part 2: Calculation using molar-composition analysis	CEN/TC 238	WG1	2020	In preparation by CEN/TC 238	★
EN ISO 12213-3	Natural gas - Calculation of compression factor - Part 3: Calculation using physical properties	CEN/TC 238	WG1	2010	In preparation by CEN/TC 238	★
EN ISO 6974-1	Natural gas – Determination of composition and associated uncertainty by gas chromatography_ General guidelines and calculation of composition	CEN/TC 238 ISO/TC 193 SC1	WG1	2018	To be identified by CEN TC 238	★
EN ISO 6974-2	Natural gas - Determination of composition and associated uncertainty by gas chromatography_ uncertainty calculations	CEN/TC 238 ISO/TC 193 SC1	WG1	2012	To be identified by CEN TC 238	★
EN ISO 6974-6	Natural gas - Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons using three capillary columns.	CEN/TC 238 ISO/TC 193 SC1	WG1	2019	To be identified by CEN TC 238	★
EN ISO 6975	Natural gas - Extended analysis - Gas-chromatographic method	CEN/TC 238 ISO/TC 193	WG1	2022		★
EN ISO 6976	Natural gas - Calculation of calorific values, density, relative density	ISO/TC 193 SC1 CEN/TC 238	WG1	2016 confirmed in 2022		★

	and Wobbe indices from composition					
EN ISO 14912	Gas analysis - Conversion of gas mixture composition data	CEN/TC 238	WG1	2006 Confirmed in 2021		
EN ISO 15970	Natural gas - Measurement of properties - Volumetric properties: density, pressure, temperature and compression factor	CEN/TC 238	WG1	2014		★
EN ISO 20765-1	Natural gas - Calculation of thermodynamic properties - Part 1: Gas phase properties for transmission and distribution applications)	CEN/TC238		2018		★
EN ISO 20765-2	Natural gas - Calculation of thermodynamic properties - Part 2: Single-phase properties (gas, liquid, and dense fluid) for extended ranges of application	CEN/TC238		2018		★
EN ISO 20765-5	Natural gas - Calculation of thermodynamic properties - Part 5: Calculation of viscosity, Joule-Thomson coefficient, and isentropic exponent	CEN/TC238		2022		★
EN 1776	Gas infrastructure- Gas measuring systems- Functional requirements	CEN/TC234	WG 5	2016	In preparation	★
ISO 10790	Measurement of fluid flow in closed conduits- Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)	ISO/TC30	SC5	2015	To be identified	★
ISO 17089	Measurement of fluid flow in closed conduits_ Ultrasonic meters for gas	ISO/TC30	SC5	2019	In preparation By CEN/TC 237 ISO/TC30	★

3.1 The Directive 2014/32/EU (MID Directive)

The directive introduces the necessity for measuring equipment to comply with harmonized European rules to be accepted in the EU market. It fixes the essential requirements that instruments or systems with a measurement function must satisfy and ensures in order to be compliant with the essential requirements and therefore circulate freely within the EU.

Directive 2014/32/EU revised and replaced Directive 2004/22/EC and had to be applied in the EU countries as of 20 April 2016.

The directive puts the measuring instruments in line with Regulation (EC) N° 765/2008 on accreditation and market surveillance and Decision N° 768/2008/EC on uniform conditions for the marketing of safe products in the EU (conformity marking).

Among the large variety of legally controlled measuring systems, used in the areas of public health and safety and of fair trading, are the utility meters: water meters, gas meters and volume-conversion devices, active electrical energy meters and thermal energy meters.

Annex IV deals with "Gas meters and Volume Conversion Devices".

In 2021 the Directive was updated by the Commission Implementing Decision (EU) 2021/1402; the Commission asked CEN e CENELEC to review some standards. The EN 1359 Diaphragm gas meters, the 12261 on turbine gas meter, the 12405-1 on gas volume conversion devices and 14236:2018 on ultrasonic gas meters are upgraded in their References, whilst the EN 13757 (1-2-3-4-5-6-7) remained unchanged. None of the reviews concerned H2NG metering.

Could this Directive be used in the case of H2NG mixture transport and distribution grids?

In our opinion, no need exists to modify the Measuring Instruments Directive (MID) itself in view of flowing H2NG blend into the natural gas grid, as it defines general rules not affected by metering technical aspects.

3.2 TEST GASES TEST PRESSURES APPLIANCES CATEGORIES - EN 437

The Standard **EN 437**, published on 31 July 2021 by CEN/TC 238, specifies the test gases, test pressures and categories of appliances relative to the use of gaseous fuels of the first, second and third families. It serves as a reference document in the specific standards for appliances [21].

The document makes recommendations for the use of the gases and pressures to be applied for the tests of appliances burning gaseous fuels. Anyway, the procedures for tests are given in the corresponding appliance standards. The test gases and the test pressures specified in this standard are in principle intended to be used with all types of appliances.

Gases are classified into three families, 1st, 2nd and 3rd family, each family may be divided into groups, identified by a letter, as a function of the Wobbe Index I_W (expressed in MJ/m^3) namely, the ratio of the gas calorific value per unit volume over the square root of its relative density in the same conditions (Fig.1).

Family	Gas	PCS (MJ/m³)	ϱ (Air = 1)	Wobbe (MJ/m³)	p (mbar)
1st	City gas	17.6	0.58	23.1	8
	Methane air	20.9	0.82	23.1	8
2nd	Natural gas	41.9	0.65	52.1	20
	Propane air	56.7	1.31	50.5	20
3rd	Propane	100.5	1.6	79.5	37
	Butane	125.6	2	87.9	30

Fig.1 Gas family classification by EN 437 [21]

The "*city gas*" belongs to the 1st family, whereas hydrogen and methane (CH_4) to the 2nd family (Fig.2). The boundary within which the Wobbe number must lie for common rich NG burners are 48 and 58 MJ/m^3; this means that for rich NG up to 98% vol. could be injected [5].

GAS	Max	Min	Family
Hydrogen	48.23	40.65	2H
Methane	53.28	47.91	2H
Ethane	68.19	62.47	3
Ethylene	63.82	60.02	3
Natural Gas	53.71	48.52	2H
Propane	81.07	74.55	3
Propylene	77.04	71.88	3
Butane	92.32	85.09	3
Isobutane	91.96	84.71	3
LPG	86.84	79.94	3
Acetylene	61.32	59.17	2H
Carbon Monoxide	12.80	12.80	1

Fig.2 Wobbe Index and family for the most common combustible gases [21]

The Standard **EN 437 was revised in order to account for hydrogen and hydrogen blended with natural gas** used as fuel and the new version adopted by the plenary CEN/TC 238 in 2019 and 2020, in parallel with CEN/TC 109 [22].

Several gaps are anyway still to be filled, in particular the gas/hydrogen analysis methods and gas/hydrogen quality monitoring; EN 437 is therefore under revision by CEN/TC 238 [16].

Several suggestions on EN437 adaption to H2GN use in the current gas grid came from the WP4 of the THYGA Project: in D4.3 “Considerations on test gases and appliance standards adaptation for H2NG supply” it is recognized that the EN 437 approach can remain the same, except for the limit gas concept, that needs to be differentiated. The authors consider that “if distributed gases are going to contain significant hydrogen concentrations, it seems indispensable to differentiate based on the applied burner technology” [23].

3.2.1 Standard Reference Conditions - ISO 13443

The standard reference conditions of temperature, pressure and humidity to be used for measurements and calculations carried out on natural gases and similar fluids are specified in the ISO 13443 standard, by ISO/TC 193 “Natural Gas”, confirmed in 2020 [24].

The standard reference conditions are essential for ensuring consistency and comparability of measurements and data related to NG. It provides a common set of parameters that allow different parties, laboratories, and organizations to communicate and exchange data accurately and reliably. The key reference conditions specified in ISO 13443 are:

- Temperature: The standard reference temperature is typically set at 20 degrees Celsius (°C) or 68 degrees Fahrenheit (°F). This temperature is used as a baseline for NG measurements and calculations.
- Pressure: The standard reference pressure is set at 101.325 kPa. This pressure is often referred to as one atmosphere (atm) and is used to normalize gas volume and density measurements.
- Humidity: The standard reference humidity condition typically assumes dry gas, which means there is no water vapor present in the gas. This condition is used to simplify calculations and is suitable for most NG applications.

Standard reference conditions are denoted by the subscript “s” as indicated below:

- Standard pressure: p_s=101,325 kPa.
- Standard Temperature: T_s=293,15 K.

Aspects of ISO 13443 Standard that need to be checked and eventually revised to account for H2NG mixture metering:

The adaptations of gas analysis methods and the standard reference conditions when dealing with H2NG measuring are still to be defined by CEN/TC 238 [16].

3.3 GAS MEASURING SYSTEMS FUNCTIONAL REQUIREMENTS – EN 1776

The functional requirements of the gas measurement devices are normed by EN 1776, published in March 2016 by CEN/TC 234 [25].

This European Standard specifies functional requirements for the design, construction, testing, commissioning/decommissioning, operation, maintenance, and where appropriate calibration, together with suitable documented provisions for all new gas measuring systems and any major changes of existing systems.

This European Standard also specifies the class of accuracy for the measuring systems and the thresholds applicable to each class. The demonstration of compliance is achieved through the selection, installation, and operation of appropriate measurement instruments, together with suitable documented provisions for calculations. Examples of demonstration of compliance are provided for each accuracy class; however, they are not prescriptive solutions.

This European Standard is applicable for gases of the 2nd family as classified in EN 437. It is also applicable for treated non-conventional combustible gases complying with EN 437 and for which a detailed technical evaluation of the functional requirements is performed, ensuring there are no other constituents or properties of the gases that can affect the metrological and physical integrity of the measuring systems; it can be applied for biomethane when injected into the natural gas grid.

This Standard needs to be updated [26].

The European Clean Hydrogen Alliance in the very recent Document "Roadmap on Hydrogen Standardization" indicates the EN 1776 is in preparation by CEN/TC 234 for complying with the transport and distribution of H2NG mixtures into the gas grids [27].

3.4 GAS METERING STANDARDS

Different gas meters typologies, based on different physical laws and gas characteristics, are used on the transport and distribution gas grid to fiscally account for gas volumes delivered.

Each meter type is regulated by an appropriate Standard. In the following each Standard is described, trying to point out the meter characteristics that could be affected by the presence of H2NG mixtures, with different H2 content, into the gas grids.

To point out the Standard aspects that need to be updated it's essential to individuate, on the basis of the results of benchmarking tests, how hydrogen influences gas properties, measurement procedures and meter materials varying the hydrogen content in the H2NG mixture.

In March 2023 was announced [16] **that all the Standards dealing with metrology-measurement in the gas grid, namely EN 12261, EN 1359, EN 14236, EN 12480, EN 17526, EN 12405-1, ISO 17089, ISO 5168 are in preparation by CEN/TC 237 and ISO TC 30 to account for H2NG**.

3.4.1 Diaphragm gas meters – EN 1359

Diaphragm gas meters are regulated by **EN 1359**, published in July 2017 by CEN/TC 237 [28].

This European Standard specifies the requirements and tests for the construction, performance, safety and production of class 1,5 diaphragm gas meters, namely a meter which has a maximum permissible error (MPE) of $\pm$3%. This applies to meters with co-axial single pipe, or two pipe connections, that are used to measure volumes of fuel gases, which are within the limits of test gases of the 1st, 2nd and 3rd families described in EN 437. The meters are designed with maximum working pressures not exceeding 0.5 bar and maximum actual flow rates not exceeding 160 $m^3\ h^{-1}$ over a minimum ambient temperature range of –10 °C to 40 °C. Additionally, the meters are intended to operate with a gas temperature range as specified by the manufacturer, with a minimum temperature range of 40 K. The instruments used should be traceable to a national or international reference standard and the uncertainty (2σ) should be better than 1/5 of the maximum value of the parameter to be tested. For differential results the repeatability (2σ)/resolution should be better than 1/5 of the maximum value of the parameter to be tested.

The allowable flow rate ranges are listed, in terms of maximum flow rate (Q_{max}), minimum flow rate (Q_{min}), able to being conform with the MID requirement $Q_{max}/Q_{min} \geq 150{:}1$; overload flowrate ($Q_r$) that refers to the flow rate of a fluid that exceeds the intended or designed capacity of the system.

The standard defines the metrological performances of that meter: the test procedures are given, together with the allowed errors of indication; the requirements in terms of pressure absorption and the test procedure to determine it; the metrological stability requirements and the test procedure to measure it; the requirements in case of overload flow rate, environmental humidity, starting flow rate, influence of other devices attached to the meter, cyclic volume. The construction and materials of the meter are indicated concerning resistance to interference, both mechanical and electromagnetic, robustness, external leak tightness, resistance to internal pressure, meter case sealing, connections and corrosion. If the meter incorporates optional features, such as a pressure measuring point for measurement correction, electrical insulating feet, magnetic index drive, or devices to prevent the registration of reverse flow, specific requirements are outlined for the incorporation and performance of these features.

The required mechanical performances are listed together with the procedures for testing them (endurance tests), the construction details and the requirement for the diaphragm and rubber components in the gas path. The effect of reagents on the meter components needs to be checked.

Diaphragm gas meters supply low pressure end-users. Therefore, this technology is prevalently installed in the distribution grids, due to the lower pressure operative conditions. However, some diaphragm meters are also installed in the gas transportation infrastructure to supply gas to equipment used for process applications like, for example, boilers in pressure reducing and metering stations.

Aspects of EN 1359 that need to be checked and eventually revised to account for H2NG mixture metering:

Materials: need to test meter materials compliance with hydrogen and hydrogen mixtures; the endurance tests need to be performed with hydrogen.

Tightness tests: EN 1359 foresees that tightness tests should be performed with air; the assumption is no longer acceptable for use with H2NG mixtures and/or pure hydrogen.

Measurement Accuracy and its dependence on hydrogen content.

A significant “long term” impact was measured on diaphragms meters. This effect, dependent on the meter manufacturer and design, was explained by the difference of design and of plastic and polymers materials used in meters [14]. The varying designs and material choices among different meter manufacturers can lead to differences in the meters' response to environmental factors, fluid properties, and wear over time. This can affect the accuracy and reliability of measurements made by these diaphragm meters during their extended service life.

Jaworski et al [29] carried out a metrological and statistical analysis to establish whether the addition of hydrogen affects the durability of diaphragm gas meters over time. The most important conclusion resulting from the conducted study indicates that, for the tested gas meter specimens, there was no significant metrological difference between the obtained changes of errors of indications after testing the durability of gas meters with varying hydrogen content (from 0 % to 15 %).

Even in [30] diaphragm meters were tested with a mixture (50 % H2 + 50 % CH4), overall, the results indicated that measurement error deviations were less than 2%.

3.4.2 Rotary Displacement Gas Meters – EN 12480

Rotary Displacement Gas Meters are regulated by **EN 12480**, published in 2018 by CEN/TC 237 [31]. This European Standard specifies ranges, construction, performances, output characteristics and testing of rotary displacement gas meters for gas volume measurement, classified as accuracy class 1; a meter can be classified as class 1 when respects the following error limits: ± 2 % for $Q_{min}<Q<Q_t$, ± 1% for $Q_t<Q<Q_{max}$, where $Q_t=0.2\ Q_{max}$ for $20\leq Q_{max}/Q_{min}\leq 30$ and $Q_t\leq 0.1\ Q_{max}$ for $20\leq Q_{max}/Q_{min}\geq 30$. This European Standard applies to rotary displacement gas meters used to measure the volume of fuel gases of at least the 1st, 2nd and 3rd gas families, the composition of which is specified in EN 437+A1, at a maximum working pressure up to 20 bar over an ambient and gas temperature range of at least −10°C to +40 °C. This European Standard applies to meters with a maximum allowable pressure and the volume of less than 6000 bar liters or with a product of pressure and diameter of less than 3 000 bar.

The standard defines the metrological performances of that meters: the test procedures are given, together with the allowed errors of indication: the uncertainty of the test rig shall be at a maximum of 1/3 of the MPE for the individual meter testing; the requirements in terms of pressure loss and the test procedure to determine it; the maximum operating pressure requirements and the test procedure to measure it; the temperature ranges requirements and the test procedure to measure it; the conformity for bidirectional meters and oil filling. The standard also defines the meter design and manufacturing requirements; the materials of the meter need to be tested concerning resistance to corrosion, penetration resistance, adhesion of the protective coating, materials for pressurized parts, strength of housing, robustness and external leak tightness. The transportation and storage requirements are given. The meter must be equipped with tappings for measuring the pressure upstream and downstream, along with additional tappings for measuring the temperature of the gas as it passes through the meter. The meter shall include an index of recording the volume of gas measured at metering conditions magnetically coupled with the meter measuring element. The requirements for the indicating device are given, together with the meter durability requirements.

The Rotary Displacement Gas Meter measuring principle is usually based on 8-shaped rotors rotating within a measurement chamber. During a full revolution of the rotors a fixed volume is displaced from the inlet to the outlet of the meter. The number of revolutions represents the amount of volume passed.

Rotary Displacement Gas Meters are utilized both on transport and distribution gas grid, as they can operate with the pressures in the European transmission grids (up to 75 bar).

Aspects of EN 12480 that need to be checked and eventually revised to account for H2NG mixture metering:

The same issues already envisaged for diaphragm meters, as indicated below.

Materials: need to test meter materials compliance with hydrogen and hydrogen mixtures; the endurance tests need to be performed with hydrogen

Tightness tests: EN 12480 foresees that tightness tests should be performed with air; the assumption is no longer acceptable for use with H2NG mixtures and/or pure hydrogen.

Measurement Accuracy and its dependence on hydrogen content, especially at low flowrate.

3.4.3 Turbine Gas Meters – EN 12261

Turbine Gas Meters are regulated by **EN 12261**, published in June 2018 by CEN/TC 237 [32].

This European Standard specifies ranges, construction, performances, output characteristics and testing of turbine gas meters for gas volume measurement. This European Standard applies to turbine gas meters used to measure the volume of fuel gases of at least the 1st, 2nd and 3rd gas families, the composition of which is specified in EN 437, at a maximum working pressure up to and including 20 bar over an ambient and gas temperature range of at least −10 °C to +40 °C.

A Turbine Gas Meter is defined within EN 12261 as: a measuring device in which the dynamic forces of the flowing gas cause a turbine wheel to rotate with a speed as a function of the volume flow rate. The number of revolutions of the turbine wheel is the basis for the indication of volume passed through the meter.

The gas meters are classified with respect to maximum flow rate, minimum flow rate and nominal diameter; the maximum and minimum flow rate are specified for the gas density for which the meter will operate. The gas for flow test is air or a gas of the 1st or 2nd gas family at a Reynolds number within ±5 % of the Reynolds number at the foreseen metering conditions. The Reynolds number is a dimensionless parameter to characterize the flow regime and predict flow behavior. Indications are given for error indication calculation.

The normative specifies the testing requirements for gas meters: gas pressure and temperature, meter position, test flow rate, installation conditions. It covers the different test types including linearity and endurance tests and sets limits on the maximum pressure loss allowed. Additionally, the normative outlines specific requirements concerning the meter design, material requirements and the meter outputs such as capacity and readability. Moreover, the normative includes guidelines for the pulse generator and electrical connections used in the gas meters. It addresses potential perturbations that could affect measurement accuracy, ensuring that the gas meters are robust and reliable in various operating conditions.

Turbine gas meters are usually installed on transmission gas grids.

Aspects of EN 12261 that need to be checked and eventually revised to account for H2NG mixture metering:

The measurement uncertainties must be checked on the turbine meters when used with H2NG due to the lower density with respect to NG.

In [33] the influence of hydrogen on the turbine natural gas meters in high pressure was tested. Commercially available high-pressure gas meters were selected as test subjects: a turbine wheel gas meter, nominal width DN 80, size G100-160 m3/h, pressure stage DP 70. The tests results showed that all measurement deviations, including those with H2 admixture, were clearly within the calibration error limits. No influence can be detected by the H2 admixture.

In [13] it is stated that up to 10 % of H2 in the natural gas, big size (> 400 m3/h) turbine and ultrasonic meters are slightly impacted.

CEN/TC 237 – N764 has validated the use of turbine meters for a mixture of up to 10 % hydrogen [4].

3.4.4 Ultrasonic Domestic Gas Meters – EN 14236 and ISO 17089

Ultrasonic gas meters are regulated by **EN 14236** (domestic gas meters), published in October 2018 by CEN/TC 237 [34], and **ISO 17089**-1 (i.e., meters for custody transfer and allocation measurement) [35].

The European Standard specifies requirements and tests for the construction, performance and safety of class 1,0 and class 1,5 battery powered ultrasonic gas meters having co-axial single pipe, or two pipe connections, used to measure volumes of distributed fuel gases of the second and/or third family, as given in EN 437, at maximum working pressures not exceeding 0.5 bar and maximum actual flow rates of up to 10 m^3/h over a minimum ambient temperature range of -10 °C to +40 °C, and minimum gas temperature span of 40 K, for domestic applications. This European Standard applies to meters where the measuring element and the register(s) are enclosed in the same case.

Ultrasonic Gas meters are devices that utilize the transit time of acoustic signals to measure the flow of single-phase homogeneous gases in closed conduits.

Ultrasonic Gas meters are used to measure gas flowing in both transmission and distribution grids.

Aspects of EN 14236 that need to be checked and eventually revised to account for H2NG mixture metering:

In [36] the effect of H2 injection in gas networks on static ultrasonic domestic gas meters, both from a theoretical and an experimental point of view, is discussed. Experimental tests demonstrated that ultrasonic gas meters are not significantly affected by H2 injection up to about 10 %. The speed of sound increases up to 12.3 % becoming generally higher than the accepted limit of 475 ms^{-1} indicated by EN 14236 for ultrasonic gas meters already at H2 content of 5 %vol.
Finally, no influence on the deterioration of metrological properties was found for domestic G4 ultrasonic gas meters tested with the use of various gas mixtures with hydrogen content up to 10%. Meters classified as G4, the most common for domestic uses, are those with minimum flow rate of 0.04

m^3/h, nominal flow rate of 4 m^3/h, maximum flow rate of 6 m^3/h, i.e., corresponding to about 38 kW thermal power with NG. In fact, both the errors of indications and the weighted mean errors remained within the permissible limits, with measured errors not exceeding $\pm$1 % and weighted mean error within $\pm$0.4 %.

3.4.5 Thermal Mass Flow meter based Gas Meters – EN 17526 and ISO 14511

Thermal mass gas meters are regulated by **EN 17526** [37], published in December 2021 by CEN/TC 237, and **ISO 14511**, published on Jan 2019 by ISO TC 30/SC5 [38].

EN 17526 specifies requirements and tests for the construction, performance, safety, and production of battery powered class 1,5 Capillary Thermal-Mass Flow sensor gas. This applies to meters having a co-axial single pipe, or two pipe connections, which are used to measure volumes of fuel gases of the 2nd and/or 3rd family, as given in EN 437. In general, the term "thermal mass flow meters" applies to a flow-measuring device using heat transfer to measure and indicate gas flowrate, as defined in ISO 14511. Although the word "mass" is present in the definition of the measurement principle, gas meters covered by this document provide the measurement of gas at base conditions of temperature and pressure. These meters have a maximum working pressure not exceeding 0.5 bar and a maximum flowrate not exceeding 160 m^3/h over a minimum ambient temperature range of −10 °C to +40 °C and a gas temperature range as specified by the manufacturer with a minimum range of 40 °C.

Thermal mass flow-based gas meters compliant to EN 17526 are installed only on the distribution gas grid, due to the pressure limit of 0.5 bar. Furthermore, thermal mass meters compliant to ISO 14511 are also installed in gas transmission grids.

Aspects of EN 17526 that need to be checked and eventually revised to account for H2NG mixture metering:

EN 17526 is the first gas meter standard updated in order to include renewable gases such as hydrogen and biomethane. This inclusion is an essential step towards accommodating the growing interest in renewable energy sources and the transition to more sustainable and eco-friendly alternatives in the gas industry.

3.4.6 Coriolis Gas Meters – ISO 10790

Coriolis gas meters are regulated by **ISO 10790**, published in 2015 and confirmed in 2020 [39].

ISO 10790 gives guidelines for the selection, installation, calibration, performance, and operation of Coriolis flowmeters for the measurement of mass flow and density. This International Standard also gives appropriate considerations regarding the type of fluids measured, as well as guidance in the determination of volume flow and other related fluid parameters. Fluids are defined as air, natural gas, water, oil, Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG), manufactured gases, mixtures, slurries, etc.

Aspects of ISO 10790 that need to be checked and eventually revised to account for H2NG mixture metering:

In principle, being the mixture a fluid foreseen by the ISO 10790, H2NG could be accepted without any normative revision.Differently from meters measuring volumes, and other indirect measurement principles, Coriolis based gas meters are a direct measure of the mass flow through the tube. Mass flow rate and density are measured independently of each other using the same device. It's theoretically the meter type that could be used in H2NG grids.

Nevertheless, experimental results showed that the use of hydrogen significantly modifies the accuracy of the Coriolis flow meter [40-42]. Therefore, to ensure precise measurements when dealing with hydrogen gas, it is essential to calibrate the Coriolis flow meter specifically with hydrogen gas, as opposed to using water for calibration. This calibration adjustment accounts for the unique properties and behavior of hydrogen, thus enhancing the meter's accuracy and reliability in hydrogen gas measurement applications.

The European Clean Hydrogen Alliance in the very recent Document "Roadmap on Hydrogen standardization" indicates the **ISO 10790 needs to be modified by CEN/TC 237 and ISO TC 31** for complying with H2NG grid, but no standardization project was identified to date [16].

3.5 GAS PROPERTIES – ISO 13686

The **ISO 13686** [43] specifies the parameters required to describe finally processed and when required, blended natural gas.

The need for an International Standard concerning the designation of natural gas quality was a basic reason for the establishment of ISO/TC 193 in 1989. To meet the need of a definition of natural gas quality, it was decided that a general statement of the recommended parameters (i.e., components and properties) should be established and that the resulting International Standard would not specify values of, or limits for, these parameters.

Furthermore, it was decided that general-purpose natural gas transmitted to local distribution systems, referred to as "natural gas", should be the first consideration. Thus, this International Standard was developed. The ISO 13686 International Standard does not impose any quality restrictions on raw gas transported via pipelines or gathering systems to processing or treating facilities.

The 13686 Standard Normative References contains the references to the standards to be used for other gases or water, contained in the natural gas, determination; each of the references Standard applies with a different procedure and group of gases.

This Standard allows synthetic natural gas use, defined as "manufactured or blended gas with properties which make it interchangeable with natural gas" where the "gas properties" are attribute of natural gas by its composition (major components, minor components and trace components) and its physical properties (calorific value, Wobbe index, compression factor, relative density and dew points).

The gas properties that need to be determined when the gas is used as a heating energy source are:

Calorific value, CV is defined as the amount of heat which would be released by the complete combustion in air of a specified quantity of gas, in such a way that the pressure at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature as that of the reactants. It is divided into two types: superior calorific value and inferior calorific value. Both superior and inferior calorific values, which differ by the heat of condensation of water formed by combustion, can be specified on a molar, mass or volumetric basis. For the volumetric basis, the pressure and temperature shall be stated at standard reference conditions. Calorific values can also be stated as dry or wet, depending on the water vapor content of the gas prior to combustion. Normally, the calorific value is expressed as the superior, dry value specified as a volumetric basis under standard reference conditions.

Density, ρ is defined as the mass of a gas divided by its volume at specified pressure and temperature. The **relative density** is defined density of a gas divided by the density of dry air of standard composition at the same specified conditions of pressure and temperature.

Compression factor, Z is the quotient of the volume of an arbitrary mass of gas, at a specified pressure and temperature, and that of the same gas under the same conditions as calculated from the ideal gas law. The compression factor, also known as the compressibility factor or the real gas factor and given the symbol Z, appears, in particular, in equations governing volumetric metering. Moreover, the conversion of volume at metering conditions to volume at defined reference conditions can properly proceed with an accurate knowledge of Z at both relevant pressure and relevant temperature conditions.

Wobbe index, I_W is defined as the volumetric-basis superior (inferior) calorific value, at specified reference conditions, divided by the square root of the relative density at the same specified metering reference conditions**.** The heat input for different natural gas compositions is the same if they have the same Wobbe index and are used under the same gas pressure.

Aspects of ISO 13686 that need to be checked and eventually revised to account for H2NG mixture metering:

The standard can be accepted as it is for H2GN blends and pure hydrogen, as the gas properties to be determined when the gas is used for energetic purposes remain the same.

3.5.1 Measurement of properties Volumetric properties: density, pressure, temperature, and compression factor – ISO EN 15970

The general measurements of gas properties are regulated by ISO 15970, converted into **EN 15970** in 2014 by CEN/TC 238 [44].

ISO 15970 gives requirements and procedures for the measurement of the properties of natural gas that are used mainly for volume calculation and volume conversion: density at reference and at operating conditions, pressure, temperature, and compression factor.

Only those methods and instruments are considered that are suitable for field operation under the conditions of natural gas transmission and distribution, installed either in-line or on-line, and **that do not involve the determination of the gas composition.**

ISO 15970 gives examples for currently used instruments that are available commercially and of interest to the natural gas industry.

The **density at reference conditions** (sometimes referred to as normal, standard or even base density), ρ_{ref} is required for conversion of volume data and can be used for other physical properties. These reference conditions are typically predefined and widely accepted, making them useful for standardizing measurements and comparisons.

The **density at operating conditions, ρ_{op}** is measured for mass-flow measurement and volume conversion using the observed line density. Like the density at reference conditions, density at operating conditions can also be utilized to determine various physical properties of the substance.

ISO 15970 is a standard that covers density transducers based on vibrating elements, normally suitable for measuring ranges of 5 kg/m^3 to 250 kg/m^3. Vibrating element density transducers are utilized in various applications to accurately measure density.

Pressure measurement deals with differential, gauge and absolute pressure transmitters. It considers both analogue and smart transmitters (i.e., microprocessor-based instruments) and, if not specified otherwise, the corresponding paragraphs refer to differential, absolute and gauge pressure transmitters without distinction.

Temperature measurements in natural gas are performed within the range of conditions under which transmission and distribution are normally carried out (253 K $<T<$ 338 K). In this field of application, resistance thermometer detectors (RTDs) are generally used.

Aspects of EN 15970 that need to be checked and eventually revised to account for H2NG mixture metering:

The measurement of gas properties is the basic aspect of its use as an energetic source and of any correction factor, calculation, and conversion. This standard needs to be continuously verified and updated, in particular in the case of flowing of gases of different physical and thermodynamic properties.

3.5.1.1 Calculation of compression factor – ISO 12213

The calculation of the gas compression factor is regulated by **ISO 12213**. ISO 12213 specifies methods for the calculation of compression factors of natural gases, natural gases containing a synthetic admixture and similar mixtures at conditions under which the mixture can exist only as a gas.

It is divided into three parts: the ISO 12213-1 by CEN/SS N21 is "Introduction and Guidelines" [45], the ISO 12213-2 by ISO/TC 19, confirmed in 2020, specifies a method for the calculation of compression factors **when the detailed composition of the gas by mole fractions is known**, together with the relevant pressures and temperatures [46], whilst the ISO 12213-3, specifies a method for the calculation of compression factors when the superior calorific value, relative density and carbon dioxide content are known, together with the relevant pressures and temperatures [47].

If hydrogen is present, as is often the case for gases with a synthetic admixture, the hydrogen content also needs to be known.

The method is primarily applicable to pipeline quality gases within the ranges of pressure and temperature at which transmission and distribution operations normally take place, with an uncertainty of about +/-0,1 %. For wider-ranging applications the uncertainty of the results increases.

Aspects of ISO 12213 that need to be checked and eventually revised to account for H2NG mixture metering:

The SGERG-88 equation, developed by Jaeschke et al. [48] for the calculation of compression factors and gas law deviation factors, was reported in 1997 in the international standard ISO 12213-3. In the ISO standard, its application is limited to the composition of "Pipeline Quality Gas", whereby a limit of 10 mol % is defined as a limit for the hydrogen content. Furthermore, the relative density is limited to the range of $0.55 \leq d \leq 0.80$; this corresponds to a range of the density at standard conditions of 0.711 kg/m³ $\leq \rho n \leq$ 1.034 kg/m³. For some compositions of natural gas, the lower limit of the relative density (or density at standard conditions) results in a maximum hydrogen content of 5 mol%. In order to enable the calculation of compression factors and gas law deviation factors based on the SGERG equation also at a higher content of hydrogen, the existing algorithm has been modified by the German Technical and Scientific Association for Gas and Water (DVGW), in such a way that the above-mentioned limitations are abolished [49].

In the paper by Dell'Isola et al. [36] the trend of the compressibility factor Z as a function of H2 injection was analysed using the available calculation algorithms of ISO 12213-2 (complete composition), ISO

12213-3, AGA NX 19 and AGA NX 19 Mod. The obtained results show that the compressibility factor at high pressures is more influenced by the presence of hydrogen than at low pressures (e.g., Z increases in the range 0.10–0.14 % at 5 bar and in the range 2.1–9.1 % at 70 bar). Moreover, the pressure influence on Z is more significantly impactful at low H2 contents. A similar behavior has been found for the volume conversion factor.

3.5.2 Calculation of calorific values, density, relative density and Wobbe indices from composition – EN ISO 6976

The **EN ISO 6976** [50], published in 2016 by ISO/TC 193 SC1, reviewed and confirmed in 2022, specifies methods for the calculation of gross calorific value, net calorific value, density, relative density, gross and net Wobbe index of natural gases, natural gas substitutes and other combustible gaseous fuels, when the composition of the gas by mole fraction is known. The methods specified provide the means of calculating the properties of the gas mixture at commonly used reference conditions. The methods of calculation require values for various physical properties of the pure components; these values, together with associated uncertainties, are provided in tables and their sources identified. Methods are given for estimating the standard uncertainties of calculated properties.

The method of calculation of the values of properties on either a molar, mass or volume basis are applicable to any natural gas, natural gas substitute or other combustible fuel that is normally gaseous, except that for properties on the volume basis the method is restricted to mixtures for which the compression factor at reference conditions is greater than 0.9.

Aspects of EN ISO 6976 that need to be checked and eventually revised to account for H2NG mixture metering:

Experimental checks of the suitability for the EN ISO 6976 to accept H2NG as “natural gas substitute” have to be performed.

The gross calorific value (GCV) for gas in the presence of hydrogen must be measured by certified analysers. This means that analysers capable of measuring the GCV of a gas containing hydrogen need to be used, and the relative standards prepared and published.

European TSO’s are involved in an analysers’ replacement program on their networks, in order to measure accurately the hydrogen content in CH4/H2 mixtures [51]

3.6 CONVERSION DEVICES

3.6.1 Volume Conversion - EN 12405-1

The gas volume conversion is regulated by EN 12405-1, published in 2018 by CEN/TC 237, and revised in 2021 [52].

This European Standard specifies the requirements and tests for the construction, performance, safety and conformity of gas-volume electronic conversion devices associated to gas meters, used to measure volumes of fuel gases of the 1st and 2nd families according to EN 437. Three kinds of conversion are treated in this European Standard:

- conversion as a function of temperature only (T conversion).
- conversion as a function of pressure and temperature with a constant compression factor (PT conversion).
- conversion as a function of pressure, temperature, taking into account also the gas compression factor (PTZ conversion).

The gas-volume conversion devices consist of a calculator and a temperature transducer or a calculator, a temperature transducer and a pressure transducer locally installed.

The volume measured at operative conditions needs to be converted to a standard state volume. The conversion is dependent on the density calculation, performed using the gas composition data.

Aspects of EN 12405-1 that need to be checked and eventually revised to account for H2NG mixture metering:

Blends of hydrogen may necessitate appropriate equations of state. The primary obstacle in applying the conversion method to H2NG mixtures containing hydrogen content ranging from 20 Vol.-% H2 up to 100 Vol.-% H2 lies in investigating the most suitable equation of state for accurately determining the density. To achieve the desired H2 content range, an updated flow computer configuration incorporating the appropriate equation of state for density calculation is necessary. Additionally, for cases involving 100 Vol.-% H2, it is crucial to ensure the availability of relevant process gas chromatograph data for volume conversion and accurate meter measurements [47].

The European Clean Hydrogen in the very recent Document “Roadmap on Hydrogen standardization” indicates that a project is **in preparation by CEN/TC 2347 and ISO TC30 for EN 12405-1 complying with H2NG grid [16]**.

3.6.2 Energy Conversion - EN 12405-2

The European Standard regulating the Conversion Devices for energy conversion of gas flowing in the grid is **EN 12405-2** [53].

The injection of hydrogen brings heavy variations in calorific value, which means new methods must be developed to determine the energy content of the gas at all points of the network.

Hydrogen and natural gas have notably different higher heating values (HHV), with HHV(H2) = 13 MJ/Nm3 and HHV (NG) = 40 MJ/Nm3. As a result, to satisfy the same energy demand, the volume of H2 to be transported must be three times that of natural gas. The gas' energy flow through a pipeline depends on several physical parameters of the gas, such as the compressibility factor Z and the friction factor f, which vary with pressure and flow rate differently from H2NG with respect to NG [5].

3.7 GAS COMPOSITION – EN ISO 6974 and EN ISO 6975

The **EN ISO 6974** 1-2-3-6 [54, 55, 56, 57] and **EN ISO 6975** [58] are the standards dealing with gas composition measurements by gas chromatographic methods.

ISO 6974 describes methods of analysis of natural gas and methods for calculating component mole fractions and uncertainties. ISO 6974 is intended for the measurement of H_2, He, O_2, N_2, CO_2 and hydrocarbons, either as individual components or as a group, for example, all hydrocarbons above C_5, defined as C_{6+}. This approach is suitable for a range of end applications, including calibrating gas mixtures and providing natural gas composition and uncertainty data to be used in the calculation of calorific value and other additive physical properties of the gas. Details of these end applications are provided in ISO 6974-3and subsequent parts of ISO 6974.

ISO 6974-1 gives guidelines for calculating the mole composition of natural gas, determined using one of the gas chromatographic methods described in ISO 6974-3 and subsequent parts of ISO 6974. ISO 6974-1 also describes all the essential steps for setting up an analysis, including outlining the structure of the analysis, defining the working ranges and establishing the analytical procedure.

This part of ISO 6974 describes the steps required to calculate the uncertainty of the component mole fractions of natural gas determined using gas chromatography.

ISO 6974-3 and subsequent parts of ISO 6974 describe different gas chromatographic methods. These methods cover both daily practice in the laboratory and on-line field applications.

ISO 6974-6 describes a gas chromatographic method for the quantitative determination of the content of helium, hydrogen, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons in natural gas samples using three capillary columns. This method is applicable to the determination of these gases within the mole fraction ranges varying from 0,000 1 % to 40 %, depending on the component analysed, and is commonly used for laboratory applications. However, it is only applicable to methane within the mole fraction range of 40 % to 100 %. These ranges do not represent the limits of detection, but the limits within which the stated precision of the method applies. Although one or more components in a sample may not be present at detectable levels, the method can still be applicable. This method can also be applicable to the analysis of natural gas substitutes.

Regarding the composition of gas mixtures, ISO 14912 defines the conversion between different quantities commonly used to express the composition of gas mixtures (i.e., mole fraction, mass fraction and volume fraction as well as mole concentration, mass concentration and volume concentration) and the conversion between different state conditions.

The EN ISO 6975 Standard describes the specifications for the quantitative analysis of the following components of natural gas: helium, hydrogen, argon, oxygen, nitrogen, carbon dioxide, some hydrocarbons and aromatic compounds, but limited to the ranges from 0.001 % to 0.5 %.

Aspects of ISO 6974 that need to be checked and eventually revised to account for H2NG mixture metering:

When hydrogen is a some % component of the gas and not purely a contaminant, the measuring analysis methods need to be adapted. The composition analysis standards need to be deeply upgraded for new chromatograph techniques. The EN ISO 6974 is going to be modified by CEN TC 238 even if the standardization topics are still to be identified [16].

Van der Veen et al [59] checked if ISO 6974 can be validated for use with hydrogen enriched natural gas. They concluded that the scope of the current ISO 6974 can be extended to cover natural gas compositions with hydrogen amount-of-substance fractions of up to 20 %.

Process gas chromatographs were in the existing natural gas infrastructure usually only designed for very low H2 concentrations ≤ 0.2 Vol.% H2. For gas chromatographs, a case-by-case approach is required. To measure relevant hydrogen contents, helium is required as an additional carrier gas. Meanwhile process gas chromatographs with H2 compatibility up to 25 Vol.% are available on the market. Therefore, the exchange of such devices is necessary but technically feasible [60].

There is a problem with the current generation of Process Gas Chromatographs (PGCs) which use helium as the carrier gas and, as a result, are unable to detect hydrogen because of the relative proximity of their thermal conductivities for helium and hydrogen (kHe = 151 W/(m·K); kH2 = 180 W/(m·K). It's possible to solve this by retrofitting an additional separating column of argon as a carrier gas for hydrogen detection or by using new process gas chromatographs licensed for the metering of hydrogen. Another possibility might be to use PGCs with two single separating columns and two types of carrier gas. Some manufacturers have already developed new gas chromatographs ready for a hydrogen content up to 10 % [61, 62].

3.8 OIML Recommendations

The Organisation Internationale de Métrologie Légale (i.e, the International Organization of Legal Metrology - OIML) representing the interests of the legal metrology community within international organizations and forums, began to propose recommendation for hydrogen uses. Examples are reported below.

OIML R139-1 refers to the International Organization of Legal Metrology's Recommendation R157-1. This recommendation addresses the metrological requirements for dynamic measuring instruments used in the measurement of hydrogen refueling stations. As hydrogen fuel becomes increasingly important for sustainable transportation, the accurate measurement of hydrogen dispensed at refueling stations becomes crucial. The implementation of OIML R139-1 helps foster confidence among consumers and stakeholders in the hydrogen refueling industry by providing reliable and accurate measurements. OIML R139-1 influence extends to regulatory bodies, manufacturers, operators, and users, making it a valuable instrument in the transition towards a greener and more energy-efficient future [63].

OIML R140 refers to the International Organization of Legal Metrology's Recommendation R140. This recommendation addresses the metrological requirements for dynamic measuring instruments used for compressed natural gas (CNG) vehicle fueling applications. OIML R140 sets stringent standards and guidelines for the design, performance, and testing of dynamic measuring instruments specifically tailored for CNG vehicle fueling. These instruments are essential for ensuring that CNG is dispensed accurately and reliably, safeguarding consumers' interests [64].

3.9 Leak detection

Measurements of gas leakages along the gas networks represent, differently from the above illustrated metrological devices regulated sector, an area in which the RCS framework results incomplete, despite the crucial importance of that detection equipment. Up to now, no permanent leak detection systems are obligatory installed along the European NG grid. Leak detection measurements are requested only for maintenance purposes, periodically and with mobile detectors, and no standard regulated requirements exists on those detectors. This lack of a stringent regulating framework will represent an issue for H2GN grid.

Very recently the concerns about methane emission influence on climate changes pull the EU Parliament and Council to plan a proposal to cover this lack [65]. The regulation of methane emissions will introduce requirements on leak detection measuring devices that will reveal being extremely useful for the safety control network in case of H2NG flowing along the gas grid.

The European Regulation on methane emissions reductions is expected to be approved and published by the end of January 2024 and will be automatically adopted by the Member States. It will be implemented in the whole gas sector, including transmission and distribution grids.

It will impose requirements on three main aspects:

- Monitoring, Reporting and Tests: annual reports quantifying methane emissions from infrastructures are foreseen.
- Requirements and restrictions on scheduled repairing and inspection activities.
- Restrictions and prohibition regarding some operative practices, such as venting and flaring.

Blending hydrogen into natural gas raises several safety issues, due to the physical and thermodynamic differences of the two gases. Table 2 [66] presents a comparison of the safety properties of natural gas and hydrogen.

Property		CH_4	H_2
Minimum Ignition Energy (MIE)	[mJ]	0,22	0,017
Ignition temperature	[°C]	537 (CH_4) – 670 (L-gas)	560
LEL-UEL	[Vol %]	4,4 - 17	4 - 77
Molecular weight	[g/mol]	18	2
Relative density	[-]	0,55	0,07

Table 2 Safety properties of hydrogen with respect to methane [66]

Differences between safety properties of H2 and CH4 are [66]:

- The explosion limits of hydrogen are much wider than those of methane.
- The specific gravity of hydrogen is much lower than air, so that pure hydrogen released with low momentum rises about 6 times faster than methane (20 m/s).
- Due to the high rate of rise, the dilution in air is faster than that of methane under these conditions (approx. 3.8 times faster).
- The required ignition energy through sparks is much lower than that of methane in a stoichiometric mixture (27%), in outdoor air installations the required ignition energy is approximately the same because it is difficult to get the mixture above 10 vol. % there.
- Attention must be given to prevention with respect to installations in buildings due to possible accumulation of H2 at ceiling. This probability is higher compared to methane (CH4).

Hydrogen leakages could be particularly dangerous as hydrogen will ignite in most cases because of the low minimum ignition energy and small unnoticed burning leak can affect the integrity of the infrastructure and is a possible source of ignition.

Operators will have to check existing detection systems to detect NG before injecting hydrogen (H2NG).

Different hydrogen detection systems are commercially available based on: Raman scattering, ultrasonic, distributed optical fiber, electrochemical detector, ultraviolet absorption spectroscopy, visual Leak Detector Tapes [66].

Gas detection devices designed for natural gas may not be accurate for mixtures of natural gas and H2. Some gas detection devices will be more sensitive for H2 than for natural gas while others are not sensitive at all to H2 and will only react to the fact that the methane is diluted. Semiconductor technology is suitable for detection of hydrogen/natural gas mixtures as it can identify methane as well as hydrogen. Most devices for measurement of the lower explosion limit of a gas mixture are configured for methane. Alarms are triggered upon reaching 10 % or 20 % of the lower explosion limit, i.e., 0.44 % or 0.88 % methane in air. The lower explosion limit declines slightly (4.36 %) with admixture of 10 % hydrogen. Limitations to the functionality are therefore not expected. Manufacturers generally understand how the addition of H2 to natural gas affects the accuracy of their equipment and devices can be adjusted and calibrated for use with hydrogen. Flame ionization detection (FID) devices can be applied only for low admixtures of hydrogen.

In current natural gas networks, non-contact methods have been developed for detecting and locating possible leaks from a distance. The physical principle that these remote detection methods are based on is the infrared absorption of methane. Unfortunately, pure H2 is not infrared active. This means that a comprehensive, branched hydrogen network requires its own sensitive, efficient remote detection technology.

The common safety and screening methods employed for pipeline grid inspections (by foot, vehicle, or helicopter) involve the use of gas detector devices. These devices usually rely on either FID (Flame Ionization Detection) or, in the case of helicopters, DIAL (Differential, Infrared Laser, Absorption Spectroscopy). Although neither of these technologies can detect hydrogen, they are considered accurate and suitable for situations where hydrogen admixtures in natural gas do not exceed 5%, as methane remains the main component of the gas.

For hydrogen, palladium field-effect transistor sensors or a compact mass spectrometer that selectively responds to H2 may be used. This technology is used for leak testing with helium and is very sensitive. However, manually checking complex systems in this manner is highly labor-intensive and time-consuming; for this reason, it is only carried out at fixed intervals, e.g., annually, in existing systems. Using imaging technology to detect and locate leaks enables inspection work to be carried out much more effectively. As with gas cameras for methane, this requires an appropriate non-contact H2 leak sensor system.

The ISO 26142 [67] standard sets out some important specifications for hydrogen sensors, regardless of the technology used. The sensors must also monitor their function independently and be able to detect the contamination or degradation of key components. In addition, the sensor elements in an H2 detector require redundancies that are independent of any technology. This means that two sensor elements, each physically operating in a different way, must be used to guarantee that even if one element fails, the system continues to function. These requirements are the “functional safety,” regulated in the standards DIN EN 61508 [68], DIN EN 61511 [69] and ISO 26262 [70].

The addition of H2 to natural gas changes the accuracy of gas detectors. Some will react on the safe side and others won't. It is essential, therefore, to re-calibrate gas detection devices when H2 could be present in natural gas to ensure that they will react on the safe side [62].

Odorization plays an important role in ensuring the safety of a natural gas network. The unpleasant smell of gas means a gas leak can be immediately noticed nearby. Odorization therefore significantly aids the quick recognition of gas leaks and helps avoid accidents. Unfortunately, there is no effective means of odorization for hydrogen. H2 can diffuse through the smallest of leaks, and unlike all other gases, it can also diffuse through a number of materials. This means conventional odorants, which have large molecules, are unsuitable for hydrogen and small hydrogen leaks therefore cannot be detected by smell. This makes having a sensitive H2 safety sensor even more important.

One concern with using traditional hardware-based leak detection methods for blended hydrogen gas is their potential compatibility issues due to the high mobility, small size, and high diffusivity of the gas with other materials. While further testing is needed to determine the effectiveness of these methods with blended hydrogen gas, some studies suggest that it could be solved with minor sensor recalibration. It is important to evaluate the reliability and compatibility of hydrogen leak detection systems for each specific operating scenario.

When using mixtures with hydrogen there are compatibility problems with the materials used. Sensors for non-destructive tests must be provided to monitor the structural integrity of H2 infrastructures, in terms of corrosion and hydrogen embrittlement.

Specialized leak detection facilities designed specifically for hydrogen may be a viable option for detecting leaks of blended hydrogen gas. There are four main types of sensors used for hydrogen detection: semiconducting metal oxide, electrochemical sensors, catalytic sensors, and thermal conductivity sensors [71], [72].

Semiconducting metal oxide (MOx) sensors are widely used in industry due to their economic nature, low power consumption, and ease of integration into various systems. These sensors offer fast response times, making them suitable for real-time gas detection applications. However, one of their disadvantages is their low accuracy and selectivity, as they can be affected by interference from other gases. Moreover, semiconducting MOx sensors are sensitive to changes in humidity and temperature, which can further impact their performance and lead to false readings.

- **Electrochemical sensors** offer good selectivity for hydrogen gas and relatively high accuracy. They operate based on the electrochemical reactions that occur when hydrogen interacts with the sensing electrode, allowing for specific and sensitive detection. Electrochemical sensors have the advantage of being portable, compact, and cost-effective, making them suitable for both fixed and portable gas detection systems. They can provide real-time monitoring, enabling rapid response to potential hazards. Moreover, these sensors often have a longer operational life compared to some other gas sensing technologies. However, they are limited in their temperature range and have slow detection times. Electrochemical sensors might have restricted performance in extreme temperatures, either high or low, which can affect their accuracy and sensitivity.

- **Catalytic sensors** have a wide range of hydrogen detection in volume and operating temperature These sensors work based on the catalytic oxidation of hydrogen, which leads to a change in resistance or heat output, allowing for sensitive and reliable detection. Catalytic sensors are well-suited for detecting a broad concentration range of hydrogen, from low ppm levels to higher percentages in volume, making them suitable for different industrial applications. They exhibit good stability and can provide continuous monitoring, offering real-time data on hydrogen concentrations. Despite their advantages, catalytic sensors are expensive compared to some other gas sensing technologies and are not highly selective for hydrogen gas.
- **Thermal conductivity sensors** have the broadest measurement range and the highest detection accuracy among the four sensor types. However, they are prone to cross-sensitivity readings with helium. Given the importance of economic and agile considerations for industrial applications, semiconductor-based hydrogen leak detection methods may be a realistic option.

The above technical considerations evidenced the need for a normative framework dedicated for the H2NG grid leak detection system metrological devices.

3.10 Results from the survey on metrological devices normative revision in view of H2NG grid

A survey (Annex A) listing the actual standards regulating metering of natural gas grid was circulated among the partners to check each relevant standard to be consider in this analysis. The objective was to determine if the standards could be used without revisions for H2NG mixture flowing in the gas grid, or if they needed to be upgraded or withdrawn. No direct answers were received, indicating that the adaption of the gas grid metrological normative framework to hydrogen injection and H2NG mixture measurement devices' suitability needs to be examined after a huge and widespread experimental pre-normative activity, which has not been performed yet.

We then proceed to analyze the published results, both project deliverables and papers, dealing with experimental checks of gas measuring devices. These devices varied in type and were based on different physical gas properties, specifically when the gas flow transitioned from natural gas to H2NG blends with different H2 volumetric percentage composition.

3.11 Similar Projects Results

Normative revision should rely on solid and documented scientific results to understand which parts of the standard need to be modified, withdrawn, or implemented, and in what direction. Generally speaking, there is still a lack of knowledge and scientific evidences on the accuracy modification when flow meters are used with hydrogen. Several European projects have been launched with the aim of collecting missing data and filling in the gaps.

One of the objectives of the **NATURALHY project** (2004-2009) [9], participated by an European consortium of 40 partners with extensive experience and skills, was to assess the current situation of standards and regulations regarding hydrogen/natural gas mixtures. The project aimed to identify necessary modifications and eventually to initiate required changes.

The three-year Euramet SRTn°03 project, entitled **NewGasMet**, was launched in June 2019, to better understand the possible impact of new gases, and hydrogen in particular, on the accuracy and lifespan of meters. The research aimed to check if the gas meters used with different types of renewable gas, and in particular with gases containing hydrogen, remain compliant with the requirements of the European Measuring Instruments Directive MID, 2014/32/EU.

In Deliverable 1 [13] the most commonly used gas meter technologies used in the European gas grids were investigated. The results of a dedicated survey stated the most present gas meter types for both H2 and H2NG are ultrasonic meters and rotary meters. However, other technologies are also present though to a slightly lesser extent, such as turbine meters, diaphragm meters, thermal mass meters and Coriolis meters. The changed thermodynamic properties of an H2NG blend compared to pure NG necessitate a complete revision of the norms for every measuring instrument type on the gas grid, as well as the conversion procedures and gas physical properties.

In the same Project, Deliverable D3 [73] from a review of the literature data the following results are reported:

- Up to 10% of H2 in the natural gas, big size (> 400m3/h) turbine and ultrasonic meters are slightly impacted. This last conclusion does not apply to the other gas meter technologies.
- Small size (< 400 m3/h) turbine, ultrasonic should be tested with hydrogen and natural gas mixtures to confirm the results for big sizes meters.
- All the other technologies (diaphragm, rotary, thermal-mass and Coriolis meters) should be tested with hydrogen and natural gas mixtures.

In the Report A2.1.15 of the same Project "Effect of the renewable gases on the uncertainty budgets of gas meters" [74] the expert group of NewGasMet WP2 made some recommendations on several standards covered by CEN/TC 237, valid for every meter:

- Validating the meter's metrological performances not with air, but with the gas closest to its intended use

- For turbine meters, to perform the assessment on the same Reynolds number range (+/-5%)
- Tests could be carried out at zero flow conditions only, to minimize the required gas volume and associated safety concerns and provide a worst-case scenario test, with the poorest signal to noise ratio.

A comprehensive overview of available test results and regulatory limits for hydrogen admission into existing natural gas infrastructure and end use was published by Marcogaz in 2019 [61], based on a consistent number of published and unpublished papers and project results. For all the most used gas meters, turbine, rotary displacement, ultrasonic and diaphragm gas meters, no significant issues are evidenced in the referenced literature up to 10 % H2 in NG. Conflicting experimental results were found at higher hydrogen concentration blends, in the 10-40% range for turbine and rotary displacement gas meters and in the 10-100 % range for diaphragm gas meters. For volume converters, most of the available studies show positive results up to 40 % H2 concentration. This overview stresses the need for more R&D on the topic. Additional tests on metrological test benches and on a wide range of meters remain necessary to come to a decision on the wider deployment of hydrogen injection into natural gas networks.

For gas volume measurements, meters based on different measuring principles are used, resulting in varying H2 sensitivity levels. According to this, a H2 compatibility of up to 10 % by volume can be assumed in principle [61]. The widely accepted limit for hydrogen concentration in natural gas is 10 %, which allows the use of all the existing gas metering system types and conversion algorithms, without any change need [75]. This assumption is based on the slight change in physical parameters of the gas blend with respect to natural gas, as supported by experimental results. Higher compatibility levels are not excluded, as they may be possible depending on the measurement method but require further investigations [76].

In the paper of Dell'Isola et al. [36], the main thermophysical parameters of H2NG mixtures have been analysed as a function of the hydrogen up to 25% vol. The results obtained show that injection of H2 into natural gas significantly impacts the relative density, specific heat and higher calorific value and speed of sound (which is a critical parameter for ultrasonic static gas meters), while the Wobbe Index is less affected. In particular:

- the relative density decreases as the H2 content increases.
- the higher calorific value significantly decreases as the H2 content increases (e.g., for gases characterized by a low content of CH4, the calorific value is reduced by 20% when the hydrogen content is equal to 25%, exceeding the lower limit indicated by the ISO 12213-2);

For H2 content larger than 25% as well as the use of the mixture at high pressures, requires additional research and the development of new algorithms. [36]

The **HIGGS** (Hydrogen in Gas Grid) Project was launched to individuate the technical and regulatory barriers towards the use of the actual natural gas grid to carry H2NG mixtures [14].

GERG, under the umbrella of CEN/TC 234, was appointed in 2019 to carry out the Project “Removing the technical barriers to use of hydrogen in natural gas networks and for gas end users”. The objectives of the project are to increase knowledge about the impact of renewable gases on the accuracy and durability of commercially available meters and to provide reliable data to adapt if needed gas meter standards [77].

The Report of WP7, “Network Equipment”, of the GERG project, “Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users” [77] highlights the barriers identified to hinder the possibility of H2NG flowing in the current natural gas grid:

1. To collect data on hydrogen's impact on different technologies of gas metering;
2. To assess the real impact of H2 on the metrological behavior of commercialized and installed gas meters;
3. To identify and quantify the long-term impacts of hydrogen on the different components of the gas meters;
4. To ensure safety on hydrogen blending operations on the existing gas networks. Recommendations are given in the Report for lowering or removing the above listed barriers: essentially to perform laboratory and field tests to investigate the effect of hydrogen on meter’s accuracy and endurance and to develop H2NG adapted calibration methods.

The EU funded **THYGA** Project (Testing Hydrogen Admixtures for Gas Appliances) [78] sets out to develop and communicate a detailed understanding of the impact of blends of natural gas and hydrogen on end use applications, specifically in the domestic and commercial sectors. WP4 of THYGA Project was on Standardization; a dedicated Workshop was organized by THYGA WP4 on March 8, 2023, with selected experts from CEN Technical Committees and manufacturers to exchange on the different topics related to certification of appliances for H2NG blends. What the Workshop pointed out is [78]: H2NG blend with up to 20% hydrogen content can be classified in the 2nd gas family according to EN 437; regarding the Wobbe index limits, H2NG with H2 % up to 6 % can be considered in the H group, up to 60% in the E group. Nevertheless, depending on gas appliance categories, using a H2NG with the same Wobbe Index but with different H2 content, could pose different risk levels.

On Deliverable 4.3 of THYGA Project [23] the authors suggest using a 20 % H2 in CH4 blend as a reference gas to test appliances.

4. GAPS TOWARDS H2NG GRIDS METERING

To be ready for H2 injection into the current gas transmission and distribution infrastructures, and the consequent need for devices installed on the grids to be compliant with the specific meter typology requirements, an urgent and essential updating activity is to be undertaken by the normative bodies and their TCs.

Several gas meters "hydrogen ready" can be already found on the market, both for distribution and transmission grid, both for H2NG blend and 100% H2, such as ultrasonic, turbine or thermal-mass type [80, 81, 82, 83].

The process is ongoing: for the standards referring to meters' metrology the designated TCs have been identified, and most of the RCS update is under preparation for each meter typology, except for Coriolis meters [16].

As a first step, the TC experts, in Agreement with the different EU national Autorities and stakeholders, should fix the appropriate H2 content in the H2NG mixture that is necessary to consider for standard revision, since it's quite unrealistic to expect a metering device to provide accurate measurements over the entire 0-100% H2 content range. A reasonable request is to ask for an immediate standards revision in order measuring devices could accept and measure with sufficient accuracy and without long-term degradation H2NG blend with a limit of H2 content <30%.

The same standards, or different ones, could govern the 100% hydrogen pipelines and distribution units metering. Within this limit, a roadmap can be defined towards the definition of standard able to accomplish H2 injection into the NG grids.

Based on the findings from the analysis of each standard in Chapter 3, as well as the results listed above from similar projects and related papers, a comprehensive list of gaps can be outlined, valid crosswise for every meter type:

- Lack of test results on physical and thermodynamic properties of H2NG mixtures. The H2NG physical properties need to be experimentally checked as a function of temperature, pression, and hydrogen content, in order to define exactly how the physical gas properties used for the measuring of each meter are affected by the H2NG composition.
- Lack of long-time and endurance tests on metering devices materials.
- Lack of data on meters metrological and mechanical behavior for flowrate greater than the maximum value foreseen by H2NG use.
- Lack of exhaustive data on the accuracy of each meters with H2NG blends with different H2 content.
- Lack of information on gas meters tightness at different H2 content in H2NG mixtures.
- Lack of information on meters calibration linearity at different H2 % content in H2NG mixtures.
- Lack of suitable modelling tools to predict the physical and thermodynamic properties of H2NG out from tested experimental conditions; the properties to be modelled should be those on which

the measurement devices are based: sound velocity within the gas, flow velocity, turbulence, uniformity etc.

The composition measurements by gas chromatography issue takes an essential importance in case of H2NG grids. The standards on that subject are considered for updating but actions are still to be taken.

A complete normative framework needs to be developed for the H2NG leaks detection.

4.1 ON-GOING ACTIVITIES in CEN TECHNICAL COMMITTEES

The Hydrogen Task Force is in the process of finalizing a state-of-the-art report on technical tests conducted on different elements of the gas value chain with a hydrogen/natural gas mixture and identification of future research actions. Currently, no ongoing projects are being considered. Laboratory tests need to be supplemented by field tests (or on test benches under operational conditions). The main limiting factors for the injection of hydrogen into transmission networks are mainly related to gas usage and storage.

- CEN/TC 234 WG5 contributed to the transport metering chain section of the report being prepared on the CEN TC 234 WG5 contributed to the transport metering chain section of the report being prepared on the “consequences of hydrogen in gas infrastructures”.
- CEN/TC 234 WG11 Contributed to the gas quality section of the report being prepared on the “consequences of hydrogen in gas infrastructures”.

CEN/TC 237 has produced a joint report with Marcogaz and Facogaz (an association representing meter manufacturers) giving a qualitative assessment of the impact of hydrogen on meters. [4]

There are currently various ongoing activities in the German Technical and Scientific Association for Gas and Water (DVGW) to adapt the gas infrastructure and the gas applications to a higher hydrogen content. In this context, the DVGW technical guidelines shall be reviewed in terms of possible limitations of the concentration of hydrogen and shall be adapted if necessary [73].

CEN/TC 237 is currently revising EN1359 and EN12480 to introduce H2NG mixtures [84].

A complete review of the European normative framework regulating the metrology of devices installed along the transmission and distribution gas grid, in the case of hydrogen injection at content percentages from 0 to 100%, was undertaken, as referenced in the European Clean Hydrogen Alliance's "Roadmap on Hydrogen Standardization," published in March 2023 [16].

5. CONCLUSION

The compelling requirements for a complete check and revision of the European normative framework regulating the metrology of devices installed along the gas transmission and distribution infrastructures, in case of H2NG from 0 to 100%, have been highlighted by several projects and papers. The work is currently in progress within several CEN TCs in charge of updating the standards, in particular CEN/TC 237 and CEN/TC 238 for standards governing gas metering devices and the determination of gas quality parameters.

The CEN TCs operate in agreement with the International Standardization Organization (ISO), receiving support from experts representing national committees, TSOs, DSOs, industrial entities, governmental bodies, and associations. The regulation process needs to rely on a widespread, solid and shared experimental activity on metrological performances of the installed meters, materials compatibility, conversion algorithms, and endurance tests to identify the gaps for H2NG measurements.

Several gaps regarding meter tightness and calibration, gas composition and safety have already been pointed out, but the explored percentage range of H2 volumes in H2NG mixture is still limited. Several standards, particularly those related to the different gas meters, will be updated in the next two to three years. A step behind is the updating of the rules on gas composition by gas-chromatography since it is still to be addressed. A normative that is still completely missing, representing a significant gap for H2NG grid exploitation, involving metrological and safety aspects, is the regulation on the leaks detection.

In conclusion, addressing the compelling requirements for updating the European normative framework is an ongoing and collaborative effort within the International, European and National normative bodies (eg. ISO, CEN, CENELEC). With support from experts and organizations across various sectors, a comprehensive and harmonized approach is being pursued to strengthen the metrology and safety aspects of devices installed along the gas grid, specifically in the context of hydrogen injection. Through these efforts, the gas industry aims to unlock the full potential of H2NG as a clean and sustainable energy solution.

Finally, this report will be the basis from which Work Package 4 (Standardization and market implementation) will identify the actions required to remove those barriers that prevent H2NG implementation and the H2 asset readiness of European gas infrastructure. In particular WP4, building on the results of WP1 (included this report), WP2, WP3 will focus on two main areas: standardization and market implementation. However, continuing the discussion about the gaps and the barriers at normative levels should be encouraged and explored among the experts in the Consortium and in the Stakeholder Advisory Board (SAB) during dedicated brainstorming moments planned in the exploitation stage.

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ANNEX A “NATURAL GAS GRID INSTRUMENTATION NORMATIVE SURVEY”

The developed survey is reported in the following pages.

TITLE: NORMATIVE SURVEY
PROJECT: THOTH2
DATE: 06/04/2023
REV: 0

INTRODUCTION AND SCOPE :
WP1 aims firstly to perform a State of the Art of the measuring devices installed on NG networks to provide exhaustive cataloguing of the installed and operated devices in terms of operative and design conditions, type and number and/or the percentage respect to the total.
Based on the results, the findings of past and ongoing projects in the research field and the relevant literature will be investigated to design a comprehensive and qualitative SoA guideline about the existing readiness level devices in HNG (Hydrogen and natural gas mixtures) networks WP 1 will check the current technological barriers to performing measures in HNG networks with different H2 percentage.
Task 1.3 :
Task 1.3 will focus on Regulations, Codes, and Standards that provide guidance and rules to metrology in NG transmission and distribution sectors. The Task will systematically review metrological and existing NG transmission and distribution standards, and the normative activities under development in the different National and European WG focusing on H2 asset readiness. The Task will point out the specific gaps that need to be updated and/or covered by new dedicated technical standards to support the NG/H 2 value chains.
INSTRUCTIONS :
The survey is developed in different sections:
1) Normative and Directives that could be relevant for measuring devices in HNG future grids (SHEET 1)
2) Technical standards (SHEET 2), ISO (SHEET 3), OIML (SHEET 4)
3) Active Technical Committee about the topic (SHEET 5)
The participants are asked to answer to the cells coloured in yellow. A dropdown list is used to simplify the answers. Comments and notes of the participants are welcomed.
GATHERING OF ANSWERS :
Please send the excel file to: paola.gislon@enea.it and to alessandro.guzzini2@unibo.it

Directive	Date	Title	Description	Can be directly applied to HNG mixtures?	Comments	Note
2014/32/UE	26/02/2014	Directive 2014/32/EU of the European parliament and of the council of 26 February 2014 on the harmonization of the laws of the member states relating to the making available on the market of measuring instruments	Covers 10 categories of measuring instruments. Adopts a decisively modern regulatory approach, leaving much more room for technological innovation and more choice for manufacturers in conformity assessment procedures. Aligns Community legislation on international standards, in particular of the OIML and covering the electronic revolution that has characterised measuring instruments since the 1970s			Replaces Directive 2004/22/EC
2021/1402	25/08/2021	Measuring instruments (MID) Commission Implementing Decision (EU) on harmonised standards for gas meters and other measuring instruments drafted in support of Directive 2014/32/EU of the European Parliament and of the Council				Implements Directive 2014/32/EU

Directive	Date	Title	Description	Would be a barrier for the currently installed device when measuring HNG mixtures?	Comments	Note
2014/34/UE	26/02/2014	Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres	It refers to the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres			Implements Directive 2014/32/EU

Name	Title	Year of publication	Replaces	Description	Tecnical Committee	Validity limits	Restrictions	Can be extended to H2NG mixtures metering?	Are experimental data/literature data on H2GN mixture application available?	Do you know technical standards from other sectors that can be applied?	Notes / comments
EN 437	**Test gases - Test pressures - Appliance** categories	2021		This document specifies the test gases, test pressures and categories of appliances relative to the use of gaseous fuels of the first, second and third families. It serves as a reference document in the specific standards for appliances.	CEN/TC 238 - Test gases, test pressures and categories of appliances	Procedures for tests are given in the corresponding appliance standards. The test gases and the test pressures specified in this standard are in principle intended to be used with all types of appliances.					
EN1359	Gas meters - **Diaphragm** gas meters	2017	EN1359	This European Standard specifies the requirements and tests for the construction, performance, safety and production of class 1,5 **diaphragm gas meters** (referred to as meters).		This applies to meters with co-axial single pipe, or two pipe connections, that are used to measure volumes of fuel gases, which are within the limits of test gases of the 1st, 2nd and 3rd families described in EN 437. The meters have maximum working pressures not exceeding 0,5 bar and maximum actual flow rates not exceeding 160 m3.h−1 over a minimum ambient temperature range of −10 °C to 40 °C and a gas temperature range as specified by the manufacturer with a minimum range of 40 K.	EN ISO 4892-3:2016 "Plastics. Methods of exposure to laboratory light sources Fluorescent UV lamps"; ISO 7724-3:1984 Paints and varnishes — Colorimetry				
EN 1776	Gas infrastructure - **Gas measuring systems** - Functional requirements	2015		This European Standard specifies functional requirements for the design, construction, testing, commissioning/decommissioning, operation, maintenance and where appropriate calibration, together with suitable documented provisions for **all new gas measuring systems and any major changes of existing systems**. This European Standard also specifies accuracy classes of measuring systems and thresholds applicable to these classes. Demonstration of compliance is achieved through the selection, installation and operation of appropriate measurement instruments, together with suitable documented provisions for calculations.		This European Standard is applicable for gases of the 2nd family as classified in EN 437. It is also applicable for treated non-conventional combustible gases complying with EN 437 and for which a detailed technical evaluation of the functional requirements (such as injected biomethane) is performed ensuring there are no other constituents or properties of the gases that can affect the metrological and physical integrity of the measuring systems.					
ISO 12213-1	Natural gas — Calculation of **compression factor** — Part 1: Introduction and guidelines	2009			ISO/TC 193/SC 1 Analysis of natural gas						
ISO 12213-2	Natural gas — Calculation of **compression factor** — Part 2: Calculation using molar-composition analysis	2009			ISO/TC 193/SC 1 Analysis of natural gas						
ISO 12213-3	Natural gas — Calculation of **compression factor** — Part 3: Calculation using physical properties	2009		ISO 12213-3:2006, specifies a method for the calculation of compression factors when the superior calorific value, relative density and carbon dioxide content are known, together with the relevant pressures and temperatures. **If hydrogen is present, as is often the case for gases with a synthetic admixture, the hydrogen content also needs to be known.** The method is primarily applicable to pipeline quality gases within the ranges of pressure p and temperature T at which transmission and distribution operations normally take place, with an uncertainty of about +/-0,1 %. For wider-ranging applications the uncertainty of the results increases.	ISO/TC 193/SC 1 Analysis of natural gas						
EN 12261	Gas meters - **Turbine** gas meters	2018	EN12261	This document specifies the measuring conditions, requirements and tests for the construction, performance and safety of class 1,0 **axial and radial turbine gas meters** with mechanical indicating devices, herein after referred to as a meter(s), having in-line pipe connections for gas flow measurement.		This document applies to turbine gas meters used to measure the volume of fuel gases of the 1st and 2nd gas families, the composition of which is specified in EN 437, at maximum working pressures up to 420 bar, actual flow rates up to 25 000 m^3/h over a gas temperature range of at least 40 K and for a climatic environmental temperature range of at least 50 K.					
EN 12405-1	Gas meters - Conversion devices - Part 1: **Volume conversion**	10 Jan 2022	EN12405-1:2018	This document specifies the requirements and tests for the construction, performance, safety and conformity of **gas volume electronic conversion devices associated to gas meters**, used to measure volumes of fuel gases of the 1st and 2nd families according to EN 437.	DPL - Gas supply	Only three kinds of conversion are treated in this document: conversion as a function of temperature only (called T conversion); conversion as a function of the pressure and of the temperature with constant compression factor (called PT conversion); conversion as a function of the pressure, the temperature and taking into account the compression factor (called PTZ conversion). This document is not relevant to temperature conversion integrated into gas meters which only indicate the converted volume. EN 12405-2 applies for energy conversion.					
EN 12405-2	Gas meters - Conversion devices - Part 2: **Energy conversion**	31 Oct 2012		This European Standard specifies the requirements and tests for the construction, performance, safety and conformity of **conversion devices used to determine the energy of fuel gases** described in the Table 1, including those of the 1st and 2nd families according to EN 437.	CEN/TC 237 - Gas meters						
EN 12405-3	Gas meters - Conversion devices - Part 3: **Flow computer**	2015		Specifies requirements and tests for construction, performance, safety and conformity of **flow computers** (FCs) used to meet the metrological and technical requirements of a high accuracy volume conversion device. They are used to **determine V of gases**	CEN/TC 237 - Gas meters	fuel gases, including 1° and 2° families according to EN 437. only flow computers with ultrasonic meters according to ISO 17089 1 or gas turbine meters conforming to EN 12261 are considered. FCs are equipped with external transducers for P and T, approved separately. provisions on P and T tranducers in Annex B and C					
EN 12480	Gas meters - **Rotary displacement** gas meters	May 2018		This European Standard specifies ranges, construction, performances, output characteristics and testing of **rotary displacement gas meters** (hereinafter referred to as RD meters or simply meters) for gas volume measurement.	CEN/TC 237	This European Standard applies to rotary displacement gas meters used to measure the volume of fuel gases of at least the 1st, 2nd and 3rd gas families, the composition of which is specified in EN 437:2003+A1:2009, at a maximum working pressure up to and including 20 bar over an ambient and gas temperature range of at least −10 °C to +40 °C. This European Standard applies to meters with a maximum allowable pressure PS and the volume V of less than 6 000 bar · litres or with a product of PS and DN of less than 3 000 bar.					
EN 14236	**Ultrasonic** domestic gas meters	2019	EN 14236	This European Standard specifies requirements and tests for the construction, performance and safety of class 1,0 and class 1,5 battery powered ultrasonic gas meters (hereinafter referred to as meters), having co-axial single pipe, or two pipe connections	CEN/TC 237	Measure volumes of distributed fuel gases of the second and/or third family, as given in EN 437, at maximum working pressures not exceeding 0,5 bar) and maximum actual flow rates of up to 10 m3/h over a minimum ambient temperature range of -10 °C to +40 °C, and minimum gas temperature span of 40 K, for domestic applications. This European Standard applies to meters where the measuring element and the register(s) are enclosed in the same case.					
EN 16314	Gas meters - **Additional functionalities**	**2013**		This European Standard specifies the **additional requirements and tests for gas meters**, conforming to EN 1359, EN 12261, EN 12480, EN 12405 and EN 14236, which have **battery powered devices** providing additional functionalities that form part of the gas meter (hereafter referred to as meter) or contained in an Additional Functionality Device (AFD). It also covers the additional requirements **when an electronic index is used rather that a mechanical one.**	CEN/TC 237	For gas meters with a maximum capacity of 40 m3/h and a maximum operating pressure of not exceeding 500 mbar.Where the option of an integral valve to the meter is specified, this standard only gives requirements for meters having a maximum capacity not exceeding 10 m3/h.					
EN 17526	Gas meter - **Thermal-mass flow-meter based** gas meter	2022	2022	This document specifies requirements and tests for the construction, performance, safety and production of battery powered class 1,5 **Capillary Thermal-Mass Flow sensor gas meters** (hereinafter referred to as meter(s)). This applies to meters having co-axial single pipe, or two pipe connections, which are used to measure volumes of fuel gases of the 2nd and/or 3rd family, as given in EN 437:2018.	CEN/TC 237	These meters have a maximum working pressure not exceeding 0,5 bar and a maximum flowrate not exceeding 160 m3/h over a minimum ambient temperature range of −10 °C to +40 °C and a gas temperature range as specified by the manufacturer with a minimum range of 40 °C.					

Standard	Title	Date	Description	Confirmed in	Technical Committee	Replaces	Can be extended to H2NG mixtures metering?	Are experimental data/literature data on H2GN mixture application available?	Do you know technical standards from other sectors that can be applied?	Notes / Comments
ISO 6974-1	Natural gas — Determination of **composition and associated uncertainty by gas chromatography** — Part 1: General guidelines and calculation of composition									
ISO 6974-2	Natural gas - Determination of **composition** and associated uncertainty by **gas chromatography** - Part 2: Uncertainty calculations	2012	This part of ISO 6974 describes the process required to determine the uncertainty associated with the mole fraction for each component from a natural gas analysis in accordance with ISO 6974-1.							
ISO 6974-3	Natural gas Determination of **composition** and associated uncertainty by **gas chromatography** Part 3: Precision and bias		This document describes the **precision** that can be expected from the **gas chromatographic method** that is set up in accordance with ISO 6974-1. The stated precision provides values for the magnitude of variability that can be expected between test results when the method described in ISO 6974-1 is applied in one or more competent laboratories. This document also gives guidance on the assessment of bias.							
ISO 6974-6	Natural gas - Determination of **composition** with defined uncertainty by **gas chromatography** - Part 6: Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons using three capillary columns		ISO 6974-6 describes a gas chromatographic method for the quantitative determination of the content of helium, hydrogen, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons in natural gas samples using three capillary columns. This method is applicable to the determination of these gases within the mole fraction ranges varying from 0,000 1 % to 40 %, depending on the component analysed, and is commonly used for laboratory applications. However, it is only applicable to methane within the mole fraction range of 40 % to 100 %. These ranges do not represent the limits of detection, but the limits within which the stated precision of the method applies. Although one or more components in a sample may not be present at detectable levels, the method can still be applicable							
ISO 6975			This International Standard describes the specifications for the quantitative analysis of the following components of natural gas: helium, hydrogen, argon, oxygen, nitrogen, carbon dioxide, saturated hydrocarbons from C1 to C5, hydrocarbon fractions from C6 upwards, aromatic compounds as benzene and toluene. This method is not intended for the determination of oxygen compounds (water vapour, methanol, glycols) or sulfur compounds.							
ISO 6976	Natural gas — **Calculation of calorific values, density, relative density and Wobbe indices from composition**	2022	Specifies methods for the calculation of gross calorific value, net calorific value, density, relative density, gross Wobbe index and net Wobbe index of natural gases, natural gas substitutes and other combustible gaseous fuels, when the composition of the gas by mole fraction is known. The methods specified provide the means of calculating the properties of the gas mixture at commonly used reference conditions.							
ISO 10723	Natural gas — Performance evaluation for **analytical systems**	2012	ISO 10723:2012 specifies a method of determining whether an analytical system for natural gas analysis is fit for purpose. It can be used either to determine a range of gas compositions to which the method can be applied, using a specified calibration gas, while satisfying previously defined criteria for the maximum errors and uncertainties on the composition or property or both, or to evaluate the range of errors and uncertainties on the composition or property (calculable from composition) or both when analysing gases within a defined range of composition, using a specified calibration gas							
ISO 10790	Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of **Coriolis flowmeters** (mass flow, density and volume flow measurements)		ISO 10790:2015 gives guidelines for the selection, installation, calibration, performance, and operation of **Coriolis flowmeters** for the measurement of mass flow and density. This International Standard also gives appropriate considerations regarding the type of fluids measured, as well as guidance in the determination of volume flow and other related fluid parameters. NOTE Fluids defined as air, natural gas, water, oil, LPG, LNG, manufactured gases, mixtures, slurries, etc.	2020	ISO/TC 30/SC 5 Velocity and mass methods					
ISO 12764	Measurement of fluid flow in closed conduits — **Flowrate measurement by means of vortex shedding flowmeters** inserted in circular cross-section conduits running full	**2017**	This document a) describes the use of vortex shedding flow meters for liquids, gases, and steam, including a glossary and a set of engineering equations used for specifying performance, b) provides technical information to assist the user in selecting, specifying and applying vortex shedding flowmeters, including influence effects, c) describes typical construction and provides recommendations for inspection, certification, and material traceability, d) describes availability of diagnostics associated with vortex shedding flowmeters, e) provides calibration guidance, f) does not apply to insertion type vortex shedding flowmeters, g) applies only to closed conduits running full, h) applies only to fluid flow that is steady or varies only slowly with time, and i) applies to fluids considered to be single-phase.		ISO/TC 30/SC 5					
ISO 13443	Natural gas **Standard reference conditions**	1996	Specifies the **standard reference conditions of temperature, pressure and humidity** to be used for measurements and calculations carried out on natural gases and similar fluids.	2020						
ISO 13686	Natural gas - **Quality** designation	2013	ISO 13686:2013 specifies the parameters required to describe finally processed and, where required, blended natural gas. The main text of ISO 13686:2013 contains a list of these parameters, their units and references to measurement standards. Informative annexes give examples of typical values for these parameters, with the main emphasis on health and safety.		CEN/SS N21, CEN/TC 238	EN ISO 13686:2005				
ISO 14511	Measurement of fluid flow in closed conduits — **Thermal mass flowmeters**	2019	This document gives guidelines for the specification, testing, inspection, installation, operation and calibration of thermal mass gas flowmeters for the metering of gases and gas mixtures. It is not applicable to measuring liquid mass flowrates using thermal mass flowmeters.							
ISO 15970	Natural gas — Measurement of properties — **Volumetric properties:** density, pressure, temperature and compression factor	**2008**	This international Standard gives requirements and procedures for the measurement of the properties of natural gas that are used mainly for volume calculation and volume conversion: density at reference and at operating conditions, pressure, temperature and compression factor.		ISO/TC 193					
ISO 17089-1	Measurement of fluid flow in closed conduits — **Ultrasonic meters** for gas — Part 1: Meters for custody transfer and allocation measurement	2019	This document specifies requirements and recommendations for ultrasonic gas flowmeters (USMs), which utilize the transit time of acoustic signals to measure the flow of single phase homogenous gases in closed conduits. This document applies to transit time ultrasonic gas flowmeters used for custody transfer and allocation metering, such as full-bore, reduced-area, high-pressure, and low-pressure meters or any combination of these. There are no limits on the minimum or maximum sizes of the meter. This document can be applied to the measurement of almost any type of gas, such as air, natural gas, and ethane.		ISO/TC 30/SC 5 Velocity and mass methods					

Recommendation	Title	Date	Description	Technical Committee	Can be extended to H2NG mixtures metering?	Are experimental data/literature data on H2GN mixture application available?	Do you know technical standards from other sectors that can be applied?	Notes
OIML R137-1	Gas meters Part 1: Metrological and technical requirements Part 2: Metrological controls and performance tests	2012		International Organization of Legal Metrology				
OIML R140	Measuring systems for gaseous fuel	2007		International Organization of Legal Metrology				

Question	Yes or no	**Could you provide information about?** (Participants, Technical Committe, main measuring devices involved (flowmeters, gas cromatographs, etc), gaps covered, When it is expected that the activities of the TC will be completed?, etc...)
Do you know normative activities under development in the different National and European WG focusing on H2 asset readiness (i e CEN/CENELEC TC)?		