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Safe Hydrogen Injection Modelling and Management for European gas network Resilience

D4.7: Gas quality measurement technologies for hydrogen injection

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ABSTRACT

Hydrogen injection into natural gas networks offers a pathway to a low-carbon economy while leveraging existing infrastructure, but it presents significant technical and regulatory challenges. Maximum allowable hydrogen fractions differ by country due to safety, supply security, and end-use considerations, requiring gas network operators to accurately monitor hydrogen levels in compliance with national regulations.

Pre-normative research identifies key requirements for measurement technologies: sensors must measure up to 30 mol% hydrogen with 0.1 mol% accuracy, respond within one minute, operate up to 100 bar and 55 °C, and support continuous data acquisition. Thousands of sensors will be needed, especially at TSO entry and exit points and DSO pressure-reducing stations, with earlier deployment prioritized for TSOs before 2030.

Currently, gas chromatography (GC) is the only mature technology meeting all requirements, though its high cost is a limitation. Raman spectroscopy could be an alternative if costs decrease, while emerging metal-hydride technologies show promise for high-pressure applications. Lower-TRL technologies like TCD or Speed-of-Sound sensors may become viable with further breakthroughs.

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

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List of Abbreviations

Table 1: List of abbreviations

Abbreviation	Meaning
ASTM	American Society for Testing and Materials
ATEX	Atmosphères Explosibles (EU directive for explosive atmospheres)
BAM	Bundesanstalt für Materialforschung und -prüfung
CEN	Comité Européen de Normalisation
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DIN	Deutsches Institut für Normung
DIS	Draft International Standard (draft stage in ISO process)
DSO	Distribution System Operator
EMPIR	European Metrology Programme for Innovation and Research
ENTSOG	European Network of Transmission System Operators for Gas
EUR	Euro
EURAMET EMN	European Association of National Metrology Institutes — European Metrology Network
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared; analytical spectroscopy technique
GC	Gas Chromatography
GERG	European Gas Research Group
H_2	Hydrogen
H_2S	Hydrogen sulfide
IMS	Ion Mass Spectrometry
IR	Infrared
ISO	International Organization for Standardization
LIBS	Laser-Induced Breakdown Spectroscopy
MS	Mass Spectrometry
NEN	Nederlands Normalisatie-instituut
NG	Natural Gas
NGC	Natural Gas Chromatograph
NH_3	Ammonia
NPS	Nano-Plasmonic Sensing
OIML	Organisation Internationale de Métrologie Légale
O_2	Oxygen
PAS	Photo-Acoustic Spectroscopy; analytical spectroscopy technique
PCB	Printed Circuit Board
PGC	Process Gas Chromatograph
PTB	Physikalisch-Technische Bundesanstalt
RISE	Research Institutes of Sweden
SCADA	Supervisory Control and Data Acquisition

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SHIMMER	Safe Hydrogen Injection Modelling and Management for European gas network Resilience
SoS	Speed-of-Sound
T&D	Transmission & Distribution
TCD	Thermal Conductivity Detector
TDLAS	Tunable Diode Laser Absorption Spectroscopy
TNO	Netherlands Organisation for Applied Scientific Research
TRL	Technology Readiness Level
TSO	Transmission System Operator
UGC	Ultra/Compact Gas Chromatograph
UL	Underwriters Laboratories
UNI	Ente Italiano di Normazione
VAC	Volts Alternating Current
WP	Work Package
kEUR	Thousand euros
ppm	Parts per million

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Executive Summary

Hydrogen injection into natural gas networks can support the transition to a low-carbon economy while using existing infrastructure, but it raises technical and regulatory challenges. Maximum allowable hydrogen volume fractions are under discussion and will vary by country due to safety, supply security, and end-use compatibility concerns. Gas network operators must comply with national regulations by accurately monitoring hydrogen concentrations, requiring clear standards and norms. This report presents pre-normative research on hydrogen monitoring, including instrumentation requirements, a review of sensor technologies, and an analysis of existing standards, and provides recommendations for future standard development relevant to policymakers, researchers, industry, and network operators.

The investigation with TSOs and DSOs identified **key requirements** for hydrogen measurement in natural gas networks. Sensors must measure hydrogen concentrations up to 30 mol% with about 0.1 mol% accuracy, a response time of around one minute, and operate under pressures up to 100 bar(g) and temperatures up to 55 °C, with continuous data acquisition. Thousands of sensors will be needed, mainly at TSO entry and exit points and, for DSOs, also at pressure-reducing stations. Sensor availability is more urgent for TSOs before 2030. Both TSOs and DSOs value combining field measurements with simulation tools.

A survey of hydrogen **measurement technologies** for natural gas grids concludes that, considering availability around 2030, only mature or near-mature technologies (TRL > 5) are relevant. For both TSO and DSO networks, gas chromatography (GC) currently remains the only technology meeting all requirements, although its high cost is a major drawback. Raman spectroscopy could be a viable alternative if costs are significantly reduced. A large future increase in sensor deployment is expected, potentially driving cost reductions. Among lower-TRL options, metal-hydride technologies appear most promising if adapted for high-pressure TSO grids. Other technologies (like TCD and Speed-of-Sound) may become viable with further technical breakthroughs.

A survey of **standards for hydrogen injection** in gas grids highlights several gaps and recommendations. With increasing hydrogen feed-in points, simple, fast, and low-cost non-GC sensors are expected to become widespread, but no operational standards currently exist, so new standards should be developed. The upcoming ISO DIS 6974-4, focused on GC measurement, only covers hydrogen <0.5%-vol and must be extended to 20–30%-vol for both online and lab analyses. Existing ISO 6974-1/2/3 and ISO 10715 standards should be reviewed for applicability to higher hydrogen fractions. Engagement with ISO TC 193 and TC 158 is recommended to implement these updates.

About the SHIMMER project: The European natural gas infrastructure provides the opportunity to accept hydrogen (H_2), as a measure to integrate low-carbon gases while leveraging the existing gas network and contributing to decarbonisation. However, there are technical and regulatory gaps that should be closed, adaptations and investments to be made to ensure that multi-gas networks across Europe will be able to operate in a reliable and safe way while providing a highly controllable gas quality and required energy demand. Aspects such as material integrity of pipelines and components, as well as the lack of harmonisation of gas quality requirements at European level must be addressed in order to facilitate the injection of hydrogen in the natural gas network.

In this context, the SHIMMER project (Safe Hydrogen Injection Modelling and Management for European gas network Resilience) was selected for funding as part of the 2023 Clean Hydrogen Partnership programme. SHIMMER aims to enable a higher integration of low-carbon gases and safer hydrogen injection management in multi-gas networks by strengthening the knowledge base and improving the understanding of risks and opportunities in hydrogen projects.

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1 Introduction

1.1 Purpose of the document and target audience

To accelerate the transition to a low-carbon economy while exploiting existing infrastructure, hydrogen can be injected into the natural gas network. However, there are many technical and regulatory gaps to be closed as adaptations and investments are required to assure that multi-gas networks across Europe can operate in a reliable and safe way while providing a highly controllable gas quality and meeting the energy demand.

Presently, the maximum allowed volume fraction of hydrogen in the grids is being discussed [1]. Motivations for setting a maximum allowed volume fraction of hydrogen are safety, security of supply, and usability of the blend by consumers [2]. The maximum allowed volume fraction of hydrogen will differ on a country-by-country basis [3] and will ultimately be enforced by a set of national laws and regulations. Gas network operators will have to demonstrate compliance with these laws and regulations by monitoring the hydrogen volume fraction in their networks. Reasonable requirements for this monitoring (for example, the required accuracy) will need to be written in a set of norms.

This document reports on pre-normative research about monitoring the hydrogen volume fraction in networks. Requirements on instrumentation are collected, and a survey of existing sensor technology is performed. A survey on existing standards regarding this topic is performed, resulting in recommendations for future adaption of standards.

The target audience of this report is broad and can be the following, without giving any limitation:

- Standardization bodies, European and national policy makers might be interested in the recommendations for standards.
- Scientific community, industrial stakeholders and measuring technology providers might be interested in knowing the sensor requirements by the DSO and TSO.
- DSO and TSO might be interested in knowing what sensor technology exists that meet their requirements. And which technologies are under development and will be available in near future.

1.2 Structure and scope of this document

The scope of this study is measuring technologies for hydrogen injections in natural gas. The investigation is described in the following chapters:

Chapter 2: Evaluation of sensor technology requirements in discussion with the TSO's and DSO's in the consortium. Special attention for requirements related to safety aspects (i.e. response time) or to number of sensors and location of sensors for different injection strategies and performance (accuracy) of the sensors in relation to performance of the gas quality modelling technologies. In addition, the requirements regarding integrating of the modelling tools with measuring technologies will be evaluated.

Chapter 3: Survey of possible technologies. Presentation of survey and a literature search and scan of available measuring technologies based on the requirements. Including. recommendations for further development of promising low-TRL technologies.

Chapter 4: Review of available standards for gas quality measuring technologies in hydrogen -NG mixtures. Including recommendations on improvements for standards for gas quality measuring technologies in hydrogen -NG mixtures.

A compliance use case would be to regulate the input of hydrogen inflow according to hydrogen already present in the grid to not exceed the legal limit of hydrogen present in the gas grid, or further local limitations due to the specific end users characteristics.

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A fiscal (legal metrological) use case would be to measure day by day the average volumetric content of hydrogen (other than the normal other hydrocarbons) of a particular area and assign a calorific value to all the gas supplied in that area.

The following topics are out of scope for the present study:

- Fiscal or legal metrological measurement: day by day measurement of the average volumetric content of hydrogen (other than the normal other hydrocarbons) of a particular area and assign a calorific value to all the gas supplied in that area. With the goal of billing customers based on amount of delivered energy.
- Leak detection (this is the scope of T3.3 of the SHIMMER project).
- Measuring very low level impurities in hydrogen relevant for Hydrogen fuel quality, e.g. product specifications like ISO 14687.
- Measuring impurities in natural gas associated with biogas injection.

1.3 Stakeholder involvement

In the work leading up to this deliverable, stakeholders were involved in the following way. The requirements established in Chapter 2 were based on input that was gathered from the DSO and TSO in the consortium, as explained in Section 2.1. For the literature survey on measuring technologies has been (among other sources) based on available outcomes of related projects like GERG-CEN-H2-PNR, MET4H2, DECARB and THOTH2.

The survey on available technologies and standards and potential standardization adaption with respect to hydrogen injection has been discussed with Karine Arrhenius (RISE), vice president of Euramet Energy Gasses.

1.4 Relationship with other deliverables

The work in this report is strongly related to Deliverable D4.5 – Guidelines and operational strategies for injection of hydrogen in the networks.

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2 Requirements for hydrogen-in-NG sensors

2.1 Way of work in establishing sensor requirements

To gather the requirements for gas quality measurement in the context of hydrogen -NG blending, TNO sent a questionnaire to the DSO and TSO partners in the SHIMMER consortium (Table 2). The questions are listed in Appendix 7.1. Answers from all partners were put into a single spreadsheet and reviewed during several virtual meetings. The results are discussed in the following Sections.

Table 2: DSO and TSO partners in SHIMMER consortium.

Company	Country	Type
Redexis	Spain	DSO
Enagas	Spain	TSO
SNAM	Italy	TSO
INRETE	Italy	DSO
GASSCO[1]	Norway	TSO
GazSystem	Poland	TSO

2.2 Rationale for measuring hydrogen volume fraction

Enagas: "After an injection point of hydrogen to the NG network we wish to continuously monitor the hydrogen content in the NG/ hydrogen blend to avoid injecting more hydrogen in the network than the amount allowed by specification/regulation [4] or integrity limitations of pipeline materials and components. The limitation applies to this injection point or to any in other location."

GazSystem: "We will be obliged to publish, among others, hydrogen from interconnectors on ENTSOG platforms. Besides this, in the future – verification if the hydrogen concentration is within the acceptable, by the Transmission Network Code, limits [5]."

Inrete: "Presently, the legal limit on hydrogen content in natural gas is 2 mol-% in Italy [6]. It will progressively increase in the next years, but it's unlikely to go beyond 20 mol-%. It will certainly not go beyond 28 mol-%, because that is the threshold over which the gas type changes according to ATEX. Allowing a hydrogen fraction >28 mol-%, would thus force us to check all our customer gas plants for compliance that different type of gas. Therefore, a sufficient working range for a hydrogen sensor is 0-30 mol-%." A summary of the given numbers can be found in Table 3.

Table 3: examples of current maximum values for hydrogen concentration.

Company	Max H_2 allowed in natural gas (2025)	Ref.	Suggestion for accuracy requirement
Redexis (Spain)	2 or 5 mol-%, following requirement in regulation	[4]	<0.05 mol-%[2]

[1] GASSCO does not plan blending of NG- hydrogen, but wants to follow developments on blending.
[2] Exact statement of Redexis: "For 2-5 vol-% hydrogen can tolerate <2% relative error. For >5 vol-% hydrogen can tolerate <5% relative error."

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Inrete (Italy)	2 mol-%	[6]	<0.05 mol-%

2.3 Points of interest in the network

DSO:

- At all City Gates (connections with the TSO network; Inrete manages 120 of the roughly 3000 city gates in Italy).
- At all points where a hydrogen production plant injects into the distribution network
- If possible, at all points where biomethane plants injects into the distribution network
- At a selection of pressure reducing stations – note that these do not always have mains electricity connection.

TSO:

- At all points where a hydrogen production plant injects into the transport network
- At all national and international interconnection points between TSOs (27 interconnects in Italy)
- At all delivery points, where gas flows to DSO or industrial end-user. There are 7000 delivery points in Italy. A majority of the gas quality systems at delivery points in Italy is owned by the customer cities or industrial end-users, with SNAM only owning and managing 22. Enagas notes that quality measurement might not be needed for delivery points where composition can be determined from quality tracking, using measurements at the injection point (if the method is allowed by metrology Authorities).
- At all underground storage facilities connected to transmission network (13 storage facilities in Italy)

The partners indicate that there is no need to measure inside the main gas line. It is ok to connect the sensor to a bypass. This configuration allows the sensor to be replaced without halting operation of the gas line and avoids issues with pigging. Gas chromatograph operates at pressures of at most a few bar, so a pressure reduction system is typically needed.

2.4 Data collection and sampling interval

All partners wish to have their sensor data logged locally, but also available remotely, for storage in a centralized database or use in a SCADA. Response time requirements vary from 1 minute to an hour. Desired communication intervals to the central database vary from minutes to daily.

2.5 Technical requirements

Based on the input from the partners, three use cases are identified and summarized in Table 4, each with somewhat different requirements.

Table 4: Overview of use cases for quality measurement.

Use case description	Requirements
City gates and H_2 injection points in the distribution network	Table 5
Pressure reduction stations	Table 6
Transmission network	Table 7

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Table 5: Instrument requirements for measuring hydrogen mol-% at city gates and hydrogen injection points in the distribution network.

Requirement	Value	Rationale
H_2 concentration	0-30 mol-%	Sec. 2.2
Accuracy	0.2%[3] - 5%[4] relative	As indicated by Italian and Spanish grid operators
Response time	<1 minute	In case the permissible H2 thresholds are exceeded, an alarm must be sent immediately
Gas temperature	-10C to +50C	City gate temperature range
Total pressure:	20mbar(g) to 5 bar(g)	Typical DSO pressure range
# sensors/country	thousands	Based on number of city gates

Table 6: Instrument requirements for measuring hydrogen mol-% at pressure reduction stations.

Requirement	Value	Rationale
H_2 concentration	0-30 mol-%	Sec. 2.2
Accuracy	0.2%[5] - 5%[6] relative	As indicated by Italian and Spanish grid operators
Response time	<5 minutes	High sampling rate monitoring is not needed at all reduction stations. Would also not be practical, since 230VAC is not always available.
Pressure	20mbar(g) to 5 bar(g)	Typical DSO pressure range
Gas temperature	-25C to +55C	Gas temperature follows ambient temperature. Reduction stations see larger ambient temperature range than city gates.

[3] Inrete requires 0.05 mol-% accuracy and mentions a maximum of 30 mol-% hydrogen.
[4] Redexis tolerates <5% relative error for >5 mol-% hydrogen.
[5] Inrete requires 0.05 mol-% accuracy and mentions a maximum of 30 mol-% hydrogen.
[6] Redexis tolerates <5% relative error for >5 mol-% hydrogen.

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# sensors/country	thousands	Number of pressure reduction stations
Sensor system should be able to run without 230 VAC.		Mains power not available at all reducing stations.

Table 7: Instrument requirements for measuring hydrogen mol-% in transmission network.

Requirement	Value	Rationale
H_2 concentration	0-30 mol-%	Sec. 2.2
Accuracy	±0.5% relative	[7]
Response time	<1 minute to < 15 minutes	Desired sampling frequency by TSO
Pressure	16-100 bar	Transmission network pressure; note that sensor is typically connected via gas conditioning system. GC works at atmospheric pressure, or
Gas temperature	+5C to +30C	Lower limit: Gassco; upper limit: Gassco & SNAM.
# sensors/country	thousands	Number of delivery points; 7000 in Italy, of which 3000 city gates. Note however that not all delivery points may require quality measurement.

2.6 What hydrogen concentration sensor do DSO/TSO plan to use and when?

Table 8 shows the sensors that the DSO/TSO partners plan to use. In addition, Enagás shared a list of instruments they had previously evaluated for possible use (**Error! Reference source not found.**).

Table 8: gas quality measurement instruments per company.

Companies that provided no information on this question are not shown here.

Company	Type	When needed
GazSystem	GC	Unknown
SNAM	metal hydride	Replacement GC under way - new ones can measure H2. Around 2030 all GC should be able to measure H_2.
Enagás	GC	All newly installed GC have capability to measure H_2. It will take several years before all GC have been replaced.
Inrete	GC	>2030

From Enagas we got a detailed list of instruments used in the grid. The type of instruments are Gas Chromatography, thermal conductivity instruments and Raman Spectroscopy instruments. Most of them are able to measure up to 20% of hydrogen in natural gas, some of them even up to 100%.

2.7 Integration of quality measurements and simulation

The DSO partners are interested in using simulation tools to determine the hydrogen concentration in their networks, but they have no concrete plans at this stage. Redexis in particular would pick this up if the number of hydrogen injection points (currently 1 in their network) would increase.

For the TSO partners the picture is mixed:

- Enagas envisions combining simulation and measurements anyway for biomethane quality tracking (including %-vol of O_2) within 5 years. Have previous experience with German simulation tool. Crucial requirement for any simulation tool would be that it can talk to SCADA system.
- GASSCO already uses the ATMOS simulation tool for natural gas (flow, pipeline parameters, including gas components, e.g. H_2S). They would add hydrogen concentration to the simulation package if and when that is added to their transmission system.
- GazSystem has simulation tools available but do not plan to use them for hydrogen concentration. There is an obligatory publication of hydrogen concentration at the cross-border interconnectors, but they plan to rely solely on measurement for now.

SNAM foresees using a combination of simulation and measurement of hydrogen volume fraction if and when gas quality will become more unstable in the future.

2.8 Overview of requirements

Table 9 is an overview of the requirements. It is based on Table 5, Table 6 and

Table 7. It serves as a check list for the sensor technology survey (Ch. 0). All interviewed TSO and DSO partners wish to have their sensor data logged locally, but also available remotely, for storage in a centralized

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database or use in a SCADA. The TSO partners in particular are interested in combining measured hydrogen mol-% measurements with simulations.

Table 9: overview of requirements.

Requirement	**Range for all DSO**	**Range for all TSO**
H_2 concentration	1 mol-% - 30 mol-%	0 mol-% -30 mol-%
Accuracy	0.06-0.25 mol-%	0.15-0.3 mol-%
Response time	1 minute – 1 hour	1-15 minutes
Pressure	20mbar(g) – 5 bar(g)	16 bar(g) – 100 bar(g)
Gas Temperature	-25C to +55C	+5C to +30C
Number of sensors needed	Thousands	Thousands
Continuous data acquisition needed?	Yes	Yes
When will sensors be needed?	>2030	<2030

3 Literature survey of hydrogen sensor technology and relevant standards

3.1 Way of work

An initial list of literature sources was compiled based on publicly available reports and project documentation. The selection criteria were: (1) scope includes measurement of composition of natural gas; (2) written in context of EU project; (3) preferably scope includes discussion on blending hydrogen into natural gas. Then one list was compiled of all sensor technologies and one list of all standards referenced in those sources. Added to these lists were all instruments and standards that were mentioned during the discussions with the TSO and DSO consortium partners about the requirements for hydrogen-in-NG sensors, as described in Ch. 2. Then, an additional internet search was performed, focusing specifically on low-TRL sensor technologies for hydrogen in any gas mixtures, which might be promising for future application in natural gas. Finally, the three resulting lists (literature sources, sensor technologies, standards) were critically reviewed for completeness by Karine Arrhenius (RISE), in her capacity as vice-Chair of the EURAMET EMN for Energy Gases. The resulting list of literature sources is in Appendix 7.2. The list of standards will be discussed in Chapter 4.

Table 10: Overview of technologies and related section.

Technology	Section
Gas chromatography	3.2.1
Ion mass spectrometry	3.2.2
Raman spectroscopy	3.2.3
IR absorption spectroscopy	3.2.4
Emission spectroscopy	3.2.5
Metal hydride sensors	3.2.6
Catalytic combustion & metal oxide sensors	3.2.7
Thermal conductivity, viscosity, speed of sound	3.2.8

Each technology on the list is presented and discussed one by one in Section 3.2. The hydrogen sensor technologies compatible with natural gas and having TRL>5 (because of the requirement for mid-term availability) are identified. The described technologies in the next section is not an exhaustive list of all available instruments, but gives representative examples of the different technologies.

Finally, in Section 0 a critical evaluation is conducted of the selected sensor technologies, based on the requirements established in Ch. 2.

3.2 Description of sensor technologies

3.2.1 Gas chromatography

Gas chromatography (GC) is a very well established technology and used by all TSO and DSO to measure the composition of natural gas. Many different GC instrument types exist, optimized for different use cases. For example, an analytical lab might opt for an instrument that is optimized for flexibility and sensitivity. TSO and DSO use so-called process GCs, which are optimized for simplicity and robustness [8] [9] [10] [11]. Several

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manufacturers offer process GCs specifically designed for natural gas analysis, including hydrogen, in a price range of 30-70 kEUR.

The working principle of GC is shown in Figure 1. A small volume of the gas to be analysed is injected into a steady flow of carrier gas, usually helium or argon. The mixture is carried through a chromatographic column, which is inside an oven with controlled temperature. The various gas species in the sample each travel through the column at a specific speed. This causes each gas species to exit the column at a specific time relative to the moment of injection – this is called the retention time for that species. A detector at the end of the column measures some property of the exiting gas (thermal conductivity, for example) as a function of time relative to the moment of injection. Figure 2 shows an example of a resulting graph, which is called a chromatogram. The chromatogram consists of a steady baseline signal with isolated peaks. The baseline signal corresponds to essentially pure carrier gas exiting the column. Each peak corresponds to a single gas species that was present in the gas sample. The area under each peak is related one-to-one to the volume fraction of the corresponding gas species in the sample.

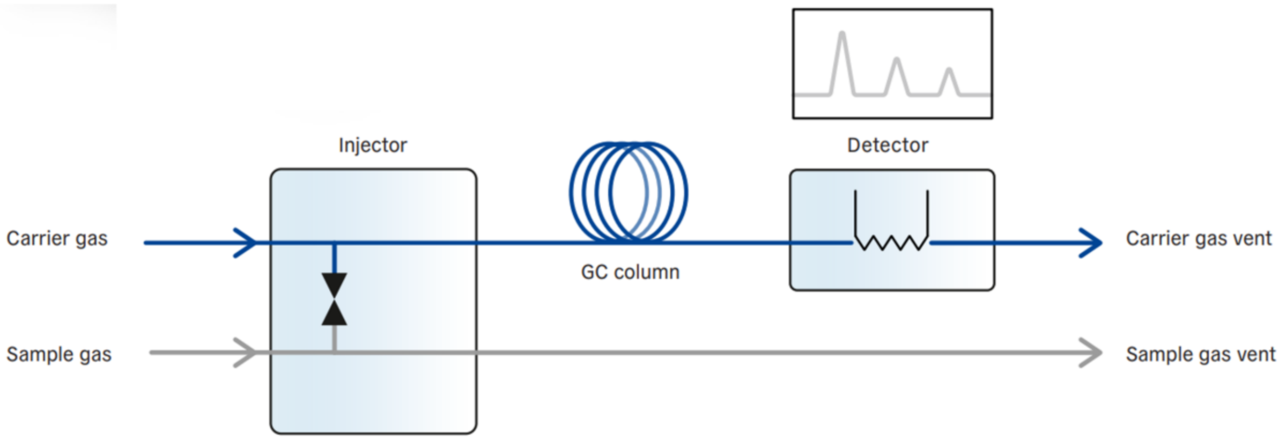

Figure 1: schematic of gas chromatograph from [11].

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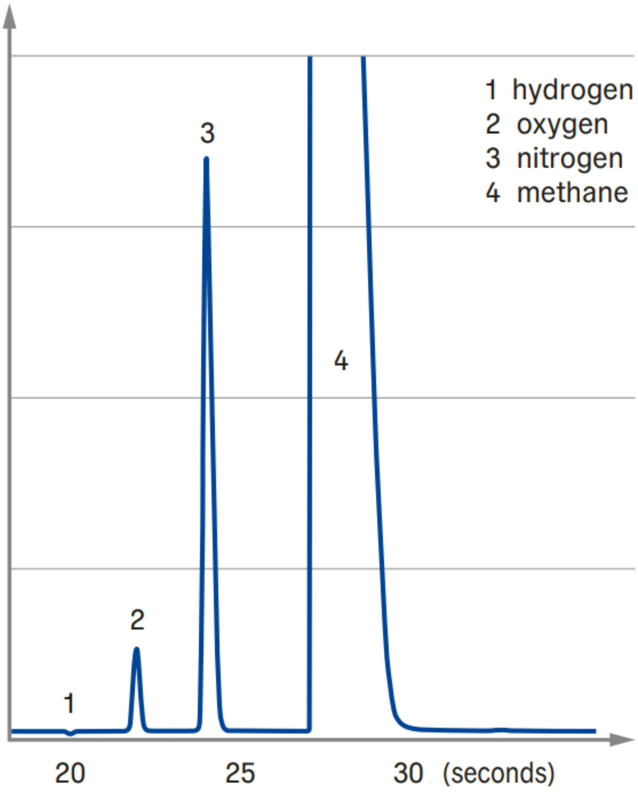

Figure 2: example of a chromatogram obtained with a thermal conductivity detector and helium carrier gas from [11]. Note that hydrogen produces a dip in the baseline signal, while all other molecules cause peaks. The reason is that hydrogen has *higher* heat conductivity than helium – all the other molecules have *lower* heat conductivity than helium.

To know the retention time and sensitivity relationships with sufficient accuracy, regular calibration with a known gas mixture is needed. For process GCs, these calibrations are fully automated. Accurate interpretation of the chromatogram is only possible for well-separated peaks. Increasing column length increases peak separation but also increases overall retention time. For process GC as used by TSO and DSO, typical retention times are of the order of one minute: this sets a fundamental lower limit to the delay between sampling time and availability of the computed mole fractions. It also sets an upper limit on the sampling frequency that can be achieved with a single GC column. Large differences in mole fractions between neighboring peaks can lead to peak interference and uncertainty, imposing maxima in the allowed mole fractions in the sample.

Chromatographic columns operate at roughly atmospheric pressure. All GCs therefore require a pressure reduction system to allow sampling from high pressure natural gas pipes. To avoid condensation of water or other contaminants that may be present, careful temperature management and filter is required. These gas conditioning systems add complexity and cost to a GC setup.

Different detector types are used in GC instruments depending on the required sensitivity and operating conditions. Examples include detectors based on thermal conductivity (TCD), flame-ionization (FID) and mass spectrometry (MS). FID involves combusting the effluent gas in a hydrogen flame. This makes FID unusable to detect any hydrogen in the effluent gas. MS based detectors can reach extreme sensitivity and specificity but are complex and costly because they involve high vacuum and high voltage (see Sec. 3.2.2).

All process GCs analyzed for the present study rely exclusively on TCD. It is the simplest detection method and sensitive enough to reach the required accuracy. The typical carrier gas used in process GC is helium. Hydrogen and helium have similar heat conductivity. Hence, the sensitivity to hydrogen of a GC running with

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helium carrier gas and using TCD is rather low. To achieve better sensitivity heavier argon may be used as carrier gas. Nevertheless, a limit of detection of 50ppm hydrogen can be achieved using helium carrier gas and TCD [11], which is sufficient to reach the requirements of Section 2.8.

3.2.2 Ion-mass spectroscopy

Ion mass spectroscopy (MS) was briefly mentioned as a detector technology used in GC. But MS based instruments can also operate without a chromatographic column. Several vendors offer MS instruments for gas analysis, including options for sampling from high pressure lines [12, 13]. One of the application domains is measuring the purity of green hydrogen. Measuring natural gas composition, including hydrogen, should certainly be possible in principle using MS. However, no mention of MS used for this application was encountered in the present literature study. The reason is likely that the systems are costly (>60kEUR) and their unique capabilities (millisecond response time and ppb sensitivity) are not needed in the context of natural gas composition monitoring.

Figure 3 shows a mass spectrometer. A continuous stream of gas to be analyzed enters the ionization source from the right. A part of the resulting molecular ions is electrically extracted from the ionizer and accelerated through the quadrupole mass filter. The mass filter consists of four parallel metallic rods, to which a combination of DC and radio-frequency voltages is applied. The resulting electric field allows only ions with specific mass-to-charge ratio to reach the ion detector, located at the left hand side of Figure 3. Using a secondary electron multiplier as detector allows detection of single ions in principle, leading to extreme overall sensitivity. By changing the applied voltages, different mass-to-charge ratios can be selected in turn, allowing measurement of an entire mass spectrum in a matter of a few seconds. Such a spectrum can be used to estimate the mole fractions of the sampled gas. Alternatively, the mass-to-charge ratio selected by the mass filter can be kept constant. That allows the mole fraction of a single, selected gas species to be monitored with millisecond time- resolution.

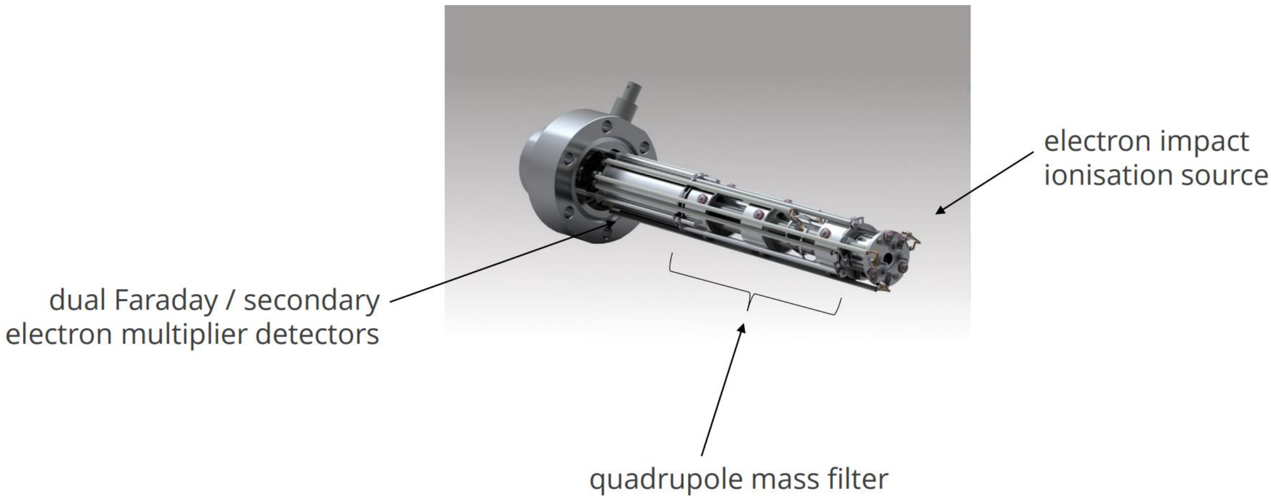

Figure 3: part of an MS gas analyser [12]. The whole device as shown is roughly 40cm in length.

The ionizer, mass filter and detector rely on mean free paths of the ions of many metres – therefore a high vacuum is required, which is created using turbo molecular pumps. Like a GC, MS gas analysers would require a gas conditioning system to allow sampling from a high pressure line. Hiden Analytical offers such conditioning systems for pressures up to 30 bar in their catalogue [12].

In this literature survey no publications were found where MS is explicitly demonstrated to measure hydrogen in natural gas. Therefore a TRL of 4 was assigned to MS in that application domain, disqualifying it for the evaluation of Sec. 0.

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

3.2.3 Raman spectroscopy

Raman spectroscopy is a proven way of measuring mole fractions of many components in natural gas, including hydrogen. Raman instruments specifically for use as natural gas composition monitors are commercially available for 50-100kEUR [14] [15] [16]. The working principle of a Raman analyser is as follows. Gas in a flow cell is irradiated with laser light. A small fraction of the laser light is scattered non-elastically by the gas molecules, which means that the scattered light has a slightly different wavelength than the incident laser light. The amount of wavelength shift is different for each gas species, and the total amount of scattered light by a given species is determined by its partial pressure. Thus, the measured spectrum of scattered light can be translated to mole fractions for many gas species simultaneously.

Crucially, the flow cell can run at pressures at least up to 75bar, so there is no need for a pressure reduction and gas conditioning system (Figure 4). This gives Raman analyzers a fast response time, making them suitable for integration in control systems of e.g. a gas fired turbine [16].

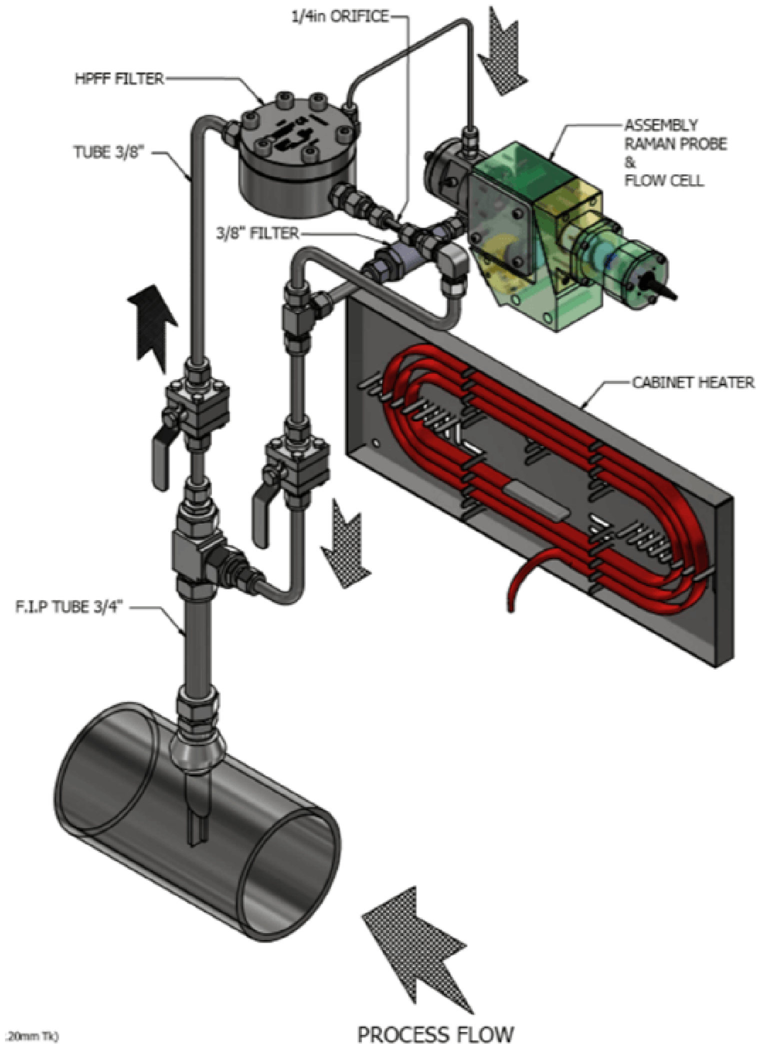

Figure 4: example of a Raman analyser directly coupled to high pressure gas line, without the need for a pressure reduction system [14].

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

3.2.4 IR absorption spectroscopy

Infrared (IR) absorption spectroscopy is a very mature technique for gas analysis, which is used in slightly different ways in a variety of instrument configurations (for example: FTIR, TDLAS, PAS). In principle is ill suited to detect hydrogen, which absorbs very little light in the IR range in comparison with many other gases. Surprisingly, a proof of principle has been published showing that a TDLAS IR absorption setup can potentially work as a hydrogen leak detector [17]. Using a modest laser, 1m integration length and 1s integration time, the device could detect hydrogen in atmospheric air down to a level of 0.02 %-mol. However, it is unlikely that this can be translated to detecting hydrogen in natural gas, since hydrocarbons absorb much more strongly than hydrogen and would likely interfere with the measurement.

3.2.5 Emission spectroscopy

In emission spectroscopy, electronic line transitions are excited in a gas sample by heat from a laser pulse or interaction with a plasma. The spectrum of the emitted light contains quantitative information about many gas species simultaneously, including hydrogen. When a laser pulse is used to excite the gas, the technique is called laser-induced breakdown spectroscopy (LIBS). LIBS to detect hydrogen in air has been experimentally demonstrated [18], but not for hydrogen in natural gas. A plasma-based emission spectroscopy device (involving vacuum system and high voltage power supply) was demonstrated specifically to measure hydrogen mole fraction in methane [19], claiming lower detection limit down to 1 mole-%. It was decided not to further explore emission spectroscopy because of its complexity and low TRL.

3.2.6 Metal hydride-based sensors

These sensors are based on the reversible formation of metal hydrides when certain noble metals are brought in contact with hydrogen gas. It is an emerging technology, with only a single[7] instrument available commercially [20]. Several other metal-hydride instruments are lower in TRL – these promise even smaller footprint and lower cost.

Hydrogen molecules are broken into atoms (a reaction called dissociation) when they come in contact with the noble metal surface. The hydrogen atoms then diffuse into the metal lattice, which absorbs it like a sponge. The metal hydride has very different electrical and optical properties from the pure metal, offering readout options through electrical resistance, capacitance and optical reflectance. Crucially, when the partial pressure of hydrogen is decreased, the hydrides revert back to metal, without the need for oxygen being present in the gas to drive this reverse reaction. This makes metal hydrides suitable for measuring hydrogen in natural gas. Embrittlement of the metal can occur when the hydrogen partial pressure is cycled, causing hysteresis in the sensor response. This is mitigated by using optimized alloys or deploying the metals in the form of nano particles. Another challenge is that reactive gas species such as carbon monoxide or sulfur containing compounds can irreversibly degrade the ability of the metals to catalyze the dissociation reaction of hydrogen molecules. This is mitigated by applying polymer coatings on the active layer.

The commercially available hydrogen sensors by the US company H2scan [20] feature two detection elements, both based on a Pd/Ni alloy. To detect hydrogen concentrations in the range 0.5 %-mole and higher, a bulk electrical resistance element is used. For very low concentrations (15 ppm to 0.5 %-mole in atmospheric air), a capacitive element is used. Figure 5 shows the HY-OPTIMA 5030. Figure 6 illustrates that lowering the limit of detection introduces sensitivity to carbon monoxide and hydrogen sulfide.

[7] Another apparently similar instrument may be available commercially, but a clear spec sheet or description could not be found [36].

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

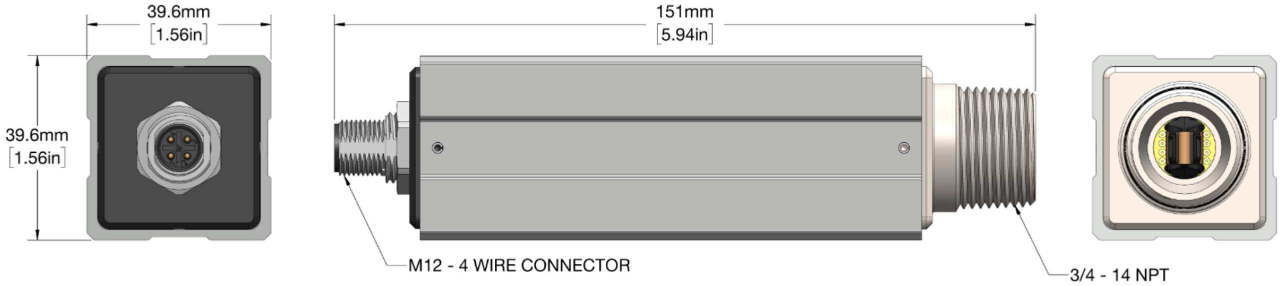

Figure 5: HY-OPTIMA 5030 Series General Use In-line Hydrogen Process Analyzer. From [20].

MODEL	5031	5032	5033	5034
Hydrogen Range Low	0%	0%	0%	0%
Hydrogen Range High	10%	5%	100%	100%
Lower Detection Limit	0.03%	0.4%	0.5%	0.5%
CO Limit	100 ppm	0	100 ppm	20%
H2S Limit	20 ppm	0	1000 ppm	3%
T90 Response Time (sec)	<90	<60	<60	<90

Figure 6: trade-offs in commercially available metal-hydride hydrogen sensing technology. From [20].

TNO optimized a material consisting of Pt nanoparticles in a porous TiO_2 matrix for use in a hydrogen sensor [21]. The material is deposited as a thin coating onto a 700x700µm interdigitated electrode. The electrical capacitance of the electrode then depends sensitively on the hydrogen partial pressure. Other electrodes on the same PCB have coatings optimized for absorbing the other species present in natural gas. The various capacitance values are recorded using standard capacitance-to-digital chips. This results in a compact sensor (Figure 7) capable of measuring the full composition of natural gas, including hydrogen (Figure 8). The technology is licenced to the UK-based company Bohr Limited for application in commercial products and is presently at TRL 5-6 [22].

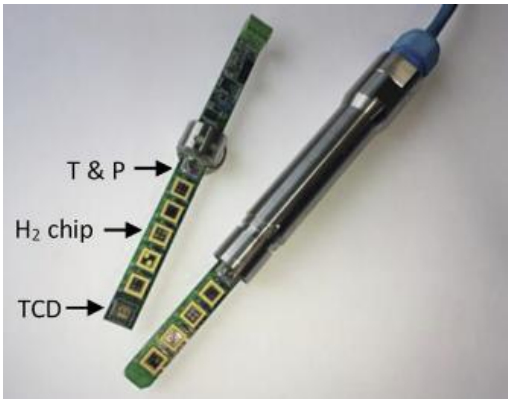

Figure 7: hydrogen sensor using Pt-based capacitive coating. Reproduced from [23].

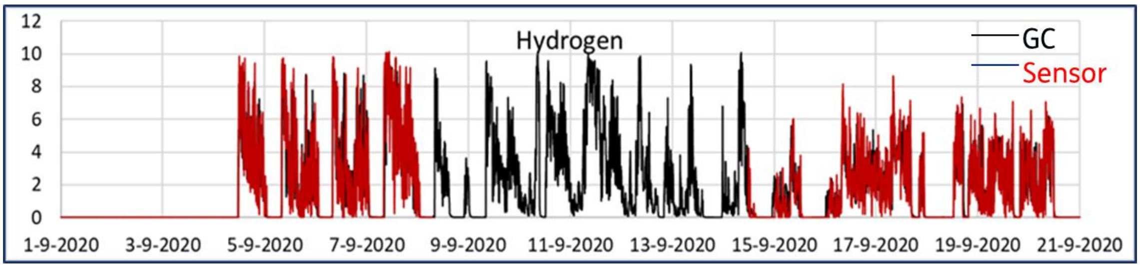

Figure 8: demonstration of hydrogen sensor using Pt based capacitive coating in a natural gas grid where hydrogen was admixed. The y-axis is the mole-% of hydrogen. Black curve: measurement with a gas chromatograph; red curve: hydrogen sensor. Reproduced from [23].

Delft University of Technology optimized and patented a class of Ta/Pd alloys as optical thin-film hydrogen sensor [24]. In lab conditions, where hydrogen is mixed with an inert gas, this material potentially has a sensing range of 7 orders of magnitude without any hysteresis (Figure 10). The working principle is sketched in Figure 9. A protective layer of Pd/Au alloy protects the sensitive layer from oxidation and catalyses the hydrogen dissociation reaction into atoms, which then diffuse into the Ta/Pd layer. A further polymer coating protects against poisoning by carbon monoxide and sulphuric compounds. Figure 10 shows a readout option using an optical fibre and a spectrometer, which potentially offers a sensitive element with tiny footprint. A simplified and low-drift readout configuration employing two LEDs and a single photo-diode was patented [25]. Unpublished lab work demonstrates that methane does not interfere with the function of the sensor, suggesting usability for measuring hydrogen in natural gas. Testing of a prototype using the two-LED configuration is presently ongoing for hydrogen and natural gas blends. No demonstrations of hydrogen and natural gas blends have been published yet, so TRL 4 is assigned.

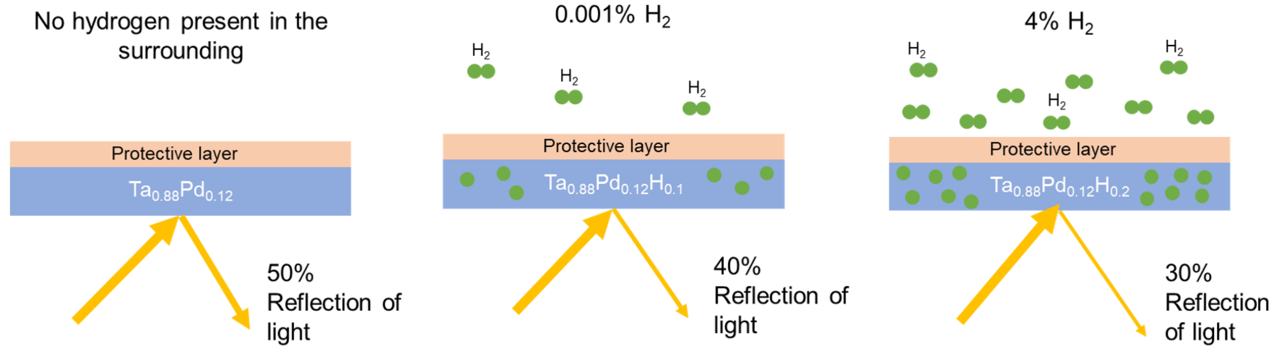

Figure 9: working principle of Ta/Pd layer as hydrogen sensor; from [26].

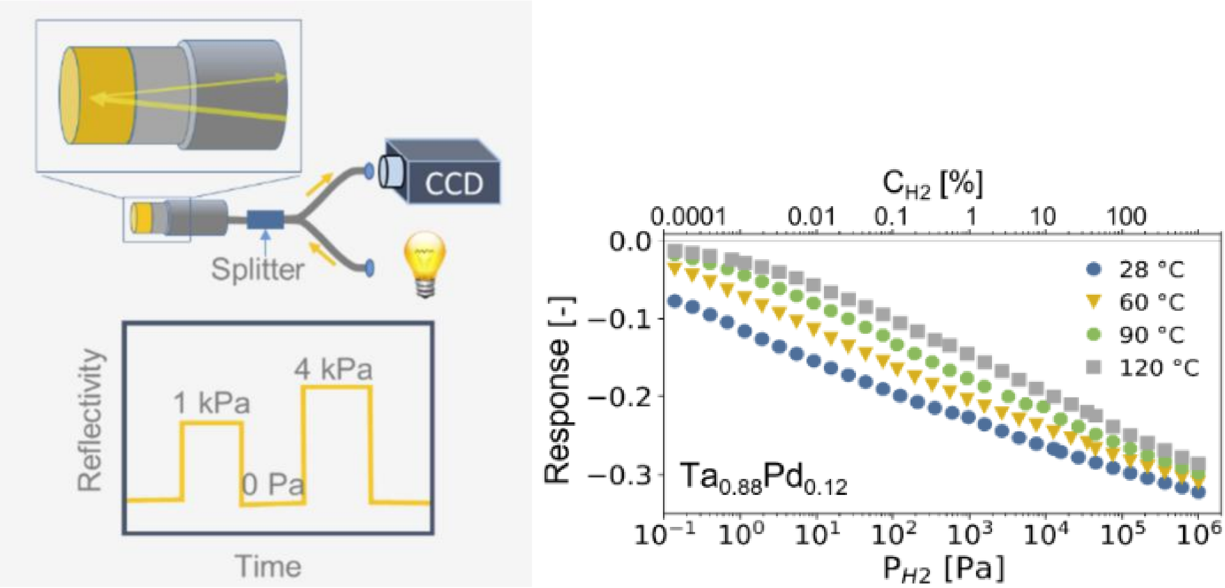

Figure 10: Left: readout option of Ta/Pd coating using a mirror on a fibre tip. Right: sensor response to hydrogen pressure over 7 orders of magnitude. Source: [26].

The devices offered by Insplorion [27] rely on nanoparticles of Pd alloyed with Au, Ag and Cu, which are deposited on a surface. The optical reflectance spectrum of the surface is measured and interpreted in terms of hydrogen concentration – a configuration called nano-plasmonic sensing (NPS). The ratio of the various metals in the alloy is tuned to obtain linear response in various ranges of hydrogen concentration. Copper is added to the alloy to reduce the issue of poisoning by carbon monoxide. Polymer coatings on the surface act as molecular filters and improve the limit of detection. The main application for which the sensors are marketed is hydrogen leak detection. In-line monitoring of hydrogen/NG blends was previously evaluated as a potential application for NPS. Indeed, unpublished lab tests in binary mixtures of methane and hydrogen suggest that methane does not impact sensor performance and hydrogen fractions at least down to 0.1 mole-% might be measurable. Since no demo in natural gas has been published, TRL 4 is assigned to NPS. Insplorion is not presently developing a product for this application.

3.2.7 Catalytic combustion and metal oxide sensors

Chemical hydrogen sensors based on catalytic combustion and metal oxide interactions are incompatible with our desire to measure hydrogen in natural gas. The reason is that both groups rely on the presence of oxygen in the gas mixture for operation – such sensors are typically applied for hydrogen leak detection. They will not be discussed further in this literature survey.

3.2.8 Thermal conductivity, viscosity, speed-of-sound

For known temperature and pressure, bulk gas properties such as thermal conductivity, viscosity and speed of sound depend only on the chemical composition of the gas. Therefore, for binary mixtures of known species at known temperature and pressure, measuring any one of those bulk properties allows determination of the mixing ratio. Thermal conductivity detectors (TCD) are sensitive to even small changes in hydrogen content in natural gas because hydrogen has 5.5 times higher thermal conductivity than methane. Figure 11 shows an example of a chip-based TCD, and an integrated instrument. Although natural gas is mostly methane, it contains many other gases at well, with unknown mole percentages, which also impact the thermal conductivity. This introduces uncertainty in the determination of the hydrogen concentration.

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

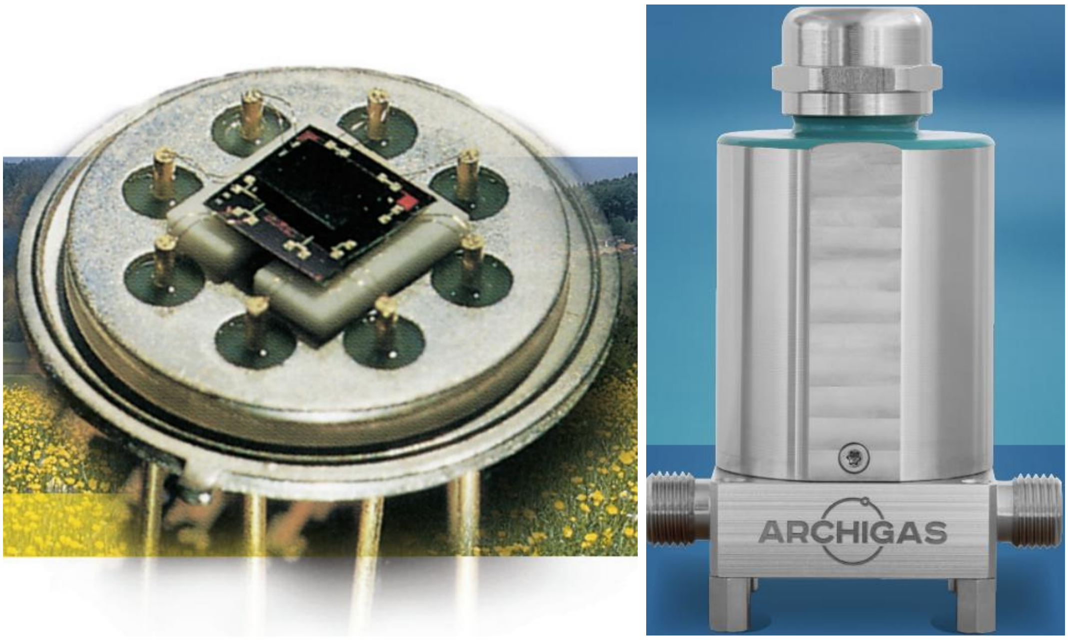

Figure 11: Left: example of a miniature TCD detector [28]. Right: example of an integrated TCD instrument [29].

Miniaturized gas viscosity detectors also exist [30] [31]. Figure 12 shows an example of an instrument featuring a viscometer, alongside a miniaturized TCD and IR device. This instrument reports several properties of natural gas, including Wobbe number, carbon dioxide content and hydrogen content. By itself, a viscometer is not well suited to determine hydrogen fraction in natural gas, since the viscosities of pure hydrogen and methane are quite similar. However, using two rather than one bulk gas properties to estimate hydrogen content can improve the accuracy of that estimate when multiple minority gases are present in the mix.

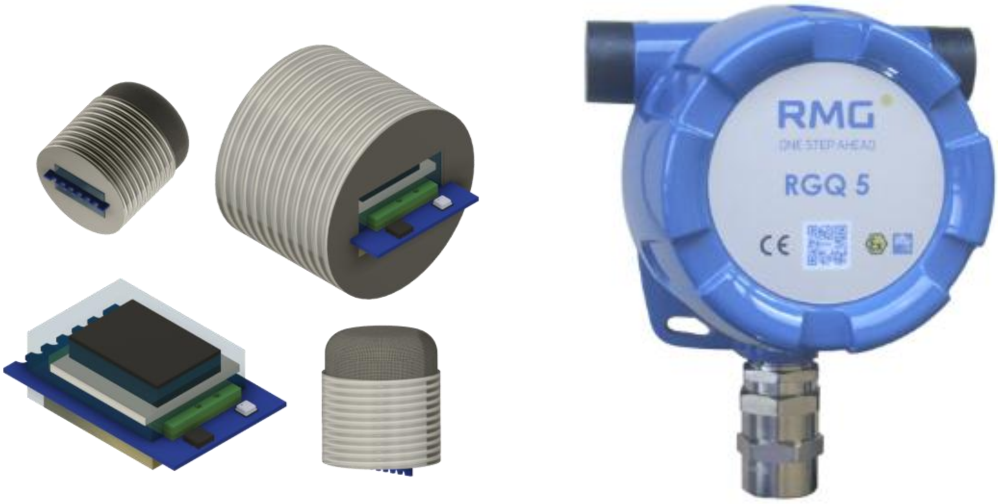

Figure 12: Left: module with miniature viscosity, TCD and IR-based sensors [32]. Right: integrated gas quality calorimeter instrument based on this module [33].

Speed-of-sound (SoS) is another bulk gas property that is used to estimate hydrogen fraction in natural gas. For hydrogen fractions up to 30 %-mole, ultrasonic gas flow meter hardware normally used for natural gas is suitable [34]. Although SoS is routinely measured and reported by any commercial ultrasonic flow meter, the

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

translation to hydrogen is not typically a standard option. The Allengra Hydrogen Flow Meter is an exception, explicitly offering computation of hydrogen/methane fraction [35]. However, it seems optimized for >30 mol-% hydrogen, making its ultrasonic potentially unsuitable for <30 mol-% hydrogen in natural gas. For this reason, TRL 8 is assigned.

3.3 Selection and evaluation of sensor technologies

Table 11 summarizes the findings per sensor technology. Technologies which are suitable for use in blends of hydrogen in natural gas, and which have TRL>5, are shaded in green. These technologies are further evaluated for usability by DSO and TSO. Other technologies are not discussed further in this study.

Table 11: technologies to measure hydrogen fraction in gas mixtures.

Principle of discrimination	Technology	Section	TRL
Physical separation of H_2 and other gases	Gas chromatography	3.2.1	9
	Ion mass spectrometry	3.2.2	4
Unique optical fingerprint of H_2	Raman spectroscopy	3.2.3	9
	IR absorption spectroscopy	3.2.4	3
	Emission spectroscopy	3.2.5	3
H_2 engages in specific chemical reactions, which measurably alter properties of a probe	Metal hydride sensors	3.2.6	4-9
	Catalytic combustion & metal oxide sensors	3.2.7	not suitable for use in H_2/NG blends
Low molecular mass of H_2 impacts bulk gas properties of mixture	Thermal conductivity, viscosity, speed of sound	3.2.8	8-9

Table 9 summarized the requirements for hydrogen detection for a DSO and for a TSO use case. The selected technologies (shaded green in Table 11) are now tested against those requirements. Table 13 shows performance for the DSO use case, and Table 15 for the TSO use case. These tables are briefly discussed below.

Modern, miniaturized process GC achieve sub minute response time. The main drawback of GC is its high cost – not only the instrument itself, but also of the gas conditioning system required to connect it to the gas line and the consumable gases. Raman spectrometers on the other hand can be used without a gas conditioning system and process gas. However, the instrument has high cost and may not achieve the required sensitivity to the low pressure ranges needed by DSO. For TSO, on the other hand, the higher end of the pressure range is incompatible with commercial Raman systems.

Metal-hydride based sensors are the only low-cost technology with truly selective sensitivity to hydrogen. This is an emerging technology with only a single commercial instrument available. Being optimized for low pressure, that instrument is not yet suitable for TSO use. It also does not cover all DSO requirements simultaneously. However, this technology holds great promise on the medium term for both TSO and DSO use cases, with several potentially more potent devices under development.

TCD and viscometers are simple and robust technology. Instruments based on them give excellent estimates of hydrogen concentrations for cases where the composition of the natural gas is known with good precision. The same holds for estimates of hydrogen fraction based on speed-of-sound measurements – a functionality which can easily be added to existing ultrasonic flow meters. However, the uncertainty in practice in the

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composition of the natural gas to which the hydrogen is added necessarily introduces uncertainty in the estimated hydrogen fraction. Quantification of that uncertainty would need be done on a case-by-case basis.

Some remarks on the rationale for the used colour coding. In general: Green means that the technology is fully matching the requirement. Orange means that the technology partly meets the requirement and that it is foreseen that further (short term) development will result in result in meeting the full requirements. Red means that the technology does not meet the requirements at all and it is not foreseen that this will be the case in short term (within 5 years).

The colour for 'Unit cost' is based on the experience of the authors with field instrumentation in gas distribution and transport, combined with the foreseen amount of instruments needed in gas grid operation in future.

The colour for 'TRL' is chosen in such a way that we assume that the instrumentation should be available within 5 years.

Table 12: explanation of colour coding used in Table 13.

Quantity	DSO requirement	Unit	Meaning of colour coding		
H_2 concentration	1-30	mol-%	30 mol-%	5 mol-%	1 mol-%
Limit of detection	0.06-0.25	mol-%	0.06 mol-%	0.15 mol-%	>0.25 mol-%
Response time	1-60	minute	1 min	15 min	>60 min
Total pressure	0.02-5	barg	full range	<1 barg	out of range
Gas Temperature	-25 to +55	C	full range	partly in range	out of range
Continuous data acquisition	Yes	-	Yes	No, but potential	No
Unit cost	n.a.	-	<10k	10-50k	>50k
TRL	n.a.	-	9	6 tot 8	<6

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Table 13: Technology evaluation for DSO application. Color coding is explained in Table 12. Appendix 7.3 shows the list of instrument with numerical value of the specs.

Quantity	DSO requirement	Unit	GC	Raman	Metal hydride (now)	Metal hydride (potential)	TCD & viscosity	Speed-of-Sound
H_2 concentration	1-30	mol-%						
Limit of detection	0.06-0.25	mol-%						
Response time	1-60	minute						
Total pressure	0.02-5	bar(g)						
Gas Temperature	-25 to +55	°C						
Continuous data acquisition	Yes	-						
Unit cost	n.a.	EUR			?			?
TRL	n.a.	-						

Table 14: explanation of color coding used in Table 15.Table 12: explanation of colour coding used in Table 13.

Quantity	DSO requirement	Unit	Meaning of colour coding		
H_2 concentration	1-30	mol-%	30 mol-%	5 mol-%	1 mol-%
Limit of detection	0.06-0.25	mol-%	0.06 mol-%	0.15 mol-%	>0.25 mol-%
Response time	1-60	minute	1 min	15 min	>60 min
Total pressure	0.02-5	barg	full range	<1 barg	out of range
Gas Temperature	-25 to +55	C	full range	partly in range	out of range
Continuous data acquisition	Yes	-	Yes	No, but potential	No
Unit cost	n.a.	-	<10k	10-50k	>50k
TRL	n.a.	-	9	6 tot 8	<6

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Table 13

Quantity	TSO requirement	Unit	Meaning of color coding		
H_2 concentration	0-30	mol-%	30 mol-%	5 mol-%	1 mol-%
Limit of detection	0.15-0.3	mol-%	0.15%	2 mol-%	>0.3 mol-%
Response time	1-15	minute	1	10	>15
Total pressure	16-100	barg	full range	<50 barg	out of range
Gas Temperature	+5 to +30	C	full range	partly in range	out of range
Continuous data acquisition	Yes	-	Yes	No, but potential	No
Unit cost	n.a.	-	<10k	10-50k	>50k
TRL	n.a.	-	9	6 tot 8	<6

The research leading to these results has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation under grant agreement n° 101111888.

Table 15: technology evaluation for TSO application. Color coding is explained in Table 14. Appendix 7.3 shows the list of instrument with numerical value of the specs.

Quantity	TSO requirement	Unit	GC	Raman	Metal hydride (now)	Metal hydride (potential)	TCD & viscosity	Speed-of-Sound
H_2 concentration	0-30	mol-%						
Limit of detection	0.15-0.3	mol-%						
Response time	1-15	minute						
Total pressure	16-100	barg						
Gas Temperature	+5 to +30	C						
Continuous data acquisition	Yes	-						
Unit cost	n.a.	EUR			?			?
TRL	n.a.	-						

3.4 Conclusion

For TSO and DSO grids the conclusion is globally the same: current measuring technologies for injection of hydrogen in natural gas fulfilling all requirements are based on GC. The largest disadvantage of the current instrument is the cost level. In future a huge increase in measuring instruments is foreseen, giving a drive for cost reduction. From the lower TRL technologies the most feasible one for fulfilling all requirements, including an acceptable price level, are the innovative metal-hydride technologies. The main challenge regarding application in TSO grids is to make them suitable for high pressure. Another challenge regarding non-GC instruments is that the technology should be approved by the national metrology authority. To get this realized will be time consuming. The same holds for application of gas quality measurement for energy billing.

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4 Review on available standards for gas quality measurement in hydrogen-NG mixtures

This chapter describes a survey on available standards on gas quality measurement in the gas grid, where a investigation has been done to determine the suitability for hydrogen admixing in the gas grid. The gaps on hydrogen admixing are analyzed and recommendations for potential future adaptation of the relevant standards are given.

4.1 Existing standards

Section 3.1 describes how a list of 34 potentially relevant norms and standards was compiled, and reviewed with Euramet. Only standards issued by ISO and/or CEN are considered in the following. All standards that were deemed to be *not* relevant within the scope of this report are listed in Appendix 7.4, with an explanation of why they are not relevant. Table 16 lists the standards that state *what* gases to measure, and in which composition ranges. Table 17 lists standards that state *how* to measure gas composition. Only standards that are potentially relevant for measuring the hydrogen content are shown, so standards pertaining specifically to measuring e.g. water dew point (EN ISO 6327:1981) or ammonia (ISO/CD 2612) are not shown. Each of the standards is briefly discussed in the text below these tables.

Table 16: standards driving quality measurement - *what* components should be measured, and what ranges are needed?

Code	Title
EN 16726:2025	Gas infrastructure - Quality of gas - Group H
EN 16723-1	Natural gas and biomethane for use in transport and biomethane for injection in natural network
EN ISO 6976:2016	Natural gas — Calculation of calorific values, density, relative density and Wobbe indices from composition

Table 17: standards covering techniques to measure quality of natural gas – *how* to measure.

Code	Title
EN ISO 6974-1:2012	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 1: General guidelines and calculation of composition
EN ISO 6974-2:2012	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 2: Uncertainty calculations
EN ISO 6974-3:2018	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 3: Precision and bias
ISO 6974-4:2000	Natural gas — Determination of composition with defined uncertainty by gas chromatography — Part 4: Determination of nitrogen, carbon dioxide and C1 to C5 and C6+ hydrocarbons for a laboratory and on-line measuring system using two columns

ISO 6974-5:2014	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 5: Isothermal method for nitrogen, carbon dioxide, C1 to C5 hydrocarbons and C6+ hydrocarbons
EN ISO 6974-6	Natural gas — Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons using three capillary columns
ISO DIS 6974-4	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 4: Guidance on gas analysis
ISO 6975:1997	Natural gas — Extended analysis
ISO 10723:2012	Natural gas — Performance evaluation for analytical systems
ISO 10715:2022	Natural gas — Gas sampling

EN 16726:2025 defines gas quality for European natural gas networks. It sets limits for Wobbe Index, density, sulfur, oxygen, CO_2, dew points, hydrogen, and methane number. It introduces Wobbe Index classes at exit points and gives entry range recommendations. The goal is safe operation and interoperability. While the main text specifies an upper limit of 2 mol% of hydrogen gas, Annex E sketches the possibility of blending in more hydrogen. Levels, up to 20%, may be possible regionally after safety checks.

EN 16723-1:2017 specifies quality ranges for biomethane injection into natural gas networks and outlines associated measurement techniques. It mandates compliance with EN 16726:2025 for common gas quality parameters and introduces additional biomethane-specific limits, such as volatile silicon, carbon monoxide (CO), ammonia (NH_3), and amines.

EN ISO 6976:2016 specifies in detail how to calculate of calorific values, density, relative density and Wobbe indices on the basis of measured gas composition. The required accuracy of the calorific value sets an error budget for the measurement of various gas components.

The ISO 6974 series establishes standardized methods for determining the composition of natural gas and the associated uncertainty using gas chromatography. Part 1 provides general guidelines and calculation principles, while Part 2 addresses uncertainty evaluation. Part 3 defines performance criteria for precision and bias, ensuring analytical methods meet required accuracy. Parts 4, 5, and 6 specify chromatographic techniques for different contexts: Part 4 for laboratory and on-line systems using two columns, Part 5 for fast isothermal on-line analysis, and Part 6 for extended component ranges (including hydrogen op to 0.5%-vol) using three capillary columns. ISO 6975 describes gas chromatographic methods for extended composition studies in a laboratory setting, including heavy hydrocarbons and aromatics.

Parts 4, 5 and 6 of ISO 6974, as well as ISO 6975 will be replaced in 2026 by a new version of ISO 6974-4, entitled ‘Guidelines and requirements for gas analysis’. A draft is presently available as ISO DIS 6974-4. The introduction of the draft text mentions that admixture of biogas, hydrogen and other gases in natural gas networks is expected to add further complexity to the chromatography spectrum. But the text does not offer any methods to specifically measure hydrogen fractions beyond the present ISO 6975 series. Similar to the current ISO 6974 series and ISO 6975, no other measurement technology than gas chromatography is considered. In particular, no methods are described to measure hydrogen concentrations higher than 0.5%-vol.

ISO 10723:2012 establishes a standardized method for evaluating the performance of analytical systems used in natural gas analysis, ensuring they are fit for purpose across defined composition ranges. It outlines procedures for determining errors and uncertainties in measured gas compositions and derived properties, based on calibration with certified reference gas mixtures. The standard emphasizes careful design of

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calibration gases, experimental protocols, and statistical validation to minimize bias and uncertainty. It recommends initial and periodic evaluations and provides guidance for benchmarking instruments. No assumptions about equipment for and/or methodology of analysis are made in the text, making the recommended performance evaluation relevant for non-GC instruments in principle. However, the practical examples in the Annexes are limited to gas chromatography. Similarly, while the main text makes no explicit reference to any of the constituent gases, the examples in the Annexes focus exclusively on natural gas without hydrogen..

ISO 10715:2022 provides guidelines for obtaining representative samples of natural gas and its substitutes in transmission and distribution systems. It covers principles of sampling, types of methods (direct, spot, incremental, and online), equipment requirements, and considerations for location, contamination, sorption, condensation, and delay time. The standard emphasizes proper design, maintenance, and verification of sampling systems to ensure accuracy in gas quality measurements for safety, operational control, and fiscal purposes, while excluding wet gas sampling and safety procedures. While the only example of an analysis instrument is an online GC, the standard is in principle instrument-agnostic. It ensures sample integrity for any downstream analysis, whether GC or non-GC. The only mention of hydrogen gas in the standard is as a trace contaminant – it is noted that hydrogen gas exhibits strong sorption to container or pipe walls.

4.2 Gap analysis

In this Section it is determined if and how each of the standards of Table 17 needs to be updated to be ready for future blending scenarios. To determine the gap, the following questions are asked:

(1) Is the discussed range of hydrogen volume fraction relevant for realistic blending scenarios?

Even though EN 16726:2025 presently allows only up to 2%-vol of hydrogen, its Annex E outlines scenarios of up to 20%-vol admixed hydrogen. Also, as discussed in Section 2.8, the TSO and DSO partners anticipate a future need for measurement techniques allowing measurement up to 30%-vol hydrogen. Such measurement techniques should at some point be specified in standards.

(2) Is the standard applicable to non-GC sensors?

If and when hydrogen admixture in the gas network takes off in the future, there may be many small and large feed-in points in the network at which hydrogen volume fraction will need to be monitored. In view of the availability of non-GC sensors and the high cost and slow response time of GC (Section 2.8), it may be attractive to use non-GC sensors for this purpose. If such sensors become wide-spread, harmonized standards will be needed.

The answers to these two questions are summarized in Table 18. As explained in Section 4.1, ISO DIS 6974-4 is expected to replace parts 4, 5 and 6 of ISO 6974, as well as ISO 6975. Therefore, only ISO DIS 6974-4 will be considered for the gap analysis. In the text after the table, these results are discussed.

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Table 18: gap analysis of quality measurement standards in the context of hydrogen blending.

Code	Title	Ok for 30%-vol hydrogen?	Applicable to non-GC sensor?
ISO 6974-1:2012	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 1: General guidelines and calculation of composition	Yes*	No
ISO 6974-2:2012	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 2: Uncertainty calculations	Yes*	No
ISO 6974-3:2018	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 3: Precision and bias	Yes*	No
ISO DIS 6974-4	Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 4: Guidance on gas analysis	No; only <0.5%-vol hydrogen	No
ISO 10723:2012	Natural gas — Performance evaluation for analytical systems	Yes, but hydrogen is not in examples in the Annex	Yes
ISO 10715:2022	Natural gas — Gas sampling	Yes**	Yes

*GC expert assessment needed to check implicit dependences on hydrogen concentration.

**Gas sampling expert assessment needed; hydrogen is assumed to be trace component

The whole series ISO 6974 is exclusively concerned with GC analysis. Parts 1-2-3 of this standard are concerned with general guidelines, uncertainty and precision. It is unclear to the authors if these standards can be used directly if and when higher hydrogen concentrations will need to be analyzed. The future standard ISO DIS 6974-4 is not currently usable for hydrogen analysis in the range up to 20%-vol foreseen for future blending scenarios. Indeed, there is currently no standard that discusses any measurement technique (GC or otherwise) to measure high concentrations of hydrogen in natural gas.

ISO 10723:2012 covers performance evaluation of analytical systems (both GC and other instruments) to measure quality of natural gas. While the examples in the Annexes do not cover hydrogen, all the concepts and prescriptions in the main text are one-to-one relevant for sensors to measure hydrogen.

ISO 10715:2022 covers sampling of natural gas, in order to perform quality measurement. The quality measurement can be done with any technology, GC or otherwise. Hydrogen is assumed to be only a trace component in the gas for this standard. Therefore, it is unclear if the recommendations are directly applicable for situations with high hydrogen fraction.

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4.3 Recommendations

The draft standard ISO DIS 6974-4 is planned to replace the current ISO 6974-4/5/6 in 2026. It is a detailed technical description of GC systems to measure natural gas composition. However, only hydrogen concentrations <0.5%-vol are discussed, so it is not ready for future blending scenarios. Therefore, a future version of ISO 6974-4 should be extended to cover analysis by GC of hydrogen fractions up to at 20%-vol and preferably up to 30%-vol. This is needed both for online and lab-based analyses.

If and when hydrogen admixture in the gas network takes off in the future, there may be many small and large feed-in points in the network at which hydrogen volume fraction will need to be monitored. In view of the availability of non-GC sensors and the high cost and slow response time of GC (Section 2.8), it can be anticipated that simple, fast and cheap non-GC sensors to exclusively measure hydrogen fraction will become widespread. Presently, no standards exist on how to operate these sensors. Therefore, such standards should be formulated.

The standards ISO 6974-1-2-3 describe general guidelines for natural gas composition determination using gas chromatography, including determination of uncertainty, precision and bias. These standards need review by a GC expert to assess readiness for 20-30%-vol hydrogen. It may be that there are implicit dependences on hydrogen concentration.

The standard ISO 10715 describes how to properly sample natural gas, in order to conduct accurate composition analysis. This standard needs review from an expert to assess if the recommended gaskets for sample containers are ready for 20-30% hydrogen.

To achieve uptake of these recommendations for standards adaption, after publication of this report the relevant Technical Committees should be contacted:

- ⇨ ISO TC 193 Natural gas
- ⇨ ISO TC 158 Analysis of gases

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5 Overall conclusions and recommendations

An investigation on the requirements for measuring technologies of hydrogen in natural gas with all involved TSO's and DSO's in this project gives the following main requirements.

- Hydrogen concentrations up to 30 mol% should be measured, with an accuracy in the order of 0.1 mol%. The response time should be at least 1 minute. The pressure and temperature ranges are in line with the specific grid conditions and should be up to 100 bar(g) and 55 °C respectively. For both TSO and DSO a continuous data acquisition is needed.
- The number of sensors needed are for both TSO and DSO in the order of thousands. For TSO the foreseen locations are at the entry and exit points. For DSO the number of sensors needed could even be more, because some DSO foresee also measuring points in the pressure reducing stations.
- The timeline for availability of the sensors for TSO is more urgent (before 2030) than for DSO (beyond 2030). Here, one can see the highest priority of hydrogen admixing at TSO in accordance with the current EU developments.
- The DSO partners are interested in using simulation tools to determine the hydrogen concentration in their networks, but they have no concrete plans at this stage. For the TSO partners the picture is mixed. Most of them already have simulation tools available. Some of them use them already for natural gas / biomethane mixtures, but not as an operational tool. All of them see an added value of the combination of simulations tools, supported by field instrumentation in case of changing gas composition in general.

The survey on measuring technologies for injection of hydrogen in natural gas grids leads to the following conclusions and recommendations. Because of needed availability around 2030 (in general) only currently available instruments and evolving technologies above TRL5 are taken into account.

- For TSO and DSO grids the conclusion is globally the same: current measuring technologies for injection of hydrogen in natural gas fulfilling all requirements are based on GC. The largest disadvantage of the current instrument is the cost level.
- Besides GC, also Raman could be used in case of substantial cost reduction
- In future a huge increase in measuring instruments is foreseen, giving a drive for cost reduction. From the lower TRL technologies the most feasible one for fulfilling all requirements, including an acceptable price level, are the innovative metal-hydride technologies. The main challenge regarding application in TSO grids is to make them suitable for high pressure.
- Other lower TRL technologies, like TCD/viscosity and Speed-of-Sound, could be interesting new technologies if technical breakthroughs are found for the lower limit of the hydrogen concentration.

The survey on relevant standards in the frame of hydrogen injection in the grid leads to the following conclusions and recommendations:

- When hydrogen admixture in the gas network takes off in the future, there may be many small and large feed-in points in the network at which hydrogen volume fraction will need to be monitored. In view of the availability of non-GC sensors and the high cost and slow response time of GC, it can be anticipated that simple, fast and cheap non-GC sensors to exclusively measure hydrogen fraction will become widespread. Presently, no standards exist on how to operate these sensors. Therefore, such standards should be formulated.
- The draft standard ISO DIS 6974-4 is planned to replace the current ISO 6974-4/5/6 in 2026. It is a detailed technical description of GC systems to measure natural gas composition. However, only hydrogen concentrations <0.5%-vol are discussed, so it is not ready for future blending scenarios. Therefore, a future version of ISO 6974-4 should be extended to cover analysis by GC of hydrogen fractions up to at 20%-vol and preferably up to 30%-vol. This is needed both for online and lab-based analyses.

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- The standards ISO 6974-1-2-3 describe general guidelines for natural gas composition determination using gas chromatography, including determination of uncertainty, precision and bias. These standards need review by a GC expert to assess readiness for 20-30%-vol hydrogen. It may be that there are implicit dependences on hydrogen concentration.
- The standard ISO 10715 describes how to properly sample natural gas, in order to conduct accurate composition analysis. This standard needs review from an expert to assess if the recommended gaskets for sample containers are ready for 20-30% hydrogen.
- To achieve uptake of these recommendations for standards adaption, after publication of this report the relevant Technical Committees should be contacted: ISO TC 193 Natural gas and ISO TC 158 Analysis of gases

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7 Appendices

7.1 Questionnaire

The questionnaire contained the following questions:

- What applications do you see for measuring hydrogen volume fraction? What will you do with the data in terms of network management?
- Where in the grid will you measure the hydrogen concentration? How many points?
- What is the requirement measurement range (minimum and maximum hydrogen volume fraction)?
- What is the required measurement accuracy?
- Do you plan continuous measurement, or taking a sample in the field and analyzing it in lab?
- In case of continuous measurement, should the sensor be inside the main gas pipe, or can it be in a bypass?
- In case of continuous measurement, what response time is needed?
- How do you collect the data? Live over the air? Locally stored, periodically collected?
- What are the operational conditions of the hydrogen concentration sensor in terms of pressure, temperature, flow rate?
- If you already use or plan to use a specific hydrogen concentration sensor, what type of sensor? If possible, share brand and model.
- Do you envision using simulation tools in determining the hydrogen concentration in your network? Do you envision combining this with sensors?
- When (what year) do you need the capability to measure hydrogen vol-% in your network?

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7.2 Initial list of literature sources used in Chapter 3 and Chapter 0

Document	Project/org	Remark
Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users. - Gerg	H2NG	Used to compile initial lists of instruments, measurement technologies and norms/standards. December 2021.
A1.3.2-Protocol-for-testing-of-sensors-final.pdf	MET4H2	MET4H2; Test protocols to determine metrological specs of H2 detection devices (specs are from ISO 26142)
Deliverable 1.1 – SoA of measuring devices installed in NG transmission and distribution networks - THOTH2	THOTH2	Aug 2023. Flow and quality. Quality is split up into "water", for which many technologies are discussed, and a single section on "GC". No specific instruments, just the physics/technology of GC. It's taken for granted that the goal of the GC is to measure energy content.
THOTH2_WP1_1.2_Barriers-and-gaps-of-SoA-NG-transmission-and-distribution-measuring-devices	THOTH2	Gas composition analysers exist to measure H2 fraction up to 100%, but not used by TSO/DSO because too new! Table 17 contains review of roughly 10 documents discussing GC application to NGH2 mix.
THOTH2_WP1_1.3_Normative-gaps-towards-H2NG-gas-grid	THOTH2	Norms for measuring flow and quality of NG/H2 mixtures; only GC mentioned; recommendations for adapting norms.
Hydrogen-regulation.pdf	Marcogaz	Recent (2024) overview of blending per EU country. Marcogaz
EMPIR-Decarb-Report-A2.3.2-M13	EMPIR decarb	A brief survey about the available techniques for fast online measurement of hydrogen in natural gas; PTB, BAM
DECARB-Hydrogen-and-hydrogen-enriched-natural-gas-Task-1.1.5-1	EMPIR decarb	Nothing about measuring quality.
20231002-H2-Infographic-2023	Marcogaz	What application can deal with what %-H2? Nothing about measurement of quality.
GERG CEN PNR - Summary Report of key findings WP1 to 8	GERG CEN H2 PNR	GERG CEN H2 PNR Project: Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users. Relevant conclusion: Dew-point and O2 sensors are available - "Gas Chromatography" is ok up to 20% H2, but not up to 100% H2.
A1.3.1 - Review state-of-the-art sensors final updated.pdf	MET4H2	MET4H2; SOA sensors in H2 industry; cites GERG list of instruments
Marcogaz_guidance.pdf	Marcogaz	Guidance Note on Energy Determination when Non-Conventional Gases are injected into the Gas Network; only talks about ENERGY determination. However, very nice and technical. Where to place GC?
BAM - Startseite - The H2Sense Hydrogen Sensor Database	BAM	BAM database of ALL H2 sensors commercially available as of 2015, hundreds of entries! MOSTLY leak detection, but there is also entry 'methane'.
Gas Quality Monitoring Report – First Edition	ENTSOG	
biostar 2c project.	GERG	how much H2 can one inject in BioMethane? Bio Methane then injected into grid.

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7.3 Technical information per instrument

Quantity	unit	gas chromatograph 1	gas chromatograph 2	gas chromatograph 3	ion mass spectrometer	Raman spectrometer 1	Raman spectrometer 2	Metal Hydride 1	Metal Hydride 2: TNO: capacitive chip	Thermal conductivity	Viscosity	speed-of-sound (ultrasonic flow meter)
H2 concentration: LoD	%-mol	?	0.001	0.1	?	0.05	0.06	0.0015	0.1	?	?	?
H2 concentration: max	%-mol	20	20	20	100	100	100	100	30	100	30	100
Response time	min	?	1	0.75	0.005	0.17	1.00	1.5	5	0.02	0.02	0.17
Operating pressure min	bar	?	1	1	0.1	10	14	1	1	0.9	1	0.8
Operating pressure max	bar	?	2	2	30	75	68.9	7	10	200	16	20
Operating temperature min	C	-20	-20	-20	?	-20	-20	-40	10	-40	-20	-20
Operating temperature max	C	60	55	55	?	55	50	60	46	90	55	80
Unit cost	kEUR	?	70	25	60	80	70	?	<10	5	13	?

7.4 Non-relevant standards

norm	body	quality of natural gas in scope?	quality measurement tech in scope?	Relevant for hydrogen fraction?
ISO 13686:2013(en), Natural gas — Quality designation	ISO	yes	no	
ISO 14532:2014(en), Natural gas — Vocabulary	ISO	yes	yes	
CEN/TS 17977 : quality of H2 in rededicated infrastucture	CEN	no		
D1945 Standard Test Method for Analysis of Natural Gas by Gas Chromatography	ASTM	yes	yes	
EN 1776:2015 Gas infrastructure - Gas measuring systems - Functional requirements	CEN	no		
Technische Richtlinien G 14 „Messgeräte für Gas; Einspeisung von Biogas in das Erdgasnetz“. Ausgabe 11/07, - PTB-OAR	PTB		no?	
Technische Richtlinien. Messgeräte für Gas. G 19 „Wasserstoff im Gasnetz“. Ausgabe Februar 2023	PTB		no?	
ISO/IEC 17025 norm voor algemene eisen voor de competentie van test- en kalibratielaboratoria	ISO	no	yes	
ISO 14111 Aardgas - Leidraad voor de herleidbaarheid in de analyse (wordt 2026 herzien)	ISO		no	
ISO 20765-2 “Natural gas - Calculation of thermodynamic properties”	ISO	no	no	

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ASTM D7607 “Standard Test Method for Analysis of Oxygen in Gaseous Fuels (Electrochemical Sensor Method)”	ASTM	yes	yes	
ISO/CD 2612 “Analysis of natural gas — Biomethane ¬-- Determination of ammonia content by Tuneable Diode Laser Absorption Spectroscopy”	ISO	yes	yes	no
EN ISO 6327:1981 “Gas analysis — Determination of the water dew point of natural gas — Cooled surface condensation hygrometers”	ISO	yes	yes	no
EN ISO 10101 “Natural gas — Determination of water by the Karl Fischer method”	ISO	yes	no	
ISO 26142:2010 “Hydrogen detection apparatus - Stationary applications” - Hydrogen	ISO	no	no	
EN 50402 “Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or oxygen - Requirements on the functional safety of fixed gas detection system” – Hydrogen	CEN	no		
EN 50402 “Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or oxygen - Requirements on the functional safety of fixed gas detection system”	CEN	no		
FM 6310/6320 “Approval Standard for combustible Gas Detectors” – Hydrogen		no		
CSA C22.2 No. 152-M1984 “Combustible Gas Detection Instruments” – Hydrogen		no		
ISO 14687: Hydrogen fuel quality		no		
UL 2075 “Gas and vapour detectors and sensors”		no	yes	

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