D4.1

Preliminary guidelines and recommendations for new standards for Gas Meters, Pressure and Temperature Sensors, Leak Detectors, Gas Analyser and Water Dew Point Sensor

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EXECUTIVE SUMMARY

The THOTH2 project, under the Clean Hydrogen JU framework, addresses a critical challenge in the energy transition: the accurate and safe metering of hydrogen and hydrogen-natural gas (H2NG) mixtures. As hydrogen becomes a key vector in decarbonizing hard-to-electrify sectors—such as heavy industry, long-distance transport, and high-temperature processes—its integration into existing gas infrastructures demands a fundamental revision of metering standards.

This deliverable D4.1 provides a comprehensive technical assessment of the limitations of current European gas metering standards (EN, ISO, OIML) when applied to hydrogen and H2NG blends. It proposes preliminary guidelines and recommendations for updating existing standards or developing new ones, with the aim of ensuring metrological accuracy, operational safety, and regulatory compliance in hydrogen-rich environments.

The key technical challenges identified are the physical and chemical properties of hydrogen. Hydrogen differs significantly from natural gas in terms of energy density, diffusivity, viscosity, and combustion characteristics. These differences impact:

- Meter sizing and flowrate calibration: Hydrogen's lower calorific value (~3.54 kWh/Std.m³ vs. ~10.5–12.5 kWh/Std.m³ for NG) requires higher volumetric flow to deliver equivalent energy.
- Leak tightness: Hydrogen's small molecular size increases the risk of leakage through seals and materials not originally designed for it.
- Material compatibility: Hydrogen can cause embrittlement and degradation in metals and polymers, affecting long-term durability.

These differences affect not only gas meters but the entire measurement chain, including leak detectors, pressure and temperature sensors, and gas analysers. Regulatory frameworks, such as the Measuring Instruments Directive (MID 2014/32/EU), lack hydrogen-specific performance criteria, creating ambiguity in certification and conformity assessment.

This deliverable provides preliminary guidelines and recommendations to bridge these gaps across all critical components:

- **Gas Meters**
  - Define hydrogen-specific test gases and calibration protocols with uncertainty budgets ≤ 1/5 of Maximum Permissible Error (MPE).
  - Update flowrate and pressure classes to reflect hydrogen's lower energy density.
  - Introduce hydrogen-based leak tightness tests and enhanced detection sensitivity.
  - Mandate material compatibility assessments and extended ageing protocols beyond 1000 hours.
  - Require clear gas compatibility marking on data plates and technical documentation.
- **Leak Detectors**
  - Adapt EN 60079 series to include H_2/NG blends and mixed-gas calibration.
  - Introduce multi-sensor arrays for accurate composition detection and alarm thresholds adapted to variable LFL/UFL.

- Require performance tests under representative hydrogen conditions and interference scenarios.

– **Pressure Sensors**
  - Extend pressure range up to 1000 bar for hydrogen storage and refuelling applications.
  - Mandate hydrogen-compatible alloys (316L, Hastelloy) and welded hermetic designs to prevent permeation.
  - Introduce hydrogen-specific endurance tests under extreme conditions (−40 °C to +85 °C).
  - Enforce ATEX/IECEx compliance for Group IIC gases and harmonization with ISO 19880 series.

– **Temperature Sensors**
  - Extend operating range to −200 °C to +600 °C for cryogenic and high-temperature hydrogen processes.
  - Require explosion-proof housings, mineral-insulated cables, and welded joints for durability.
  - Implement hydrogen-specific thermal cycling and ageing tests; ensure compliance with ATEX and IEC 60079.

– **Gas Analysers**
  - Harmonize ISO 6974 series and ISO 6976:2026 with ISO 14687:2025, SAE J2719:2020, ISO 17124:2022, and ISO 21087:2019 for hydrogen impurity analysis.
  - Harmonize sampling standards ISO 10715:2022 with ISO 19880-9:2024 for H_2/NG mixtures and pure hydrogen.
  - Enforce ATEX/IECEx safety for analyser shelters and require sub-ppb detection limits for critical impurities.
  - Integrate hydrogen-specific calibration and uncertainty models into ISO/TC 193 framework with a view to ISO/ 158, ISO/TC 197 and CEN/TC 234 frameworks.

– **Water dew point sensors**
  - Amend or revise existing dew point sensor standards to explicitly include pure hydrogen applications.
  - Develop a hydrogen-specific annex addressing materials, sampling, calibration, and safety.
  - Set a joint working group between ISO/TC 193 and ISO/TC 197 to avoid duplication and ensure consistency.
  - Liaise with IEC committees responsible for explosive atmosphere equipment to ensure coherent safety requirements.

Implementing these recommendations will ensure metrological integrity, operational safety, and regulatory clarity for hydrogen deployment. It will accelerate Europe's hydrogen roadmap, foster international harmonization, and enable a secure, efficient, and sustainable energy future.

1. INTRODUCTION

The global energy landscape is undergoing a historic transformation. Faced with the urgent need to reduce greenhouse gas emissions, limit global warming, and ensure long-term energy security, countries around the world are shifting away from fossil fuels toward cleaner, more sustainable energy sources. This shift, commonly referred to as the energy transition, is not just a technological evolution, but a systemic change that touches every part of the energy value chain, from production and distribution to consumption and regulation.

At the heart of this transition lies the challenge of decarbonizing sectors that are traditionally difficult to electrify, such as heavy industry, long-distance transport, and high-temperature manufacturing. This is where hydrogen emerges as a gamechanger. As a clean energy carrier, hydrogen can be produced from renewable sources (green hydrogen), stored for long periods, and used in a wide range of applications without emitting carbon dioxide at the point of use.

Hydrogen's versatility makes it a key pillar of future energy systems. It can be blended with natural gas, used in fuel cells to power vehicles, or serve as a feedstock in industrial processes. However, to fully integrate hydrogen into existing infrastructure, especially in residential and industrial gas networks, measurement and safety standards must evolve. One critical component of this infrastructure is the gas meter, which ensures accurate billing, safety monitoring, and system efficiency.

Traditional gas meters were designed with natural gas in mind. But hydrogen has very different physical and chemical properties: it is lighter, more diffusive, and has a lower energy content per volume. These differences pose challenges for accurate metering, leak detection, and long-term durability. As a result, existing metering standards must be updated or reimagined to accommodate hydrogen and hydrogen-natural gas blends.

Accurate metering is not just a technical requirement; it is a regulatory and economic necessity. Consumers must be billed fairly, and utilities must be able to track and manage energy flows with precision. Inaccurate measurements could lead to disputes, financial losses, and even safety risks if leaks go undetected or flow rates are misjudged.

Moreover, as hydrogen is introduced into existing gas grids, either as a blend or in pure form, meters and other metering devices must be redesigned or requalified to meet new standards for material compatibility, measurement accuracy, and long-term durability.

In short, adapting gas metering systems is not a minor upgrade, it is a fundamental step towards building a hydrogen-ready energy system. Without it, the transition to hydrogen could be delayed, less efficient, or even unsafe. Therefore, updating metering standards and technologies must be a top priority for regulators, manufacturers, and energy providers alike.

This report presents how gas metering standards can and should evolve to support the safe and effective deployment of hydrogen in modern energy systems. It highlights the technical challenges, reviews current initiatives, and proposes recommendations for regulators, manufacturers, and policymakers.

2. Why Hydrogen Requires New Metering Standards

Hydrogen's distinct physical and chemical properties introduce a range of technical challenges that existing gas metering systems, designed primarily for natural gas, are not equipped to handle.

2.1. Lower Energy Density

Hydrogen has a much lower calorific value (3.54 kWh/Std.m^3) than natural gas (10.5 to 12.5 kWh/Std.m^3), approximately 1/3. This means that a Std.m^3 of hydrogen contains significantly less energy than the same volume of natural gas. Gas meters, typically measure volume, not energy content. If these meters are used without Gross Calorific Value (GCV) measurement, the delivered energy will be overestimated, leading to inaccurate billing and potential disputes between consumers and suppliers. To ensure fairness and transparency, all the energy metering systems must be recalibrated or redesigned to accurately convert volume to energy when hydrogen or hydrogen blends are used.

2.2. Higher Diffusivity and Leakage Risk

Hydrogen is the smallest and lightest molecule in the periodic table. Its high diffusivity allows it to escape through microscopic gaps in materials and seals that are otherwise impermeable to natural gas. This increases the risk of undetected leaks, which can lead to energy loss, safety hazards, and environmental concerns. Moreover, hydrogen can cause material degradation, such as embrittlement in certain metals, which can compromise the long-term integrity of metering components. Therefore, hydrogen-compatible materials and enhanced hydrogen leak detection protocols must be incorporated into new or existing metering standards.

2.2.1. Different Combustion Characteristics

Hydrogen's combustion behaviour differs significantly from that of natural gas. It has:

- A higher flame speed, which can affect burner design and safety systems: 1.85 m/s for hydrogen whereas it is 0.44 m/s for methane.
- A lower ignition energy (19 µJ compared to 280 µJ), making it much easier to ignite unintentionally.

Substance	MIE (µJ)
Hydrogen	19
Methane	280
Ethane	240
Propane	250
Methanol	140

Table 1 – Minimum Ignition Energy (MIE) for some fuel gases

- A wider flammability range compared to natural gas (LEL - Lower Explosive Limit of 5% and UEL - Upper Explosive Limit of 15%), increasing the risk of explosion in case of leaks (LEL = 4% and UEL = 75% for H2).

These characteristics require stricter safety requirements for metering systems, especially in residential and industrial settings. Meters must be designed to operate safely under these conditions and to interface reliably with hydrogen-ready appliances and safety devices.

2.3. Impact on Smart Metering and Digital Infrastructure

As energy systems become more digital and data-driven, smart meters are playing an increasingly important role in monitoring consumption, detecting anomalies, and enabling dynamic pricing. However, most smart meters currently in use are calibrated for natural gas and may not perform accurately with hydrogen. New standards must ensure that smart metering technologies are fully compatible with hydrogen, both in terms of measurement accuracy and communication protocols.

In conclusion, hydrogen's unique properties require a comprehensive rethinking of gas metering standards. This includes not only technical recalibration but also material upgrades, safety enhancements, and digital integration. Without these changes, the transition to hydrogen could be hindered by inefficiencies, safety risks, and consumer mistrust. Updating metering standards is therefore a foundational step in building a safe, reliable, and hydrogen-ready energy future.

3. Current regulatory texts and standards applied to gas meters and their limitations.

Many operators are involved in the gas network (i.e. gas producers, gas utilities, transport, the gas industry, private individuals) and all require accurate measurements in order to bill transactions according to commercial contracts. Therefore, gas meters are certified according to the **Measuring Instruments Directive (2014/32/EU)**, using EN or OIML standards, which have been written for natural gas applications. With new uses, there is a significant impact, from the introduction of energy gases from renewable sources, on the design of normative documents and calibration test benches.

All the existing meter standards used in Europe (**ISO/TC 30** and **CEN/TC 237**) are designed for natural gas therefore their updating to accommodate hydrogen use is crucial for several reasons:

- **Accuracy and Safety:** Hydrogen has different physical properties compared to natural gas, such as lower density and higher diffusivity. These differences can affect the accuracy of gas meters designed for natural gas. Ensuring that meters can accurately measure hydrogen is essential for both billing and safety purposes.
- **Compatibility:** Existing gas meters may not be compatible with hydrogen or hydrogen-natural gas blends. Updating standards ensures that meters are designed to handle these new fuel types without compromising performance.
- **Infrastructure Readiness:** As the hydrogen economy grows, integrating hydrogen into the existing gas infrastructure requires meters that can accurately measure hydrogen flow and volume. This helps in a smooth transition from natural gas to hydrogen.
- **Regulatory Compliance:** Updated standards ensure that gas meters comply with new regulations and industry guidelines for hydrogen use. This is important for maintaining consistency and reliability across the industry.

By updating these standards, Standardization bodies support a safe and an efficient use of hydrogen as a clean energy source, paving the way for a more sustainable future.

3.1. The current European regulatory frame

Gas meters in Europe are primarily regulated under the **Measuring Instruments Directive (MID) 2014/32/EU**, which sets the essential requirements for accuracy, reliability, and safety of measuring instruments, including those used for natural gas. These standards are harmonized across EU member states and are mirrored in all the European countries national regulations.

The MID and related standards (such as **OIML R137**, **ISO/TC 30** and **CEN/TC 237**) define:

- Accuracy classes and maximum permissible errors (MPE).
- Durability and environmental performance (e.g., temperature, pressure).
- Leak tightness and mechanical integrity.
- Marking, documentation, and conformity assessment procedures.

These standards have been effective in ensuring the safe and accurate metering of natural gas across Europe. However, they were not developed with hydrogen in mind.

In the following, all the requirements and tests of the MID-002, the OIML R137 and the CEN/TC 237 and ISO/TC 30 standards are presented.

3.1.1. Measuring Instruments Directive (MID) 2014/32/EU

The MID is a European Union directive that harmonizes the legal requirements for placing measuring instruments on the market. It ensures that instruments used for legal metrology (e.g., billing, taxation, safety) meet consistent standards across the EU.

Gas meters covered by MID must:

- Accurately measure volume under specified conditions.
- Be compliant with metrological and technical requirements.
- Undergo conformity assessment procedures by notified bodies.
- Bear the CE marking and MID marking to indicate compliance.

The directive applies to meters used for **natural gas**, **biogas**, and other combustible gases traditionally used in residential, commercial, and industrial settings.

The MID does not explicitly mention hydrogen as a target gas for MI-002 gas meters. However, it does not prohibit its use either. The directive is gas-type agnostic, provided the meter meets the required performance criteria for the intended gas.

3.1.2. UK Guidance and EU Trends

A UK guidance note (2025) [1]confirms that domestic gas meters can be certified for hydrogen use under the MID framework, provided they meet the necessary performance and safety criteria.

This reflects a broader EU trend toward hydrogen-readiness in metering infrastructure.

The UK has been actively developing standards and guidance for hydrogen metering, particularly in the context of Hydrogen-Enriched Natural Gas (HENG) and pure hydrogen applications.

The UK Measuring Instruments Regulations 2016 (SI 2016/1153) mirrors the EU Measuring Instruments Directive (MID) 2014/32/EU, ensuring harmonized standards for gas meters. Certification of gas meters in the UK is overseen by the Office for Product Safety and Standards (OPSS):

- UK gas meters are assessed against CEN/TC 237 standards and OIML R 137, which define performance and testing protocols.
- Experimental work has been conducted to adapt these standards for hydrogen and H2NG, focusing on:
    - Traceable calibration and verification.
    - Durability and leak tightness testing.

[1] https://www.gov.uk/government/publications/sustainability-reporting-guidance-2025-26/sustainability-reporting-guidance-2025-26

- Definition of suitable test gases for hydrogen applications.

The European Union is rapidly advancing its hydrogen strategy, with a strong focus on standardization and regulatory clarity.

The **European Hydrogen Observatory**[2] **(EHO)** tracks 32 key policies affecting hydrogen deployment across the EU. The Major legislative frameworks include:

- Hydrogen and Decarbonized Gas Market Package
- Net Zero Industry Act
- Renewable Energy Directive (RED III)

The EU have put in place an important Standardization Efforts: EU standardization bodies such as CEN, CENELEC, ISO, IEC, and OIML are actively developing hydrogen-related standards.

As a conclusion: EU and UK efforts are converging toward harmonized standards for hydrogen metering, but significant gaps remain. Some urgent actions have been defined:

- Updating existing gas meter standards to accommodate hydrogen.
- Developing traceable calibration methods and impurity detection protocols for both pure hydrogen and for H2NG.
- Enhancing international collaboration for standard harmonization.

These steps are essential to ensure accurate, reliable, and safe hydrogen metering across domestic, industrial, and transport sectors.

In the following parts, the compliance of each metering technology regarding the MID.

[2] https://observatory.clean-hydrogen.europa.eu/sites/default/files/2025-01/The%20European%20hydrogen%20policy%20landscape-%20January%202025.pdf

4. Recommendations for new and/or update standards for gas meters

4.1. Rotary gas meters (EN 12480:2018)

The 2018 edition of Standard EN 12480 includes Annex ZA.1, which serves as an optional pathway to demonstrate compliance with the core requirements of the Measuring Instruments Directive (MID 2014/32/EU). This annex establishes a correspondence between the MID criteria and specific clauses within EN 12480. To assess the suitability of rotary gas meters for Hydrogen applications, each relevant clause or subclause linked in Table ZA.1 was systematically examined.

4.1.1. Recommendations for the flowrate range, the pressure range and the meter sizes

Under identical pressure conditions, natural gas or methane delivers over three times more energy per cubic meter than pure hydrogen. As a result, meeting the same energy demand with hydrogen requires a significantly larger gas volume. This can be addressed in two primary ways:

- By increasing the operating pressure, thereby raising the energy density (expressed in MJ/m³).
- By boosting the flow rate through higher dynamic pressure, in accordance with Bernoulli's principle.

In practical terms, gas meters designed for pure hydrogen must be appropriately sized to accommodate the increased volumetric flow. If the pressure remains unchanged, the meter's physical dimensions may need to be roughly three times larger than those used for natural gas. Alternatively, if higher pressure is applied, it is essential to verify that the meter's maximum allowable pressure—defined by the manufacturer and referenced in §9.1 of EN 12480—is compatible with the intended application.

No formal recommendations are currently provided regarding flow rate, pressure range, or meter sizing, for the following reasons:

- **Flow Rate**: EN 12480 (Chapter 1) does not impose specific limits on flow rate, allowing flexibility for increased throughput without requiring changes to the standard. However, a new Q_{min}, Q_t and Q_{max} have to be defined.
- **Pressure Range**: While higher pressures may be desirable for hydrogen applications, s1.2
- uch considerations fall under the scope of the Pressure Equipment Directive (2014/68/EU), not the MID (2014/32/EU).
- **Meter Size**: EN 12480 supports pattern approval across meter size ranges. However, the demand for larger meter sizes must be demonstrated by end-users, particularly for hydrogen use cases where higher volumes are expected.

4.1.2. Recommendations for the used test gases

In MID (2014/32/EU) ANNEX IV requirement 1.3 the following requirement is stated "the gas meter shall be designed for the range of gases …. of the country of destination". We identified the following reasons to define new test gases for inclusion in the gas meter scope to accommodate pure hydrogen and H2NG mixture:

The existing standards from CEN/TC 237 for gas meters refer to EN 437:2018, which categorizes gases into the first, second, and third families. This reference was primarily selected due to historical context at the time, no alternative specifications were available rather than its direct relevance to gas metering applications, as EN 437 was originally developed for gas appliances. The compositions defined in EN 437 include mixtures with notable hydrogen content. According to Chapter 5 of EN 12480:2018, the evaluation of measurement accuracy (metrological performance) must be conducted using air or gases listed within the scope namely, the EN 437 families. However, the weighted mean error, which is used to assess meter accuracy, can vary depending on the gas medium. Therefore, a meter that meets accuracy criteria when tested with air or standard gases may not necessarily comply when evaluated with a different gas type such as hydrogen.

4.1.3. Recommendations for calibration and verification

The Measuring Instruments Directive (MID 2014/32/EU), specifically Annex 1 clause 1.1 and Annex IV clause 2, outlines the requirements concerning the maximum permissible error (MPE) for gas meters. These performance criteria are detailed in Chapter 5 of EN 12480:2018, which includes the following provisions:

- §5.2.2: "Testing must be conducted using air with a density of 1.2 kg/m³, or with a gas defined within the scope of the standard."
- §5.2.2b: "Upon customer request, the error of indication may be evaluated under conditions that closely reflect actual operating environments."

Currently, the scope defined in Chapter 1 of EN 12480:2018 relies on the gas families listed in EN 437, allowing air to be used for testing without requiring modifications. However, for meters intended to measure renewable gases, the expert group advises that performance validation should be carried out using the test gas from Table 1 that most closely resembles the meter's intended application.

It is important to highlight that §5.2.2b lacks clarity regarding whether "specified conditions" include the type of gas, in addition to temperature and pressure. Also, no documented studies were found that address the long-term effects of hydrogen on meter durability. Therefore, further research into the accuracy implications of biomethane substitution could significantly contribute to the current body of knowledge.

4.1.4. Recommendations for durability

According to the Measuring Instruments Directive (MID 2014/32/EU), Annex 1 clause 5 stipulates that any measuring instrument must be engineered to maintain stable and reliable metrological performance over its expected operational lifespan, under the environmental conditions for which it is intended. Additional guidance is provided in Annex IV clause 4, which aligns with Chapter 8 of EN 12480 and is referenced in Table ZA.1 of the standard. EN 12480 applies exclusively to meters classified under accuracy class 1.0.

Chapter 8 (§8.2) specifies that durability testing should be conducted at the meter's maximum flow rate (Q_{max}), using a gas or air with a minimum density of 1.2 kg/m^3. After this exposure, the meter's error of indication must be reassessed.

When applied to HENG, the following considerations are recommended:

- Durability testing should be performed using a test gas from Table 1 that closely matches the meter's intended hydrogen application.

- The standard 1000-hour exposure period may be insufficient to fully meet MID durability requirements for hydrogen. Long-term performance data, obtained through traceable recalibrations over extended operational periods, will be essential to validate meter stability.
- For evaluating measurement accuracy post-exposure, the procedures outlined in section 3.2 of this document should be followed.

The hydrogen presents unique challenges due to its molecular properties, such as high diffusivity and potential material compatibility issues. While no specific durability concerns have been documented for natural gas hydrogen's impact on meter components over time remains an active area of investigation. Further studies are needed to assess long-term metrological stability and material resilience in hydrogen-rich environments.

4.1.5. Recommendations for Tightness

Annex ZA Table ZA.1 of EN 12480:2018 establishes a connection between clause 6.3.3, which addresses external leak tightness, and the suitability requirements outlined in the Measuring Instruments Directive (MID 2014/32/EU), specifically Annex 1 clauses 7.2 and 7.5. These MID provisions emphasize that measuring instruments must be robust and constructed from materials appropriate for their intended operating conditions.

Within EN 12480:2018, the relevant subclauses state:

- §6.3.3.1: "Meters must remain leak-tight under normal usage conditions."
- §6.3.3.2: "No detectable leakage shall be present."
- §6.3.3.3: "Leak tests must be conducted using air, nitrogen, or other inert gases."

Based on industry feedback and questionnaire data, highlight that these provisions may be insufficient when applied to pure hydrogen. Due to its extremely small molecular size, hydrogen poses a higher risk of both internal and external leakage, which could compromise measurement accuracy and raise safety concerns, including explosion hazards.

To address these challenges, the gas metering sector must develop and validate leak tightness testing protocols specifically tailored for rotary gas meters operating with hydrogen and hydrogen-enriched natural gas (HENG). In particular, the test media specified in §6.3.3.3 may need to be revised to include pure hydrogen, ensuring that the testing conditions accurately reflect real-world applications and risks.

4.1.6. Other recommendations

Annex 1, clause 9.1 of the Measuring Instruments Directive (MID 2014/32/EU) outlines the requirements for instrument inscriptions, including the need to specify the conditions under which the device is intended to operate—particularly: §(c) "information in respect of the conditions of use."

This MID requirement is reflected in Chapter 9 of EN 12480:2018 and referenced in Table ZA.1 of the standard. However, EN 12480 currently does not mandate that the meter's data plate indicate its compatibility with specific gas types. As the range of gases used in metering expands, especially with the integration of renewable gases such as hydrogen, biomethane, and syngas, ensuring clarity on meter suitability becomes increasingly important.

Given the diversity of gas compositions, it may be impractical to certify conformity for every test gas listed in Table Therefore, we recommend that, where relevant, manufacturers should clearly indicate on the meter's data plate the specific renewable gas types for which the device is designed and validated. This approach would help end-users identify appropriate applications and avoid misuse. This recommendation is not applicable to conventional natural gas, which remains the default reference gas in most metering standards.

4.2. Turbine gas meters (EN 12261:2024)

The EN 12261:2024 standard includes Annex ZA.1, which provides a voluntary framework for demonstrating compliance with the essential requirements of the Measuring Instruments Directive (MID 2014/32/EU). This annex establishes a direct correspondence between the MID provisions and specific clauses within EN 12261, facilitating conformity assessment for turbine gas meters.

To evaluate the applicability of this standard to renewable gas measurement, each clause and subclause referenced in Table ZA.1 was systematically reviewed in relation to the various renewable gases identified in section 3.1. Based on this analysis, tailored recommendations were developed for each entry in the table and compiled into this report.

4.2.1. Recommendations for the flowrate range, the pressure range and the meter sizes

Annex 1, clause 7.2 of the Measuring Instruments Directive (MID 2014/32/EU) requires that gas meters be designed in accordance with their intended use and operating conditions. This requirement is reflected in Chapter 4 of the EN 12261:2024 standard, which outlines classification criteria for flow rate, pressure range, and meter dimensions.

In the context of hydrogen metering, several specific considerations emerge due to the physical and energetic characteristics of hydrogen:

1. **Flow Rate**: Although EN 12261 currently allows for flow rates up to 25,000 m^3/h, hydrogen's lower energy density means that significantly higher volumetric flows may be required to deliver equivalent energy compared to natural gas. Fortunately, increasing the flow rate does not inherently compromise the metrological integrity of turbine meters, provided the design accommodates the associated dynamic pressures.
2. **Pressure Range**: The standard defines a maximum operating pressure of 420 bar, which is sufficient for most industrial applications. However, hydrogen refuelling stations, particularly for mobility, may require pressures up to 875 bar. In such cases, meter design must comply not only with MID but also with the Pressure Equipment Directive (PED 2014/68/EU). These high-pressure applications necessitate specialized materials and structural reinforcements to ensure safety and performance.
3. **Meter Size**: EN 12261:2024 supports a wide range of meter diameters, up to 750 mm. For hydrogen applications where large volumes are required at low pressure, larger meter sizes may be necessary. While current market offerings may suffice for many use cases, future demand for oversized meters will need to be driven by end-user requirements and validated through performance testing.

It is important to note that hydrogen has approximately one-third the energy density of methane or natural gas. Therefore, when operating at constant pressure, the meter must handle proportionally higher flow rates. This can be achieved either by increasing the meter size or by raising the operating pressure, provided the meter's maximum allowable pressure, as specified by the manufacturer and referenced in EN 12261:2024, is not exceeded.

In summary, while the current standard provides flexibility, hydrogen's unique properties call for careful consideration of flow dynamics, pressure resilience, and sizing to ensure safe and accurate metering across diverse applications. Especially knowing that the turbine metering technology is highly Reynolds-dependent, therefore it is important to keep in mind that the pressure range, the flowrate range and hence the meter size for a used turbine meter should fit the operational needs and therefore be calibrated, even with a different fluid, with a comparable Reynolds number range.

4.2.2. Recommendations for the used test gases

Annex IV, clause 1.3 of the Measuring Instruments Directive (MID 2014/32/EU) requires that gas meters be designed to accommodate the range of gases used in the country of deployment. In the context of hydrogen integration, this requirement highlights the need to reassess the suitability of existing test gases.

To ensure accurate and reliable metering performance with hydrogen, the following rationale supports the definition of new test gases:

- Alignment with Future Use: As hydrogen becomes a key component of energy systems, it is essential to define test gases that reflect its expected role in metering applications.
- Limitations of Current Calibration Protocols: EN 12261:2024 prescribes calibration using air or gases from the first and second families (as per EN 437), or any other gas that yields comparable metrological results within ±5% of the Reynolds number expected during operation (§5.1). However, the transferability of calibration results from air or EN 437 gases to hydrogen-rich mixtures has not been sufficiently validated.

Given hydrogen's distinct physical properties, such as low density, high diffusivity, and unique flow behaviour, existing calibration standards may not adequately capture its impact on turbine meter performance. Therefore, dedicated hydrogen-based test gases must be developed and integrated into the scope of EN 12261:2024 to ensure compliance and measurement accuracy.

4.2.3. Recommendations for calibration and verification

The EN 12261:2024 standard outlines the requirements for metrological performance in section 5.2, stating that the meter's indication error must remain within the maximum permissible limits defined in Table 4, while considering transitional flow rates specified in Table 5.

EN 12261:2024 (E)

Table 4 — Maximum permissible errors

Flow rate Q	Maximum permissible errors
$Q_{min} \leq Q < Q_t$	±2 %
$Q_t \leq Q \leq Q_{max}$	±1 %

Table 5 — Transitional flow rate Q_t

Rangeability	Q_t
1 : 20	0,20 · Q_{max}
1 : 30	0,15 · Q_{max}
≥ 1 : 50	0,10 · Q_{max}

When applied to hydrogen, these requirements demand a more nuanced approach. Due to hydrogen's distinct physical properties, such as low density, high diffusivity, and unique flow behaviour, standard calibration procedures using air or conventional gases may not yield representative results. Turbine meters, in particular, are sensitive to variations in flow dynamics, as their accuracy is closely tied to the Reynolds number of the gas being measured.

To ensure reliable performance in hydrogen applications, the expert group recommends that turbine meters be tested using a hydrogen-based gas mixture that closely reflects the meter's intended operational environment. This test gas should be selected from Table 1 of this document. Furthermore, the calibration and performance evaluation should be conducted within a Reynolds number range that deviates no more than ±5% from the expected operating conditions. This ensures that the meter's response to hydrogen flow is accurately characterized and that any deviations in measurement are properly accounted for.

By aligning test conditions with the specific flow characteristics of hydrogen, manufacturers and metrology institutes can better assess the suitability of turbine meters for hydrogen-rich environments and support the safe and accurate deployment of hydrogen infrastructure.

4.2.4. Recommendations for durability

Annex 1, clause 5 of the Measuring Instruments Directive (MID 2014/32/EU) requires that any measuring instrument be designed to maintain stable metrological performance over its expected service life, under the environmental conditions for which it is intended. This durability requirement is further detailed in Annex IV, clause 4, and is reflected in several sections of EN 12261:2024, particularly in Chapters 4, 5, and 6, as referenced in Annex ZA.

In the context of hydrogen metering, this requirement takes on added complexity. Hydrogen, due to its small molecular size and high reactivity, can interact with materials in ways that differ significantly from natural gas. These interactions may lead to mechanical degradation, dimensional changes, or embrittlement of internal components over time.

To properly assess the long-term stability of turbine gas meters exposed to hydrogen, aging tests must be conducted using representative hydrogen-based test gases, whether pure hydrogen or hydrogen enriched blends. These tests should simulate real operational conditions, including pressure, temperature, and flow dynamics, to capture potential material fatigue or performance drift.

Although EN 12261:2024 defines a test duration that may be sufficient for conventional gases, current data on hydrogen exposure is limited. Insights from the NEWGASMET project (D3) have shown that after 12 months of static hydrogen exposure, certain meter technologies, such as diaphragm, ultrasonic, and thermal mass flow meters, exhibited durability issues that failed to meet MID requirements. However, since turbine meters operate on a fundamentally different mechanical principle, these findings cannot be directly extrapolated.

Therefore, dedicated long-term testing campaigns are needed for turbine meters specifically, using hydrogen as the working fluid. These tests should aim to identify the onset of aging effects, quantify performance drift, and validate whether the meters can maintain compliance with MID-defined accuracy thresholds over time. Only through such targeted studies can the industry build the necessary confidence to deploy turbine meters in hydrogen-rich environments.

4.2.5. Recommendations for Tightness

Paragraph 6.2.4 of the EN 12261:2024 standard specifies that turbine gas meters must be leak-tight under normal operating conditions. This requirement is critical to ensuring both measurement integrity and operational safety.

However, when applied to hydrogen, this requirement demands additional scrutiny. Due to the extremely small molecular size of hydrogen, it is significantly more prone to permeation and leakage than conventional gases such as methane or air. Even minor imperfections in seals, joints, or materials can result in measurable leakage, which may compromise metrological performance and pose safety risks, including flammability and explosion hazards.

Therefore, for turbine meters intended to operate with pure hydrogen or hydrogen-enriched natural gas (HENG), standard leak tightness tests, typically performed with inert gases like air or nitrogen, may not be sufficient. The industry must develop and adopt hydrogen-specific leak testing protocols that reflect the unique behaviour of hydrogen under pressure. These tests should include:

- Use of hydrogen as the test medium, rather than surrogate gases, to ensure realistic simulation of operational conditions.
- Enhanced sensitivity thresholds for leak detection, given hydrogen's ability to escape through microscopic pathways.
- Material compatibility assessments, particularly for seals, gaskets, and internal components, to prevent degradation over time.

Building experience through rigorous testing and validation will be essential for manufacturers and metrology institutes to ensure turbine meters meet MID durability and safety requirements when deployed in hydrogen infrastructure.

4.3. Diaphragm gas meters (EN 1359:2017)

The EN 1359:2017 standard includes Annex ZA.1, which provides a structured pathway for demonstrating compliance with the essential requirements of the Measuring Instruments Directive (MID 2014/32/EU). This annex establishes a direct correspondence between the MID provisions and specific clauses within EN 1359:2017.

To assess the applicability of diaphragm gas meters for renewable gas usage, each clause and subclause referenced in Table ZA.1 was carefully reviewed in relation to the various renewable gases identified in section 3.1. Based on this analysis, targeted recommendations were developed for each entry in the table and incorporated into the present report.

4.3.1. Recommendations for the flowrate range, the pressure range and the meter sizes

According to the MID directive Annex I, clause 7.2, gas meters must be designed for their intended use and operating conditions. This requirement is directly linked to Chapter 4 of the EN 1359:2017 standard, titled "Working Conditions", and specifically to section 4.1: Flow Range: "The flow rate range shall be one of those given in Table 1."

Table 1 of EN 1359:2017 specifies a maximum actual flow rate of 160 m^3/h, which is sufficient to cover the operational range of domestic gas meters, even when measuring hydrogen.

However, in pure hydrogen applications, the energy content per cubic meter is approximately three times lower than that of natural gas. Therefore, to meet the same energy demand, the volume of delivered gas must increase proportionally. This can be achieved through one of the following approaches:

- Increasing the line pressure (by a factor of about 3) to raise the energy density (MJ/m^3).
- Increasing the volumetric flow rate through the meter.

If the line pressure remains unchanged, the meter size must be adapted to accommodate the higher flow rate required for hydrogen. In such cases, the meter size may need to be increased by a factor of approximately 3 compared to natural gas applications to ensure accurate measurement and compliance with performance requirements.

Alternatively, if the pressure is increased, it must be verified that the maximum allowable pressure (i.e., the maximum pressure for which the meter is designed, as specified by the manufacturer) is suitable for the intended hydrogen application.

Therefore, for Hydrogen Measurement:

- Flow Rate: The maximum flow rate of 160 m^3/h defined in Chapter 1 of EN 1359 is adequate for domestic hydrogen metering applications.
- Pressure Range: **EN 1359:2017** defines a maximum operating pressure of 0.5 bar. Therefore, increasing the line pressure is not recommended for hydrogen measurement within the scope of this standard.
- Meter Size: For applications where pressure remains constant, it is recommended to select a meter size that accommodates the increased flow rate required for hydrogen, ensuring compliance with accuracy and durability requirements.

4.3.2. Recommendations for the used test gases

Annex IV, clause 1.3 of the Measuring Instruments Directive (**MID 2014/32/EU**) stipulates that gas meters must be designed to accommodate the range of gases used in the country where they are deployed. In the context of hydrogen integration, this requirement necessitates a re-evaluation of the test gases used for performance validation.

The current **EN 1359:2017** standard prescribes calibration using air, which may not be representative for hydrogen or hydrogen-enriched mixtures. Although some EN 437 test gases contain notable hydrogen concentrations, the expert group of the WP4 has determined that the transferability of air-based calibrations to hydrogen-rich gases is insufficiently characterized and cannot be assumed without further evidence.

To address this gap, it is recommended to define and use dedicated hydrogen test gases that reflect realistic operational conditions. These gases should be selected based on standards such as:

- **ISO 14687:2025** and **EN 17124:2022**, which specifies the hydrogen fuel quality.
- The **EASEE-gas Reference CBP Hydrogen Quality Specification**

For diaphragm meters intended to operate with hydrogen or hydrogen blends, it is strongly recommended that **EN 1359:2017** include a provision requiring performance testing with a gas mixture that closely resembles the intended hydrogen application. Alternatively, if air or natural gas is used for calibration, its transferability to hydrogen must be demonstrated through:

- Traceable calibrations with uncertainties no greater than one-fifth of the maximum permissible error (MPE),
- Material compatibility assessments of all internal components,
- Long-term static exposure tests using hydrogen.

These measures are essential to ensure that diaphragm meters maintain accuracy, safety, and reliability when deployed in hydrogen infrastructure.

4.3.3. Recommendations for calibration and verification

To ensure reliable metrological performance of diaphragm gas meters in hydrogen applications, it is recommended that EN 1359:2017 be updated to include specific provisions for calibration and verification using hydrogen or hydrogen-enriched test gases. Given the unique physical properties of hydrogen, such as low density, high diffusivity, and potential material interactions, standard calibration with air may not be representative or sufficient. Therefore, meters intended for use with hydrogen should be calibrated using gas mixtures that closely resemble the operational conditions, as defined in Table 1 of EN1359:2017. Where direct calibration with hydrogen is not feasible, transferability from air or natural gas must be demonstrated through traceable calibration procedures with uncertainties not exceeding one-fifth of the maximum permissible error (MPE). Additionally, verification protocols should include long-term exposure tests to assess stability and drift over time, as well as material compatibility evaluations to ensure that internal components are resistant to hydrogen-induced degradation. These recommendations aim to support the safe and accurate deployment of diaphragm meters in hydrogen infrastructure, while maintaining compliance with MID (2014/32/EU) requirements.

Annex IV, clause 1.3 of the Measuring Instruments Directive (MID 2014/32/EU) stipulates that gas meters must be designed to operate reliably across the range of gases used in the country of destination. In the context of hydrogen deployment, this requirement calls for a reassessment of the calibration and testing procedures currently defined in EN 1359:2017.

The expert group identified several key reasons to introduce new test gases specifically tailored for hydrogen applications:

- **Adaptation to future gas compositions**: As hydrogen becomes increasingly integrated into energy systems, test gases must reflect its expected use in domestic and industrial metering.
- **Limitations of current calibration protocols**: While EN 437 includes test gases with significant hydrogen content, EN 1359:2017 prescribes calibration exclusively with air. The expert group considers the transferability of air-based calibrations to hydrogen-rich mixtures insufficiently validated, raising concerns about accuracy and reliability.

4.3.4. Recommendations for durability

To ensure long-term reliability and compliance with MID (2014/32/EU) Annex 1 – Clause 5, diaphragm gas meters intended for hydrogen service must be designed and tested to maintain stable metrological performance over their expected operational lifespan. Hydrogen presents unique durability challenges due to its small molecular size, high diffusivity, and potential for material degradation, including embrittlement and accelerated aging of polymers and elastomers. It is therefore recommended that EN 1359:2017 include specific provisions for durability testing under hydrogen exposure. These tests should simulate realistic operating conditions, including pressure, temperature, and gas composition, and be conducted over extended periods, ideally exceeding the standard 1000-hour benchmark, to capture long-term effects. Static exposure tests with pure hydrogen, as well as dynamic flow tests with hydrogen-enriched mixtures, should be used to assess mechanical integrity, sealing performance, and metrological drift. In addition, materials used in the construction of diaphragm meters should be evaluated for hydrogen compatibility, with particular attention to sealing elements, diaphragms, and internal moving parts. Where applicable, manufacturers should provide evidence of durability through traceable recalibrations, aging simulations, and post-exposure performance verification. These measures are essential to ensure that diaphragm meters remain accurate, safe, and robust when deployed in hydrogen-rich environments, and to support their conformity with MID requirements over time.

In accordance with Annex 1, clause 5 of Directive 2014/32/EU (MID), diaphragm gas meters must be designed to maintain stable metrological performance over their expected operational lifetime, under the environmental conditions for which they are intended. This durability requirement is further detailed in Annex IV, clause 4, and corresponds to several provisions in EN 1359:2017, as referenced in Annex ZA.1. These include:

- §5.2 – Pressure Absorption: Defines the maximum allowable pressure drop across the meter, as specified in Table 3.
- §5.3 – Starting Flow Rate: Establishes the minimum flow rate at which the meter begins to register, detailed in Table 4.
- §7.1.2 – Durability: Describes endurance testing procedures based on meter size.
- §7.1.3 – Error of Indication at Declared Temperature Limits: Specifies testing conditions to verify meter accuracy across temperature ranges.
- §7.3.5 – Ageing: Outlines long-term exposure tests at defined temperature and time intervals.

Currently, all these tests are performed using air as the test medium. However, for meters intended to operate with hydrogen or hydrogen-enriched natural gas (HENG), this approach is insufficient. Hydrogen's unique properties, such as its small molecular size, high diffusivity, and potential for material degradation, can significantly affect meter performance over time.

It is therefore recommended that EN 1359:2017 be revised to require durability testing with gas mixtures representative of hydrogen applications, as defined in Table 1 of this document. These tests should simulate realistic operating conditions, including pressure, temperature, and flow dynamics, and extend beyond the standard 1000-hour exposure period to capture long-term effects such as embrittlement, seal degradation, and metrological drift.

Where direct hydrogen testing is not feasible, the transferability of air or natural gas-based tests must be demonstrated. These measures are essential to ensure that diaphragm meters remain accurate, safe, and compliant when deployed in hydrogen-rich environments, and to support their conformity with MID requirements over time.

4.3.5. Recommendations for Tightness

To ensure safe and reliable operation of diaphragm gas meters in hydrogen environments, EN 1359:2017 should be updated to include enhanced requirements for internal and external gas tightness. Hydrogen's molecular characteristics, particularly its small size and high permeability, make it significantly more prone to leakage than conventional gases. This necessitates a redefinition of tightness criteria beyond those currently validated with air. It is recommended that leak testing procedures be adapted to include hydrogen as the test medium, or alternatively, that the equivalence of inert gas testing be demonstrated through validated correlation studies. Furthermore, the standard should require that sealing materials, welds, and mechanical joints be assessed for hydrogen compatibility, including resistance to permeation, fatigue, and chemical degradation. The use of hydrogen-specific detection methods, such as mass spectrometry or hydrogen sensors with ppm-level sensitivity, should be encouraged to ensure accurate leak quantification. In addition, meters should be tested under both static and dynamic conditions to reflect real-world operational scenarios, including pressure cycling and temperature variation. These measures are essential not only for maintaining metrological integrity but also for ensuring compliance with explosion safety standards and minimizing environmental risks associated with hydrogen leakage. By incorporating these recommendations, EN 1359:2017 can better support the deployment of diaphragm meters in hydrogen infrastructure and contribute to the safe expansion of hydrogen-based energy systems.

In accordance with MID Directive 2014/32/EU, Annex 1 – Clause 7.2, measuring instruments must be robust and constructed from materials suitable for their intended operating conditions. EN 1359:2017 addresses external leak tightness in clause 6.3.3, which is referenced in Annex ZA.1 of the standard. Specifically, §6.3.3.1 requires that meters remain leak-tight under normal use, and §6.3.3.2 outlines a three-stage test procedure, including pressurization to at least 1.5 times the declared maximum pressure, and not less than 350 mbar.

While these provisions are adequate for conventional gases, they are not sufficient for hydrogen applications. Hydrogen's extremely small molecular size and high diffusivity increase the risk of both internal and external leakage, which can compromise metrological accuracy and pose serious safety hazards, including explosion risks. Findings from the THOTH2 Deliverable D1 highlight the need for hydrogen-specific leak testing protocols, as current methods using air or inert gases may not detect leakage levels relevant to hydrogen.

It is therefore recommended that EN 1359:2017 be updated to include dedicated leak tightness requirements for hydrogen and hydrogen-enriched natural gas (H2NG). These should include:

- Use of hydrogen as the test medium in tightness verification procedures, replacing or supplementing air or nitrogen.
- Enhanced detection sensitivity, employing hydrogen-specific leak detectors capable of identifying minute leakage rates at ppm levels.
- Material compatibility assessments, ensuring that seals, diaphragms, and housing materials are resistant to hydrogen permeation and degradation.
- Testing under dynamic conditions, including pressure cycling and thermal variation, to simulate real-world operational stresses.

Additionally, internal leakage pathways, such as through valve seats, diaphragms, or mechanical interfaces, should be evaluated with hydrogen to ensure that performance remains within MID-defined tolerances. These tests should be standardized and traceable, and manufacturers should provide documented evidence of compliance for meters intended for hydrogen service.

4.3.6. Other recommendations

In accordance with MID Directive 2014/32/EU, Annex 1 – Clause 9.1, gas meters must include inscriptions that clearly state the conditions under which the instrument is intended to operate. Specifically, clause 9.1(c) requires that the meter provide "information in respect of the conditions of use." This requirement is linked to Chapter 8 of EN 1359:2017. However, the current version of the standard does not mandate that the data plate indicate the specific gas types for which the meter is approved.

Given the increasing diversity of gases in modern energy systems—particularly with the introduction of hydrogen and hydrogen-enriched natural gas (H2NG)—it is essential to provide clear, visible information on the meter's compatibility with specific gas compositions. This is especially critical for hydrogen, due to its unique physical and chemical properties, which can affect both metrological performance and material integrity.

It is therefore recommended that EN 1359:2017 be updated to require that the data plate (or an equivalent permanent marking) explicitly indicate the gas types and concentration ranges for which the diaphragm meter is certified. For hydrogen applications, this could include standardized markings such as:

- "H_2-ready" for meters tested and approved for pure hydrogen,
- "$H_2 \leq 20\%$" for meters suitable for hydrogen-enriched natural gas up to 20% by volume,
- Or other clearly defined thresholds based on validated test conditions.

These markings should be based on the test gases defined in Table 1 of this document and supported by traceable calibration and durability data. In addition, the marking system should be harmonized across manufacturers to ensure consistency and avoid misinterpretation by installers, operators, and regulatory bodies.

4.4. Domestic Ultrasonic gas meters (EN 14236:2018)

The standard EN 14236:2018 – Ultrasonic Domestic Gas Meters includes Annex ZA, which contains Table ZA.1. This table serves as a voluntary means of demonstrating conformity with the essential requirements of the Measuring Instruments Directive (MID) 2014/32/EU, by mapping each MID requirement to corresponding clauses and subclauses within the standard.

In the context of hydrogen metering, a dedicated evaluation was carried out to assess the applicability and robustness of EN 14236:2018 when used with pure hydrogen or hydrogen-enriched gas mixtures. This involved a systematic review of each clause and subclause referenced in Table ZA.1, with the aim of identifying potential gaps, limitations, or necessary adaptations when the meter is exposed to hydrogen-specific conditions such as:

- Lower energy density per unit volume,
- Higher diffusivity and permeability of hydrogen,
- Potential impacts on ultrasonic signal propagation,
- Material compatibility and long-term durability.

This review was conducted for all relevant renewable and low-carbon gases considered in the scope of the project (as defined in section 3.1), with a particular focus on pure hydrogen.

4.4.1. Recommendations for the flowrate range, the pressure range and the meter sizes

The MID Annex I – Clause 7.2 requires that gas meters be designed for their intended use and working conditions. This requirement is directly linked to Chapter 4 of EN 14236:2018, which defines the normal operating conditions of the meter.

Specifically, Clause 4.1 – Flow Range states: "The values of maximum flow rates and those corresponding values of the upper limits of the minimum flow rates shall be those given in Table 1."

However, when measuring hydrogen or hydrogen-enriched gases, several key differences from natural gas must be considered:

- At a given pressure, hydrogen contains approximately three times less energy per cubic meter than natural gas or methane.
- To meet the same energy demand, the volume of gas delivered must increase significantly.

- This can be achieved by:
  - Increasing the line pressure, thereby increasing the energy density (MJ/m^3),
  - Increasing the flow rate, which may require larger meter sizes or higher dynamic pressure (as described by the Bernoulli equation).

These factors have direct implications for the design and sizing of ultrasonic gas meters intended for hydrogen service.

Below the recommendations of the WP4 expert group.

Chapter 4 - EN 14236:2018: To ensure accurate and reliable metering of hydrogen and hydrogen blends, the following recommendations are proposed:

Clause 4.1 and Table 1: Review and Update Flowrate Ranges

- The flowrate ranges defined in Table 1 should be re-evaluated to reflect the increased volumetric flow required for hydrogen applications.
- For meters operating at constant pressure, the maximum flowrate capacity may need to be increased by a factor of 2 to 3, depending on the hydrogen concentration.
- Consider introducing new flowrate categories specific to hydrogen and H_2/NG blends.

Pressure Range Considerations

- EN 14236 currently defines a maximum operating pressure suitable for natural gas applications.
- For hydrogen, especially in industrial or high-demand settings, higher operating pressures may be required to reduce volumetric flow and maintain compact meter sizes.
- It is recommended that:
  - The maximum allowable pressure for hydrogen applications be clearly defined and validated.
  - Pressure testing protocols be adapted to reflect hydrogen-specific safety and performance requirements.

Meter Size Adaptation

- Meter sizing should be based on the expected flowrate range for hydrogen, which may be significantly higher than for natural gas at equivalent energy demand.
- Manufacturers should:
  - Provide guidance on meter selection based on hydrogen concentration and operating pressure.
  - Clearly indicate the suitability of each meter model for hydrogen or H_2/NG blends.

Declaration of Intended Gas Type

- To comply with MID Annex, I – Clause 7.2, meters should include a declaration of the intended gas type (e.g., natural gas, hydrogen, H_2/NG blend).
- This information should be included in the technical documentation and data plate, ensuring transparency and correct application.

4.4.2. Recommendations for the used test gases

In accordance with MID Annex IV, Requirement 1.3, gas meters must be designed to operate with the range of gases applicable in the country of destination. This requirement becomes particularly relevant as the gas composition evolves to include partly renewable gases and pure hydrogen.

To ensure that ultrasonic gas meters conform to MID requirements under these new conditions, the WP4 expert group recommends the definition and adoption of new test gases that reflect the expected future gas compositions. The following points summarize the rationale and proposed actions:

- Need for Updated Test Gases: The current test gases defined in EN 14236:2018, Chapter 5 include:
    - 99.5% methane for second family gases,
    - 99.5% propane or butane for third family gases.

These gases do not adequately represent the physical and chemical properties of **hydrogen** or **hydrogen-enriched mixtures**, particularly in terms of:

- Acoustic velocity and density,
- Diffusivity and permeability,
- Energy content per unit volume.

On the other hand, EN 14236:2018 prescribes both air and gas calibrations. However, the transferability of calibration results from EN 437:2021 test gases to hydrogen or hydrogen blends has not been sufficiently validated.

This raises concerns about the accuracy, repeatability, and long-term reliability of meters when used with hydrogen, especially in domestic applications.

To address these gaps, the following recommendations are proposed for integration into EN 14236:

- Define a set of representative hydrogen test gases, including:
    - Pure hydrogen (H_2),
    - Hydrogen-methane blends (e.g., H_2NG mixtures with 5%–30% H_2),
- Establish calibration and verification procedures using these gases to ensure:
    - Compliance with MID essential requirements,
    - Consistent metrological performance across the full range of expected gas compositions.
- Include hydrogen-specific test conditions in performance and durability testing, such as:
    - Long-term exposure to hydrogen,
    - Leak tightness and material compatibility assessments,
    - Acoustic signal behaviour in hydrogen environments.
- Collaborate with relevant standardization bodies (e.g., CEN/TC 237 WG 9) to harmonize these recommendations with ongoing work on hydrogen readiness and renewable gas metering.

4.4.3. Recommendations for calibration and verification

In accordance with the Measuring Instruments Directive (MID), particularly Annex I – Clause 1.1 and Annex IV – Clause 2, gas meters must comply with the specified maximum permissible error (MPE) under their intended operating conditions.

The metrological performance requirements for ultrasonic gas meters are defined in Chapter 5 of EN 14236:2018, and include:

- 5.3.2a – Error on air, and
- 5.3.2b – Error on gas (excluding air).

While the standard currently allows for calibration using both air and a reference gas (typically 99.5% CH_4, propane, or butane), the transferability of calibration results from air or standard gases to (partly) renewable gases, including hydrogen, has not been sufficiently demonstrated.

Furthermore, Annex A.2 of EN 14236:2018 identifies several physical properties that significantly influence ultrasonic meter performance:

- (a) Speed of sound range
- (b) Attenuation range
- (c) Viscosity range
- (d) Density / specific gravity range

As shown in Table 2 of the standard, the introduction of renewable gases—particularly hydrogen—alters the boundaries of these physical properties. For example:

- Hydrogen introduces a new minimum for both density and viscosity and significantly increases the speed of sound.

These shifts can affect the accuracy, repeatability, and stability of ultrasonic measurements if not properly accounted for during calibration and verification.

Therefore, to ensure compliance with MID and maintain metrological integrity when measuring hydrogen or hydrogen-enriched gases, the following recommendations are proposed (Section 5.3.2b):

- Calibration with Representative Gases: For (partly) renewable gas applications, including hydrogen, the calibration gas used in 5.3.2b should be representative of the operational gas composition. This includes:
    - Pure hydrogen (H_2),
    - Hydrogen-methane blends (e.g., 5%–30% H_2),
- Operational Condition Matching: Calibration and verification should be performed under conditions (pressure, temperature, flow rate) that closely match the intended field application to ensure realistic performance assessment.
- Transferability Validation: If calibration is performed using air or standard natural gas, the transferability to hydrogen or renewable gases must be demonstrated through:
    - Traceable calibration comparisons, and

    - Uncertainty budgets with a target of ≤ 1/5 of the MPE, as per MID guidelines.
- Extended Testing Protocols: Additional tests should be introduced to assess:
    - Long-term stability under hydrogen exposure,
    - Acoustic signal behaviour in low-density, high-speed-of-sound gases,
    - Material compatibility and potential degradation effects.
- Documentation and Declaration: Manufacturers should clearly document:
    - The gas types for which the meter is calibrated and verified,
    - The limits of applicability for each gas type,
    - Any correction algorithms or compensation methods used.

4.4.4. Recommendations for durability

The Measuring Instruments Directive (MID), specifically Annex I – Clause 5, requires that gas meters be designed to maintain adequate stability of their metrological characteristics over their declared lifetime, under the environmental conditions for which they are intended. Further specifications are provided in Annex IV – Clause 4, which corresponds to multiple clauses in EN 14236:2018, as referenced in Annex ZA.1.

In the context of hydrogen and renewable gas applications, the following clauses of EN 14236:2018 are particularly relevant to durability and require reconsideration:

Clause 5.5 – Pressure Absorption

5.5.1 Requirement: The pressure absorption of the meter is measured using air at a density of 1.2 kg/m³ at Qmax, with the differential pressure recorded across the meter.

Issue: Hydrogen and other renewable gases have significantly different density and viscosity compared to air or natural gas. This affects the pressure drop across the meter, which may lead to deviations in performance or increased wear over time.

We recommend:

- The maximum allowable pressure absorption should be re-evaluated for hydrogen and hydrogen blends.
- Pressure drop testing should be conducted using representative gases under realistic operating conditions to ensure durability and performance consistency.

Clause 5.7 – Immunity to Contaminants

5.7.1 Requirement: After exposure to dust, the pressure absorption must not exceed 2.2 mbar.

5.7.2 Test: The meter is exposed to dust using air at Qmax for 5 minutes, followed by the introduction of 5 g of dust into the rig.

Issue: Hydrogen and renewable gases differ in flow velocity, density, and viscosity, which can affect the entrainment and deposition of contaminants. Additionally, the required flow rate to deliver equivalent energy may vary significantly between gases.

The WP4 experts recommend:

- The suitability of air as a test medium for contaminant immunity should be reassessed.
- Tests should be adapted to reflect the actual flow conditions of hydrogen or hydrogen mixtures.
- Consider introducing gas-specific contaminant tests to evaluate long-term meter resilience under realistic operating scenarios.

Clause 6.13 – Ageing

6.13.2 Test: Meters are tested at 0.1 Qmax and Qmax using air, then exposed to elevated temperatures as defined in Table 9.

Issue: Hydrogen can cause material degradation, including hydrogen embrittlement, especially in metallic and polymeric components. This phenomenon may not be detected through ageing tests conducted with air.

Our recommendation:

- The ageing test should be extended to include exposure to hydrogen under representative pressure and temperature conditions.
- Materials used in the meter should be evaluated for hydrogen compatibility, including resistance to embrittlement and permeability.
- If hydrogen exposure significantly affects durability, air-based ageing tests should no longer be considered sufficient for hydrogen applications.

As an intermediate conclusion: To ensure compliance with MID and maintain long-term metrological stability, it is recommended that:

- Durability tests be adapted to reflect the physical and chemical properties of hydrogen, including its low density, high diffusivity, and potential for material interaction.
- Test gases used in durability assessments should match the intended operational gas composition.
- Material selection and design should be validated for hydrogen exposure over the declared lifetime of the meter.

4.4.5. Recommendations for Tightness

The **EN 14236:2018** standard links **Clause 6.2.4 – External Leak Tightness** to the **MID Annex I – Clause 7.2**, which states: “A measuring instrument shall be robust and its materials of construction shall be suitable for the conditions in which it is intended to be used.”

The relevant clauses in EN 14236 read:

- **6.2.4.1**: “The meter shall be leak tight under normal conditions of use. When tested in accordance with 6.2.4.2, the meter shall not leak.”
- **6.2.4.2**: “Pressurize the meter, at normal laboratory temperature, with air to 1.5 times the declared maximum working pressure and check for leaks.”

While this procedure is suitable for conventional gases such as natural gas or air, it may not be sufficient for hydrogen or hydrogen-enriched natural gas (HENG) due to the unique physical properties of hydrogen, including:

- Extremely small molecular size, which increases the risk of leakage through seals, joints, and porous materials.
- High diffusivity, which can lead to internal leakage affecting metrological performance.
- Potential explosion hazards, requiring stricter safety validation (as referenced in Clause 7.5 – Explosion Safety of EN 14236).

And to ensure safe and accurate operation of ultrasonic gas meters in hydrogen environments, the following recommendations are proposed:

- **Test Medium Adaptation**
  - The leak tightness test described in 6.2.4.2 should be adapted to include pure hydrogen or a representative hydrogen blend as the test medium, especially for meters intended for hydrogen service.
  - This ensures that leakage behaviour is evaluated under realistic operating conditions, accounting for hydrogen's unique properties.
- **Enhanced Leak Detection Sensitivity**
  - Leak detection methods should be capable of identifying micro-leaks that may not be detectable with air.
  - Techniques such as helium leak detection or hydrogen-specific sensors may be required to meet safety and performance standards.
- **Material Compatibility Assessment**
  - All materials in contact with hydrogen should be evaluated for permeability, embrittlement risk, and long-term sealing performance.
  - Particular attention should be paid to elastomers, polymers, and welds, which may degrade or allow permeation over time.
- **Pressure Testing Protocols**
  - The pressure test should reflect the maximum allowable working pressure for hydrogen applications, which may differ from natural gas systems.
  - Consideration should be given to cyclic pressure testing to simulate real-world operating conditions and assess fatigue resistance.
- **Documentation and Declaration**
  - Manufacturers should clearly declare the gas types for which the meter has been tested for tightness.
  - The test conditions, including gas composition, pressure, temperature, and detection method, should be documented and traceable.

As a conclusion, given the safety-critical nature of hydrogen applications, it is essential that tightness testing procedures in EN 14236:2018 be updated to reflect the specific challenges posed by hydrogen. These recommendations aim to ensure that ultrasonic gas meters remain safe, accurate, and compliant throughout their operational life when used with hydrogen or hydrogen-enriched gases.

4.4.6. Other recommendations

In the context of hydrogen and hydrogen-enriched gases, several additional considerations must be addressed to ensure ultrasonic gas meters remain compliant with the Measuring Instruments Directive (MID) and maintain reliable performance under evolving operating conditions.

Clause 13 of EN 14236: Immunity to Electromagnetic Disturbances

MID Annex I – Clause 1.3.4 refers to the influence of external quantities on the meter, including electromagnetic disturbances. This is linked to Clause 13 of EN 14236, which requires that: "The meter and in particular its electronic hardware shall be designed and manufactured in such a way so as to minimize the effects of magnetic fields, electrostatic discharge and other electromagnetic disturbances."

Currently, air is used as the test gas for EMC testing (Clauses 13.2.1, 13.3.1, and 13.4.1). While this is acceptable for natural gas meters, it may not be sufficiently representative for meters operating with hydrogen or H_2/NG blends, where:

- Signal-to-noise ratio (SNR) may degrade due to hydrogen's acoustic properties.
- Electromagnetic interference may have a more pronounced effect on signal processing in low-density gases.

The WP4 expert group recommend:

- For meters intended to operate with hydrogen or H_2/NG blends, EMC tests should be adapted to use the relevant test gas from Table 1.
- Due to safety concerns with flammable gases, tests may be conducted at zero-flow conditions, which represent a worst-case scenario for SNR and minimize gas volume and risk.
- The impact of gas composition on electromagnetic immunity should be evaluated and documented.

Clause 14 of EN 14236: Ultrasonic (Acoustic) Noise Interference

Clause 14.2.1 outlines a test sequence using air at both zero flow and Qmax to assess the meter's immunity to acoustic noise.

However, hydrogen and hydrogen blends can significantly alter the acoustic environment inside the meter, potentially leading to:

- Increased background noise,
- Reduced signal clarity,
- Greater susceptibility to external acoustic interference.

The WP4 expert group recommend:

- For meters intended for hydrogen service, the test gas used in Clause 14 should be replaced with the relevant hydrogen-based mixture from Table 1.
- To mitigate safety risks, tests may be limited to zero-flow conditions, which still provide meaningful insights into worst-case SNR performance.
- Manufacturers should validate the acoustic robustness of the meter under hydrogen conditions and document any necessary signal processing adaptations.

Clause 9 of EN 14236: Inscription and Gas Suitability Declaration

MID Annex I – Clause 9.1(c) requires that meters include: "Information in respect of the conditions of use."

This is linked to Clause 9 of EN 14236. Currently, there is no requirement to indicate the gas type for which the meter is suitable. With the increasing diversity of (partly) renewable gases, including hydrogen, this lack of clarity may lead to misapplication or non-compliance.

The WP4 expert group recommend:

- Manufacturers should clearly indicate on the data plate the specific gas types for which the meter is calibrated and verified.
- This includes hydrogen, H_2/NG blends, biomethane, and other renewable gases listed in Table 1.
- This recommendation does not apply to natural gas-only meters but is essential for meters intended for multi-gas or hydrogen applications.

4.5. Thermal-mass gas meters (EN 17526:2021)

The standard EN 17526:2021 – Gas meters – Thermal-mass flowmeter-based gas meters includes Annex ZA.1, which provides a voluntary pathway for demonstrating conformity with the essential requirements of the Measuring Instruments Directive (MID) 2014/32/EU. This annex links MID requirements to corresponding clauses within the standard.

To assess the suitability of thermal-mass flow meters for (partly) renewable gases, including pure hydrogen, a systematic review was conducted. Each clause and subclause referenced in Table ZA.1 was revisited to evaluate its applicability to the physical and operational characteristics of hydrogen and hydrogen-enriched mixtures, as outlined in section 3.1 of the evaluation framework.

4.5.1. Recommendations for the flowrate range, the pressure range and the meter sizes

The Measuring Instruments Directive (MID) Annex I – Clause 7.2 requires that gas meters be designed for their intended use and working conditions. This requirement is linked to Chapter 4 of EN 17526:2021, which defines the working conditions of thermal-mass flow meters.

Specifically, Clause 4.3 – Flow Range states: "The flow rate range shall be one of those given in Table 1."

However, the increasing use of (partly) renewable gases, including pure hydrogen, biogas, and syngas, introduces significant variations in energy content per unit volume compared to natural gas or methane. For example:

- Hydrogen has approximately three times less energy per cubic meter than natural gas.

- Clean biogas (e.g., 60% CH_4 / 40% CO_2) and syngas (e.g., 30% H_2 / 30% CO) also have lower calorific values, requiring higher volumetric flow rates to meet the same energy demand.

This has direct implications for meter sizing, flowrate capacity, and pressure handling.

Let's start with the **flowrate range adaptation:**

- The flowrate ranges defined in Table 1 of EN 17526:2021 should be reviewed and extended to accommodate the higher volumetric flow rates required for hydrogen and low-calorific renewable gases.
- For meters operating at constant pressure, the maximum flowrate (Qmax) may need to be increased by a factor of 2 to 3 to ensure accurate energy delivery measurement.
- It is recommended to introduce dedicated flowrate classes for hydrogen and H_2-rich mixtures.

For the **pressure range Considerations:**

- One way to compensate for hydrogen's low energy density is to increase the line pressure, thereby reducing the required volumetric flow.
- However, this approach is only viable if the meter's maximum allowable operating pressure (MAP), as defined by the manufacturer, is suitable for hydrogen service.
- It is recommended that:
    - The pressure range definitions in EN 17526:2021 be reviewed for hydrogen compatibility.
    - Hydrogen-specific pressure classes be introduced, with appropriate safety margins and material validation.

For the **meter size:**

- For applications where pressure cannot be increased, the physical size of the meter may need to be increased to handle the higher flowrate while maintaining measurement accuracy and low pressure drop.
- Manufacturers should:
    - Provide clear sizing guidelines for hydrogen and renewable gas applications.
    - Indicate the suitability of each meter model for specific gas types and flow conditions.

Finally for **declaration of intended gas type**

- To comply with MID Annex, I – Clause 7.2, meters should include a declaration of the intended gas type(s) (e.g., natural gas, hydrogen, biogas, syngas).
- This information should be included in:
    - The technical documentation,
    - The data plate, and
    - The user manual.

4.5.2. Recommendations for the used test gases

In accordance with MID Annex IV – Clause 1.3, gas meters must be designed for the range of gases applicable in the country of destination. This requirement becomes increasingly important as gas grids evolve to include (partly) renewable gases, such as hydrogen, biomethane, syngas, and hydrogen-enriched natural gas (HENG).

To ensure that ultrasonic gas meters conform to MID requirements under these new conditions, the expert group recommends the definition and adoption of representative test gases that reflect the expected future gas compositions.

The current calibration and verification procedures in EN 14236:2018 rely on air and standard gases (e.g., 99.5% CH_4, propane, or butane). However, the transferability of calibration results from these gases to hydrogen or other renewable gases has not been sufficiently validated. Therefore, new test gases are needed to:

- Reflect the physical properties (e.g., density, viscosity, speed of sound) of renewable gases,
- Ensure metrological accuracy under real-world operating conditions,
- Comply with MID requirements for suitability and performance.

These test gases should be used:

- In performance verification, durability, tightness, and EMC testing to ensure meters are suitable for their intended gas compositions.
- For hydrogen and HENG applications, zero-flow testing may be used to minimize safety risks while still evaluating worst-case signal-to-noise conditions.

The calibration procedures should be adapted to include traceable methods and uncertainty budgets that meet MID requirements (e.g., ≤ 1/5 MPE).

As a conclusion, to ensure ultrasonic gas meters remain accurate, safe, and MID-compliant in the context of hydrogen and renewable gas applications, EN 14236:2018 should be updated to include a defined set of representative test gases, along with adapted calibration and verification procedures. These updates will support the transition to low-carbon gas systems and ensure robust metrological performance across diverse gas compositions.

4.5.3. Recommendations for calibration and verification

The Measuring Instruments Directive (MID), particularly Annex I – Clause 1.1 and Annex IV – Clause 2, defines the requirements for maximum permissible error (MPE) and the conditions under which metrological performance must be verified. These requirements are addressed in Chapter 5 of EN 14236:2018, which outlines the procedures for calibration and verification using air and standard test gases.

However, with the increasing use of (partly) renewable gases, including hydrogen, the current calibration framework must be reconsidered to ensure accuracy and compliance under new operating conditions.

The **transferability of calibration results** from air or standard gases (e.g., methane, propane) to hydrogen or hydrogen-enriched mixtures has **not been sufficiently validated**.

The hydrogen’s unique physical properties, such as **low density**, **high diffusivity**, and **distinct acoustic behaviour**, can significantly affect ultrasonic signal propagation and measurement accuracy.

The WP4 expert group recommend.

- Calibration procedures should include direct testing with hydrogen and H_2/NG blends, using representative compositions defined in the renewable gas test set (see Table 1).
- The mean error (Ex) for hydrogen should be compared with that obtained using air and standard gases to assess transferability.
- If transferability cannot be demonstrated within MID-defined uncertainty limits (e.g., ≤ 1/5 MPE), then all subsequent tests must be performed using both air and the relevant hydrogen-based test gas.

On the other hand, considering the Gas-Air Relationship and Error Limits

- EN 14236 should adopt a similar approach to EN 17526:2021 Clause 5.4, which defines acceptable limits for the difference in mean errors between air and test gases.
- This ensures that meters calibrated with air remain accurate when used with hydrogen or other renewable gases.

We recommend:

- Introduce a gas-air error comparison clause in EN 14236, specifying acceptable limits for deviation in mean error across different gases.
- If the deviation exceeds the defined threshold, dual-gas calibration should be mandatory.

Considering the **physical properties:**

- For thermal-mass and ultrasonic meters, gas-dependent parameters such as **ρ·cp (density × specific heat capacity)** and **speed of sound** are critical to performance.
- Hydrogen significantly alters these parameters, which may affect signal processing and flow measurement.

Our recommendations are:

- Define a range of physical property values (e.g., speed of sound, ρ·cp) within which the meter maintains MID-compliant accuracy.
- Manufacturers should provide a performance envelope indicating the gas compositions and conditions under which the meter operates reliably.

Finally to support field deployment, manufacturers should provide:

- A list of validated test gases (e.g., H_2 injection levels, biomethane, syngas),
- The associated calibration uncertainty for each gas,
- Clear guidance for end users on meter suitability and expected performance.

4.5.4. Recommendations for durability

The MID Annex I – Clause 5 requires that gas meters be designed to maintain adequate stability of their metrological characteristics over their declared lifetime, under the environmental conditions for which they are intended. Further specifications are provided in Annex IV – Clause 4, which correspond to several clauses in EN 14236:2018, particularly those related to pressure absorption, immunity to contaminants, and ageing.

As gas grids evolve to include hydrogen and other (partly) renewable gases, the durability of ultrasonic gas meters must be reassessed to ensure long-term performance and safety under these new operating conditions.

Considering the **Pressure Absorption (Clause 5.5 Equivalent):** meters are currently tested for pressure absorption using air at a density of 1.2 kg/m³ at Qmax. However, hydrogen and other renewable gases have significantly different density and viscosity, which can affect the pressure drop across the meter.

Our recommendations are:

- The maximum allowable pressure absorption should be re-evaluated for hydrogen and hydrogen blends.
- Pressure absorption tests should be conducted using representative gases under realistic operating conditions.
- Manufacturers should define acceptable pressure drop ranges for hydrogen to ensure consistent performance and avoid excessive energy losses.

About the **Immunity to Contaminants (Clause 5.7 Equivalent)**

Contaminant testing is currently performed using air and a dust rig. However, the entrainment and deposition behaviour of contaminants can vary significantly with gas composition, flow velocity, and viscosity.

Our recommendations are:

- The suitability of air as a test medium for contaminant immunity should be reassessed for hydrogen applications.
- Tests should be adapted to reflect the actual flow conditions of hydrogen or hydrogen mixtures, including:
    - Higher flow velocities required to deliver equivalent energy,
    - Different particle transport dynamics due to gas properties.
- Consider introducing gas-specific contaminant tests to evaluate long-term meter resilience under realistic hydrogen conditions.

Concerning the **Ageing and Material Compatibility (Clause 6.12 Equivalent)**

Ageing tests are currently performed under zero-flow conditions with elevated temperature and humidity, using air. However, hydrogen embrittlement, permeation, and material degradation are known risks in hydrogen environments, especially for metallic and polymeric components.

The WP4 experts recommend:

- Ageing tests should be extended to include exposure to hydrogen, under representative pressure and temperature conditions.
- Materials used in the meter should be evaluated for:
    - Hydrogen embrittlement resistance,
    - Permeability and sealing integrity,
    - Long-term mechanical and chemical stability.
- If hydrogen exposure significantly affects durability, air-based ageing tests should no longer be considered sufficient for hydrogen applications.

Finally, about **the Declaration of Durability Conditions,** the manufacturers should clearly declare:

- The gas types for which the meter has been durability-tested,
- The environmental conditions (temperature, humidity, pressure) under which the meter maintains its metrological stability,
- Any limitations or maintenance intervals specific to hydrogen service.

Recommendations for Tightness

The EN 14236:2018 standard, through its alignment with MID Annex I – Clause 7.2, requires that gas meters be robust and constructed from materials suitable for the conditions in which they are intended to operate. This includes ensuring external leak tightness, which is critical for both metrological integrity and safety, especially when measuring hydrogen or hydrogen-enriched natural gas (HENG).

Hydrogen presents unique challenges due to its small molecular size, high diffusivity, and flammability, which can lead to internal and external leakage risks that are not adequately addressed by current air-based testing procedures.

Let's start with the **Current Leak Tightness Testing Limitations**

The current leak tightness test procedure (e.g., Clause 6.3.3.2 of EN 17526:2021) involves pressurizing the meter with air at various pressure levels (25 mbar, ≥1.5×MAP, and again at 25 mbar) and checking for leaks. While suitable for natural gas, this method may not detect micro-leaks that are critical when using hydrogen.

Considering the **Hydrogen-Specific Leak Tightness Challenges**

- Hydrogen molecules are significantly smaller than methane or air molecules, increasing the likelihood of leakage through seals, joints, and porous materials.
- Even minor leaks can affect measurement accuracy and pose explosion hazards, especially in enclosed environments.
- The literature (NEWGASMET) highlights the need for representative and relevant leak tightness tests for hydrogen applications.

The WP4 expert group propose to the EN 14236 – Tightness Testing

To ensure ultrasonic gas meters are safe and reliable when used with hydrogen or HENG, the following recommendations are proposed:

- Adaptation of Test Medium
    - The test medium used in leak tightness testing should be modified to include pure hydrogen or a representative hydrogen blend, especially for meters intended for hydrogen service.
    - Where safety constraints exist, helium may be used as a surrogate due to its similar molecular size and non-flammable nature.
- Enhanced Leak Detection Sensitivity
    - Leak detection methods must be capable of identifying micro-leaks that may not be detectable with air.
    - Recommended techniques include:

- *Hydrogen-specific sensors,*
    - *Mass spectrometry,*
    - *Pressure decay methods with high-resolution instrumentation.*
- Material Compatibility and Design Review
  - All materials in contact with hydrogen should be assessed for:
    - *Permeability,*
    - *Hydrogen embrittlement,*
    - *Long-term sealing performance.*
  - Special attention should be given to elastomers, polymers, welds, and sealing interfaces.
- Pressure Cycling and Fatigue Testing
  - Leak tightness tests should include cyclic pressure testing to simulate real-world operating conditions and assess fatigue resistance under hydrogen exposure.
- Declaration of Gas Compatibility
  - Manufacturers should clearly declare:
    - *The gas types for which the meter has been leak-tested,*
    - *The maximum allowable pressure for each gas type,*
    - *Any limitations or maintenance intervals specific to hydrogen service.*

As an intermediate conclusion: to ensure ultrasonic gas meters remain safe, accurate, and MID-compliant in hydrogen applications, EN 14236:2018 should be updated to include:

- Hydrogen-specific leak tightness testing protocols,
- Enhanced detection methods,
- Material compatibility assessments, and
- Clear manufacturer declarations.

4.5.5. Other recommendations

The Measuring Instruments Directive (MID) Annex I – Clause 9.1(c) requires that gas meters include:

"Information in respect of the conditions of use."

This requirement is linked to Chapter 9 of EN 14236:2018, which addresses inscription and marking. However, the current version of the standard does not require manufacturers to indicate the suitability of the meter for specific gas types, including hydrogen or other (partly) renewable gases.

As the gas grid transitions toward greater diversity in gas compositions, including pure hydrogen, hydrogen-methane blends, biomethane, and syngas, it becomes increasingly important to provide clear and standardized information on meter compatibility.

The Proposed Recommendations for EN 14236:2018 – Chapter 9 (Inscription) are:

- Declaration of Gas Compatibility on the Data Plate

- For meters intended to operate with (partly) renewable gases, including hydrogen, the data plate should clearly indicate:
- The gas types for which the meter is suitable,
- The maximum hydrogen concentration (e.g., 10%, 20%, 30%, or 100% H_2),
- Any limitations or conditions (e.g., pressure range, temperature range, installation requirements).

– Reference to Validated Test Gases

- The gas types listed on the data plate should correspond to the validated test gases defined in the standard (e.g., Table 1 of the THOTH2 expert group).
- These include:
    - *Hydrogen injection blends (CH_4 + 5%–30% H_2),*
    - *Pure hydrogen (100% H_2),*
    - *Biomethane (compliant with EN 16723-1 and CEN/TR 17238),*
    - *Clean biogas (CH_4 + 40% CO_2),*
    - *Syngas (CH_4 + 30% H_2 + 30% CO).*

– Exclusion of Natural Gas-Only Meters

- This recommendation does not apply to meters intended solely for natural gas, where compatibility is already assumed and standardized.
- However, for meters marketed as multi-gas compatible, including hydrogen, this declaration becomes essential.

- Supporting Documentation: in addition to the data plate, the technical documentation and user manual should include:
    - A list of compatible gases,
    - The performance envelope (e.g., flowrate, pressure, temperature),
    - Any maintenance or inspection intervals specific to hydrogen service.

5. Recommendations for new and/or update standards other measurement devices

In the following paragraphs leak detectors, pressure and temperature sensors and gas analysers will be individually addressed.

5.1. Leak detectors (EN 60079-29-1, EN 60079-29-2, EN 50724)

The performance requirements, test methods, selection, installation, use, and maintenance of gas sensors for monitoring explosive atmospheres are regulated by the standards EN 60079-29-1 and EN 60079-29-2. In addition, fixed ultrasonic gas leak detectors are covered by EN 50724. Together, these standards provide detailed guidance on testing and selecting sensors for detecting explosive atmospheres in common applications.

However, the introduction of hydrogen/natural gas blends into the grid brings new variables and challenges. These must be addressed in the guidelines to ensure that sensor performance is properly evaluated for detecting leaks of hydrogen/natural gas mixtures across different concentrations and component ratios.

5.1.1. Recommendations for selection and use of detectors for H2/NG blend detection

Different ratios of H2/NG in air show different lower (LFL) and upper flammable limits (UFL). Therefore, the precise evaluation of the actual composition of H2/NG mixture is of paramount importance to evaluate correctly the LFL and UFL, and to provide the alarm at appropriate LFL and UFL%. As stated in EN 60079-29-2 standard, section 5, except for IR sensors, the current available sensing technologies lack selectivity to a specific flammable gas in a mixture of flammable gases. Therefore, a specific evaluation on the sensing performance of a device dedicated to H2/NG blends leak detection is necessary, considering also other potential interfering gases.

Furthermore, section 6.2.2 of standard EN 60079-29-2 states that “when the composition of a mixture is unknown, or if a range of gases are likely to be present in the area to be monitored, it is recommended that the sensor is calibrated to the gas to which it is least sensitive”. Also in this case, a modification of the standard should be considered, because of the different LFL and UFL of the various NG/H2 mixtures, which can change in composition during a leakage due to different factors, including the different permeation capabilities of these two gases through the materials. A detector, composed by a single sensor or an array of sensors able to provide the specific concentration of both NG and H2 simultaneously is necessary.

5.1.2. Recommendations for performance requirements and testing of detectors for flammable gases

The standard EN 60079-29-1 specifies that sensors intended exclusively for hydrogen monitoring should be calibrated using hydrogen as the calibration gas. However, for H2/NG leakage monitoring, this standard needs to be expanded, as it would no longer be adequate for this specific application. Specifically, section 5.4.20 of standard EN 60079-29-1 proposes tests to evaluate the sensing performance of defined technologies in the detection of NG. While these tests consider the presence of potential interfering gases, they do not include H2/NG blends. This part of the standard should be expanded including H2/NG blends, at different ratios, for the testing and performance evaluation of H2/NG leak detectors.

5.2. Pressure sensors

Pressure sensors, traditionally designed for natural gas or other combustible gases, face new challenges when exposed to high hydrogen content or pure hydrogen. Existing standards do not fully address these challenges, which could compromise safety and reliability. This part outlines the recommended updates to international and European standards to ensure pressure sensors are suitable for hydrogen environments.

5.2.1. Hydrogen-Specific Challenges

Hydrogen differs significantly from other gases due to its small molecular size, high diffusivity, and ability to cause material embrittlement. These characteristics increase the risk of leakage, structural degradation, and measurement inaccuracies. Furthermore, hydrogen networks often operate at high pressures and must simultaneously maintain safety requirements due to hydrogen's low ignition energy and wide flammability range. Standards must evolve to comprehensively address these risks.

5.2.2. Material Compatibility Requirements

One of the most critical updates involves specifying materials that resist hydrogen-induced damage. Components in contact with hydrogen should be made from alloys such as 316L stainless steel or Hastelloy, which offer proven resistance to embrittlement and permeation. High-strength steels, which are prone to hydrogen cracking, should be explicitly prohibited. Gold-plated membrane solutions are also used to ensure compatibility with hydrogen. These recommendations align with **CEN/TS 18173:2025**, which provides guidelines for material compatibility in hydrogen applications.

5.2.3. Design and Construction Considerations

Sensor design must minimize hydrogen permeation and leakage. Standards should require materials or specialized coatings instead of oil-filled cavities to avoid hydrogen absorption that can lead to the performance decrease. Welded or hermetically sealed designs should be preferred to prevent diffusion through joints. These principles are consistent with **ISO 19880-1:2020**, which sets requirements for components used in hydrogen fuelling stations.

5.2.4. Performance and Endurance Testing

Current test protocols for pressure sensors are insufficient for operation in a hydrogen environment. The research campaign underway in WP3 will indicate which methods should be used to performance and endurance tests. Recommendations could certainly include testing long-term exposure to operating pressure at extreme ambient temperatures. These tests must evaluate long-term stability, drift, and zero shift caused by hydrogen permeation. The approach can draw on methodologies outlined in **ISO 26142:2010**, which addresses performance testing for hydrogen detection devices.

5.2.5. Safety and Hazardous Location Compliance

Hydrogen's explosive characteristics demand rigorous safety measures. Standards should incorporate ATEX and IECEx requirements for explosive atmospheres, ensuring compliance with **EN IEC 60079-10-1** for zone classification and equipment protection levels for Group IIC gases (which includes hydrogen). Intrinsic safety and flameproof designs must be mandatory for sensors deployed in hazardous locations.

5.2.6. Pressure Range and Accuracy Specifications

Hydrogen applications also require ensuring measurement accuracy across the entire pressure range found in DSO and TSO networks for hydrogen-specific conditions, considering the effects of temperature and permeation.

Sensors should be calibrated using hydrogen or a mixture with hydrogen, not using standard pressure calibrators but specialized equipment, such as hydraulic pressure comparators or deadweight testers, have to be used.

5.2.7. Integration with Existing Hydrogen Standards

To maintain consistency across the hydrogen value chain, pressure sensor standards should harmonize with existing frameworks such as the **ISO 19880** series for fuelling stations and the CEN/CENELEC Hydrogen Roadmap, which outlines infrastructure and safety requirements.

All these are summarised in the following table:

Aspect	Current Standards	Proposed Updates for Hydrogen
Material Requirements	General metallic compatibility for natural gas systems	Mandatory hydrogen-compatible alloys (e.g., 316L, Hastelloy); prohibit embrittlement-prone steels
Design Guidelines	Standard diaphragm and sealing designs	Solid metal diaphragms, welded seals, hydrogen diffusion-resistant coatings
Performance Testing	Pressure and temperature tests for natural gas	Hydrogen-specific endurance tests: 350–1000 bar, −40 °C to +85 °C, permeation and drift checks
Safety Compliance	ATEX/IECEx for explosive atmospheres (Group IIA/IIB gases)	Explicit classification for Group IIC (hydrogen); intrinsic safety and flameproof requirements
Pressure Range	Up to ~400 bar for natural gas	Extended range up to 1000 bar for hydrogen storage and refuelling
Integration with Standards	Limited reference to hydrogen-specific norms	Harmonization with ISO 19880 series

5.3. Temperature sensors

This part is dedicated to temperature sensors installed directly in the hydrogen flow. For the case where thermowell is used, only the tightness and material resistance of the thermowell are required, not the sensor itself. Temperature sensors, which play a critical role in process control and safety, must meet stringent requirements to operate reliably in hydrogen systems. Current standards for combustible gas applications do not fully address hydrogen's unique properties, such as high diffusivity, flammability, and material compatibility issues. This paragraph outlines the necessary updates to international and European standards to ensure temperature sensors are suitable for pure hydrogen environments.

5.3.1. Hydrogen Specific Challenges

Hydrogen is highly diffusive and can permeate through materials, leading to potential leakage and sensor degradation. It also poses risks of hydrogen embrittlement in certain metals and requires sensors to withstand extreme conditions, including high pressures (up to 700 bar) and wide temperature ranges (−200 °C to +600 °C). Furthermore, hydrogen's low ignition energy and wide flammability range demand robust safety measures for sensors installed in hazardous areas.

5.3.2. Material Compatibility Requirements

Current standards often assume compatibility with natural gas, but hydrogen requires stricter material specifications. Temperature sensors should use hydrogen-compatible alloys such as 316L stainless steel or Hastelloy and incorporate hermetically sealed welds to prevent hydrogen ingress. These recommendations align with CEN/CENELEC Hydrogen Roadmap and **ISO/TC 197** guidelines for hydrogen technologies.

5.3.3. Design and Construction Considerations

Sensor designs must minimize hydrogen permeation and ensure explosion-proof integrity. Standards should **require ATEX and IECEx-certified housings** for hazardous zones (Zone 0, 1, 2), flame-path engineering, and ingress protection (IP65–IP68). Designs should also include mineral-insulated cables and welded joints for durability under high pressure and temperature conditions.

5.3.4. Performance and Endurance Testing

Existing test protocols for temperature sensors do not account for hydrogen-specific conditions. Standards should introduce:

- Thermal cycling tests under hydrogen exposure.
- Long-term stability assessments for drift and insulation resistance.
- Explosion-proof validation per **EN IEC 60079** and **ATEX Directive 2014/34/EU**.

These updates should reference **ISO 19880-1:2020**, which provides general requirements for hydrogen fuelling stations, including pre-cooling and thermal management systems.

5.3.5. Safety and Hazardous Location Compliance

Hydrogen's explosive nature requires compliance with ATEX and IECEx schemes. Standards should mandate:

- Intrinsic safety for electrical components.
- Temperature class compliance (T3–T6) to prevent ignition.
- Explosion containment testing under IEC 60079 series.

5.3.6. Integration with Hydrogen Standards

To ensure consistency, temperature sensor standards should harmonize with:

- ISO 19880 series for fuelling stations.
- CEN/CENELEC Hydrogen Standardization Roadmap for infrastructure and safety.

– ISO 14687 for hydrogen purity, relevant for calibration and thermal compensation.

All these are summarised in the following table:

Aspect	Current Standards	Proposed Updates for Hydrogen
Material Requirements	General metallic compatibility for natural gas systems	Hydrogen-compatible alloys (316L, Hastelloy); hermetic sealing; ATEX-certified designs
Design Guidelines	Standard RTD/thermocouple designs	Explosion-proof housings, welded joints, mineral-insulated cables, ingress protection (IP68)
Performance Testing	Thermal accuracy and calibration under air/natural gas	Hydrogen-specific thermal cycling, drift tests, explosion containment per IEC 60079
Safety Compliance	ATEX/IECEx for explosive atmospheres (general gases)	Explicit compliance for hydrogen (Group IIC); T-class rating; intrinsic safety
Temperature Range	−50 °C to +250 °C typical	Extended range −200 °C to +600 °C for hydrogen processes
Integration with Standards	Limited reference to hydrogen-specific norms	Harmonization with ISO 19880 series, ISO 14687, and CEN/CENELEC Hydrogen Roadmap

5.4. Gas analysers – Other standards

The rise of hydrogen imposes specific analytical requirements: extremely low impurity thresholds (ppb–ppm), increased risks associated with explosive atmospheres (Group IIC), and challenges in representative sampling when hydrogen is pure or blended with natural gas. Existing normative frameworks (ISO 6974/6976 for natural gas, ISO 10715 for sampling, IEC 60079 for explosive atmospheres) must be extended and harmonized with hydrogen fuel quality standards (ISO 14687) and analytical methods (ISO 21087) to ensure metrological traceability, safety, and inter-laboratory comparability.

5.4.1. Analytical Challenges Specific to Hydrogen

Hydrogen presents:

- **High diffusivity and low ignition threshold**, requiring ATEX/IECEx compliance for all analysers, installations, and analyser shelters.
- **Critical impurities** (CO, H_2S/sulfur compounds, HCHO, NH_3, halogenated species, H2O, hydrocarbons) requiring quantification at ppm, ppb, or, for certain species — such as formaldehyde, ammonia, and halogenated compounds — sub-ppb levels, in accordance with ISO 14687/SAE J2719.

  Impacts on GC methods (choice of carrier gas, detectors, calibration, and uncertainty), especially when hydrogen is used as a carrier gas or when the sample contains a high fraction of H2.

5.4.2. Analytical Technologies and Their Limitations

- **GC/GC-MS** (TCD, FID with methaniser, PDD/PDHID, SCD, MS) for multi-component profiling and trace analysis; ISO 6974 defines the framework for natural gas, but its use with H_2 requires adaptations (columns, certified standards including H_2, uncertainty evaluation models); ISO 21087/ISO 14687 specify methods and thresholds for hydrogen fuel.

- **Spectroscopic techniques** (CRDS, FTIR, TDLAS) for H_2O, CO_2, CO, O_2, HCl, NH_3, etc., useful for achieving sub-ppb LODs for selected impurities in compliance with ISO 21087 and ISO 14687.
- **Process MS (quadrupole)** for broad-spectrum monitoring and trace confirmation; often combined with GC to enhance analytical robustness.
- **Trace water sensors/analysers** (CMH, QCM, CRDS, TDLAS, polymer and alumina oxide capacitive sensors), depending on the technology they are useful for laboratory or field analyses of trace water content (moisture in gas) with different levels of resolution, accuracy and long-term stability.
- **Stationary H_2 detection (safety)** according to ISO 26142, integrated into analyser shelters/Ex rooms, in line with IEC 60079-29 (gas detectors) and IEC 60079-16 (ventilation of analyser shelters).
- **Online and automated sampling systems** are increasingly implemented to ensure continuous monitoring, rapid detection of impurities, and timely corrective actions, supporting both safety and hydrogen quality assurance

5.4.3. Sampling, Conditioning, and Sample Representativity

Sampling systems must ensure representativity (avoiding adsorption/losses, leaks), including for H_2/NG mixtures. ISO 10715:2022 provides principles for natural gas and substitutes; its extension to H_2/NG mixtures (and pure hydrogen) and harmonization with ISO 19880-9:2024 is strategic, as is alignment with CEN/TC 234 (gas quality, H_2 in networks) and CEN/TR 17797, which identifies standardization needs related to hydrogen injection.

5.4.4. Safety, ATEX/IECEx, and Analyzer Shelters

Analysers, shelters, and GC systems in hazardous areas must comply with IEC 60079 (covering equipment, classification, intrinsic safety "i", ventilation of analyser shelters, gas detectors); this is particularly critical with hydrogen (Group IIC). IEC 60079-0/-10-1/-11/-29 and the IECEx scheme govern design, installation, maintenance, and certification.

5.4.5. Harmonization with Hydrogen Standards

For hydrogen fuels (stations, distribution), ISO 19880-1 sets general requirements for fuelling stations; ISO 14687:2025 and ISO 17124:2022 specify fuel quality (impurity list and thresholds), while ISO 21087:2019 defines analytical methods and required performance. Industrial GC/GC-MS/CRDS solutions directly reference these standards.

All these are summarised in the following table:

Aspect	Current Standards / Practices	Recommended Updates for Pure H_2 & H_2/NG
Hydrogen Fuel Quality / Analytical Targets	ISO 14687:2019/2025 (impurity specification and thresholds); ISO 21087 (methods/performance analysis).	Integrate ISO 14687 into all analyser/GC specifications (impurity list, LOD/LOQ) and require method validation compliant with ISO 21087 for H_2-rich matrices.

GC Methods (Natural Gas)	ISO 6974 series (general, precision/bias, column/detector configurations); ISO 6976 (calorific calculations).	Issue an H_2 addendum to ISO 6974 for (i) standards covering H_2 up to 40% (or 100% in lab), (ii) handling carrier gas effects with H_2, (iii) specific uncertainties; include guidance for PDD/PDHID/SCD & methaniser.
Sampling / Conditioning	ISO 10715:2022 for natural gas and substitutes (representative sampling).	Extend ISO 10715 to H_2/NG mixtures (anti-leak practices, H_2-compatible materials and seals); link to CEN/TC 234 (WG11 "Gas Quality").
Safety Detection for H_2 (Ambient)	ISO 26142:2010 (stationary H_2 detection); IEC 60079-29 (gas detectors).	Require ISO 26142 + IEC 60079-29-1/-29-2 for shelters/analyser houses; ventilation per IEC 60079-16; zone classification per IEC 60079-10-1 (Group IIC).
ATEX/IECEx (Equipment, Installation)	IEC 60079-0/-1/-2/-11/-14/-17 (Ex "d", "p", "i", etc.); IECEx scheme.	Make intrinsically safe design mandatory for GC/CRDS/MS analysers in H_2 zones; strengthen maintenance/inspection procedures (IEC 60079-17) and personnel qualification.
Hydrogen Stations / Interfaces	ISO 19880-1:2020 (hydrogen stations — general requirements).	Harmonize on-site analytical specifications with ISO 19880-1 (quality, instrumentation, testing); integrate GC/CRDS benches compliant with ISO 21087 for HRS control.
Analytical Capabilities & LOD/LOQ	Supplier solutions (e.g. Agilent, Shimadzu, Process Insights, Thermo Fisher, etc.) aligned with ISO 14687/21087.	Require sub-ppb LOD for critical impurities (CO, sulfur compounds, HCHO), verified by inter-comparisons; traceability via H_2-adapted CRMs.
Hydrogen as Carrier Gas (GC)	Industrial practices advise precautions (safety, analyte reactivity) when using H_2 as carrier gas.	Publish a technical note annexed to ISO 6974/ISO 21087 detailing safe conditions for H_2 carrier use (columns, MS pumping, flow limits, analyte compatibility, detector-specific considerations).
Networks & H_2/NG Blending	CEN/TR 17797 (consequences & standardization needs); CEN/TC 234 (Gas Quality, H_2 in networks).	Add standardized analytical requirements for WI, PCS, density, and impurities in presence of H_2; integrate cross-references ISO 6974 ↔ ISO 14687/21087 into EN 16726 (Group H gas quality).

5.5. Gas analysers – ISO/TC 193

A specific focus was made for gas analysers and ISO/TC 193 guidelines were primarily designed for natural gas and its substitutes, which differ significantly from hydrogen in terms of physical properties and safety requirements. This report outlines necessary updates to ensure analysers and related standards are compatible with hydrogen applications.

ISO/TC 193 focuses on natural gas and substitutes, covering terminology, quality specifications, sampling, analysis, and thermophysical property calculations (e.g., ISO 6976, ISO 20765 series).

Hydrogen differs significantly from methane-based gases in terms of molecular size, diffusivity, and thermophysical properties. These differences create challenges for gas composition analysers and chromatographs:

- **Permeation and Leakage:** Hydrogen molecules can diffuse through seals, tubing, and sensor elements, affecting measurement stability and trace impurity accuracy.
- **Material Embrittlement:** Certain metals and elastomers degrade under hydrogen exposure.
- **Thermophysical Properties:** Hydrogen's viscosity, compressibility, and Joule-Thomson coefficient differ from natural gas, impacting calibration models and detector response.
- **Safety Risks:** Hydrogen's low ignition energy and wide flammability range require enhanced safety measures.

These factors necessitate updates in calibration procedures, uncertainty models, material specifications, sampling systems, and safety compliance for gas analysis technologies.

5.5.1. Gap Analysis

Existing ISO/TC 193 standards assume methane-based compositions, which differ from hydrogen in molecular size, diffusivity, and safety considerations. A liaison with **ISO/TC 158** (Analysis of gases) and **ISO/TC 197** (Hydrogen technologies) and their experts is envisaged.

5.5.2. Calibration and Performance Evaluation

Current standards such as **ISO 10723:2012** (Performance evaluation for analytical systems) and **ISO 6976:2016** (Calculation of calorific values and Wobbe index) are designed for natural gas. They should be revised to:

- Include calibration procedures for pure hydrogen and hydrogen-rich mixtures.
- Adapt uncertainty models to account for hydrogen's unique properties.
- Validate analyser performance under hydrogen-specific conditions, including high pressure and temperature variations.
- Test detector linearity and response factors with hydrogen matrices to ensure accurate quantification across the full concentration range.
- Implement matrix-specific correction factors where hydrogen affects carrier gas behaviour, thermal conductivity, or detector response

A liaison with **ISO/TC 158** (Analysis of gases) and **ISO/TC 197** (Hydrogen technologies) will speed up the revision process.

5.5.3. Material and Design Considerations

Gas analysers and chromatographs should use hydrogen-compatible materials for wetted parts and seals to prevent embrittlement and leakage. Designs must minimize hydrogen permeation through joints, tubing, and sensor housings.

5.5.4. Safety Compliance

Analysers for hydrogen must comply with ATEX and IECEx standards for explosive atmospheres, specifically addressing Group IIC gases (hydrogen), as per **EN IEC 60079-10-1:2020**. Intrinsic safety and flameproof designs should be mandatory for hazardous locations.

5.5.5. Proposed Updates

- **Expand Scope:** Explicitly include pure hydrogen and hydrogen-rich mixtures in ISO/TC 193 documents.
- **Property Calculations:** Update **ISO 20765** to incorporate hydrogen-specific algorithms for viscosity, compressibility, and speed of sound.
- **Sampling and Analysis:** Revise **ISO 6976** and **ISO 10723** to include hydrogen calibration and uncertainty models.
- **Safety and Odorization:** Add guidance for hydrogen systems, noting the impracticality of odorization.
- **Collaboration:** Establish joint working groups with ISO/TC 197 (Hydrogen Technologies) to harmonize hydrogen-related standards.

All these are summarised in the following table:

Aspect	Current Standards	Proposed Updates for Hydrogen
Calibration	ISO 10723 for natural gas analysers	Include hydrogen calibration procedures and uncertainty models
Property Calculations	ISO 6976, ISO 20765 for methane-based gases	Extend to hydrogen-specific thermophysical models
Material Requirements	General metallic compatibility	Hydrogen-compatible alloys, tubing, and seals; prohibit embrittlement-prone materials
Safety Compliance	ATEX/IECEx for hydrocarbons	Explicit classification for Group IIC (hydrogen); intrinsic safety and flameproof requirements
Sampling & Analysis	ISO 6976, ISO 10723 for natural gas	Include hydrogen calibration and uncertainty models. Harmonize sampling standards ISO 10715 with ISO 19880-9; ensure representative sampling and prevent hydrogen permeation.
Safety	Explosion risk for hydrocarbons	Add hydrogen-specific ignition and permeation considerations
Odorization	Odorants for methane-based gases	Provide guidance for hydrogen or note impracticality of odorization
ISO/TC 193 Scope	Natural gas and substitutes	Add hydrogen-rich mixtures explicitly and liaise with ISO/TC 158 and ISO/TC 197 for pure hydrogen

5.6. Water dew point sensor

Water content is a key quality and safety parameter in combustible gas systems. In hydrogen applications, excessive moisture can affect fuel pipelines, gas meters, valves, safety devices, compressors, and storage systems. Existing standards addressing water dew point sensors are mainly designed for natural gas, compressed air, or industrial gases and do not sufficiently consider the specific properties of pure hydrogen.

The purpose of this part is to:

- Identify gaps in existing standards covering water dew point sensors used in combustible gases.
- Propose technical updates required to enable the use of such sensors with pure hydrogen.
- Support future amendments, revisions, or New Work Item Proposals (NWIP) within ISO and CEN technical committees.

This document focuses on sensor performance, materials, sampling, calibration, and safety, without prescribing specific sensor technologies.

5.6.1. Moisture Requirements in Hydrogen Systems and measurement range

Hydrogen applications typically require very low water content, often corresponding to frost points below −60 °C and in some cases below −80 °C, in line with hydrogen fuel quality specifications (e.g. ISO 14687). Existing standards for combustible gas dew point sensors may not define adequate performance criteria in this range. Standards should explicitly define acceptable measurement ranges for hydrogen applications, including:

- Lower frost point limits down to at least −80 °C.
- Clear distinction between dew point and frost point measurement.
- Performance requirements under hydrogen pressure and flow conditions.

5.6.2. Accuracy, Response Time, and Stability

Current performance criteria in natural gas standards may not be sufficient at very low moisture levels. Updated standards should specify:

- Maximum allowable measurement uncertainty at low frost points (< -60 °C).
- Response time under hydrogen flow.
- Long-term drift and sensor aging effects in hydrogen service.

5.6.3. Hydrogen Compatibility of Wetted Parts

Standards should require that all materials in contact with hydrogen (sensor surfaces, housings, seals) be demonstrated as compatible with hydrogen exposure. This includes resistance to:

- Hydrogen embrittlement.
- Permeation and leakage.
- Material degradation over time.

Materials known to be unsuitable for hydrogen service should be explicitly excluded or restricted.

5.6.4. Sensor Technology Neutrality

The standards should remain technology-neutral (e.g. chilled mirror, capacitive, quartz crystal microbalance) while defining minimum hydrogen compatibility and performance criteria applicable to all technologies.

5.6.5. Sampling Line Design

Due to hydrogen's high diffusivity, sampling systems must be designed to maintain representative moisture concentration, therefore, standards should address:

- Enhanced leak-tightness requirements.
- Selection of hydrogen-compatible tubing and fittings.
- Minimization of adsorption and desorption effects at very low water concentrations.

5.6.6. Installation Conditions

Guidance should be added for installation in hydrogen systems, including:

- Flow, pressure, and temperature requirements.
- Avoidance of dead volumes and cold spots.
- Compatibility with hydrogen purification and compression systems.

5.6.7. Calibration and Metrological Traceability

Calibration procedures defined for air or natural gas may not be directly applicable to hydrogen. Standards should require:

- Calibration in hydrogen or validated equivalent matrices.
- Explicit evaluation of gas matrix effects on sensor response.
- Defined recalibration intervals for hydrogen service.

Calibration and verification should be traceable to national or international humidity standards at low frost points. Alignment with hydrogen fuel quality assurance chains is recommended.

5.6.8. Safety and Explosive Atmosphere Requirements

Water dew point sensors used in hydrogen systems must comply with applicable explosive atmosphere standards. Dew point standards should explicitly reference:

- Hydrogen as a Group IIC gas.
- IEC 60079 series requirements for equipment, installations, and analyser shelters.
- Requirements for intrinsic safety, flameproof enclosures, or pressurized housings, where applicable.

Standards should include guidance on:

- Electrical interfaces and grounding.
- Maintenance and servicing under hydrogen service.
- Mitigation of ignition risks related to measurement systems.

5.6.9. Relationship with Hydrogen Quality and Infrastructure Standards

To ensure consistency across the hydrogen value chain, updated dew point sensor standards should be harmonized with:

- Hydrogen fuel quality specifications defining maximum allowable water content.
- Hydrogen infrastructure standards for refuelling stations, pipelines, and storage.
- Standards developed under ISO/TC 197 and CEN hydrogen-related committees.

This alignment will ensure that moisture measurement supports regulatory compliance, interoperability, and safety.

5.6.10. Recommendations for Standardization Actions

The following actions are proposed for consideration by ISO and CEN committees:

1) **Amendment or revision** of existing dew point sensor standards to explicitly include pure hydrogen applications.
2) **Development of a hydrogen-specific annex** addressing materials, sampling, calibration, and safety.
3) **Joint working activities** between ISO/TC 193 and ISO/TC 197 to avoid duplication and ensure consistency.
4) **Liaison with IEC committees** responsible for explosive atmosphere equipment to ensure coherent safety requirements.

Therefore, existing standards for water dew point sensors do not fully address the specific requirements of pure hydrogen service. Targeted updates covering measurement performance, material compatibility, sampling, calibration, and safety are necessary to enable reliable and safe moisture measurements in hydrogen systems. This working document provides a technical basis for future standardization work within ISO and CEN.

Summary and Conclusions

Hydrogen's integration into gas infrastructures is not a minor upgrade, it is a **systemic transformation** requiring a complete overhaul of measurement standards. Existing frameworks optimized for natural gas fail to address hydrogen's unique properties, creating risks in accuracy, safety, and durability.

The THOTH2 analysis identifies **critical gaps** in standards for gas meters (EN 12480, EN 12261, EN 1359, EN 14236, EN 17526) and ancillary devices (leak detectors, pressure and temperature sensors, gas analysers). These gaps include:

- Calibration and verification protocols based on air or methane, not transferable to hydrogen.
- Material and sealing requirements that do not prevent hydrogen permeation or embrittlement.
- Durability and ageing tests, insufficient for hydrogen exposure.
- Leak tightness criteria overlooking hydrogen's high diffusivity.
- Lack of hydrogen-specific safety and performance requirements for sensors and analysers.

To address these issues, the report recommends a comprehensive update of standards across all measurement technologies:

- **Gas Meters**
  - Define hydrogen-specific test gases and calibration procedures.
  - Update flowrate and pressure ranges to reflect hydrogen's lower energy density.
  - Introduce hydrogen-based leak tightness tests and enhanced detection methods.
  - Mandate material compatibility assessments and extended ageing protocols.
  - Revise marking requirements to clearly indicate gas compatibility.
- **Leak Detectors**
  - Adapt EN 60079 series for H_2/NG blends and mixed-gas calibration.
  - Require multi-sensor solutions for accurate composition detection.
  - Update alarm thresholds for variable flammability limits and interference scenarios.
- **Pressure Sensors**
  - Extend pressure range to 1000 bar and enforce hydrogen-compatible materials.
  - Introduce hydrogen endurance tests under extreme conditions.
  - Mandate ATEX/IECEx compliance for Group IIC gases.
- **Temperature Sensors**
  - Require explosion-proof designs and extended operating ranges.
  - Implement hydrogen-specific thermal cycling and ageing tests.
  - Harmonize with ISO 19880 series for hydrogen infrastructure.

- **Gas Analysers**
    - Harmonize ISO 6974 series and ISO 6976:2026 with ISO 14687:2025 and ISO 17124:2022 for hydrogen purity analysis; update ISO 10715 for hydrogen calibration and uncertainty models.
    - Enforce impurity detection down to sub-ppb levels and harmonize sampling standards and ensure representative sample collection.
    - Ensure ATEX/IECEx compliance for analyser shelters and harmonize with ISO 14687 and ISO 21087.
    - Liaise with ISO/TC 158, ISO/TC 197 and CEN/TC 234 for shared know-how on hydrogen gas analysis.
- **Water dew point sensors**
    - Amendment or revision of existing dew point sensor standards to explicitly include pure hydrogen applications.
    - Development of a hydrogen-specific annex addressing materials, sampling, calibration, and safety.
    - Joint working activities between ISO/TC 193 and ISO/TC 197 to avoid duplication and ensure consistency.
    - Liaison with IEC committees responsible for explosive atmosphere equipment to ensure coherent safety requirements.

As a conclusion, implementing these recommendations will:

- **Guarantee accurate billing and metrological integrity.**
- **Prevent safety hazards associated with hydrogen's unique properties.**
- **Support the EU's hydrogen roadmap and international standard harmonization.**
- **Enable a robust hydrogen economy and secure Europe's leadership in clean energy technologies.**

Annex 1: Proposed Test Gases compositions

The following test gases, defined by the **THOTH2 WP4 expert group**, are recommended for all the studied standards:

Name	Composition	Notes
Hydrogen composition n° 1	CH4 + 10% H2 or NG + 10% H2	NG must comply with EN 16723-1
Hydrogen composition n° 2	CH4 + 20% H2 or NG + 20% H2	NG must comply with EN 16723-1
Hydrogen composition n° 3	CH4 + 30% H2 or NG + 30% H2	Metrological test not required if meter fails at previous concentration
Pure Hydrogen	100% H2 Or > 98% H2	Pure hydrogen test

Annex 2: Standards status

In this last annex, a table of all the standards dealing with flowmeters and flow measurement is given with a focus if they are or no impacted by hydrogen or H2NG blends.

Standard number	Title	Technical Committee	Last revision	Status	Affected by H2NG replacing NG
EN 12480	Gas meters - Rotary displacement gas meters	CEN/TC 237	2018	In revision By CEN/TC 237 ISO/TC 30	★
EN 12261	Gas meters - turbine gas meters	CEN/TC 237	2021	In revision By CEN/TC 237 ISO/TC 30	★
EN 12405-1	Gas meters - Conversion devices - Part 1: Volume conversion	CEN/TC 237	2021	In revision By CEN/TC 237 ISO/TC 30	★
EN 12405-2	Gas meters - Conversion devices - Part 2: Energy conversion	CEN/TC 237	2021		★
EN 12405-3	Gas meters - Conversion devices - Part 3: Flow computer	CEN/TC 237	2015		
TR 16061	Gas meters - Smart gas meters	CEN/TC 237	2010		
EN 16314	Gas meters Additional functionalities	CEN/TC 237	2013		
EN 1359	Gas meters - Diaphragm meters	CEN/TC 237	2017	In revision By CEN/TC 237 ISO/TC 30	★
EN 14236	Gas meters – Ultrasonic domestic gas meters	CEN/TC 237	2018	In revision By CEN/TC 237 ISO/TC 30	★
EN 17526	Gas meters – Thermal mass flow meter-based gas meters	CEN/TC 237	2022	Waiting for the publication of the new version By CEN/TC 237 ISO/TC 30	★
EN 437	Test gases - Test pressures - Appliance categories	CEN/TC 238	2021	Under revision by CEN TC 238	★
EN ISO 6974-1	Natural gas – Determination of composition and associated uncertainty by gas chromatography_ General	CEN/TC 238 ISO/TC 193 SC1	2018	To be identified by CEN TC 238	★

	guidelines and calculation of composition				
EN ISO 6974-2	Natural gas - Determination of composition and associated uncertainty by gas chromatography_ uncertainty calculations	CEN/TC 238 ISO/TC 193 SC1	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	2019	To be identified by CEN TC 238	★
EN ISO 6975	Natural gas - Extended analysis - Gas-chromatographic method	CEN/TC 238 ISO/TC 193	2022		★
EN ISO 6976	Natural gas - Calculation of calorific values, density, relative density and Wobbe indices from composition	ISO/TC 193 SC1 CEN/TC 238	2016 confirmed in 2022		★
EN ISO 14912	Gas analysis - Conversion of gas mixture composition data	CEN/TC 238	2006 Confirmed in 2021		
EN ISO 15970	Natural gas - Measurement of properties - Volumetric properties: density, pressure, temperature and compression factor	CEN/TC 238	2014		★
EN ISO 20765-1	Natural gas - Calculation of thermodynamic properties - Part 1: Gas phase properties for transmission and distribution applications)	CEN/TC 238	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/TC 238	2018		★
EN ISO 20765-5	Natural gas - Calculation of thermodynamic properties - Part 5: Calculation of viscosity, Joule-Thomson coefficient, and isentropic exponent	CEN/TC 238	2022		★
EN 1776	Gas infrastructure- Gas measuring systems- Functional requirements	CEN/TC 234	2016	In revision	★

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/TC 30	2015	To be identified	★
ISO 17089	Measurement of fluid flow in closed conduits_ Ultrasonic meters for gas	ISO/TC 30	2019	In revision By CEN/TC 237 ISO/TC 30	★

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