D1.2

Barriers and gaps of SoA NG transmission and distribution measuring devices in H2NG flows

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Acronyms and symbols

ATEX cert.	Certificate for equipment intended for use in explosive atmospheres
CEN	Comite Europeen de Normalisation
CENELEC	European Committee for Electrotechnical Standardization
CRDS	Cavity ring-down spectroscopy
D	Relative density
DNV	Det Norske Veritas
DSO	Distribution System Operator
DVGW	German Technical and Scientific Association for Gas and Water
EMC	Electro Magnetic Compatibility
EVCD	Electronic Volume Conversion Device
FID	Flame Ionization Detector
FTIR	Fourier-transform infrared spectroscopy
FW	Firm ware
GC	Gas Chromatography
GC-FPD	Gas chromatography-fFlame pPhotometric dDetector
GC-MS	Gas chromatography-mass spectrometry
GC-PDHID	Plasma discharge hydrogen-induced detection
GC-SCD	Gas chromatography with sulfur chemiluminescence detection
GC-TCD	Gas chromatography with thermal conductivity detection
GS(M)R	Gas Safety (Management) Regulations
H2NG	Hydrogen added natural gas (hydrogen content in natural gas from 0 to 100%)
Hi	Inferior calorific value; molar
HiM	Net heating value based on mass
HiV	Net heating value based on volume
Hs	Heating value; molar
HsM	Gross heating value based on mass
HsV	Gross heating value based on volume

M	Molar mass (of the mixture)
MID	Measuring Instruments Directive
MPE	Maximum Permissible Error
MZ	Methane number
N/A	Not applicable
NDIR	Non-Dispersive Infrared
NG	Natural gas
Ofgem	The Office of Gas and Electricity Markets
OIML	International Organization of Legal Metrology
PGC	Process Gas Chromatographs
PTB	The Physikalisch-Technische Bundesanstalt
Qmax	Maximum Flow Rate
Qmin	Minimum Flow Rate
RDTD	Resistance Temperature Detector
Rho	Density at base conditions(standard density)
SNR	Signal to noise ratio
SoA	State of Aart
TCD	Thermal Conductivity Detector
THC	Total hydrocarbon content
THT	Tetrahydrothiophene
TSO	Transmission System Operator
Vol.	Volume
Wi	Net Wobbe index
WME	Weighted mean error
WP	Work package
Ws	Gross Wobbe index
Z	Compressibility factor

The extended name of the THOTH2 partners is reported in the Deliverable D1.2 as indicated in Table 1.

Table 1. Partners' extended name, country and acronym.

Partner extended name (country)	Acronym
SNAM S.P.A. (ITALY)	SNAM
ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA (ITALY)	UNIBO
LE GROUPE EUROPEEN DE RECHERCHES GAZIERES (BELGIUM)	GERG
OPERATOR GAZOCIAGOW PRZESYLOWYCH GAZ-SYSTEM SPOLKA AKCYJNA (POLAND)	GS
GRTGAZ (FRANCE)	GRTGAZ
INSTYTUT NAFTY I GAZU - PANSTWOWY INSTYTUT BADAWCZY (POLAND)	INIG
ENAGAS TRANSPORTE SA (SPAIN)	ENAGAS
FONDAZIONE BRUNO KESSLER (ITALY)	FBK
EIDGENOSSISCHES INSTITUT FUR METROLOGIE METAS (SWITZERLAND)	METAS
INRETE DISTRIBUZIONE ENERGIA S.P.A. (ITALY)	INRETE
CESAME-EXADEBIT SA (FRANCE)	CESAME
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE (ITALY)	ENEA
ISTITUTO NAZIONALE DI RICERCA METROLOGICA (ITALY)	INRIM

1. Introduction and executive summary

Injecting hydrogen into existing gas networks requires several actions to assess the content of hydrogen in the H2NG mixture that can be transported through gas pipelines. One of the areas that needs to be evaluated is the field of gas quality and quantity measurements. The Task 1.2 "Technical and performance barriers and limitations" aimed to identify barriers and gaps related to measurement devices such as gas meters, volume converters, pressure and temperature transducers, process gas chromatographs, dew point transducers, and leak detectors. By defining this measurement area, it allows identifying gaps and barriers concerning custody transfer measurements (gas volume and heating value). Due to the different physicochemical properties of hydrogen and methane, the identification of barriers and considerations includes not only the measurement capabilities of devices for H2NG mixtures but also the resistance of design solutions to the effects of hydrogen. The assessment of the state-of-the-art technology was conducted based on a literature review, including the outcomes of projects such as "HyDeploy 2 Project" and "HyWay 27: hydrogen transmission using the existing natural gas grid?". The literature review was complemented by feedback gathered from surveys sent to manufacturers of measurement devices, selected based on the results of Task 1.1. The analyses conducted allowed identifying the following gaps and barriers:

- In the area of gas composition analyzers: there are solutions available that allow measuring the composition of H2NG mixtures with up to 100% hydrogen content. However, these solutions are not currently utilized by Transmission System Operators (TSOs) and Distribution System Operators (DSOs), since they entered in the market recently.
- In the area of dew point transducers: there are solutions resistant to hydrogen up to 20% content, and they are partially used by TSOs and DSOs.
- In the area of leak detectors: there are solutions that can be used by operational services on gas networks transporting H2NG mixtures. These detectors allow measuring hydrogen content in the air from 0 to 100% of the lower explosive limit. This range is sufficient to ensure safe network operation. However, such leak detectors are not currently employed by TSOs and DSOs.

2. SoA devices in NG infrastructure

As the interest in hydrogen as an alternative energy source grows, the adaptability of measurement devices in natural gas infrastructure to hydrogen-natural gas mixtures has become a crucial area of research. Task 1.1 involved analyzing the metering equipment installed in the Italian, French, Polish, and Spanish gas networks.

Data was collected from four natural gas transmission operators, namely SNAM, GAZ-SYSTEM, Enagás, and GRTGAZ, which together have a total gas network length exceeding 96,000 kilometers, representing around 50% of the entire length of the EU's natural gas transport infrastructure which accounts around 200,000 km. Regarding the gas distribution infrastructure, data has been provided by INRETE, partner of the THOTH2 project and one of the main Italian DSO. Task 1.2. focuses on identifying, in a comprehensive manner, the known and potential technical barriers that affect the metering equipment currently operating in NG networks in the case of H2NG operation.

To achieve this goal, it was assumed to review research work and publications completed to date, and to interview device manufacturers regarding H2Ready of their devices. Given the vast number of possible combinations in measuring devices, operative conditions (such as pressure, temperature, and flow), and installation conditions, this investigation will incorporate inputs from Task 1.1.

The primary objective of Task 1.2 is to thoroughly examine the existing literature and conduct questionnaires with sector stakeholders. The aim was to identify the state of the art (SoA) and any missing information related to the operative conditions that were identified in Task 1.1.

Once the gaps are categorized, the task group will proceed to evaluate potential solutions for each area of concern while taking into consideration the primary barriers that might hinder the implementation of these proposed solutions. The outcomes of this task will be shared with WP2, where the missing information at the state of the art will be confirmed.

The successful achievement of the task's goals was ensured through the participation of the consortium's primary users, such as gas Transmission System Operators (TSOs) and Distribution System Operators (DSOs).

A review of the literature and reports is presented in Section 2.1.

To conduct a survey of device manufacturers effectively, the first step was to create a comprehensive database of these devices. To accomplish this, the teams involved in Task 1.1 and Task 1.2 collaborated to prepare a summary of all measuring devices available in the market. The data was categorized based on the technology used, manufacturer details, and specific device models.

To streamline the analysis process, the teams made a decision to exclude devices that accounted for less than 5% of the total quantity in a given technology. This helped focus on the most prevalent and widely used devices in the industry.

The collected information and data on measuring devices have been organized and presented in Tables 2-7, providing a concise and clear overview of the available devices and their characteristics. This database will serve as a valuable resource for conducting the survey and gaining insights into the adaptation of these devices for hydrogen-natural gas mixtures.

However, the answers of the manufacturers have been anonymized for confidentiality reasons.

Legend for Table 2.

	Turbine
	Rotary
	Ultrasonic
	Coriolis
	Thermal mass
	Diaphragm

Table 2. Gas meters from European TSOs.

Manufacturer	Type
ACTARIS / SCHLUMBERGER / ITRON	FLUXI 2000/TZ
ACTARIS / SCHLUMBERGER / ITRON	MZ
ACTARIS / SCHLUMBERGER / ITRON	DELTA
ACTARIS / SCHLUMBERGER / ITRON	QD25
ALSI	MARK II TURBOMETER
CALDON	CAMERON LEFM 380Ci
COMMON	CGT-01
COMMON	CGT-02
COMMON	CGR-01
COMMON	CGR-FX
DANIEL	DANIEL
ELSTER - INSTROMET - HONEYWELL	EQZ
ELSTER - INSTROMET - HONEYWELL	SRZ
ELSTER - INSTROMET - HONEYWELL	TRZ
ELSTER - INSTROMET - HONEYWELL	TRZ2
ELSTER - INSTROMET - HONEYWELL	SM-RI-X-K
ELSTER - INSTROMET - HONEYWELL	Q75
ELSTER - INSTROMET - HONEYWELL	Q/QA
ELSTER - INSTROMET - HONEYWELL	IRM
ELSTER - INSTROMET - HONEYWELL	RVG
ELSTER - INSTROMET - HONEYWELL	RABO
ELSTER - INSTROMET - HONEYWELL	RABO
ELSTER - INSTROMET - HONEYWELL	QSONIC
ELSTER - INSTROMET - HONEYWELL	SENIOR SONIC
EMERSON	T200
ENDRESS HAUSER	PROMASS F300
ENDRESS HAUSER	PROMASS F500
ENERGO FLOW	GFE-202
FLEXIM	FLUXUS
FMC TECHNOLOGIES - INTERGROTECH - TECHNIP FMC	MPU
FMG	FMT-LX
FMG	FMR
GE SENSING	XGM868I
GFO-RM	API-GFO
KROHNE	ALTOSONIC V12

Manufacturer	Type
KROHNE	OPTISONIC 7300
OFFICINE OROBICHE	DARF
PETROL	FA11-12-C8
PETROL	FH11-12-C8
PIETRO FIORENTINI / DRESSER	IMTM-CT
PIETRO FIORENTINI / DRESSER	IM-RM
PIETRO FIORENTINI / DRESSER	FIOSONIC
PIETRO FIORENTINI / DRESSER	FIOSONIC
RHEONIK	RHM 15 L
RMA	ECO SONIC X12
RMG	TRZ3
RMG	USZ-08
ROMET	RMT
SICK	FLOWSIC 600
SICK	FLOWSIC 500
SICK	FLOWSIC300
SIEMENS	SITRANS
TANCY	TBQM
TRANSUS INSTRUMENTS	UIM 4F
ULTRAFLUX	ULTRAFLUX
VEMMTEC	IGTM
VEMMTEC	OMEGA VI
ENDRESS HAUSER	PROLINE I-MASS-F.100
KURZ - PETROLVALVES	534FTB-06A
KURZ - PETROLVALVES	534FTB-06H
FCI	ST51
ELSTER - INSTROMET - HONEYWELL	BK
ACTARIS / SCHLUMBERGER / ITRON	ACD
ACTARIS / SCHLUMBERGER / ITRON	G
INTERGAZ	BK
METRIX	UG
METRIX	2G10
METRIX	2G25
METRIX	2G40
METRIX	2G65
METRIX	3G4
METRIX	4G6
METRIX	6G4
METRIX	6G6
ELEKTROMETAL	EM-G
ITRON	UNKNOWN

Table 3. Pressure and temperature transmitters from European TSOs.

Manufacturer	Pressure transmitter	Temperature transmitter
	Type	
YOKOGAWA	EJA310	YTA110
	EJA430	YTA310
	EJA510	YTA 610
	EJA530	YTA 70
	EJX110	YTA70-E/DS2
	EJX310	YTA70-E/KS2
	EJX430	YTA70-J/KS2
	EJX510	-
	EJX530	-
	EJX610	-
ROSEMOUNT	1151	3144
	2088	644H
	3051	-
	2051	-
	2052	-
	2053	-
	2054	-
APLISENS	APC-2000	APT-2000ALW
	APR-2000	APT-28
	P 205	APTOPGB
	PC-28	APTOPZ
	PC-50	APTR-1
	PS-28 SMART/M/PD	AT2/CT-Z1
	-	ATX-2
	-	CT-16/220/PT100
	-	CT3
	-	CT-GN1
	-	LI-24G
	-	PT-100
ABB	266NSH	TS 02/TS 02-Ex
	AMD 200	-
	AMD 230	-
	ASD 800	-
	ASD 810	-
COMMON	3051 CA	-
	3051 CG	-
EMERSON	2088	644H
	3051	-
ENDRESS-HAUSER	Cerabar M PMP51	Omnigrad S TC88
	Cerbar S PMP71	Omnigrad S TR88
		Omnigrad T TST434
		TMT 142R
		TMT 182
		TMT82
		TR01
		TST434-J1A3BK
HONEYWELL	ST 3000	-
	STA 940	-
	STD 120	-
	STD 924	-
	STG 170V	-
	STG 944	-
	STG 974	-
	YSTA97L	-
SIEMENS	7MF4020	-

Table 4. Gas chromatographs from European TSOs.

Manufacturer	Type
Gas composition	
ABB	NCG 8206
	PGC 1000
	TOTALFLOW 8100
	BTU 8000
	NGC8206
AGILENT	490
DANIEL	500/2350
	700
	DANALYSER 571
	DANALYSER 575 E
YAMATAKE	HGC303
SRA INSTRUMENTS	A-3000 NGA+
DANALYZER	700XA
	370XA
	500
	500 FPD
	700
	700E
	700LW
	700XA
	700XA FPD
	700AX
ENCAL	3000
	3000 DUAL
	3000QUAD
MECI	CVM16
	MGC16
	PES15
Odorant (THT) and sulfur compounds	
Agilent	990
Chrompack-THT	CP2002
Emerson	Danalyzer™ Model 500 FPD
Varian	4900

Table 5. Volume converters from European TSOs.

Manufacturer	Type
ELSTER / HONEYWELL	ENCORE FC1
EX-I FLOW	SFC3000
INSTROMET / HONEYWELL	FC2000
KROHNE	SUMMIT 8800
D&D ELETTRONICA	IMP-8FC
D&D ELETTRONICA	IMP-FC-1/PS
D&D ELETTRONICA	IMP-FC2
I.G.S. DATAFLOW	FLOWTI 702-1
I.G.S. DATAFLOW	FLOWTI 704
I.G.S. DATAFLOW	FLOWTI T702
I.G.S. DATAFLOW	LOGTI L222
I.G.S. DATAFLOW	FLOWTI T600
I.G.S. DATAFLOW	FLOWTI T502
FIORENTINI	Explorer plus
FIORENTINI	FIOMEC 12
FIORENTINI	FloWEB
FIORENTINI	EXPLORER
FIORENTINI	FIOMEC 10
FIORENTINI	FIOMEC 22
FIORENTINI	FIOMEC
FIORENTINI	FIOMEC 21
I.G.S. DATAFLOW	FLOWTI T500
I.G.S. DATAFLOW	FLOWTI T504
SCHLUMBERGER	COMPLEX 3C
SCHLUMBERGER	COMPLEX C
SCHLUMBERGER	COMPLEX 3V
SCHLUMBERGER	SEVC-D
SCHLUMBERGER	PTZ EX
SCHLUMBERGER	COMPLEX V
SCHLUMBERGER	CORIN
KAMSTRUP	UNIGAS 300
FIMIGAS	ICARUS
FIMIGAS	VESCOM 3
CPL	ECOR3
CPL	ECOR2
CPL	EFLO
EMERSON	FloBoss S600
EMERSON	FloBoss S600+
PLUM	MACMAT II
PLUM	MACMAT IV
PLUM	MACMAT III
PLUM	MACBAT II
PLUM	MACBAT IV
PLUM	MACMAT
PLUM	MACBAT
PLUM	MACBAT III
INTEGROTECH	MSP-02-FC
INTEGROTECH	MSPR-4.0-FC
COMMON	CMK-02
COMMON	CMK-01

Manufacturer	Type
COMMON	CMK-03
COMMON	DOMINO
RMG	ERZ 2000
ELGAS	ELCOR 95
MECI	CDN 12-3
MECI	CDN 16
MECI	CDV 12
MECI	CDV 15
MECI	CDV 15 - 3B
MECI	CDV 15 - 3H
MECI	CDV 15 - 3L
SIS	ENVOL
SIS	MEDITEL

Table 6. Water and hydrocarbon dew points analysers from European TSOs.

Manufacturer	Model
Water dew point	
Ametek	OLV 3050
Bartec	L1660
E+E Elektronik	EE300EX
Endress & Hauser	Spectrasensor
GE Industrial	MIS-2
	MMS3
General Electric	Aurora H2O
Honeywell	4112
Michell Instruments	Condumax II
	Easidew PRO IS
	PROMET EExd
	SPF52
	Transmet I.S.
	TDL 600
Hydrocarbon dew point	
Ametek	241CE II
Michell Instruments	Condumax II

Table 7. Fixed and Portable leak detectors from European TSOs.

Manufacturer	Type
CROWCON	Triple Plus
	Gasman
	Gasman II
FLUKE	ii900
GAS TRAC (SENSIT)	LZ-30
SENSIT	HGX-3P
ALTER	MGX70
ATEST-GAZ	SmartGas 4
	ALPA PicoGaz
	DG
	ALPA -SmArt
	ALPA SmArtGaz-3
	PW-017
	PW-044
	SmartGas 4
DET-TRONICS	PIRECLB4A1T1
DRAGER	Polytron Ex
	XAM-2500
	XTR 0000
GAZEX	DEX/A
	DEX/C
	DEX/F
	DEX/F4
	DEX/F4-B
	DEX/F4-C
	DEX/F6-B
	DEX/FA
	DEX/FA-B
	DEX/P4
	DEX/T
	DEX-12/N
	DEX-1R2/N
	DEX-22/NL
	DEX-71
	DEX-72/N
	DG
	DG/F
	DG-12
	DG-12/N
	MS-12/N2F
JBK FHU	NET-EX-STD-3G-PEL-CH4
MSA	Altair 4
	Altair 5
OLDHAM	OLCT 100XP
	CEX 800
	OLCT 100XP
	CEX 810 AD
	CEX 800

2.1 Design survey for devices manufacturers

Data from Tables 2 to 7 served as the foundation for creating the survey form, which involved carefully selecting relevant questions to obtain essential details for the research problem.

Creating a survey on natural gas transmission network measurement devices required an organized approach, leading to the development of a structured questionnaire that encompassed both essential research aspects and appropriate formal elements. This ensured the consistency and reliability of the collected data.

Clear instructions were included at the beginning of the survey to provide respondents with guidelines on accurately completing the form. This ensured that respondents had the necessary information to provide precise and accurate answers (Figure 1).

INSTRUCTIONS

Required information / data: To maintain the survey as general as possible, we did not specify the models of gas meters you are manufacturing. Therefore, since the answer to some of the following questions could be different based on the model of the gas meter, if possible, please specify it in the available "free" space.
However, in case of doubts or where we believe integration could be helpful to avoid the wrong interpretation, we will contact you directly through the contact information you indicated in the previous sheet.
If you are implementing a gas meter project that still needs an EU Type Examination Certificate but will have one and can be helpful for our project (H2Ready), feel free to provide its parameters.

How to use the excel file: to move from one sheet to another, you can directly select the sheet or you can use the automatic links in the **GREEN CELLS.**

How and where fill the data: data should be filled in the following way based on the colour of the cell:
1) **YELLOW CELLS**: automatic answer from a defined list has to be selected. Based on your answers, different questions appears automatically in the sheet
2) **SKY BLUE CELLS**: you should write your answers in the cells.

ERRORS: if a **RED CELLS** automatically appears, an error in filling the survey occurred. Follow the indications to solve it.

Acronyms:
H2NG - mixture of natural gas and hydrogen
NG - natural gas
H2 - hydrogen

Question	
Are the instruction clear?	YES

LINKs	**Select the link below**
GO TO THE INTRODUCTION AND AIMS	'Introduction and aims'!A1

Figure 1. First sheet of the survey – instructions.

In the following part of the survey, an introduction was included to explain the context and objectives of the research. The significance of the gathered data and its utilization in the studies were described – as depicted in Figure 2.

INTRODUCTION AND AIMS

THOTH2 project is funded by the Clean Hydrogen Partnership (**G.A. n. 101101540**) and coordinated by SNAM.

The EU's energy strategy requires an immediate shift in focus toward energy independence and a transition to green energy. However, technological, economic, and normative constraints must be overcome for innovative solutions to be accepted by society.

THOTH2 project aims to answer how new mixtures may coexist with existing installed devices in the gas value chain, such as measurement ones, to promote H2 blending in the future. The question could be addressed by specific testing. The normative framework, which includes testing procedures for mixes of hydrogen and natural gas (H2NG), is still being built.

When conveying pure H2 or H2NG mixtures, **THOTH2 intends to fill the gaps in normative standards related to procedures and protocols for assessing the performances and determining the limits and tolerances of State of the Art (SoA) measurement instruments in NG transmission and distribution systems**. To test various measuring devices installed in the grids, such as gas meters, gas volume conversion devices, pressure and temperature transducers, gas quality analyzers, and gas leak detectors, at various operational conditions, **THOTH2 will develop specialized methodologies**.

The findings of THOTH2 will help form suggestions for the Technical Committees (TC) of International Standard Bodies, Gas Transmission and Distribution Operators (TSOs, DSOs), Manufacturers of Measuring Devices, and Calibration Service Providers.

INDEX

n°	Title
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2	Introduction and aims
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4	Measuring devices list
4.1	Gas meters
4.2	Gas pressure and temperature transmitters
4.3	Volume converters
4.4	Gas quality analysers (cromatographs)
4.5	Leak detectors
4.6	Trace water sensors
5	End of the survey

PLEASE PROCEED TO THE "CONSENT FORM" SHEET - USE THE LINK BELOW (GREEN CELL)

LINKs	Select the link below
CONSENT FORM	Consent form'!A1

Figure 2. Second sheet of the survey - introduction and aims.

Important elements of the survey included formal sections, comprising:

- Data Confidentiality Statement: Respondents were assured that all collected data would be treated confidentially and used exclusively for research purposes – as shown in Figure 3.
- Consent to Participate: Consent was requested to ensure compliance with ethical principles regarding participation in the survey – as indicated in Figure 3.
- Contact Information: A space was provided for respondents to voluntarily submit their contact details, enabling potential follow-up in case of questions or the need for information clarification – as presented in Figure 3.

CONSENT FORM

Dear Participant,
The information provided by you in this questionnaire will be used for research purposes and the results will form part of a deliverable and a journal paper, which will be published online and made available to the public. **Your personal information WILL NOT be published**. You may withdraw from the research at any time, and your personal data will be immediately deleted. Anonymised research data will be archived on a secure virtual drive of the THOTH2 project.

I consent to my personal data as outlined above, being used for this research. I understand that all personal data will be held and processed in the strict confidence and deleted at the end of this research	YES, I WANT TO CONTINUE	CONTINUE TO THE CONTACT INFORMATION SHEET - USE THE LINK BELOW

CONTACT INFORMATION

AUTOMATIC CHECK

YOU ARE READY TO PROCEED

Please, provide the following information - (*) compulsory info

Name and surname (*)

Company (*)

Country

Contact mail (*)

Telephone number

ERROR - YOU MISS SOME INFORMATION ABOVE

OTHER USEFUL LINKs	You can select one of the link below to return back
RETURN TO THE HOMEPAGE	Introduction and aims'!A1

Figure 3. Third sheet of the survey - consent form, contact information.

The survey consisted of a series of questions regarding measurement devices, such as the types of devices used in the network, their distribution, and technical specifications. The questions were carefully chosen to acquire as much detailed information as possible related to the researched topic.

During the creation of the form, the goal was to enable survey respondents to have direct access to specific devices, which was facilitated through hyperlinks. This way, survey participants interested in particular devices could simply click on the relevant hyperlink, redirecting them to a detailed page associated with that specific device. As a result, accessing information became much easier, and the survey participants could focus on the areas of the project that interested them.

Providing this functionality expedited the process of data collection and analysis – as shown in Figure 4.

INSTRUCTIONS

AUTOMATIC CHECK

YOU ARE READY TO PROCEED - ANSWER TO THE FOLLOWING QUESTIONS

Go to the sheet referred to the measuring technology you are producing

Technology	**Select the link to the sheet below**
Gas meters	'Gas meter'!A1
Pressure & temperature tranducers and transmitters	''Pressure and temperature transmitters'!A1
Volume converters	'Volume converters'!A1'
Gas quality analyser (cromatographs)	'Quality analysers'!A1
Leak detectors	'Leak detectors'!A1
Trace water sensors	'Trace water'!A1

OTHER USEFUL LINKs	**You can select one of the link below to return back**
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 4. Fourth sheet of the survey - list of devices with hyperlinks.

The following six cards contained questions about device technology, with each device having its own card - Figure 5 to 10. Some of the most important questions addressed to the manufacturers were:

- Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name and specify if it is for gas distribution or transportation grids.
- For the models indicated in the previous row, please select the technology type of the indicated model, e.g., turbine, rotor piston, ultrasonic, diaphragm, thermal mass, Coriolis, other.
- Please indicate the maximum amount of hydrogen, e.g. [20 % vol].
- In your opinion, why the CURRENTLY installed devices cannot measure H2NG mixtures with a higher amount? Please comment (metrological issues, certification issues, materials, other).
- Have you ever experimentally tested your meters with HNG mixtures?
- Have you ever experimentally tested this model with HNG mixture? If yes, please indicate the maximum amount.

- Could you briefly describe the results?
- Have you developed new test methods, or have you referred to some existing standards?
- Please describe the tests if you have developed in-house or please indicate the technical standards you used.
- Are you developing new models with a higher H2 allowed percentage for installation in NG transportation and distribution networks? Please indicate the technology type and maximum amount of H2 content.

Gas meter - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS		
		You have to select your answer from the list
		You have to compile the cell with your answer
		"Let's go" check - positive
		"Let's go" check - negative (errors)
		Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name and specify if it is for gas distribution or transportation grids								
For the models indicated in the previous row, please select the technology type of the indicated model, e.g., turbine, rotor piston, ultrasonic, diaphragm, thermal mass, coriolis, other								
Please indicate the EU Type Examination Certificate for the above mentioned models								
Please indicate the maximum amount of hydrogen, e.g. [20 %vol]								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (metrological issues, certification issues, materials, other).								
Have you ever experimentally tested your meters with HNG mixtures? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
Have you ever experimentally tested this model with HNG mixture? If yes please indicate the maximum amount (e.g., YES, 20%vol)								
Could you briefly describe the results? (e.g., metrological performances verification, material degradation, etc.)								
Have you developed new test methods or have you referred to some existing standards? SELECT YES OR NO IN THE YELLOW CELL								
Please describe the tests if you have developed in house or please indicate the technical standards you used								
Are you developping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL								

Figure 5. Fifth sheet of the survey – Gas meters.

Pressure and temperature transmitters - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS		
	(yellow)	You have to select your answer from the list
	(light blue)	You have to compile the cell with your answer
	(green)	"Let's go" check - positive
	(red)	"Let's go" check - negative (errors)
	(light green)	Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name								
Is the device a pressure or temperature transmitters?								
For the models indicated in the previous row, define the technology type: 1) If pressure transmitters, e.g., absolute, differential, gauge 2) If temperature transmitters, e.g., thermocouple, thermistor, RTD								
Please indicate the maximum amount of hydrogen, e.g. [20 %vol]								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (metrological issues, certification issues, materials, other).								

Have you ever experimentally tested your measuring devices with HNG mixtures? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
Have you ever experimentally tested this model with HNG mixture? If yes please indicate the maximum amount (e.g., YES, 20%vol)								
Could you briefly describe the results? (e.g., metrological performances verification, material degradation, etc.)								
Have you developed new test methods or have you referred to some existing standards? SELECT YES OR NO IN THE YELLOW CELL								
Please describe the tests if you have developed in house or please indicate the technical standards you used								

Are you developping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES			
QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL YOU ARE DEVELOPING			
Please indicate the technology type, e.g., pressure or temperature transmitter				
Please indicate for the above mentioned models the nominal pressure range, [bar], e.g. 0-75 bar				
Please indicate for the above mentioned models the nominal temperature range, [barg], e.g. 0-350 barg				
Please indicate for the above mentioned models the maximum amount of H2 content, e.g. (30%vol)				

YOU HAVE FINISHED THIS SECTION. GO TO ANOTHER TECHNOLOGY (SEE LINKS BELOW) OR GO TO THE END OF THE SURVEY

OTHER USEFUL LINKS	You can select one of the link below to return back or go to the end
END OF THE SURVEY	End of the survey'!A1
MEASURING DEVICE LIST	Measuring device list'!A2
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 6. Sixth sheet of the survey – Pressure and temperature transmitters.

Volume converters - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS		
	Yellow	You have to select your answer from the list
	Light blue	You have to compile the cell with your answer
	Green	"Let's go" check - positive
	Red	"Let's go" check - negative (errors)
	Light green	Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name								
Specifiy if the model is a type 1 or type 2								
Please indicate the Z formulas implemented, e.g., [AGA8, S-GERG88]								
Please indicate the maximum amount of H2 content in the H2NG mixture that can be accepted without affecting calculation accuracy, e.g., [20%vol]								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (certification issues, other).								
Are you developing new algorithms for the calculation of the Z factor? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
If yes please indicate the maximum amount of H2 the model could accept in the mixture (e.g., YES, 20%vol)								

Are you developopping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL YOU ARE DEVELOPING			
Have you developed new models? SPECIFY IF THE MODEL IS A TYPE 1 OR TYPE 2				
Please indicate for the above mentioned model the maximum amount of H2 content, e.g. (30%vol)				

YOU HAVE FINISHED THIS SECTION. GO TO ANOTHER TECHNOLOGY (SEE LINKS BELOW) OR GO TO THE END OF THE SURVEY

OTHER USEFUL LINKS	You can select one of the link below to return back or go to the end
END OF THE SURVEY	End of the survey'!A1
MEASURING DEVICE LIST	Measuring device list'!A2
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 7. Seventh sheet of the survey – Volume converters.

Gas cromatographs - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS	(yellow)	You have to select your answer from the list
	(light blue)	You have to compile the cell with your answer
	(green)	"Let's go" check - positive
	(red)	"Let's go" check - negative (errors)
	(light green)	Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name								
Please indicate the available configurations allow the determination of the content of at least such components as: hydrocarbons C1-C6+, N2, CO2, H2?								
For each configuration reported in cell "C11", please indicate what type of gas is being measured? e.g. natural gas, refinery gas, biogas								
For each configuration reported in cell "C11", please indicate what is the measurement range for CH4 [%mol/mol]; H2 [%mol/mol]								
For each configuration reported in cell "C11", what type of detectors the chromatograph is equipped with, e.g. TCD, FID, etc?								
For each configuration reported in cell "C11", what carrier gas can be used, e.g., helium, nitrogen, etc.?								
For each configuration reported in cell "C11", what conversion method is used for the measurement? (e.g., AGA8-G1, AGA8-G2, SGERG-88, ISO 6976, GPA 2172, ASTM D 3588)								
For each configuration, what gas energy parameters are calculated on the basis of the obtained gas composition, e.g., ☐ heat of combustion (unit): ... ☐ calorific value (unit): ... ☐ Wobbe number (unit): ... ☐ density (unit): ... ☐ relative density ☐ compressibility factor ☐ other, please specify... Please specify the reference conditions for calculating the above-mentioned energy parameters, e.g., T_1 combustion temperature [°C], T_2 volume measurement temperature [°C], p pressure [bar])								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (metrological issues, certification issues, materials, other).								
Have you ever experimentally tested your measuring devices with HNG mixtures? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
Have you ever experimentally tested this model with HNG mixture? If yes please indicate the maximum amount (e.g., YES, 20%vol)								
Could you briefly describe the results? (e.g., metrological performances verification, material degradation, etc.)								
Have you developed new test methods or have you referred to some existing standards? SELECT YES OR NO IN THE YELLOW CELL								
Please describe the tests if you have developed in house or please indicate the technical standards you used								

Are you developping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES			
QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL YOU ARE DEVELOPING			
Please indicate the model				
Please indicate the available configurations allow the determination of the content of at least such components as: hydrocarbons C1-C6+, N2, CO2, H2?				
Please indicate what is the measurement range for CH4 [%mol/mol]; H2 [%mol/mol]				

YOU HAVE FINISHED THIS SECTION. GO TO ANOTHER TECHNOLOGY (SEE LINKS BELOW) OR GO TO THE END OF THE SURVEY

OTHER USEFUL LINKS	You can select one of the link below to return back or go to the end
END OF THE SURVEY	End of the survey'!A1
MEASURING DEVICE LIST	Measuring device list'!A2
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 8. Eighth sheet of the survey – Gas chromatographs.

Leak detectors - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS	
(yellow)	You have to select your answer from the list
(light blue)	You have to compile the cell with your answer
(green)	"Let's go" check - positive
(red)	"Let's go" check - negative (errors)
(light green)	Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY used in NG transportation and distribution networks do you produce? Please indicate the commercial name								
For the models indicated in the previous row, define the technology type, e.g., MOS gas sensors, Photoacoustic gas sensors, TDLAS gas sensor, NDIR gas sensors, etc.								
Please indicate the maximum amount of hydrogen, e.g. [20 %vol]								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (metrological issues, certification issues, materials, other).								

Have you ever experimentally tested your measuring devices with HNG mixtures? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
Have you ever experimentally tested this model with HNG mixture? If yes please indicate the maximum amount (e.g., YES, 20%vol)								
Could you briefly describe the results? (e.g., detection performances verification, material degradation, etc.)								
Have you developed new test methods or have you referred to some existing standards? SELECT YES OR NO IN THE YELLOW CELL								
Please describe the tests if you have developed in house or please indicate the technical standards you used								

Are you developping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES			
QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL YOU ARE DEVELOPING			
Please indicate the technology type, e.g., MOS gas sensors, Photoacoustic gas sensors, TDLAS gas sensor, NDIR gas sensors, etc				
Please indicate for the above mentioned models the maximum amount of H2 content, e.g. (30%vol)				

YOU HAVE FINISHED THIS SECTION. GO TO ANOTHER TECHNOLOGY (SEE LINKS BELOW) OR GO TO THE END OF THE SURVEY

OTHER USEFUL LINKS	You can select one of the link below to return back or go to the end
END OF THE SURVEY	End of the survey'!A1
MEASURING DEVICE LIST	Measuring device list'!A2
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 9. Ninth sheet of the survey – Leak detectors.

Trace water sensors - please indicate the data in the table below - if you need more spaces, add them

LEGEND COLOURS		
	(yellow)	You have to select your answer from the list
	(light blue)	You have to compile the cell with your answer
	(green)	"Let's go" check - positive
	(red)	"Let's go" check - negative (errors)
	(light green)	Links

QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL							
Which models that are CURRENTLY installed in NG transportation and distribution networks do you produce? Please indicate the commercial name								
Please specify the operative pressure range, [barg]								
Please specify the range of moisture concentration (or amount fraction) of water, [ppm]								
Please indicate the dew/frost point temperature range, [C] - specifying the reference pressure [bar]								
Please indicate the maximum amount of hydrogen, e.g. [20 %vol]								
In your opinion why the CURRENTLY installed devices cannot measure H2NG mixtures with higher amount? Please comment (metrological issues, certification issues, materials, other).								

Have you ever experimentally tested your measuring devices with HNG mixtures? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES							
Have you ever experimentally tested this model with HNG mixture? If yes please indicate the maximum amount (e.g., YES, 20%vol)								
Could you briefly describe the results? (e.g., metrological performances verification, material degradation, etc.)								
Have you developed new test methods or have you referred to some existing standards? SELECT YES OR NO IN THE YELLOW CELL								
Please describe the tests if you have developed in house or please indicate the technical standards you used								

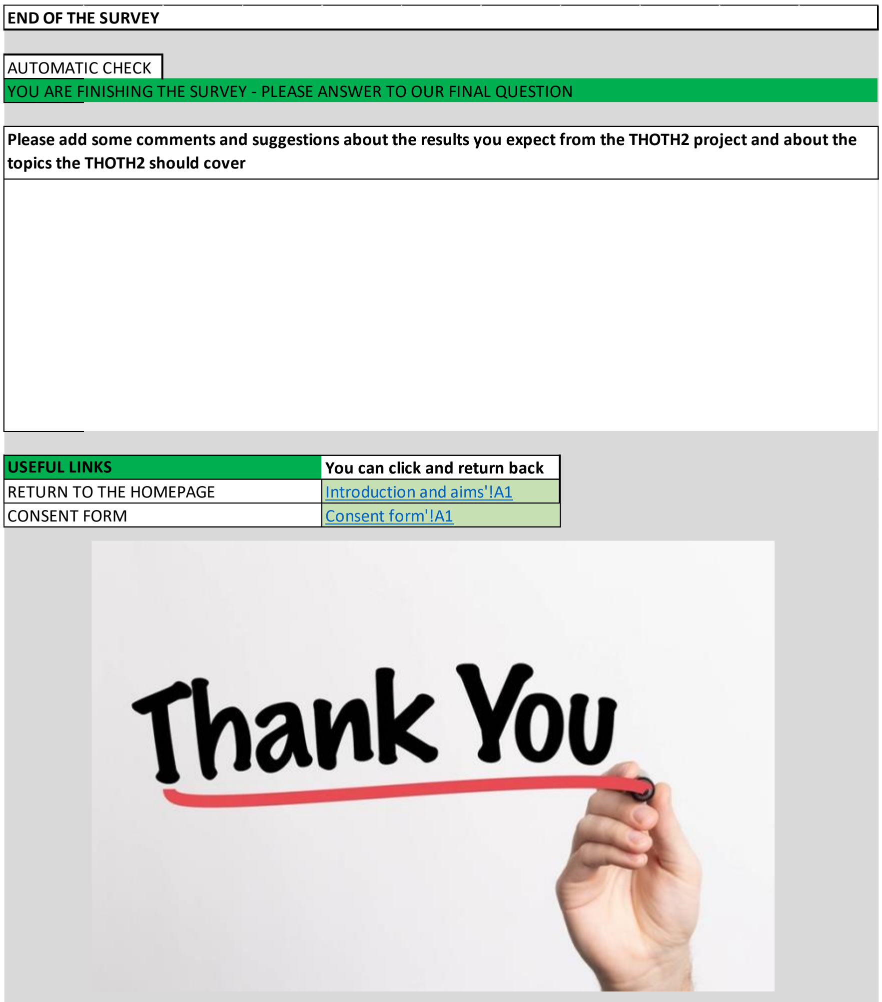
Are you developping new models with higher H2 allowed percentage for the installation in NG transportation and distribution networks? SELECT "YES" OR "NO" IN THE YELLOW CELL	YES			
QUESTIONS:	ANSWERS - EACH COLUMN SHOULD BE REFERRED TO A DIFFERENT & SPECIFIC MODEL YOU ARE DEVELOPING			
Please indicate the model				
Please specify the range of moisture concentration (or amount fraction) of water, [ppm]				
Please indicate the dew/frost point temperature range, [C] - specifying the reference pressure [bar]				
Please indicate for the above mentioned models the maximum amount of H2 content, e.g. (30%vol)				

YOU HAVE FINISHED THIS SECTION. GO TO ANOTHER TECHNOLOGY (SEE LINKS BELOW) OR GO TO THE END OF THE SURVEY

OTHER USEFUL LINKS	You can select one of the link below to return back or go to the end
END OF THE SURVEY	End of the survey'!A1
MEASURING DEVICE LIST	Measuring device list'!A2
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 10. Tenth sheet of the survey – Trace water sensors.

At the conclusion of the survey, a thank-you note was included to express gratitude to the participants for their valuable contribution to the study. We sincerely thanked the respondents for dedicating their time and supporting our research efforts. Their input and cooperation were crucial in helping us gather essential data and insights for our study.


END OF THE SURVEY

AUTOMATIC CHECK

YOU ARE FINISHING THE SURVEY - PLEASE ANSWER TO OUR FINAL QUESTION

Please add some comments and suggestions about the results you expect from the THOTH2 project and about the topics the THOTH2 should cover

USEFUL LINKS	You can click and return back
RETURN TO THE HOMEPAGE	Introduction and aims'!A1
CONSENT FORM	Consent form'!A1

Figure 11. Eleventh sheet of the survey – End of the survey.

The comprehensive survey successfully combined formal aspects with relevant research questions. Carefully selected questions and formal sections, such as the Data Confidentiality Statement and Consent to Participate, ensured data integrity and reliability.

Providing direct access to specific devices through hyperlinks facilitated an efficient and streamlined process for participants, allowing them to focus on areas of interest and expediting data collection and analysis.

The data collected will significantly contribute to our research goals, providing essential insights into measurement devices in NG networks, regarding H2NG mixtures.

2.2 Review of literature

As part of Task 1.2, an analysis was conducted on reports from previously completed projects and publications that examined the impact of adding hydrogen to natural gas or pure hydrogen on the measurement accuracy of equipment. This analysis resulted in the collection of 70 literature items, which contained valuable information and research findings related to this subject and 42 Product Data Sheets.

Each partner involved in the project received about 10 literature items to analyze and draw conclusions for the measuring devices. The findings and insights from this analysis is summarized in Table 8.

Sections 3.1.1÷3.1.7 summarize the conclusions of the analysis of available publications for each device.

Table 8. Summary of publications reviewed.

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
1	Non-combustion-related-impact-of-hydrogen-admixture-material-compatibility	THyGA 24.06.2020	INIG
2	Hydrogen transportation pipelines	AIGA 033/06 GLOBALLY HARMONISED DOCUMENT	
3	Assessing the Durability and Integrity of Natural Gas Infrastructures for Transporting and Distributing Mixtures of Hydrogen and Natural Gas	Publication	
4	Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues	Technical Report NREL/TP-5600-51995, March 2013	
5	Conversion of the UK gas system to transport hydrogen	Publication http://dx.doi.org/10.1016/j.ijhydene.2013.03.070	
6	Domestic Gas Meter Durability in Hydrogen and Natural Gas Mixtures	publication https://doi.org/10.3390/en14227555	
7	Einfluss von Wasserstoff auf die Energiemessung und Abrechnung	Report DVGW G 3-02-12	
8	Wasserstofftoleranz der Erdgasinfrastruktur inklusive aller assoziierten Anlagen	Report DVGW G 1-02-12	
9	Hydrogen Pipeline Systems	EIGA IGC Doc 121/14	
10	GIE Position on Blending Hydrogen into Existing Gas Infrastructure	Gas Infrastructure Europe Paper	
11	Transporting Pure Hydrogen by Repurposing Existing Gas Infrastructure: Overview of existing studies and reflections on the conditions for repurposing	ACER Report 16 July 2021	GRTGAZ
12	HyWay 27: hydrogen transmission using the existing natural gas grid?	Final report HyWay 27 (June 2021)	
13	DETECTION AND MEASURING OF PURE HYDROGEN AND BLENDS OF NATURAL GAS WITH HYDROGEN	Marcogaz (April 2021)	
14	Hydrogen regulation/standards survey. Summary of answers	Marcogaz (22 October 2020)	
15	IMPACT OF HYDROGEN ON EXISTING ATEX EQUIPMENT AND ZONES	Marcogaz (April 2021)	
16	LIQUEFIED NATURAL GAS AND HYDROGEN AS TRANSPORTATION FUEL	Marcogaz (June 2021)	
17	OVERVIEW OF AVAILABLE TEST RESULTS AND REGULATORY LIMITS FOR HYDROGEN ADMISSION INTO EXISTING NATURAL GAS INFRASTRUCTURE AND END USE	Marcogaz (01-10-2019 - TF_H2-427)	
18	Hydrogen infrastructure development in The Netherlands	Publication doi:10.1016/j.ijhydene.2006.10.044	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
19	Hydrogen Europe Vision on the Role of Hydrogen and Gas Infrastructure on the Road Toward a Climate Neutral Economy	Hydrogen Europe (April 2019)	
20	Hyready WP Trans Set-up	DNV GL 2014 Presentation	
21	Get prepared for hydrogen addition to natural gas, get HYREADY! Issues for the gas distribution grid	DNV GL 2013 Presentation	GS
22	Preparing for the hydrogen economy by using the existing natural gas system as a catalyst	Naturalhy Final Publishable Activity Report (25.03.2010)	
23	Review of Hydrogen to Reduce Carbon Emissions	IDEA Sustaining Sponsor Webinar Series	
24	Role of hydrogen in resolvong electricity grid issues.pdf	Publication http://dx.doi.org/10.1016/j.ijhydene.2015.03.137	
25	Technical Reference for H2 Compatibility of Materials	SANDIA Report SAND2012-7321	
26	Technical and economic conditions for injecting hydrogen into natural gas networks	Final report June 2019	
27	The Use Of The Natural-Gas Pipeline Infrastructure For Hydrogen Transport In A Changing Market Structure	TME WORKING PAPER - Energy and Environment (WP EN2006-008)	
28	READINESS OF GAS INFRASTRUCTURE OPERATORS TO SAFELY COPE WITH RENEWABLE GASES INCLUDING HYDROGEN	Marcogaz Position paper (January 2022)	
29	DECARBONISING THE GAS VALUE CHAIN CHALLENGES, SOLUTIONS AND RECOMMENDATIONS	PRIME MOVERS' GROUP ON GAS QUALITY AND H2 HANDLING SUBGROUP 2 WORK (2021)	
30	Field test of hydrogen in the natural gas grid	DCC Project Report (August 2010): EFP05 J.nr. 033001/33031-0053	
31	PILOT PROJECT ON HYDROGEN INJECTION IN NATURAL GAS ON ISLAND OF AMELAND IN THE NETHERLANDS	IGRS Seul 2011 Kiwa Gas Technology	UNIBO
32	Einspeisung von Wasserstoff in das Erdgasnetz. Messgeräte für Gas	PTB G19 (12/2014)	
33	Calculation of Compression Factors and Gas Law Deviation Factors Using the Modified SGERG-Equation SGERG-mod-H2	DVGW Technical Report PK 1-5-3 (30 January 2021)	
34	Report on the impact of renewable gases, and mixtures with natural gas, on the accuracy, cost and lifetime of gas meters	NEWGASMET – Deliverable D1 (EMPIR JRP 18NRM06)	
35	Study of the Effect of Addition of Hydrogen to Natural Gas on Diaphragm Gas Meters	Publication https://doi.org/10.3390/en13113006	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
36	Hydrogen Addition to Natural Gas Feasibility Study	Northern Gas Networks Ltd. & National Grid, Report No.: 1103VHX3-Rep-1, Rev. A	
37	THE LIMITATIONS OF HYDROGEN BLENDING IN THE EUROPEAN GAS GRID	Fraunhofer Institute for Energy Economics and Energy System Technology (IEE), January 2022	
38	Admissible Hydrogen Concentrations in Natural Gas Systems	Publication Klaus Altfeld and Dave Pinchbeck	
39	Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology	Technical Report NREL/TP-5400-81704 (October 2022)	
40	Hydrogen Research Projects 2022	DVGW	
41	The effect of hydrogen on the physical properties of natural gas and the metrological characteristics of its metering system	Publication DOI:10.33955/2307-2180(6)2019.45-50	SNAM
42	A roadmap for local gas distribution networks to become the leading hydrogen distribution infrastructure	Ready4H2: Europe's Local Hydrogen Distribution Networks, PART 3	
42b	The Ready4H2 project consists of 91 European gas distribution companies and organisations working together to support the built-up of a strong hydrogen market and create a common European understanding of the future related to the transformation of the gas distributors towards climate neutrality.	Ready4H2: Europe's Local Hydrogen Networks - PART 1: Local gas networks are getting ready to convert	
43	Local gas networks are getting ready to convert	Ready4H2: Europe's Local Hydrogen Distribution Networks, PART 2	
44	Effect of the renewable gases on the uncertainty budgets of gas meters	NEWGASMET – Report A2.1.15	
45	Report on gas tightness testing of domestic gas meters and compact conversion devices (EVCD) for hydrogen applications	NEWGASMET – Report A2.2.2	
46	Effect of hydrogen admixture on the accuracy of a rotary flow meter	NEWGASMET – Report A3.3.3	
47	Bench marking flow standards for use in testing the accuracy of flow meters with renewable gases	NEWGASMET – Report A3.1.1	
48	Criteria and proposals for EMC tests on Ultrasonic meters with Non-Conventional Gases	NEWGASMET – Report A2.2.2	
49	Literature overview for renewable gases flowmetering	NEWGASMET – Report - Deliverable D1	
50	Report stating the acceptable range of gas compositions, which will be suitable for use with metrology gas meters and which support the new "renewable" framework	NEWGASMET – Report - Deliverable D2	
51	Report on the tests which need to be performed during calibration to enable the use of renewable gases with existing gas meters	NEWGASMET – Report - Deliverable D3	INRE TE

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
52	Report on recommendations for the traceable calibration (type testing) and verification procedures for rotary displacement, turbine, diaphragm, domestic ultrasonic, thermal mass flow gas flow meters which measure renewable gases, in compliance with the requirements of the 2014/32/EU Measuring Instruments Directive	NEWGASMET – Report - Deliverable D4	
53	Report on the durability of the materials, electrical insulation and internal components of domestic gas meters after exposure to renewable gases, the effects that renewable gas flow has on the durability of gas meters and how this effects their accuracy, and recommendations for improving current calibration and verification facilities.	NEWGASMET – Report - Deliverable D5	
54	Report on the inter-comparison of 2 flow calibration standards with N2, H2 and CH4 including the test protocol, validated calibration methods and uncertainty budgets	NEWGASMET – Report - Deliverable D6	
55	Report on the type testing procedures for domestic and commercial gas meters with hydrogen and one other test gas (air, nitrogen, methane or natural gas)	NEWGASMET – Report - Deliverable D7	
56	HyDeploy 2 Project	HyDeploy 2: Winlaton Trial Report // September 2022.	
57	Hydrogen and hydrogen-enriched natural gas in European gas grids: understanding operating conditions for decarbonized gas grids	Decarb project. Report Task 1.1	
58	Literature review on hydrogen and carbon dioxide for primary reference materials for decarbonised gas grids	Decarb project. Report A2.1.1	
59	Standards or technical specifications for QA hydrogen (for heat), biomethane and carbon dioxide for CCS	Decarb project. Report A2.2.1	
60	Maximum admissible leaks in hydrogen and hydrogen-enriched natural gas pipelines	Decarb project. Report A4.1.2	
61	Hydrogen purity	Hy4Heat project. WP2 'Hydrogen quality standards'	ENAGAS
62	Safety assesment	Hy4Heat project. WP7 'Safety assessment'	
63	TBD	Hy4Heat project. WP10 'Developing hydrogen gas meters'	
64	TBD	MET4H2 project. WP2 'Flow measurement'	
65	TBD	MET4H2 project. WP3 'Hydrogen gas quality'	
66	TBD	MET4H2 project. WP4 'Measurement uncertainties in the totalization of quantity, energy and purity content'	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
67	3rd Report, February 2022 (Non public web page)	H2GAR collaboration. WG4 'Metering/Other instrumentation'	
68	Joint Industrial Project on Suitability of Flow Meters for Renewable Gases, DNV Report no. 10246727-U1, November 2021 (Non public report)	DNV Project 'Joint Industrial Project on Suitability of Flow Meters for Renewable Gases'	
69	JIP renewable gases; Results on performance of turbine and ultrasonic flow meters up to 30% Hydrogen and 20% CO2. DNV Paper 12 Proceeding/Presentation of the North Sea Flow Measurement Workshop, October 2021	DNV Project 'Joint Industrial Project on Suitability of Flow Meters for Renewable Gases'	
70	Emerson, 2015, Model 500 Natural Gas Chromatograph NGC-PDS-Model-500	Product Data Sheet	INIG
71	Emerson, 2012, Model 700 Natural Gas Chromatograph 71-PDS-NGC-Model700	Product Data Sheet	
72	Emerson, 2020, Rosemount™ 370XA Gas Chromatograph, Low-Cost and Compact with Full Performance for Dedicated Applications	Product Data Sheet	
73	Emerson, 2022, Reliable gas composition analysis to control your process and ensure product quality	Product Data Sheet	
74	Intergaz, 2013, Chromatograf EnCal3000	Technical Data Sheet	
75	Elster GmbH, 2018, Gaschromatograph EnCal3000	Hardware manual	
76	ABB MEASUREMENT & ANALYTICS, 2021, Portable NGC Natural gas chromatograph	Product Data Sheet	
77	ABB MEASUREMENT & ANALYTICS, 2021, PGC5000 and PGC1000 Series The replacement solution for ABB legacy GC's (PGC2000, 3100) and third-party analyzers	Product Data Sheet	
78	Agilent Technologies, 2017, Agilent 490 Micro Gas Chromatograph,	User Manual	
79	ISO 21087:2019. Gas analysis - Analytical methods for hydrogen fuel – Proton exchange membrane (PEM) fuel cell applications for road vehicles	Standard	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
80	Bartec, 2013, Hygrophil F5673,	Operating manual	
81	Michell Instruments, 2021, Condumax II Hydrocarbon Dew-Point Analyzer	Product Data Sheet	
82	Michell Instruments, 2018, Promet EExd Process Moisture Analyzer	Product Data Sheet	
83	Michell Instruments, Transmet IS Dewpoint Transmitter	Product Data Sheet	
84	https://www.draeger.com/en-us_us/Products/X-am-8000?s=438	Products catalog	
85	https://www.sisco.com/handheld-h2-gas-detector#quickTab-54	Products catalog	
86	Riken Keiki Co. Ldt, Portable Gas Detector, Model NP-1000	Product Data Sheet	
87	UST Umweltsensortechnik GmbH, 2023, Gas leak detector PEAKER®s H2 D	Technical Data Sheet	
88	https://www.mru.eu/en/products/detail/400gd/	Product Data Sheet	
89	https://www.mru.eu/en/products/detail/500gd	Product Data Sheet	
90	http://integrotech.com.pl/zdjecia/KartyKatalogoweNowe/Integrotech_karta_MPU.pd f	Product Data Sheet	
91	http://integrotech.com.pl/zdjecia/file/MPU1200_Instrukcja_konserwacji_i_Obs%C5% 82ugi-NEW.pdf	Product Data Sheet	
92	familyOverview_FLOWSIC500_g180262_en	Product Data Sheet	
93	familyOverview_FLOWSIC600_g57523_en	Product Data Sheet	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
94	ALTOSONIC V12 Ultrasonic gas flowmeter for custody transfer	Product Data Sheet	
95	Function Manual - SITRANS F Ultrasonic flowmeters SITRANS FST030	Product Data Sheet	
96	Operating Instructions - SITRANS F Ultrasonic flowmeters SITRANS FUG1010	Product Data Sheet	
97	Minisonic - user manual	Product Data Sheet	
98	Minisonic II - user manual	Product Data Sheet	
99	Uf 811 - user manual	Product Data Sheet	
100	Uf 821 - user manual	Product Data Sheet	
101	Uf 831 - user manual	Product Data Sheet	
102	Uf 841 - user manual	Product Data Sheet	
103	Delta Rotary-Meters 224-099-2801	Instruction manual	
104	RVG and RVG-ST Rotary gas meters	Product Data Sheet	
105	Rotary series FMR	Product Data Sheet	
106	Rotary Gas Meters RMT	Installation Instructions, Product specifications	
107	Gas Turbine Meter IGTM-CT AND IGTM-WT	Installation, Operation and Maintenance Manual	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
108	Injection of hydrogen to the natural gas network – Suitability of Elster Gas metering technology	Manufacturer declaration	
109	Turbine Meters TRZ 03 and TRZ 03-K	Operating Instructions	
110	Thermal Mass Flow meter FCI ST51 / ST51A	Product Data Sheet	
111	In-line thermal mass flow transmitters SERIES 534FTB	Product Data Sheet	
112	Technical specifications. In-line thermal mass flow transmitters SERIES 534FTB	Technical specifications	
113	ELSTER / HONEYWELL ENCORE FC1	Product Data Sheet	
114	EX-I FLOW SFC3000	Product brochure	
115	KROHNESUMMIT 8800	Product specification	
116	D&D ELETTRONICA IMP-8FC	Product specification	
117	D&D ELETTRONICA IMP-FC-1/PS	Product Data Sheet	
118	D&D ELETTRONICA IMP-FC2	Product specification	
119	FIORENTINI Explorer plus	User manual	
120	FIORENTINI FloWEB	Product brochure	
121	KAMSTRUP UNIGAS 300	Product Data Sheet	

No. of the publication	Title of the publication	Description	Who was responsible for the analysis
122	FIMIGAS ICARUS	Product brochure	
123	FIMIGAS VESCOM 3	Product brochure	
124	FLONIDAN UNIFLOW 1200	Product technical specification	
125	ACTARISCORUS	Product technical specification	
126	PLUM MACMAT II	technical documentation and installation instructions	
127	INTEGROTECH MSP-02-FC	Product Data Sheet	
128	COMMON CMK-02	Product technical specification	

3. Natural gas measuring devices: gaps and limitations

3.1 Gaps and limitations from the literature review

Based on the conducted literature review, gaps and limitations were identified. They are presented in this section of the report. To ensure clarity, the identified gaps and limitations have been presented separately for each type of measurement device in a tabular form. The document number in the first column of Tables 9÷19 corresponds to the publication referenced in the previous chapter of the report (Table 8).

3.1.1 Gas meters

Tables 9-14 contain information collected during the literature review for various types of gas meters.

3.1.1.1 Turbine gas meters

Table 9. The information obtained from the literature review for turbine gas meters.

Document number	Main points
7	The measurement of natural gases with an admixture of up to 10% hydrogen by volume can be performed using all types of meters, according to the information provided by the device manufacturers. Some types of meters can be used up to 100% hydrogen by volume. However, the effect of reducing the measuring range, especially the minimum flow (Qmin), due to the change in density, is visible. To test the effect of hydrogen on conventional high-pressure natural gas meters, a project commissioned by E.ON carried out measurements on a pigsar™ high-pressure meter test rig. The influence of the addition of H2 on the measuring characteristics of the turbine gas meter can be practically excluded at moderate amounts of H2 up to 10% by volume. Further bench testing is recommended.
17	No significant impact was observed with the addition of hydrogen up to 10%. For higher percentage values (up to 40%), there were inconclusive findings or conflicting conclusions.
26	Gas meters - the measurement uncertainties must be checked on the turbine meters due to the low density of the CH4/H2 mixture. However, other technologies, and in particular ultrasound, accept a hydrogen content of up to 15% with little or no dispersion. The tests carried out as part of GRHYD (G65 meters: small tertiary sector) show that the presence of hydrogen (up to 20% volume) in the gas would lead to a metering difference of between -1% and +2.5%. It should be noted, however, that these tests were not performed on a metrological test bench and that CEN CENELEC21 has validated the use of turbine meters for a mixture of up to 10% hydrogen.
29	Flow measurement The DBI quotes a general readiness for 5 % vol. H2 and case-by-case decisions for higher H2 shares. The measurement uncertainties must be checked on the turbine meters due to the low density of the H2NG mixture. A DBI analysis also limits the maximum H2 share for gas turbines to 8 % vol. for fluctuating H2 contents, based on a maximum Wobbe Index variation of 2 %. Some gas turbines are declared as not suitable over 2 Vol.-% vol. hydrogen in the fuel gas by the OEM22.
32	The use of gas measurement devices "of any technologies" shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a manufacturer's declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer's declaration.
34	High pressure gas meters test. The measurements were carried out on the high-pressure meter test bench Pigsar. Meter tested: turbine wheel gas meter, nominal width DN 80, size G100 – 160 m3/h, pressure stage DP 70. Testing conditions: Flowrate during tests: 70%, 40%, 25% and 10% of the maximum flow of the test specimens (i.e, 160 m3/h). H2 percentages during tests: 2.5, 5, 7.5 and 10% volumetric H2 share of the total volume flow. Pressure and temperature: 29 bar, 17 °C. RESULTS: all measurement deviations, including those with H2 admixture, were clearly within the calibration error limits. No influence can be detected by the H2 admixture.
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
39	Measurement uncertainties for turbine flow meters can also arise when fluid velocities exceed meter design specifications.
44	Reference standard EN 12261. As general indication, the expert groups (defined within the NewGasMet project) recommend to use a test-gas which is identical with the gas intended for the meter to measure or make a transferability to another gas from air or natural gas. In addition It is reported a table with the renewable test gases (including H2) defined by the NEWGASMET expert group. While when different or alternative test-gas than the one the meter are designed to measure are used, this can lead to another calibration result which have to be corrected for which again will lead to an increase in the uncertainty.
49.	There is no influence on the measurement behaviour of the turbine meter by the H2 addition up to 10 vol. %. Further tests are recommended in which the influence of inhomogeneous mixtures (e.g. nonhomogeneous distribution, plug flow) on the measurement behaviour is investigated.
51	Turbine meter with natural gas and 10% H2 (1 type) has been tested. No influence up to this value.

Document number	Main points
57	Test work with several 6” turbine meters show that their response in the Reynolds domain is similar between hydrogen-enriched natural gas (up to 30 % hydrogen concentration and 16 - 32 bara range) and natural gas.

3.1.1.2 Rotary piston gas meters

Table 10. The information obtained from the literature review for rotary piston gas meters.

Document number	Main points
32	The use of gas measurement devices “of any technologies” shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a manufacturer’s declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer’s declaration.
34	Test included the impact of 6% to 20% of hydrogen content in the natural gas on rotary gas meter and the long-term impact on accuracy from 6% to 20% of hydrogen exposure of the tested flowmeter. Meter tested: rotary gas meter: 1 m3/h to 100 m3 /h. The rotary meter is very stable, and the error is between 0 to +0.38%. It is within the specifications of the EN 12480. H2 injection induces an overall undercounting of the meter. The injection of H2 has a real impact on the metrological behaviour of all the tested and used (on the distribution grid) meters. Not significant deviation between the error results obtained with 10% and 20% of H2. This is very encouraging for the infield tests. Long term impact is substantially absent for the rotary meter because the measuring cell is made of aluminum.
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
44	Reference standard EN 12480. As general indication, the expert groups (defined within the NewGasMet project) recommend to use a test-gas which is identical with the gas intended for the meter to measure or make a transferability to another gas from air or natural gas. In addition It is reported a table with the renewable test gases (including H2) defined by the NEWGASMET expert group. While when different or alternative test-gas than the one the meter are designed to measure are used, this can lead to another calibration result which have to be corrected for which again will lead to an increase in the uncertainty.
46	Using VSL’s high-pressure Gas Oil Piston Prover (GOPP) primary standard, the effect of mixing hydrogen with natural gas on the performance of a high-pressure gas rotary flow meter was investigated. The error of a rotary flow meter was determined using the best possible uncertainty, by calibration with the primary standard for high pressure natural gas flow. The rotary flow meter was calibrated using both natural gas and hydrogen enriched natural gas (nominally 15% hydrogen), at two different pressures: 9 and 16 bar. Results indicate that, for the rotary flow meter and hydrogen admixtures used, the differences in the meter errors between high-pressure hydrogen-enriched natural gas calibration and high-pressure natural gas calibration are smaller than the corresponding differences between atmospheric pressure air calibration and high-pressure natural gas calibration. Results indicate that, for the rotary flow meter and hydrogen admixtures (<20 % H2) used, the meter error differences between high-pressure hydrogen admixture calibration and high-pressure natural gas calibration are smaller than the meter error differences between atmospheric pressure air calibration and high-pressure natural gas calibration.
51	Rotary gas meter (only one type) with natural gas and 6%, 10% and 20% of H2 have been tested. No effect was measured.
55	VSL, supported by HONEYWELL, ITRON and SICK have performed test with a rotary gas meter at elevated pressure (9 and 16 bar) with HENG using a piston prover. The meter was an ITRON S1 Flow G100, Size G100, DN 50. The meter was calibrated at 9 and 16 bar at 7 different flow rates from 5 to 160 m3 /h, with both NG and HENG. The nominal amount of H2 was 15%vol. Most differences are negative, indicating that the meter tends to underreport flow of HENG, as expected due to increased leakage along the rotors of the meter. Although differences between errors with NG and HENG are mostly negative, these changes are insignificant from a metrological standpoint. Results indicate that, for the rotary flow meter and hydrogen admixtures (<20 % H2) used, the meter error differences between high-pressure hydrogen admixture calibration and high-pressure natural gas calibration are smaller than the meter error differences between atmospheric pressure air calibration and high-pressure natural gas calibration
57	The difference observed with rotary meters between natural gas and hydrogen enriched natural gas were typically well within 0.15 %.

3.1.1.3 Ultrasonic gas meters

Table 11. The information obtained from the literature review for ultrasonic gas meters.

Document number	Main points
7	The measurement of natural gases with an admixture of up to 10% hydrogen by volume can be performed using all types of meters, according to the information provided by the device manufacturers. Some types of meters can be used up to 100% hydrogen by volume. However, the effect of reducing the measuring range, especially the minimum flow (Qmin), due to the change in density, is visible. To test the effect of hydrogen on conventional high-pressure natural gas meters, a project commissioned by E.ON carried out measurements on a pigsar™ high-pressure meter test rig. As long as the H2 content does not exceed 10% by volume, the effect on the ultrasonic gas meter is imperceptible if the hydrogen is well mixed with the natural gas. Further bench testing is recommended, especially for domestic gas meters.

Document number	Main points
17	No significant impact was observed with the addition of hydrogen up to 10%.
32	The use of gas measurement devices “of any technologies” shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a manufacturer’s declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer’s declaration.
34	High pressure gas meters test. The measurements were carried out on the high-pressure meter test bench Pigsar. Meter tested: ultrasonic gas meter, nominal width DN 80, size G100 – 160 m3/h, pressure stage DP 70. Testing conditions: Flowrate during tests: 70%, 40%, 25% and 10% of the maximum flow of the test specimens (i.e, 160 m3/h) H2 percentages during tests: 2.5, 5, 7.5 and 10% volumetric H2 share of the total volume flow. Pressure and temperature: 29 bar, 17 C. RESULTS: all measurement deviations, including those with H2 admixture, were clearly within the calibration error limits. Apart from the measuring point at 10% Qmax. no influence by the H2 supply can be measured. At the measuring points at 0 %-Qmin there is an apparent tendency for the ultrasonic meter: The measurement deviation changes by approx. 0.9% with a change in the H2 concentration. In this case, however, this change may also be due to the high short-term repeatability of the meter measurement results, especially in the case of small flows, and is therefore not a clear indication of a gas species dependence.
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
39	Measurement uncertainties for ultrasonic flow meters can also arise when fluid velocities exceed meter design specifications.
44	Reference standard EN 14236. As general indication, the expert groups (defined within the NewGasMet project) recommend to use a test-gas which is identical with the gas intended for the meter to measure or make a transferability to another gas from air or natural gas. In addition It is reported a table with the renewable test gases (including H2) defined by the NEWGASMET expert group. While when different or alternative test-gas than the one the meter are designed to measure are used, this can lead to another calibration result which have to be corrected for which again will lead to an increase in the uncertainty.
47	Investigated the possibility for the use of Ultrasonic meters for metering hydrogen flows at transient conditions at flow ranges between 30 l/min and 240 l/min. An overall error of ± 1 % can be achieved.
48	Concerns have been raised regarding the applicability of test gases (that represent renewable gases) for EMC tests for static meters. Today such tests are performed in air, but there is a clear agreement that the behaviour of the meter during EMC tests can be influenced by the renewable gas type, in particular H2. At least, this agreement exists for the ultrasonic measurement technology. However, it is not simply possible to redesign the current EMC tests by replacing air with the defined gas mixtures, as this would be quite impractical, especially considering the explosive nature of the test gases. Considering the current measurement technology, a greater attenuation of the ultrasonic signal is expected with the defined test mixtures, which also determines a poorer signal to noise ratio (SNR). Knowing that the issue is related to SNR, one possibility would be that the manufacturers define the minimum accepted SNR to ensure MPE and repeatability under EM disturbances. However, the minimum SNR is difficult to test and any manipulation of this characteristic would require intrusive tests or even additional features of the meter firm ware (FW) to manipulate the signal e.g., by reducing the transmit power or adding a correlated noise source.
49	There is no influence on the measurement behaviour of the ultrasonic meter by the H2 addition up to 10 vol. % in the event of a good mix-up. Further tests are recommended in which the influence of inhomogeneous mixtures (e.g. nonhomogeneous distribution, plug flow) on the measurement behaviour is investigated.
51	Ultrasonic meter with natural gas and 10% H2 (1 type) has been tested. No influence up to this value.
57	Tests with ultrasonic meters generally show poorer results than for turbine meters. However, the ultrasonic meters response varies between tested meters, and it appears to be considerably influenced by the meter settings. The studies available in the literature show that ultrasonic domestic meters response depends on the meter type/vendor. Errors outside MPE limits are possible for ultrasonic meters and discrepancies between methane and blends result are generally greater than for diaphragm meters. There are indications that the discrepancy between methane and blends results decreases by decreasing the hydrogen concentration, with performance considerably increasing below a certain hydrogen concentration threshold. However, further investigation is required on this point.

3.1.1.4 Coriolis gas meters

Table 12. The information obtained from the literature review for coriolis gas meters.

Document number	Main points
32	The use of gas measurement devices “of any technologies” shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a manufacturer’s declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer’s declaration.
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
47	At hydrogen refueling stations Coriolis flow meters are commonly used. Calibrating Coriolis meters against critical flow venturi nozzles under transient conditions showed an expanded uncertainty of 0.45 % for the totally metered mass. When comparing the mass metered by a Coriolis meter of a hydrogen refueling station with a gravimetric standard, the majority of the results were within the MPE of the OIML R139 of 3 % and 5 %, respectively.

49	In the report are considered pure hydrogen and blending of H2NG. The results found in the literature shows that there is a large deviation at low flow rate from -10% to 5%. This deviation must be analysed in more details since it applies to the measuring system and not the flow meter itself. It appears that the relatively large errors could be due to the Coriolis meter as there is an unquantified error from using it with high pressure hydrogen when calibrated with water. With H2, the Coriolis meter overcounts at low flow rate in contrast with its usual behaviour. Finally, for the 100% H2 gas, all the scientific papers dealing with metering show that flow meters (specially the Coriolis meters) might deviate from the original calibration when this latter is not realised within the process conditions and medium (fluid).
57	Coriolis meters are found to perform well within ±0.5 % both with hydrogen-enriched natural gas (up to 30 % hydrogen concentration and 16 - 32 bara range) and natural gas if they are properly compensated for pressure (related to the mechanical load the pressure induces on the tubes) and speed of sound effects (related to the compressibility of the medium in the tubes).

3.1.1.5 Thermal gas meters

Table 13. The information obtained from the literature review for thermal gas meters.

Document number	Main points
6	The durability was carried out with a 2E natural gas mixture with 15% hydrogen addition and 2E natural gas without hydrogen at flow rates 0.4Qmax and 0.7Qmax and 3Qmin and Qmax, respectively. For the test samples subjected to the durability tests, no significant metrological influence of added hydrogen was found on the obtained average drift of errors of indications after the durability tests. - For tested thermal gas meters, no statistically significant influence of the hydrogen content in the gas was found on the change in gas meter errors of indications after they were subjected to the durability tests. Analyzing the average drift of errors of indications for the control sample 2E/H0 and the test sample 2E/H15, it can be concluded that the differences between these changes are smaller than the uncertainty of determining the difference, and therefore these should be considered metrologically insignificant. - No significant differences were found between the average weighted mean error (WME) changes for the tested gas mixtures. - During the durability tests, no damage was found that would compromise operational safety. All gas meters thermal—remained tight after the durability tests.
32	The use of gas measurement devices “of any technologies” shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a manufacturer’s declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer’s declaration.
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
44	Reference standard EN 17526. As general indication, the expert groups (defined within the NewGasMet project) recommend to use a test-gas which is identical with the gas intended for the meter to measure or make a transferability to another gas from air or natural gas. In addition It is reported a table with the renewable test gases (including H2) defined by the NEWGASMET expert group. While when different or alternative test-gas than the one the meter are designed to measure are used, this can lead to another calibration result which have to be corrected for which again will lead to an increase in the uncertainty. As example, it is reported that “results from the durability test indicate that current diaphragm and thermal mass flow gas meters, intended for use with natural gas, show shifts in measurement error when exposed to pure hydrogen which stay within the legal limits of the current documentary standards”.
53	Tested 3 thermal mass gas meters from one manufacturer (G4) after calibration with air. The gas meters were tested for durability with 100% H2 for 6 months and 12 months. On the tests where finished the meters were again calibrated with air. For the flow rates in the range of Qt to Qmax, none of the differences in the error after the durability test and the error before the durability test exceed 2 %. For the flow rates in the range of Qt to Qmax, none of the differences in the error after the durability test and the error before the durability test exceed 2 %. A wider spread is observed with respect to diaphragm gas meter error shifts. All tested thermal mass gas meters were within tolerance of the initial MPE for gas meters of accuracy class 1.5 before they were subjected to durability testing with hydrogen. All tested thermal mass gas meters were within tolerance of twice initial MPE for gas meters of accuracy class 1.5 after they were subjected to durability testing with hydrogen.
55	NEL have tested one G4 domestic thermal mass gas meter (prototype) with nitrogen and hydrogen gas flows with two different flow meter types using critical nozzles or rotary meter as references. Meter was calibrated at atmospheric pressure only, with 2 gases at 3 flow rates. The selected flow rates were 0.6, 1.2 and 6 m3/h. The measurements were repeated 3 times in both laboratories to investigate calibration differences. The results are inside the MPE. A significant shift in error is observed between the results for hydrogen and nitrogen. However, the difference is smaller than the “gas-air relationship” clause in EN 17526:2021. The differences are caused by the adjustment (parameter setting of the microchip-based flow sensor) during the production process. The sensor is able to distinguish between the calibration gases.
57	Thermal domestic mass flow meter response is generally found within the MPE limits. For all the meters technologies there is a lack of test results above 20 % hydrogen and with 100 % hydrogen.

3.1.1.6 Diaphragm gas meters

Table 14. The information obtained from the literature review for diaghragm gas meters.

Document number	Main points
3	The paper presents the ongoing work within both Durability and Integrity Work Packages of the Naturalhy project. This work covers a gap in knowledge on risk assessment required for delivering H2+natural gas blends by means of the existing natural gas grids in safe operation. Durability of domestic gas meters: The most common domestic gas meters are membranes meters, made with a polymeric membrane which is sensitive to H2 permeation. Several potential effects of H2 are expected; - Potential influence on metering accuracy; the fact that hydrogen particles are smaller than natural gas ones may cause leakages through the membrane. In such a case, the measuring accuracy would be impaired, - Potential influence on safety; the dimensions of hydrogen particles may lead to a leakage into the atmosphere through connection sealing, - Potential influence on durability; Hydrogen physicals characteristics may damage the internal parts of the meter. At the end of the gas chain, the most common domestic gas meters with a polymeric membrane are not show-stoppers and can reliably meter mixtures of hydrogen with NG up to 50 %vol. of H2.
4	The report cites durability of domestic gas meters test results from three manufacturers' gas meters with natural gas containing 17% hydrogen. As their conclusion, it was found that the variation in indications was less than 0.1% which, with a maximum permissible error of 4% (at the date of publication), is a negligible value and it can be assumed that no changes to the distribution systems are necessary up to this hydrogen content. Reference was also made to a publication on the testing of natural gas meters with a hydrogen content of 50%. Changes in indication errors were within 2% and decreased at lower flow rates. The conclusions were that up to 50% hydrogen content in natural gas, the changes in errors relative to the MPE (which was 4% at the time) were insignificant. However, at higher hydrogen contents, calibration of the gas meter may be needed. It was also pointed out that one of the unresolved gaps is the impact of contaminants introduced with the hydrogen into the network in case the purity of the hydrogen is not adequate.
6	The paper presents durability tests of the domestic gas meters. For the test samples subjected to the durability tests, regardless of whether they were gas meters in service (after 10 years of operation) or new gas meters, no significant metrological influence of added hydrogen was found on the obtained average drift of errors of indications after the durability tests. Apart from single Type−1 gas meters tested in sample 2E/H0 (without hydrogen addition), in which most likely internal leakage occurred, the gas meters meet the metrological requirements for a durability test according to EN 1359. - For the majority of diaphragm gas meters no statistically significant influence of the hydrogen content in the gas was found on the change in gas meter errors of indications after they were subjected to the durability tests. For the new Type−4 diaphragm gas meters and in-service Type−7 gas meters, after the 10,000 h durability test, statistically significant differences were found in the average drift of the errors of indications of gas meters subjected to the durability test with a 2E natural gas mixture with 15% hydrogen addition and 2E natural gas without hydrogen at flow rates 0.4Qmax and 0.7Qmax and 3Qmin and Qmax, respectively. Analyzing the average drift of errors of indications for the control sample 2E/H0 and the test sample 2E/H15, it can be concluded that the differences between these changes are smaller than the uncertainty of determining the difference, and therefore these should be considered metrologically insignificant. - For all types of gas meters subjected to the durability test after 10,000 h, no significant differences were found between the average weighted mean error (WME) changes for the tested gas mixtures, and almost all gas meter errors were within ±1.2%, except for single gas meters (four meters). - During the durability tests, no damage was found that would compromise operational safety. All gas meters remained tight after the durability tests.
7	The measurement of natural gases with an admixture of up to 10% hydrogen by volume can be performed using all types of meters, according to the information provided by the device manufacturers. Some types of meters can be used up to 100% hydrogen by volume. However, the effect of reducing the measuring range, especially the minimum flow (Qmin), due to the change in density, is visible. From a safety point of view, up to 10% vol. H2, no additional permeation and leakage hazards are to be feared. However, confirmation by verification of seals, screw connections and gas meter connectors is required, especially in the case of old devices. In the future, equipment manufacturers will be required to specify the exact range of use of meters in relation to H2 concentration.
8	All manufacturers demonstrated the suitability of their gas meters to the level of 10% H2 within the limits of the calibration error. Some gas meters are even rated for 100% H2, with or without restrictions. However, it is recommended to review and consider measuring ranges and operating parameters up to 10% H2. According to the information provided by the manufacturers, it is currently also not possible to confirm the reduction of the target lifetime of gas meters at 10% H2 content. In some cases, tests were also carried out on a test bench. From the point of view of material technology, the components can be said to be H2 resistant up to 10% by volume and applied pressures. From a safety point of view, no additional permeation and leakage hazards are expected up to 10% H2. However, it is necessary and recommended to confirm this observation by checking gaskets, screw connections and joints in gas meters. In the case of new gas meters, manufacturers in particular are required to adapt the test specifications (including DVGW-Cert) for gas meters.
26	The tests carried out as part of GRHYD (G4 meters: private customers) show that the presence of hydrogen (up to 20% volume) in the gas would lead to a metering difference of between -1% and +2.5%. It should be noted, however, that these tests were not performed on a metrological test bench.
32	The use of gas measurement devices "of any technologies" shall be safe provided that the hydrogen content of the natural gas is less than 5% by volume. The use of meters is permitted for a proportion between 5 and 10% by volume of hydrogen, provided the manufacturer explicitly permits this. For the use of meters with natural gas containing > 10% hydrogen by volume, a

Document number	Main points
	manufacturer's declaration as well as a PTB declaration of clearance must be submitted in addition to the manufacturer's declaration.
34	Tests included the impact of 6% to 20% of hydrogen content in the natural gas on the diaphragm flowmeter and the long-term impact on accuracy from 6% to 20% of hydrogen exposure of the tested flowmeters. Meters tested: Diaphragm (METER 1): 0,04 m3/h to 6 m3/h ; 2) Diaphragm (METER 2): 0,04 m3 /h to 6 m3 /h. The flowrate error of the two domestic meters is within the specifications of the EN 1359. The two benches have very comparable and stable results. The shift is less than 0.8% and the repeatability is less than 0.26% The meter 1 is highly impacted compared to meter 2. The additional error has been calculated (2% to -1%) for the meter 1 and -1.4% to -0.1% for the meter 2. The injection of H2 has a real impact on the metrological behaviour of all the tested and used (on the distribution grid) meters. Not significant deviation between the error results obtained with 10% and 20% of H2. This is very encouraging for the infield tests. A significant "long term" impact is measured on diaphragms meters maybe due to the difference of design and of plastic and polymers materials uses in meters.
35	Durability tests: up to 15% with steps of 5% starting from 0%vol on diaphragm G4 meters. The following results were obtained: 1) No damage was identified in the meter after the durability tests. 2) no significant metrological difference was found between the obtained average drift of errors of indications after the durability test using natural gas mixtures with different hydrogen concentration(from 0% to 15%). It was find a significant metrological impact of prolonged operation of the gas meters on their errors of indications, but it should not be considered as dependent on the hydrogen concentration in the gas but rather on the wear of the internal components (the same occurred also for meter tested at 0%vol).
37	For gas volume measurements, meters of different measuring principles are used with divergent H2 sensitivity. According to this, a H2 compatibility of up to 10% by volume can be assumed in principle. Higher compatibility levels are not excluded depending on the measurement method but require further investigation.
44	As general indication, the expert groups (defined within the NewGasMet project) recommend to use a test-gas which is identical with the gas intended for the meter to measure or make a transferability to another gas from air or natural gas. In addition It is reported a table with the renewable test gases (including H2) defined by the NEWGASMET expert group. While when different or alternative test-gas than the one the meter are designed to measure are used, this can lead to another calibration result which have to be corrected for which again will lead to an increase in the uncertainty. As example, it is reported that "results from the durability test indicate that current diaphragm and thermal mass flow gas meters, intended for use with natural gas, show shifts in measurement error when exposed to pure hydrogen which stay within the legal limits of the current documentary standards".
45	Several meters were installed in series and were connected by stainless steel pipes. During the test time, a decrease (steady decrease after temperature correction) of 6 mbar in nearly 8 days was measured, which is lower than the criteria of acceptance (1,8 mbar per day) defined and identified in the report itself. Conclusion: even after relative long times the leakage behaviour of the used polymers (sealing of meter housing and sealing of meter fittings) does not increase observable. This is an important result for the usability of these meters in gas grids with hydrogen.
49	For the 2 tested diaphragm meters the impact of H2 (10% and 20%) is significant and must be taken into account. A "long-term" impact was noted for these diaphragm meters. The calibration curve of these meters drifted substantially between before and after tests with hydrogen mixtures. This result needs to be confirmed with a larger number of meters.
51	Diaphragm gas meters with natural gas and 6%, 10% and 20% of H2 have been tested. As a results, the injection of H2 has a real impact (>0.5%) on the metrological behaviour of all the tested diaphragm meter (three types). Also a significant "long term" impact is measured on diaphragms meters. This effect is dependent on the meter manufacturer and the design of the metering cell of each meter.
53	Tested 3 diaphragm gas meters from two different manufacturers (G4) after calibration with air. The gas meters were tested for durability with 100% H2 for 3 months and 12 months. On the tests where finished the meters were again calibrated with air. For the flow rates in the range of Qt to Qmax, none of the differences in the error after the durability test and the error before the durability test exceed 2 %. All tested diaphragm gas meters were within tolerance of initial MPE for gas meters of accuracy class 1.5 before they were subjected to durability testing with hydrogen. All tested diaphragm gas meters were within tolerance of twice initial MPE for gas meters of accuracy class 1.5 after they were subjected to durability testing with hydrogen. The exposure to pure hydrogen does not produce any apparent effect on the diaphragms of Manufacturer 1, while some limited, local modifications are visible on the diaphragms of Manufacturer 2, after 12 months in hydrogen.
55	PTB and NEL have tested domestic gas meters with nitrogen and hydrogen gas flows with two different flow meter types using critical nozzles or rotary meter as references 3 + 3 G6 diaphragm from two different manufacturer. Each meter was calibrated at atmospheric pressure only, with 2 gases (with nitrogen and hydrogen) at 3 flow rates. The selected flow rates were 0.6, 1.2 and 10 m3/h. The measurements were repeated 3 times in both laboratories to investigate calibration differences. The comparison measurements carried by NEL and PTB show the ability to carry out tests needed for the conformity assessments of gas meters with the needed quality. The uncertainty requirements for such tests given in OIML R137 are fulfilled by the used test facilities of both partners. The agreement between the results is acceptable for meters of type B, even if there is no additional uncertainty influence by a meter shift taken into account. For all meters there is no systematically difference between type A and B meter to observe, when nitrogen and hydrogen is used as test gas. This statement is valid for diaphragm gas meter only because such meter using a volumetric principle. For other gas meter principles this has to be investigated separately.
57	The studies available in the literature show that diaphragm meters generally perform within the Maximum Permissible Error limits with hydrogen-enriched natural gas blends (up to 20 % hydrogen). Methane and blends result generally agree within 0.3 %, and the differences are primarily observed at low flow rates less than 10 % of Qmax.

3.1.2 Pressure and temperature transmitters

Table 15 contains information collected during the literature review for pressure and temperature transmitters.

Table 15. The information obtained from the literature review for pressure and temperature transmitters.

Document number	Main points
53	Durability test of pressure and temperature transmitters. For the tests, first of all, the tested pressure sensors were calibrated with nitrogen. The pressure sensors were maintained in hydrogen environment for 12 months and after that recalibrated with nitrogen at 20 C. It should be noted that since the temperature sensor doesn't come into contact with the gas (it is installed in a thermowell), only the pressure sensor was investigated. The MPE for pressure sensors to be satisfied is defined by EN 12405-1 (0.20 % from the measured valued under reference conditions and 0.50 % form measured value at rated operating conditions). The highest shift of the error was found at the minimum pressure. For one piece of EVCD it was 0.27 % that is above 0.20 % from the measured value what is MPE for the pressure sensors. But it is necessary point out that the uncertainty of measurement at Pmin was in the range U(k=2) = (0.09 - 0.18) % at this pressure point. (The main source of uncertainty in this pressure point was readability from LCD of the EVCD because it was in several cases 0.001 bar at 0.800 bar.) No important shift was found at the pressure point Pmax (6 bar g).

3.1.3 Volume converters

Table 16 contains information collected during the literature review for volume converters.

Table 16. The information obtained from the literature review for volume converters.

Document number	Main points
7	The equations of state AGA8 and SGERG are basically intended for calculating the K number for hydrogen-doped natural gases. As part of this work, an assessment was made based on both measurements and comparison with the GERG 2004 reference equation. It appears that the AGA8 equation can be applied up to 10% vol. without any restrictions and meets the accuracy requirements of 0.1% specified in G486 even for concentrations up to 30% by volume. For the SGERG equation, an accuracy of 0.1% is possible up to 10% H2 by volume in some natural gases, as long as the pressure does not exceed 50 bar. When in doubt, verify against the GERG-2004 or AGA8 equation.
8	According to the DVGW project G3-02-12 "Influence of hydrogen on the measurement of gas properties, energy measurement and billing", quantity conversion factors can in principle be used for gas mixtures containing up to 10% H2 by volume (also for variable concentrations). For admixtures up to 50% vol. H2 deviations using the AGA8 equation do not exceed 0.1% over the entire pressure range (K number deviation).
32	For the compressibility number used in volume correctors or active pressure gas meters, the sole influence of hydrogen is determined: The hydrogen content can be neglected if the product of overpressure (numerical value in bar) and hydrogen content (numerical value in percent) is less than or equal to 15: (xH2[%] × peff[bar]) ≤ 15. Furthermore, according to the PTB Technical Guideline G9, with electronic correctors, in which all gas data for the calculation of the compressibility number are recorded by sensors or measuring devices (K = f(p,T,xgas)), hydrogen contents of up to 0.2% can be neglected, i.e. assumed as 0%.
33	The report reports the steps to modify the SGERG-88 model to calculate the compression factor of gas mixtures containing hydrogen. To make it possible one solution is to suppress the CO correction factor and create the so-called SGERG-mod-H2. The equation of state "SGERG-mod-H2" is suitable for the calculation of natural gases with admixtures of up to 100 mol-% H2. At pressures up to 50 bar, the deviations from the measured values, as well as from the equation GERG-2008 are less than ±0.1%. For higher pressures up to 100 bar, deviations of up to ±0.5% might occur. Although the equation can theoretically be applied to hydrogen concentrations of up to 100 mol%, numerical problems can occur at very high concentrations of H2. Therefore, it is recommended to limit the application range to 30 mol% H2. For the equation SGERG-88, for a hydrogen content of up to 10 mol-% and pressures up to 50 bar, an uncertainty of 0.1 % is expected. The AGA8 equation and the GERG-2008 equation generally agree better than ± 0.1% for the measured values for all data sets in the entire pressure range. It can thus be expected that these equations of state can be used for any desired H2 fractions without significantly affecting the underlying 0.1% uncertainty of the equations.
57	The density difference between GERG-2008 and AGA8-DC92 models is well within ±0.03 % for a typical natural gas blend with up to 50 % hydrogen concentration and pressure between 5 and 50 bara. Studies in the literature show that GERG-2008 is within ±0.05 % of the experimental density results for up to 10 % hydrogen concentration natural gas blends and within ±0.1 % up to 30 % hydrogen concentration. The speed of sound difference between GERG-2008 and AGA8-DC92 models is well within ±0.05 % for a typical natural gas blend with up to 20 % hydrogen concentration and pressure between 5 and 50 bara. Further work is required to assess GERG-2008 and AGA8-DC92 performance against experimental data. However, tests at DNV with ultrasonic meters suggest that values are within 0.1 %. Further investigation is required to fully assess and further develop GERG-2008 and AGA8-DC92 models.

3.1.4 Gas Analyzers

Gas analyzers play a crucial role in accurately characterizing the composition of gas mixtures, including measuring hydrogen concentrations. As the interest in hydrogen as an alternative energy source grows, there is an increasing demand to adapt gas analyzers for the effective analysis and quantification of hydrogen in gas blends. Below is the table containing the literature review on the use of gas analyzers for H2NG mixtures (Table 17).

Table 17. The information obtained from the literature review for gas analyzers.

Document number	Main points
26	Measurement - Gas Chromatographs The material of gas chromatographs in contact with the process gas can be assumed to be ready for 100 % vol. H2. Concerning the function, gas chromatographs can measure determine the gas composition of blends of hydrogen and natural gas. Depending on the technology, above 20 % vol. of H2 shares are possible. Still, some existing GCs cannot measure hydrogen.
36	Analysers suitable for billing purposes There are no technical barriers to the analysis of H2 in natural gas to the accuracy required by Ofgem for billing purposes since the components that require measurement are all present in refinery gases and the gas chromatographic analysis of refinery gases is a well-established technique. Many instrument manufacturers make high quality laboratory refinery analysers. One example is Agilent Technologies who manufacture a 3-channel (Fid channel and 2 TCD channels) version of their 7890A gas chromatograph (GC) that analyses in parallel for H2 and helium (He) on one channel, CH4 to C6+ on a second channel and the permanent gases oxygen (O2), nitrogen (N2), carbon monoxide (CO) and carbon dioxide (CO2) on the third. The total analysis time is 6 minutes. Agilent also manufacture a Fast Refinery Gas Analyser using their 490 Micro GC QUAD. This uses four analytical channels to provide a full separation up to C6 in 2 minutes. The GC does not separate H2 and He, but since the He content of natural gas is very low, around 100 ppm, this may not be an issue. The two GCs currently approved by Ofgem for fiscal measurements do not separate N2, O2, H2 and He but report them as a composite N2. The impact on the accuracy of the fiscal measurement of low concentrations of He eluting with H2 would need to be quantified.
37	Gas quality: The most important measuring devices within the gas infrastructure are volumetric meters and process gas chromatographs for gas composition measurements. Process gas chromatographs were in the existing natural gas infrastructure usually only designed for very low H2 concentrations ≤ 0.2 Vol.-% H2. For gas chromatographs, a case-by-case approach is required. To measure relevant hydrogen contents, helium is required as an additional carrier gas. Meanwhile process gas chromatographs with H2- compatibilities up to 25 Vol.-% are available at the market. Therefore the one installed in the network can be substituted. To obtain an analysis time comparable with the current system, Emerson has proposed to use the Model 700 GC. It would comprise a standard natural gas system, as used at present, plus a second system measuring hydrogen [and helium] using a thermal conductivity detector and nitrogen or more usually argon as the second carrier gas. The standard hydrogen range is 5% max but Emerson is confident that this can be extended to 20%. Elster is recommending the Encal 3000 configured similarly to the Emerson system and using argon as the second carrier gas. At present it is available with a 0 to 5% hydrogen range but higher concentrations of hydrogen can be accommodated
39	Gas Composition Analysis Hydrogen blending scenarios could range from very small injection quantities (e.g., 1% by volume) to 50%+ hydrogen by volume on up to 100% hydrogen. Accurately identifying gas composition is important for all of these scenarios to ensure that the blend ratio stays below technical limits given modifications made to the system and to ensure accurate billing and tracking of gas heat content. Gas chromatography provides the primary method for determining pipeline gas composition and calorific values in order to ensure billing and network control. This technology detects gas mixture component concentrations by analyzing differences in component thermal conductivities and gas mobilities. Current gas chromatography methods employed on natural gas networks utilize helium as a carrier gas. Measurement inaccuracies can result from using helium, as it has a similar thermal conductivity to hydrogen. Alternative methods for measuring hydrogen within a natural gas mixture include using a single-column gas chromatograph with argon as the carrier gas or a dual-column gas chromatograph with helium and argon as carrier gases. Sensors are another developing technology to detect hydrogen, in conjunction with conventional gas composition analysis methods or with sensors detecting other hydrocarbon compounds . Blokland et al. (2021) developed a platinum-based sensor to reversibly detect hydrogen in natural gas. This technology was demonstrated in the HyDeploy project and was shown to detect hydrogen in gas mixtures up to 30 vol % composition at pressures up to 10 bar.
38	Gas quality: The current generation of process gas chromatographs (PGC) which use helium as the carrier gas are unable to detect hydrogen because of the relative proximity of their thermal conductivities (helium = 151 W/m*K; hydrogen = 180 W/m*K.). To solve the problem different solutions are available like: 1) add an additional separating column of argon as a carrier gas for hydrogen detection; 2) using new process gas chromatographs licensed for the metering of hydrogen; 3) to use PGCs with two single separating columns and two types of carrier gas. Commercial PGC able to measure up to 10% exist
59	For water content, methods such as chilled mirror hygrometer, quartz crystal microbalance, cavity ring-down spectroscopy (CRDS), and gas chromatography-mass spectrometry (GC-MS) are mentioned. Total hydrocarbon content (THC) can be measured using gas chromatography with flame ionization detection (GC/FID), methaniser GC-FID, GC-MS, or Fourier-transform infrared spectroscopy (FTIR). Methods for measuring oxygen include electrochemical sensors, GC-MS with jet pulse injection, gas chromatography with thermal conductivity detection (GC-TCD) and plasma discharge hydrogen-induced detection (GC-PDHID), and CRDS. Carbon monoxide can be measured using GC-PDHID, methaniser-GC-FID, FTIR, or CRDS. Sulphur compounds can be analyzed using gas chromatography with sulfur chemiluminescence detection (GC-SCD) or GC-FPD.

Document number	Main points
26	Measurement - Gas Chromatographs The material of gas chromatographs in contact with the process gas can be assumed to be ready for 100 % vol. H2. Concerning the function, gas chromatographs can measure determine the gas composition of blends of hydrogen and natural gas. Depending on the technology, above 20 % vol. of H2 shares are possible. Still, some existing GCs cannot measure hydrogen.
70 and 71	For the Danalyzer™ Model 500 and Danalyzer™ Model 700, only applications marked with 570HH and 6HH codes allow for the determination of hydrogen content in the NGH2 mixture. However, for the 500HH application, there is no information available regarding the percentage of hydrogen in the mixture. On the other hand, the manufacturer states that the 6HH application enables the determination of hydrogen content in the range of 0-10%.
72 and 73	The Rosemount 370XA and Rosemount 700XA models are customer configurable models. With appropriate configurations, these models allow for the determination of the hydrogen content in the mixture in the range from 0.1 to 100%.
74 and 75	The typical measurement range of the EnCal3000 model is the determination of C1-C6+ (optionally C1-C9+) hydrocarbons, nitrogen and carbon dioxide. However, similar to chromatographs manufactured by Emerson, this model can be configured to meet customer-specific requirements. One possible channel configuration for analyzing hydrogen and natural gas involves the use of two chromatography columns: • COX column, 1m long for the components He, H2, N2, CH4, CO2 and C2H6, • 5CB column, 8m long for the higher hydrocarbons (C3H8 to C9H20).
76 and 77	The NCG 8206 model manufactured by ABB is a typical solution dedicated to natural gas analysis. It enables determination of components such as: C1-C6+ (optionally C1-C9+) hydrocarbons, nitrogen, carbon dioxide and optionally hydrogen sulfide in the mixture. To determine the composition of H2NG mixtures, it is possible to use the PGC 1000 model because the PGC1000 is a field-mounted GC capable of measurements of C1 through C9+, inerts, H2S, H2, H2O, CO, O2, etc., in various mixtures.
78	The Micro GC is a self-contained package that includes all the typical components found in a gas chromatograph. It comes in different versions, such as the dual channel cabinet version (offering one or two GC channels) or the quad channel cabinet version (providing up to four GC channels). The possibility of using various types of chromatographic columns and carrier gases makes it possible to determine all typical components determined by gas chromatography, including hydrogen, in a gas mixture. However, to measure the hydrogen content accurately, the system needs to be properly configured and set up for hydrogen analysis. With the right configuration, the Micro GC becomes a valuable tool for analyzing complex gas mixtures in various applications.
79	The determination of sulfur compounds' content using chromatographs equipped with FPD or PFPD detectors in mixtures of natural gas and hydrogen can be carried out in the same way as before. This is because hydrogen, as the gas supplying the detector, does not adversely affect the analysis results. The ISO 21087:2019 standard titled "Gas analysis - Analytical methods for hydrogen fuel – Proton exchange membrane (PEM) fuel cell applications for road vehicles" recommends the use of the GC-FPD technique to determine the content of sulfur compounds in 100% hydrogen.

3.1.6 Trace water sensors

Trace water sensors are essential tools for accurately measuring moisture content in gas mixtures, including those containing hydrogen. As the utilization of hydrogen as an alternative energy source gains momentum, the need for trace water sensors that can effectively operate in hydrogen blends becomes increasingly important.

Below you can find the table with literature review on trace water sensors' use for H2/NG mixtures (Table 18).

Table 18. The information obtained from the literature review for trace water sensors.

Document number	Main points
59	The water dew point is proposedly (ISO6327 [39]) determined with a hygrometer by detecting water vapour condensation occurring on a cooled surface or by checking the stability of the condensation on this surface. For the hydrocarbon dew point temperature, the methods proposed require the knowledge of the composition (obtained by chromatography) in order to calculate the parameter using an appropriate equation of state (ISO23874 [30]) or the use of chilled mirror type instruments (ISO/TR12148:2009 [32]). ISO/TR 11150:2007 Natural gas – hydrocarbon dew point and hydrocarbon content, International Organization for Standardization, Geneva, Switzerland, 2007. ISO6327:2008 Gas analysis — Determination of the water dew point of natural gas — Cooled Surface condensation hygrometers, International Organization for Standardization, Geneva, Switzerland, 2008
36	To evaluate the impact of hydrogen, a stepwise calculation approach has been adopted. Initially, the UK national average gas composition was used and water added to establish a concentration at which the water dew point matches the limit value in the standard Network Entry criteria. With this theoretical water content limit, further calculations are performed to assess the impact on the water dew point temperature as a function of both hydrogen content from 0 – 20 mol% and system pressure from 20 bar to 80 bar. Thermodynamically, gas hydrate should form before a liquid water phase. At 80 bar, the hydrate formation temperature is calculated to be -6.1C, and with 20 mol% H2 added it is -6.0 C. Thus, as for liquid water, H2 lowers the dew temperature – but not by very much.

Document number	Main points
	In conclusion: H2 lowers the dew temperature, but by less than (about) 1 C below 80 bar. This may be an issue if the natural gas is very close to the dewpoint at the point the hydrogen is added. If water dew point measurement and oxygen content or hydrogen purity measurements are included in the hydrogen electrolyser installation then these measurements should not be required on the blended gas stream as the incoming natural gas must already be GS(M)R compliant. Only, if the water dewpoint or the oxygen concentration are at risk of exceeding GS(M)R values would it be expected that this risk assessment may recommend installation of water dewpoint or the oxygen measurement devices in the outgoing natural gas\hydrogen stream
80	The manufacturer states that the water dew point transmitter is resistant to hydrogen.
81 and 82	Suitable for use with natural gas containing up to 20% hydrogen with no further modification required. An example application is catalytic reformer recycle hydrogen.
83	Typically Transmet IS will be used for the fiscal metering of natural gas dew point, of the moisture content in catalytic reformer gases, or in the measurement of hydrogen coolant for power plant stators.

3.1.7 Leak detectors

The safety of gas network operation requires technical services to be equipped with leak detectors. If H2NG mixtures are to be transported through gas networks, it is important to enable the technical service to detect both methane and hydrogen leaks. This is because methane and hydrogen have different properties in terms of permeability, particle size, etc. Table 19 shows SoA for hydrogen leak detectors.

Table 19. The information obtained from the literature review for leak detectors.

Document number	Main points
84	Drager offers 4 models of hydrogen leak detectors: DrägerSensor Cat-Ex 125 PR, DrägerSensor Cat-Ex 125 PR-Gas, DrägerSensor XXS H2 and DrägerSensor XXS H2 HC.
85	Sisco offers reliable portable hydrogen gas detector with a measurement range from 0 to 500 ppm, 1000 ppm, 2000 ppm, or 5000 ppm.
86	Riken Keiki NP-1000-H2 Portable Hydrogen Monitor is designed specifically to measure Hydrogen (H2) in Inert Atmospheres. In Addition to being able to Monitor Hydrogen (H2) in Nitrogen or Carbon Dioxide it can also measure Hydrogen (H2) in Air for applications requiring a % Volume range. The NP-1000-H2 Hydrogen Detector has a dual rangle of 0-10% and 0-100% Volume which is Autoranging so the most accurate range is automatically selected for the application.
87	PEAKER®s H2 is handheld gas leak detector for the selective detection of Hydrogen (H2) with a measurement range from 0 ppm up to the Lower Explosive Limit (LEL) H.
88-89	Mru offers 2 models of hydrogen leak detectors: 400GD and 500DG with a measurement range from 0 ppm to 2,0%.

3.2 Gaps and limitations from survey analysis

The next step in identifying gaps and limitations involved creating and sending a survey to manufacturers of measurement devices. The method of creating the survey is described in section 2.1 of this report. Below, the information obtained from manufacturers is compiled. To ensure greater clarity in the report, the gathered information is presented separately for each of the analyzed groups of measurement devices (sections 3.2.1-3.2.7) – Tables 20-31.

In order to better identify and analyze the data, it was marked with colors as per the points below:

- devices identified in the TSOs and responses received from manufacturers about them were marked in green
- devices which information have been received from the manufacturers on, but not identifid in the TSOs were marked in orange.

For confidentiality reasons, the answers have been anonymized. Specifically, Manufacturers will be listed as "MAN. 1, …, N" while the models as "MOD. 1, …, N". The same anonymized name of the manufacturer will be maintained for all the document.

3.2.1 Gas meters

Below are the gathered information from the survey conducted with gas meter manufacturers. The information has been collected separately for each type of gas meter, and it is presented in Tables 20-25.

3.2.1.1 Turbine gas meters

Table 20. Survey data collected from manufacturers of turbine gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.1	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	50%	metrological issues	YES, 15%H2, 50%H2	Rangeability less then on NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	MOD.2		50%	metrological issues	YES, 15%H2, 50%H2	-	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	MOD.3		50%	metrological issues	YES, 15%H2, 50%H2	Rangeability less then on NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	MOD.4		50%	metrological issues	YES, 15%H2, 50%H2	Rangeability less then on NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	Develop new turbine gas meter model for 100% H2							
MAN.2	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	25% vol	ATEX class limit	YES, 30%	accuracy and repeatibility, (JIP & JTP), low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	EN12261
	Develop new turbine gas meter model for 100% H2							
MAN.3	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	100	lack of test rigs and EN standards	YES, 30%	very good results at elevated pressure	PROCEDURE FROM THE EXISTING STANDARDS	Tests performed at DNV/NL (traceability to PTB/GER)
	MOD.2		100	lack of test rigs and EN standards	YES, 30%	very good results at elevated pressure	PROCEDURE FROM THE EXISTING STANDARDS	Tests performed at DNV/NL (traceability to PTB/GER)
	Develop new turbine gas meter model MOD.1 and MOD.2 for 100% H2							

3.2.1.2 Rotary piston gas meters

Table 21. Survey data collected from manufacturers of rotary piston gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.1	MOD.5	NOT SHOWN FOR CONFIDENTIALITY	100%	N/A	YES, 50%H2, 100%H2	Error of indication the same as in NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	MOD.6		100%	N/A	YES, 50%H2, 100%H2	Error of indication the same as in NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
	MOD.7		100%	N/A	YES, 50%H2, 100%H2	Error of indication the same as in NG	Tests developed in house	Error of indication on H2, Durability on mixture of NG and H2
MAN.2	MOD.2	NOT SHOWN FOR CONFIDENTIALITY	25% vol	ATEX class limit	YES, 30% H2	accuracy and repeatibility, (JIP & JTP), low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	EN12480
	Develop new rotary piston gas meter model for 100% H2							
MAN.3	MOD.3	NOT SHOWN FOR CONFIDENTIALITY	100%	lack of test rigs and EN standards	NO	-	-	-
	MOD.4		100%	lack of test rigs and EN standards	NO	-	-	-
	Develop new rotary piston gas meter model MOD.3 and MOD.4 for 100% H2							

3.2.1.3 Ultrasonic gas meters

Table 22. Survey data collected from manufacturers of ultrasonic gas meters.

Manufacturer	Type/ Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.2	MOD.3	NOT SHOWN FOR CONFIDENTIALITY	30% vol (in H2NG mixtures); 100% vol	lacking of reference system for calibration with 100% vol H2	YES, 30%H2, 100%H2	accuracy and repeatibility, (JIP & JTP), low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	ISO17089-1
	MOD.4		20% vol	ATEX class limit	YES, 25%	accuracy and repeatibility before and after endurance test with H2NG (5000 hours), low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	EN1359
	Develop new ultrasonic gas meter model for 100% H2							
MAN.3	MOD.5	NOT SHOWN FOR CONFIDENTIALITY	30%	lack of test rigs and EN standards metrological issue, used transducer needs improvement	YES, 30%	metrological performance verification (repeatability, drift)	PROCEDURE FROM THE EXISTING STANDARDS	repeatability and reproduceability according OIML R137-1, ISO17089-1
	Develop new ultrasonic gas meter model 100% H2							
MAN. 4	MOD.1	-	50%	Materials	YES, 50%	No degradation in performance	PROCEDURE FROM THE EXISTING STANDARDS	-
MAN.5	MOD.1	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. MOD.1 is expired (Sucesssor MOD.6 and MOD.7).	NO, but installations in H2 services in Refineries	No issues on the meter due to hydrogen measurement	-	-
	MOD.2	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges	NO, but installations in H2 services in Refineries	-	-	-

				of the media. Model MOD.1 is expired (Sucesssor MOD.6 and MOD.7).				
	MOD.3	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. Model MOD.1 is expired (Sucesssor MOD.6 and MOD.7).	YES, 30%	Test confirmed the meter accuracy statement	PROCEDURE FROM THE EXISTING STANDARDS	JIP by DNV in the Netherlands
	MOD.4	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. Model MOD.4 is expired (Sucesssor MOD.8).	NO, but installations in H2 services in Refineries	No issues on the meter due to hydrogen measurement	-	-
	MOD.5	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. Model MOD.5 is expired (Sucesssor MOD.8).	NO, but installations in H2 services in Refineries	No issues on the meter due to hydrogen measurement	-	-
	MOD.6	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. MOD.6 can calculate compressibility factor and molecular weight from measured sound speed.	YES, 100%	Test confirmed the meter accuracy statement	PROCEDURE FROM THE EXISTING STANDARDS	Tests by DNV in the Netherlands
	MOD.7	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. MOD.7 can calculate compressibility factor and molecular weight from measured sound speed.	-	-	-	-

	MOD.8	None, it is a process and monitoring device. Not possible for Clamp-on.	up to 100%	no issues; applications must be evaluated if meter settings have to be adapted to new sound speed ranges of the media. MOD.8 can calculate compressibility factor and molecular weight from measured sound speed.	-	-	-	-
MAN.6	MOD.1	ISO17025 (wrong)	no limit	yes possible with specific adjustment	YES, JIP Project at DNV Groningen from 06/20 to 06/21	With activation of NGE (special internal sw) performances are within instrument specs, both accuracy and repeatability even at 30%H2 in NG		No special test in house developped
MAN.7	MOD.1	-	20%	The ATEX improvements needs to be implemented for electronics to measure up to 100%	NO			
	Develop new ultrasonic gas meter model up to 30% H2							
MAN.8	MOD.1	EMC Directive 89/336/EEC , 73/23/EEC LVD (Installation Category II, Pollution Degree 2)	100%	-	-	-	-	-
	MOD.2	EMC Directive 89/336/EEC, 73/23/ EEC LVD (Installation Category II, Pollution Degree 2), PED 97/23/EC for DN<25	100%	-	YES, 30%	1% deviation against reference, satisfactory	PROCEDURE FROM THE EXISTING STANDARDS	ISO17025, Static testing, blended testing, transducer testing, algorithm testing, etc
	MOD.3	EMC Directive 2004/108/EC , 2006/95/ EC LVD (Installation Category II, Pollution Degree 2) , PED 97/23/EC for DN<25	100%	-	-	-	-	Static testing, blended testing, transducer testing, algorithm testing, etc

	MOD.4	EMC Directive 2004/108/EC, 2006/95/ EC LVD (Installation Category II, Pollution Degree 2), PED 97/23/EC for DN<25	100%	-	-	-	-	Static testing, blended testing, transducer testing, algorithm testing, etc
	MOD.5	EMC Directive 2004/108/EC, 2006/95/EC LVD (Installation Category II, Pollution Degree 2), PED 97/23/ EC for DN<25	100%	-	-	-	-	Static testing, blended testing, transducer testing, algorithm testing, etc
	Develop new ultrasonic gas meter model 100% H2							
MAN. 9	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	30% vol acc. to DNV JIP	Formal certification is missing due to missing certified H2 calibration labs	Yes, 100% H2 vol.	Stable performance within class 1	Test in house	A test to measure and adjust delay time
	Develop new ultrasonic gas meter model 100% H2							
MAN.10	MOD.1 MOD.2	NOT SHOWN FOR CONFIDENTIALITY	30% vol	ATEX class limit transferability of uncertainty from NG to 100%H2 lack of standards lack of calibration labs technology limititation (different devices for NG and H2)	Yes, 30% vol	Successfully passed tested at PTB which allow to extent MID to 30%H2. devices perform as expected	PROCEDURE FROM THE EXISTING STANDARDS	-
	Develop new ultrasonic gas meter model 100% H2							

3.2.1.4 Coriolis gas meters

Table 23. Survey data collected from manufacturers of coriolis gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN. 4	MOD.2	NOT SHOWN FOR CONFIDENTIALITY	-	-	-	-	-	-
	MOD.3		-	-	-	-	-	-
	MOD.4		-	-	-	-	-	-
	MOD.5		10, 20, 30 and 100%	So far, MAN.4 has been able to test Coriolis flowmeters with different level of H2 concentration in NG. However, there is really a lack of metrological infrastructure (Primary/secondary standards) capable to calibrate large sizes (DN > 100 mm)	YES, 10,20 and 30%	Results within manufacturer specifications	PROCEDURE FROM THE EXISTING STANDARDS	The test performed at DNV with blended gases was partially based on recommendations written in the ISO 17089 Calibration of Ultrasonics flowmeters.
MAN.9	MOD.2	NO ANSWER	NO ANSWER	NO ANSWER	NOT KNOWN	-	-	-
	Develop new Coriolis meters up to 100% H2							
MAN.11	MOD.1	No MID, only DAKKS available on request	0...100%	"Meter technology can reach up to 100% H2 or mixtures of different compositions. No metrological certificate available."	YES Standard application available for gas mixtures up to 100% H2	-	-	-

3.2.1.5 Thermal Mass gas meters

Table 24. Survey data collected from manufacturers of thermal mass gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.4	MOD.6	-	The amount of hydrogen within the mixture can be freely selected by customer up to 100%	Our device can measure H2NG mixture without limitation. The repeatability is high, but the accuracy is impacted by the amount of hydrogen.	YES, up to 30%vol	Up to 10%, hydrogen has a negligible effect on the measurement accuracy. Above 10% is the accuracy is decreasing with increasing amount of hydrogen. We assume that the thermo-physical properties of the mixture from the database used for the calculation is not accurate enough.	PROCEDURE FROM THE EXISTING STANDARDS	We have performed measurement in the Multiphase Flow Facility at DNV in Groningen (NL) whose system was accredited by PTB. We do not know the technical standards used.
	Develop new thermal mass gas meter model up to 30% H2							
MAN. 11	MOD.2	NONE	0…100%	Meter technology can reach up to 100% H2 or mixtures of different compositions. No metrological certificate available.	-	-	-	-
MAN.12	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	100% process measurement	-	YES, 100%vol	factory approval and certificate	PROCEDURE FROM THE EXISTING STANDARDS	CE standard
MAN.13	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	2%	Devices not approved for higher percentages of H2 (MID)	YES, 23%vol	metrological error outside MPE for class 1,5	TESTS DEVELOPED IN HOUSE	as per EN17526:2021 using additional G222 mixture (23% H2+methane), test gas not present in EN17526:2021
	MOD.2		2%	Devices not approved for higher percentages of H2 (MID)	YES, 23%vol	metrological error outside MPE for class 1,5	TESTS DEVELOPED IN HOUSE	as per EN17526:2021 using additional G222 mixture (23% H2+methane), test gas not present in EN17526:2021

	MOD.3		23%	Devices not approved for higher percentages of H2 (MID)	YES, 23%vol	within MID accuracy class 1,5 MPE	TESTS DEVELOPED IN HOUSE	as per EN17526:2021 using additional G222 mixture (23% H2+methane), test gas not present in EN17526:2021
	MOD.4		23%	Devices not approved for higher percentages of H2 (MID)	YES, 23%vol	within MID accuracy class 1,5 MPE	TESTS DEVELOPED IN HOUSE	as per EN17526:2021 using additional G222 mixture (23% H2+methane), test gas not present in EN17526:2021
	MOD.5	NOT SHOWN FOR CONFIDENTIALITY	>98% by volume	Not applicable	YES, >98%vol (ISO14687 type I grade A)	within MID accuracy class 1,5 MPE	TESTS DEVELOPED IN HOUSE	as per EN14236:2018 with additional test for pure hydrogen (e.g. accuracy and tightness)
	Develop new thermal mass gas meter model up to 30% H2							

3.2.1.6 Diaphragm gas meters

Table 25. Survey data collected from manufacturers of diaphrahm gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.14	MOD.1	NOT SHOWN FOR CONFIDENTIALITY	5%	Certification issues. Metrological and material would be fine for higher amount	NO	-	-	-
	Develop new diaphragm gas meter model for 20% H2							
MAN.2	MOD.5	NOT SHOWN FOR CONFIDENTIALITY	20% vol	ATEX class limit	YES, 25%	accuracy and repeatibility before and after endurance test with H2NG (5000 hours, low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	EN1359
	MOD.6		20% vol	ATEX class limit	YES, 25%	accuracy and repeatibility before and after endurance test with H2NG (5000 hours, low fugitive emission	PROCEDURE FROM THE EXISTING STANDARDS	EN1359
MAN.7	MOD.2		1	We didn't recognise any metrological or materials problems.	YES, 100%	Possitive acc. OIML	PROCEDURE FROM THE EXISTING STANDARDS	OIML
	MOD.3		1	We didn't recognise any metrological or materials problems.	NO	-	-	-
	MOD.4		1	We didn't recognise any metrological or materials problems.	NO	-	-	-

	MOD.5		1	We didn't recognise any metrological or materials problems.	YES, 100%	The results are in the EN 1359 limits	PROCEDURE FROM THE EXISTING STANDARDS	EN 1359
	MOD.6		1	We didn't recognise any metrological or materials problems.	NO			
	MOD.7	-	0,5	-	NO			
	MOD.8	-	0	-	NO			
	Develop new diaphragm gas meter model for 100% H2							
MAN.3	MOD.6	NOT SHOWN FOR CONFIDENTIALITY	100%	lack of test rigs and EN standards	YES, 30%	higher variation in error / 30% is limit for a standard ultrasonic meter	PROCEDURE FROM THE EXISTING STANDARDS	Test at PTB/GER lab

3.2.1.7 Other gas meters

Table 25. Survey data collected from manufacturers of diaphrahm gas meters.

Manufacturer	Type/Model	EU Type Examination Certificate	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.11	MOD.3	None	0...100%	"Meter technology can reach up to 100% H2 or mixtures of different compositions. No metrological certificate available."	-	-	-	-

3.2.2 Pressure transmitters

Table 26 contains data collected from surveys obtained from manufacturers of pressure transmitters.

Table 26. Survey data collected from manufacturers of pressure transmitters.

Manufacturer	Type/Model	Technology type of the indicated model: (absolute, differential, gauge)	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount [%vol]	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.1	MOD.8	Absolute/differential	33%	ATEX cert.	YES, 15%	Measurement error has not changed beyond MPE	Tests developed in house	Indication error before and after the experiment
	Develop new pressure transmitter model for 100% H2 [range 0-35 barg]							
MAN.15	MOD.1 MOD.2 MOD.3 MOD.4 MOD.5	Absolute/gauge	0 or 100%H2, 100% for high pressure only and with gold-plated diaphragm	behavior of thin membranes in the hydrogen presence hasn't been fully investigated,	NO	not applicable	not applicable	not applicable
	MOD.6 MOD.7 MOD.8 MOD.9	Differential	0%	not applicable	not applicable	not applicable	not applicable	not applicable
	Develop new pressure transmitter model (but no more information)							
MAN.11	MOD. 4	Gauge, Differential and Absolute	Up to 100%	No Limits	YES, 100%	-	PROCEDURE FROM EXISTING STANDARDS	-
MAN.12	MOD.2	Gauge	up to 100%	not applicable	YES, 100%	factory approval and certificate	PROCEDURE FROM THE EXISTING STANDARDS	CE standard
	MOD.3	Differential	up to 100%	not applicable	YES, 100%	factory approval and certificate		CE standard
	MOD.4	Absolute	up to 100%	not applicable	YES, 100%	factory approval and certificate		CE standard
MAN.8	MOD.6	Absolute	up to 20%	Material brittleness	YES	-	PROCEDURE FROM THE EXISTING STANDARDS	-
	MOD.7	Absolute/gauge	up to 20%	Material brittleness	-	-	-	-
	Develop new pressure transmitter model for 100% H2 [pressure range 35÷350 barg, temperature range 20÷100°C]							

3.2.3 Temperature transmitters

Table 27 contains data collected from surveys obtained from manufacturers of temperature transmitters.

Table 27. Survey data collected from manufacturers of temperature transmitters.

Manufacturer	Type/Model	Technology type of the indicated model: (thermocouple, thermistor, RTD)	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount [%vol]	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.15	MOD.10 MOD.11 MOD.12 MOD.13 MOD.14 MOD.15 MOD.16	thermocouple, RDT	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
MAN. 11	MOD. 5	RTD, Non-Invasive	Up to 100%	Can measure only if Reynolds number > 10000	-	-	-	-
MAN.12	MOD.5	all temperature sensor: rtd, T/C, resistance	till 100%	not applicable	YES, 100%	factory approval and certificate	PROCEDURE FROM THE EXISTING STANDARDS	CE standard

3.2.4 Volume converters

Table 28 contains data collected from surveys obtained from manufacturers of volume converters.

Table 28. Survey data collected from manufacturers of volume converters.

Manufacturer	Model	Type of volume converter	Z formulas implemented	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content?	Developed new algorithm	Maximum amount of H2 the model could accept in the mixture with new algorithms
MAN.1	MOD.9	type 1	AGA8-92DC, S-GERG-88, AGA8-Gross1, AGA8-Gross2, AGA-NX19mod., GERG-91mod., Peng-Robinson 100% H2.	10%	The MID harmonized standard allows 10% H2	GERG-2008, GERG-88 mod H2	100%
	MOD.10	type 1	Peng-Robinson 100% H2	100%	-	GERG-2008, GERG-88 mod H2., 100%	100%
	MOD.11	type 1	AGA8-92DC, S-GERG-88, AGA8-Gross1, AGA8-Gross2, AGA-NX19mod., GERG-91mod.	10%	1) The MID harmonized standard allows 10% H2. 2) Type of explosion-proof construction	production discontinued	-
	MOD.12	type 1	S-GERG-88,	10%	1) The MID harmonized standard allows 10% H2. 2) Type of explosion-proof construction	production discontinued	-
	MOD.13	type 2	S-GERG-88,	10%	1) The MID harmonized standard allows 10% H2. 2) Type of explosion-proof construction	production discontinued	-
	Develop new model of volume converter type 1 for 100% H2						
MAN.2	MOD.7	type 1	ISO12213-2 (AGA8-DC92) | ISO12213-3 (SGERG-88) | AGA-NX19	Depending of Z formula selected	ATEX classification IIB, no Z calculation for higher then 40%	NO	-
	Develop new volume converter model for 100% H2 - pressure range: 0.8 ÷ 2 barA | 0.6 ÷ 3.5 barA | 0.9 ÷ 10 barA | 5 ÷ 24 barA | 10 ÷ 40 barA | 20 ÷ 80 barA and temperature range: -25 °C ÷ +60 °C						

MAN. 11	MOD.6	Type 2 (no POT protocol as per UNI/TS 11629 available)	AGA 5, AGA 8 Part 1 (AGA8:1994), AGA 8 Part 2 (GERG2008), AGA 10 AGA NX19-Mod GERG-2008 GPA 2145, GPA 2172 GSSSD MR113 ISO 5167, ISO 6976, ISO 12213 Parts 2 and 3, ISO 20765 parts 1 and 2 MI 3213 S-GERG	Up to 100% H2	No technological constraints. Current MID legislations includes limits in H2 content: 23% test gases (EN437), 10% for compressibility factor calculation as per ISO12213.	NO	-
MAN.16	MOD.1	Type 2	AGA8, SGERG88	100%	None	I DON'T KNOW	-
MAN.9	MOD.3	type 2	AGA8 1994, 2017, Sgerg88, approved compressibiltytables	depending on the standards: AGA8 1994 100%, 40% AGA8-part 1, 100% AGA8-part 2 (2017)	approved H2 calculations not yet implemented in various brands of flowcomputers. The summit can be upgraded to latest firmware with approved calculations	YES	0-100%
MAN.17	MOD.1	type 2	1. AGA8-92DC 2. MGERG-88 3. AGA-G1 4. AGA-G2 5. K1-constant 6. SGERG-88	-	-	YES	100%
	MOD.2	type 2	1. AGA8-92DC 2. MGERG-88 3. AGA-G1 4. AGA-G2 5. K1-constant 6. SGERG-88	-	-		

	MOD.3	type 1	1. AGA8-92DC 2. SERG-88 3. AGA-G1 4. AGA-G2 5. AGA NX-19mod 6. K1-constant 7. SGERG-mod-H2	It Is Possible to blend hydrogen with natural gas from 0% to 100%.	In my opinion there is an major factors are involved in why current devices are not measuring H2NG. 1. Physical Properties: Hydrogen and natural gas have different physical properties, such as density, heat capacity, and compressibility, which can affect the performance of gas meters and volume correctors. If the device is not specifically designed and calibrated for hydrogen or H2NG mixtures, the readings may be inaccurate.		
MAN.12	MOD.6	type 1	Compressibility calculation in accordance with AGA-NX19 mod, AGA 8 (GC1 or GC2), AGA 8 DC-92, S-GERG 88, AGA-NX19 or fixed EK280: SGERG-mod-H2 can be used up to 100 % according to MID approval	100%	not applicable	I DON'T KNOW	-
	MOD.7	type 2	Compressibility: SGERG, AGA-NX19, AGA Report No. 8 (full gas composition), constant k-factor, heating value & relative density: ISO 6976 (mass or volume based). Gas quality values: ISO 6976, GPA 2172, AGA Report No 10 VOS comparison Orifi ce calculations: AGA 3, ISO 5167 SGERG-mod-H2 and AGA8-	100%	not applicable		

			92DC can be used up to 100 % according to MID approval.				
MAN.18	MOD.1 (OUT OF PRODUCTION)	Type 1	AGA NX-19	not declared	-	-	-
	MOD.2 (OUT OF PRODUCTION)	Type 2	AGA NX-19	not declared	-	-	-
	MOD.3 (OUT OF PRODUCTION)	Type 2	AGA NX-19	not declared	-	-	-
	MOD.4 (OUT OF PRODUCTION)	Type 1	AGA NX-19	not declared	-	-	-
	MOD.5	Type 2	S-GERG88 AGA8-1992	10%vol	Z formulas implemented	-	-
	MOD.6	Type 2	S-GERG88 AGA8-1992	10%vol	Z formulas implemented	-	-

3.2.5 Gas Analyzers

Table 29 contains data collected from surveys obtained from manufacturers of gas analyzers.

Table 29. Survey data collected from manufacturers of gas analyzers.

Manufacturer	Model	Configurations allow the determination of the content of at least such components as: hydrocarbons C1-C6+, N2, CO2, H2	Type of gas is being measured (e.g. natural gas, refinery gas, biogas)	Measurement range for CH4 [%mol/mol]; H2 [%mol/mol]	Type of detectors the chromatograph is equipped with (e.g. TCD, FID, etc)	Carrier gas (e.g., helium, nitrogen, etc.)	Conversion method for the measurement (e.g., AGA8-G1, AGA8-G2, SGERG-88, ISO 6976, GPA 2172, ASTM D 3588)	Gas energy parameters are calculated on the basis of the obtained gas composition, e.g., ☐ heat of combustion (unit): ... ☐ calorific value (unit): ... ☐ Wobbe number (unit): ... ☐ density (unit): ... ☐ relative density ☐ compressibility factor ☐ other, please specify... Reference conditions for calculating the above-mentioned energy parameters, e.g., T_1 combustion temperature [°C], T_2 volume measurement temperature [°C], p pressure [bar])	Problem of currently installed devices in the context of measuring H2NG mixtures with higher content
	-	-	-	-	-	-	-	-	-
MAN.2	*Develop new model of gas analyzer (GEDRA - Gas Energy Density Raman Analyser) for Methane 80-100* *Hydrogen 0.05-20 [%mol/mol] Methane 80-100* *Ethane 0.05-15* *Propane 0.05-4* *n-Butane 0.05-4* *i-Butane 0.05-4* *Nitrogen 0.05-10* *Carbon dioxide 0.05-4* *Hydrogen 0.05-20*								

MAN.12	MOD.8	Till C9+, N2, CO2, H2, H2S, THT, TBM, THT + TBM, NTS	Natural gas, biogas, refinery gas	0-100% for CH4, 0-100% for H2	Measure columns (till qty 4 different columns) measure rate from 3 minutes to more depending by measurement type	Tipicaly Helium, Argon	Complete stand-alone operation, including all calculations and generation of report formats, without need for operator intervention. Calculations in acc. with ISO 6976, GPA 2172, GOST 22667 or ASTM D3588	all mentioned even if more . Rference condition configurable depending by customer requiremens. Other as but not only: Displayed value (abbreviation) Meaning (of the abbreviation of value) / physical quantity Hs Heating value; molar HsV Gross heating value based on volume HsM Gross heating value based on mass Hi Inferior calorific value; molar HiV Net heating value based on volume HiM Net heating value based on mass Z Compressibility factor (Z) , Ws Gross Wobbe index Wi Net Wobbe index d Relative density Rho Density at base conditions(standard density) M molar mass (of the mixture) MZ methane number	already available till 100% for process measurement, for MID measurement till 20% , at development and approval stage for upper H2 percentage

	MOD.9	Wobbe Index , Calorific Power, NG density , CH4 percentage, Methane number, Co2, N2	natural gas	CH4 70-100 %mol, H2 measure at final upgrading/approval device stage before selling	TCD (thermal conductivity + infrared+ temperature and pressure compensation) 6 sec. measure rate	No carrier gas required	Metering ranges NB0122 EC TC8494R1 , * according to ISO 6976 at T1=25 °C, T2=0 °C # according to ISO 6976, ASTM 3588, GPA 2172 at all known reference conditions , Accuracy Class A according to OIML R 140 for a CVDD	all mentioned even if more . Rference condition configurable depending by customer requiremens. Other as but not only: Displayed value (abbreviation) Meaning (of the abbreviation of value) / physical quantity Hs Heating value; molar HsV Gross heating value based on volume HsM Gross heating value based on mass Hi Inferior calorific value; molar HiV Net heating value based on volume HiM Net heating value based on mass Z Compressibility factor (Z) , Ws Gross Wobbe index Wi Net Wobbe index d Relative density Rho Density at base conditions(standard density) M molar mass (of the mixture) MZ methane number	at development and approval stage for H2 measuremen
MAN. 11	MOD. 7	C1-C6+, N2, CO2, H2	Natural gas, blending, NG-H2, Biomethane	CH4 55-100%, H2 0-10 %	TCD	Helium	ISO 6976	CALORIFIC VALUE, DENSITY, CO2, H2	Metrological issues and Certification Issues
	MOD. 8	C1-C6+, N2, CO2	Natural gas, biomethane	CH4 55-100%	TCD	Helium			
	A new model is under development.								

MAN.19	MOD.1	H2	Natural gas	1%	Electrochemical H2S sensor	Air	-	concentration	-
	-	Mercaptans	Natural gas	1 to 100 mg/m3	Electrochemical H2S sensor	Air	-	concentration	-
	-	THT	Natural gas	1 to 100 mg/m3	Electrochemical H2S sensor	Air	-	concentration	-
MAN.8	MOD.8	Oxygen	Natural gas	ppm and %	Galvanic fuel cell	No carrier gas/utilities needed, units measure on process gas	-	Not applicable	Not applicable
	MOD.9	Hydrogen	Natural gas/biogas/ refinery gas	%	Thermal conductivity	No carrier gas/utilities needed, units measure on process gas	-	Not applicable	Not applicable
MAN.20	MOD.1	MOD.1 2 channels with molecula sieve coloum and Pora Plot Q	natural ga, biogas, syngas, biomethane and hydrogen	CH4 0-100%, H2 0-100%	TCD	Ar+He or Ar+ H2 or N2 + He or N2+H2	ISO 6976	HHV, LHV,Wobbe number, relative density, compressibility factor. Reference conditions (T1,T2): 0-15°C, 15-15°C,	Because mostly use TCD with Helium as carrier gas, so the amount of Hydrogen quantificable is fisically limited. Almost all the installed devices don't have the right coloumn to separate Hydrogen from Nitrogen and oxygen.

3.2.6 Trace water sensors

Table 30 contains data collected from surveys obtained from manufacturers of trace water sensors.

Table 30. Survey data collected from manufacturers of trace water sensors.

Manufacturer	Type/Model	Operative pressure range [barg]	range of moisture concentration of water [ppm]	dew/frost point temperature range, [°C] - specifying the reference pressure [bar]	maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount	Briefly describe the results

MAN.21	MOD.1	0,3	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable	We're not aware of any specific tests of HNG mixtures.	We see no reason why there should be any problems with HNG mixtures as our products are already used on pure hydrogen and natural gas
	MOD.2	350	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable		
	MOD.3	0,3	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable		
	MOD.4	350	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable		
	MOD.5	0,5	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable		
	MOD.6	0,5	0.0016 - 23,086	-110 to +20 at 1 bar	100	not applicable		
MAN.22	MOD.1	10	0,1 - 23000	As above at 1 bar	No limit	not applicable	YES, 20%	Cooled mirror dew point meter
MAN.8	MOD.10	Up to 172 with heated pressure regulator	0-5000	"-71 ⁰C to -2,6 ⁰C at atmospheric pressure	100	Not applicable	YES, 100%	Performs to product specification
	MOD.11	Up to 345	up to 10,000	"+20 ⁰C to -110 ⁰C" up to 345 bar	100	Not applicable	YES, 100%	Performs to product specification
	MOD.12	Up to 345	Up to 10,000	"+20 ⁰C to -110 ⁰C" up to 345 bar	100	Not applicable	YES, 100%	Performs to product specification

3.2.7 Leak detectors

Table 31 contains data collected from surveys obtained from manufacturers of leak detectors.

Table 31. Survey data collected from manufacturers of leak detectors.

Manufacturer	Type/Model	Technology type of the indicated model: (thermocouple, thermistor, RTD)	Maximum amount of hydrogen [%vol]	Problem of currently installed equipment in the context of measuring H2NG mixtures with higher content	Experimental tests with a mixture of HNG? Maximum amount [%vol]	Briefly describe the results	Test methods used	Description of the test method or technical standards
MAN.23	MOD.1	catalytic NDIR other available: MPS (during implementation)	4%vol measuring range (H2 catalytic) - the H2 amount in the pipeline is not a problem for gas leakage detection	installation requirements, sensor technology used, do you need higher concentrations measurment?	YES, Coke oven gas	it works	PROCEDURE FROM THE EXISTING STANDARDS	-

	MOD.2	catalytic	4%vol (H2) 4,4%vol (CH4) - the H2 amount in the pipeline is not a problem for gas leakage detection	installation requirements, sensor technology used, do you need higher concentrations measurment?	YES, Coke oven gas	it works	PROCEDURE FROM THE EXISTING STANDARDS	-
	Develop new Molecular Property SpectrometerTM - 4%vol measuring range - the H2 amount in the pipeline is not a problem for gas leakage detection							
MAN. 11	MOD. 9	TDLAS - ICOS	0%	Original project was only for the detection of CH4 and C2H6. Future developement will include also H2	Not known	-	-	-
MAN.12	MOD.10	Catalytic Sensor	100%LIE	N/A	NO	-	-	-
	MOD.11	Catalytic sensor	100%LIE	N/A	-			
	MOD.12	Tuned piezoelectric transducer	40 dB to 140 dB	-	-			
MAN.19	MOD.2	MOS	100%	-	YES, 20%	to achive a good measurement of natural gas we needed to change calibration curve and amplifcation we detected cross sensitvity with CO	TESTS DEVELOPED IN HOUSE	we developed our internal circuit to mix natural gas and hydrogen and we perform test in own developed chamber for sensors.
	MOD.3	TDLAS	-	No data available	-			
	MOD.4	TDLAS	-	No data available	-			
	MOD.5	NDIR	-	No data avilabe	-			
	MOD.6	MOS	100%	-	YES, 20%	to achive a good measurement of natural gas we needed to change calibration curve and amplifcation we detected cross sensitvity with CO	TESTS DEVELOPED IN HOUSE	we developed our internal circuit to mix natural gas and hydrogen and we perform test in own developed chamber for sensors.

	Develop new model with MOS gas sensors - 100%H2							
MAN.9	MOD.4	PROPRIETARY TECHNOLOGY	100%	Common technologies suffer through damping in gas applications or cannot model mixtures correctly. Our proprietary technology uses a leak signature analysis using pattern recognition which makes the system robust against imbalances in the process, e.g. due to changing compositions of hydrogen and natural gas.	YES, 100%	The proprietary technology, which has proven to be a leading technology for continuous internal monitoring of pipelines, has been successfully adapted to energy transition applications. Through the possibility to adapt the model to the different requirements the overall result is better. The installation and configuration demands on the modelling part are dramatically reduced. Due to the Signature Analysis the system is less sensitive against inaccuracies in the process and modelling of the fluid. The technology is industrial proven for hydrogen as well as carbon capture applications and is ready for the energy transition. Smallest detectable leak rates are typically 0.5% and below. Leak detection time in seconds, confirmation within minutes It has an exceptionally low false alarm rate due to onsite optimization. Due to the pattern recognition process it detects smallest leaks reliably and delivers repeatable results over a long period. Leak size information is	PROCEDURE FROM THE EXISTING STANDARDS	Technical Rules for Pipelines (TRFL), API 1130

						statistically refined and the leak localization is best-in-class by Gradient Intersection Method and Extended - Negative Pressure Wave Method.		

4. Conclusion and solutions

Paragraphs 4.1 - 4.7 present conclusions and possible solutions for each area of concern resulting from the implementation of the work performed under Task 1.2.

4.1 Gas meters

4.1.1 Turbine

The influence of hydrogen (H2) on turbine gas meters is practically negligible at moderate amounts of H2 up to 10% vol. [7, 26, 32, 34, 37, 51]. Also during tests conducted on several 6" turbine meters revealed that their response in the Reynolds domain is comparable between hydrogen-enriched natural gas (up to 30% hydrogen concentration and 16 - 32 bar range) and natural gas. In contrast, tests with ultrasonic meters generally yielded poorer results compared to turbine meters. However, the response of ultrasonic meters varied among the tested meters and seemed to be significantly influenced by the meter settings [57]. However, due to the change in the density of natural gas after the addition of hydrogen, one can observe an effect resulting in a reduction of the meter's measurement range, especially at Qmin [7, 26,29]. The authors of most publications recommend further testing of turbine gas meters with higher hydrogen percentages The planned research should include cases of inhomogeneous mixtures, such as nonhomogeneous distribution or plug flow [49]. As a general indication, the expert groups within the NewGasMet project recommend using a test-gas identical to the intended gas for the meter's measurement or performing transferability tests with air or natural gas. A table with renewable test gases (including H2) defined by the NEWGASMET expert group is provided. Using a different test-gas can lead to calibration differences and increased uncertainty [44].

Unfortunately, not all manufacturers completed the surveys concerning their products, and for devices where no survey was received, the analysis was conducted based on available technical documentation found on the Internet. The manufacturers who provided completed surveys for their gas meters declared maximum hydrogen content in the gas ranging from 25% to even 100%. It should be noted that these values may apply only for process purposes, as for settlement purposes, the gas meter must have the approval of the EU Type Examination Certificate, which also confirms its capability to measure gas with the declared hydrogen content.

Upon analyzing the submitted surveys, it was found that only “MAN.3-MOD.1” and “MAN.3-MOD.2” type gas meters have the EU Type Examination Certificate covering gas measurement with up to 10% hydrogen content. This indicates a lack of a clear pathway for certifying measuring devices for mixed natural gas and hydrogen. This legislative gap was highlighted by most gas meter manufacturers in the submitted surveys. Another issue mentioned is the lack of adequately large research facilities with the capability to conduct tests with higher hydrogen contents and under high pressure. The main metrological problem reported by manufacturers is the lack of uniform procedures and measurement facilities. The primary metrological challenges are related to the decrease in the medium's density as hydrogen content increases. As a result, it may be necessary to limit the meter's range by increasing the Qmin of gas meters, which aligns with the publications mentioned above.

For those manufacturers that do not answer to the survey, an analysis of the public information available in the internet has been performed. As a result of the analysis of the technical documentation for the IGTM gas meter type, it was found that VEMMTEC declares the capability to measure gas mixtures of natural gas with hydrogen by using gas meters designed for measuring city gas, which may contain up to 60% H2 [104]. However, other manufacturers declare an allowable hydrogen content of up to 10%, confirmed by the EU Type Examination Certificate. They also indicate the possible need to change the measurement range of gas meters due to the change in the relative density of natural gas after the addition of hydrogen [104,105,106].

In summary, based on the analyzed materials, it can be stated that the majority of currently used turbine gas meters can be utilized for measuring natural gas with 10% H2, even for fiscal purposes. However, further research is necessary to verify the impact of higher hydrogen concentrations on measurement systems relying on turbine gas meters. Specifically, the influence on the measurement range from Qmin to Qt needs to be verified, as changes in the medium's density may lead to significant variations, requiring recalibration of the gas meters or limiting their measurement range.

4.1.2 Rotary Piston

Based on the publication [32], it can be concluded that the use of rotary gas meters to measure mixtures of natural gas and hydrogen can be carried out without any restrictions up to 5%. For the hydrogen content above 10%, there should be a manufacturer's declaration and confirmation by the certification body. The tests carried out under the NewGasMet project [34], conducted up to 20% H2, confirmed that the errors of indications of rotary gas meters are within the MPE, but there may be a slight error shift (to negative errors). This may have a real impact on settlements if we do not know the gas meter errors and it is not included in the correction of the gas meter curve when determining the volume. Long-term tests of gas meters with a concentration of 20% hydrogen showed no effect on its operation, indicating that the aluminum construction is resistant to hydrogen. Based on the results of the NewGasMet project [44], it is recommended to calibrate gas meters with the use of test gas, for which gas meters are expected to be used, which will reduce errors in settlement. The rotary gas meter high-pressure tests carried out at 9 and 16 bar, in comparison with the piston primary standard, when measuring natural gas and natural gas with hydrogen admixture up to 20%, indicate that the error differences between the high-pressure calibration with the use of hydrogen-enriched natural gas and the high-pressure calibration with natural gas are less than the corresponding differences between air calibration at atmospheric pressure and natural gas calibration at high pressure [46, 51, 55]. During the tests under the EMPIR Metrology for Decarbonizing the Gas Grid project [57], it was found that the difference in errors of indication observed in the case of rotary gas meters between natural gas and hydrogen-enriched natural gas was usually within 0.15%.

Based on the answers given by the manufacturers of rotary gas meters in the surveys, presented in 3.2.1.2, Table 21, it can be concluded that all manufacturers confirmed the suitability for measuring mixtures of natural gas with hydrogen up to a concentration of 30%. Most of the gas meters mentioned in the answers are also useful for measuring 100% hydrogen. Some of the manufacturers conducted tests using hydrogen and mixtures of natural gas and hydrogen. Therefore, from the technical point of view, it can be confirmed that gas meters can be used both for mixtures of natural gases with hydrogen and 100% hydrogen. The problems raised in the surveys are limitations due to ATEX requirements and the lack of measurement rigs and standards appropriate for testing gas meters with the use of hydrogen. For some of the identified rotary gas meters in the distribution and transmission networks listed in Table 1, no responses from manufacturers were received. After analyzing the results from Task 1.1, it was indicated which of these gas meters are quantitatively negligible (i.e. below 1% of all installed gas meters) and they were omitted in further analyses. For gas meters, the number of which in the TSO networks is significant, an analysis of the technical documentation/catalogue sheets/manufacturer's instructions was carried out. Based on the documentation for the Delta Itron [100], RVG Instromet [101], FMR FMG [102], RMT Romet [103] gas meters, it was found that they are intended for fiscal measurements of natural gases and have MID certificates, based on the EN 12480 and/or OIML R 137 recommendations. The documentation does not indicate that they are useful for measuring mixtures with hydrogen and 100% hydrogen, however, manufacturers provide that gas meters can also be made for other non-corrosive gases, but they should be considered for applications outside MID, not in fiscal settlements.

Therefore, an equally important issue, apart from technical possibilities, is the formal approval of gas meters for measuring natural gases with significant hydrogen content up to 30% and pure hydrogen. This should be confirmed by the manufacturer's declaration and Test certificate.

As the most important summary of the usefulness of rotary gas meters, in the context of hydrogen admixture up to 30%, no problems are expected even for gas meters for which there is no feedback from manufacturers, and which may currently be located on the distribution and transmission network. On the other hand, gas meters formally used for fiscal purpose must, in addition to the manufacturer's declaration, be approved by a certification body.

4.1.3 Ultrasonic

The results of previous studies [7, 17, 32, 34, 37, 39, 44, 47-49, 51, 57] are promising and indicate that ultrasonic gas meters maintain high measurement accuracy in the presence of H2 up to 10% by volume. Studies conducted on gas meters with different technical solutions and hydrogen sensitivity have shown that all measurement deviations, including those related to the presence of H2, fall within the calibration error limits.

It is worth noting that during the [34] study, at measurement points close to the minimum flow rate (Qmin), there was a slight tendency to change the measurement deviation by about 0.9% with the change in H2 concentration. However, it should be emphasized that this change may be a result of short-term repeatability of measurements at low flows and not a clear indicator of gas dependency.

Particular attention should be paid to situations where the fluid velocity exceeds the flow meter's design specifications or when measuring heterogeneous mixtures, as this may lead to exceeding the MPE [7, 39].

For some of the identified ultrasonic gas meters on distribution and transmission networks listed in Table 1, no responses were received from manufacturers. That is, the responses obtained from surveys distributed among manufacturers present a more promising picture of ultrasonic gas meter technology. We received responses from eight manufacturers. All manufacturers of industrial ultrasonic gas meters confirmed the suitability of their devices for up to 30% hydrogen. “MAN.9” declared the ability of its “MOD.1” to measure up to 30% vol according with DNV JIP. Furthermore, he declared that in-house testing up to 100% have already been performed. The same percentage has been declared by “MAN.10” for its “MOD.1” and “MOD.2”. Clamp-on ultrasonic gas meters produced by MAN.5, MAN.6, and MAN.8 are capable of measuring gas mixtures with up to 100% hydrogen and pure hydrogen. The manufacturers' declaration is based on conducted tests and previous experiences in the refinery industry. However, these meters are intended for process purposes and cannot be covered by an EU type approval certificate and used for fiscal purposes.

Currently installed meters on transmission networks achieve the best results with “MAN.2-MOD.3”i. This gas meter has EU type approval, and the manufacturer predicts its capability to measure up to 30% hydrogen in mixtures and pure hydrogen, based on test results conducted at 30% and 100% hydrogen concentrations.

The “MOD.1” meter by “MAN.4” also performs well, with a maximum hydrogen content of 50% in gas mixtures, as confirmed in laboratory tests. The main issue for higher hydrogen contents is related to the materials used.

For sections of transmission networks where introducing hydrogen up to 30% by volume is permissible, the “MOD.5” gas meter by “MAN.3” will be a suitable solution. It has EU type approval and has been laboratory tested up to 30% H2 concentration without any issues in this range.

The main problems highlighted in the surveys are limitations due to materials, lack of measurement points, and proper norms for testing hydrogen-compatible gas meters.

We also received responses from two manufacturers of domestic ultrasonic gas meters working on gas distribution networks: “MAN.2-MOD.4” model and “MAN.7-MOD.1” model. These manufacturers confirmed the suitability of their gas meters for up to 20% hydrogen in gas mixtures. They also stated that the main limitation for higher hydrogen contents is related to ATEX compliance issues. “MAN.10” declared that the main limitations are referred to: i) ATEX class limit, ii) transferability of uncertainty from NG to 100%H2, iii) lack of standards, iv) lack of calibration labs, v) technology limititation (different devices for NG and H2).

After analyzing the results from Task 1.1, the meters that are quantitatively negligible (i.e., below 1% of all ultrasonic gas meters) were omitted from further analysis. For gas meters that are significant in quantity on TSO and DSO networks, an analysis of technical documentation/catalog sheets/manufacturer's instructions was conducted. Specifically, the following documents were investigated: MPU FMC TECHNOLOGIES [90-91], SITRANS FST 030 SIEMENS [92], SITRANS FUG 1010 SIEMENS [93], Uf 811, Uf 821, Uf 831, Uf 841 Ultraflux [94-99]. For some of these models it was decided to investigate from the technical available documentation about their suitability for measuring mixtures with hydrogen and 100% hydrogen. From the available information it is not possible to confirm about their suitability to measure H2 and NG mixtures or pure hydrogen. More investigation is suggested.

It should be noted that in the absence of EU type approval for gas mixtures containing hydrogen or pure hydrogen, gas meters cannot be used for settlement purposes from a formal standpoint. Therefore, alongside the manufacturers' declaration, the certification process for these media should be implemented. Furthermore, MAN.9 declared that the formal certification is missing due to missing certified H2 calibration labs.

4.1.4 Coriolis

Based on an analysis of the literature [32, 37, 47, 49], it can be concluded that Coriolis flowmeters can be safely applied to natural gas mixtures with hydrogen concentrations <10%H2. The literature [57] shows that Coriolis flowmeters perform well up to 30%vol. and 16 - 32 bara providing adequate compensation for pressure and sound velocity effects.

However, based on the many years of experience of gas meter and flowmeter testing laboratory staff, it can be concluded that Coriolis flowmeters can be used up to 100% H2, a fact that is further confirmed by the response to a survey given by “MAN.4”, which declares that their “MOD.2” instrument works correctly with H2NG mixtures of 10, 20, 30 and 100% H2. This flow meter has been tested by the manufacturer at concentrations of 10, 20 and 30% H2. For higher levels, there is a lack of suitable metrology infrastructure capable of calibrating large sizes (DN > 100 mm), which does not preclude their correct operation. The metrological performances were confirmed also by “MAN. 11” even if the device cannot exhibit any EU Certificate.

Due to the lack of responses to the survey by RHEONIK, the technical documentation of their RHM 015 type Coriolis flowmeter was analyzed, but no information was found on the possibility of using this flowmeter with natural gas with an admixture of hydrogen.

It should be noted that in the absence of EU type approval for gas mixtures containing hydrogen or pure hydrogen, Coriolis gas meter cannot be used for settlement purposes from a formal standpoint. Therefore, alongside the manufacturers' declaration, the certification process for these media should be implemented.

4.1.5 Thermal Mass

From the information provided in the literature [32] [37] [57], it can be inferred that thermal gas meters can be successfully used to measure gas with up to 10% hydrogen content. For higher values, their proper functioning is not excluded, but it is not confirmed by studies.

In the literature [44], a group of experts points out the issue of using a different or alternative test gas than the one the meter was designed for. There are concerns that the measurement error may shift after exposing the gas meter to pure hydrogen, but even with such a shift, these errors should still fall within the allowed limits.

As part of the study [6], a durability test of domestic thermal gas meters was conducted using a mixture of 2E natural gas with 15% hydrogen addition and 2E natural gas without hydrogen as a reference. After each period, the measurement errors were verified outdoors at flow rates of 0.4Qmax and 0.7Qmax, as well as 3Qmin and Qmax. For the tested samples subjected to durability tests, no significant metrological influence of added hydrogen on the average drift of measurement errors was observed.

Additional confirmation of the resistance of thermal gas meters to hydrogen is a 6 and 12-month durability test using 100% H2 [53], where 3 G4 gas meters were tested. All tested gas meters remained within the tolerance of double initial error (MPE) for the range from Qt to Qmax, for accuracy class 1.5.

Furthermore, the company NEL tested one prototype G4 gas meter [55] using nitrogen and hydrogen. Measurements were repeated three times in both laboratories to examine calibration differences. The results are within the MPE. A significant shift in the error between hydrogen and nitrogen results was observed. However, the difference is smaller than the "gas-air ratio" clause in the EN 17526:2021 standard. The differences are due to regulation (setting of microprocessor flow sensor parameters) during the production process. The sensor is capable of distinguishing calibration gases.

The responses obtained from surveys distributed among manufacturers present a more promising picture of ultrasonic gas meter technology. We received responses from three manufacturers. All manufacturers of industrial thermal gas meters confirmed the suitability of their devices for up to 100% hydrogen. However, only the “MOD.1” gas meter by “MAN.12” has EU type approval and has been tested for the suitability of measuring pure hydrogen. In the case of the second type of gas meter, “MOD.6” by “MAN.4”, despite the manufacturer declaring any hydrogen content in gas mixtures, they tested their product up to 30% H2. As indicated by the manufacturer, the repeatability of their gas meter is at a high level; however, the measurement accuracy deteriorates with increasing hydrogen concentration, starting from 10%.

We also received a response from the manufacturer of domestic thermal gas meters, “MAN.13”, operating on gas distribution networks. The “MOD.1 and MOD.2” has EU type approval for a gas mixture containing 2% hydrogen. They conducted tests with 23% hydrogen content, which resulted in a negative outcome. Errors exceeded class 1.5 MPE. The manufacturer also offers modified versions of “MOD.3” versions for gas distribution and “MOD.4” versions for gas distribution, which are approved for mixtures with 23% hydrogen content. The most interesting offer from the manufacturer is the “MOD.5” for gas distribution, which has EU type approval for >98% hydrogen.

For some of the identified thermal gas meters on distribution and transmission networks listed in Table 1, not all manufacturers provided responses. For these gas meters, an analysis of technical documentation/catalog sheets/manufacturer's instructions was conducted. Based on the documentation for the ST51 gas meter by Instrol [107], it is not possible to determine its suitability for measuring mixtures with hydrogen and 100% hydrogen.

The analysis of documentation for the 534FTB gas meters produced by KURZ-PETROVALVES confirmed their suitability for measuring 100% hydrogen [107-108].

4.1.6 Diaphragm

In the analyzed publications, it was recognized that adding 10% hydrogen to natural gas will not have an impact on the performance and safety of diaphragm gas meters [3,4,7,8,32,37]. However, the results of studies conducted with higher concentrations of hydrogen are not as conclusive. The authors of publication [26], describing the results of studies on diaphragm gas meters with a 20% hydrogen mixture in natural gas, report a significant impact of this addition on metrological properties, ranging from -1% to 2.5%. However, this is an isolated finding. Most of the analyzed publications indicate a change in error within the range of 0.3% to 0.8%. This impact occurs in flow rates below 0.1Qmax [3,4,6,32,55,57].

An important fact is that none of the analyzed reports recorded a negative impact of hydrogen, even pure H2, on the safety of diaphragm gas meter operations during long-term tests. However, the influence on the membranes and other internal parts largely depends on the solutions implemented by each specific manufacturer [3,4,6,35,45,49,53,55].

Analyzing the data from TSOs, it can be stated that diaphragm gas meters are present in the transmission network of only one company and can be divided into two main suppliers (”MAN.3” and “MAN.7”). However, it should be noted that a significantly greater number of such devices operate at measurement points for individual customers in the distribution networks of various countries.

All identified manufacturers of diaphragm gas meters have submitted completed questionnaires regarding their meters. “MAN.3”, being the producer of the largest percentage of gas meters in TSO, assumes the ability to measure pure hydrogen by its gas meters. However, currently, it has only been verified up to a 30% HNG mixture. The manufacturer attributes this limitation to the lack of appropriate measurement facilities and European standards. On the other hand, “MAN. 7” declares the ability to measure 100% H2, confirmed by tests in accordance with OIML recommendations. Importantly, these tests will contribute to obtaining a UE Type Examination Certificate, enabling the gas meters to be used for fiscal purposes.

In conclusion, due to the volumetric measurement method, diaphragm gas meters are generally insensitive to the gas composition. The analyzed publications and differences in declarations from different manufacturers indicate that this is an individual matter for each specific type and largely depends on the solutions implemented. Therefore, there is a need to conduct tests on diaphragm gas meters with mixtures containing at least 30% H2, especially for types that do not have a UE Type Examination Certificate with regard to the allowance for hydrogen mixtures. It is also necessary to propose changes in European standards related to type testing of diaphragm gas meters.

4.2 Pressure transmitters

In literature reference number [53], an experiment was described involving the long-term exposure of 7 pressure transmitters to hydrogen. From the obtained results, it can be inferred that the largest error shift was observed at the minimum pressure, while no significant error shift was observed at the maximum pressure point.

Only one manufacturer of devices recognized in the gas grids declared that their models are suitable for hydrogen operation. For example, “MAN.1” declares correct operation of the absolute/differential transmitter at hydrogen concentrations up to 33%, while the transmitters have been tested up to 15%. The manufacturer is encountering problems in obtaining ATEX certification. “MAN.15” declares correct operation of its absolute/gauge pressure transmitters for hydrogen concentrations of 0% or 100%, but 100% H2 only for high pressure and using a gold-plated transmitter diaphragm. In addition, it has not carried out any experiments with the HNG mixture. For differential transducers, he does not allow the possibility of measuring hydrogen-containing gas. “MAN.11” declares capability of measuring up to 100% H2. He also indicates that a gold plated version is under development aiming to reach long-term performance for H-shield.

Among the commercially available pressure transmitters capable of measuring the pressure of H2NG mixtures are:

- “MAN.12” model “MOD.2” for gauge,
- “MAN.12”, model “MOD.3” for differential,
- “MAN.12”, model “MOD.4” for absolute.

All of the above-mentioned transmitters are capable of measuring the pressure of a gas with a hydrogen concentration of up to 100%, which is confirmed by tests carried out by the manufacturer.

In addition, below are transmitters whose manufacturer declares that they can measure for hydrogen concentrations in the gas up to 20%:

- MAN.8-MOD.6, for absolute,
- MAN.8-MOD.7, for absolute/gauge.

4.3 Temperature transmitters

In literature position [53], pressure and temperature transmitters were examined. It was found that the temperature sensor is mounted in a thermowell placed inside the pipe through which the gas flows. This means that the temperature sensor does not have any direct contact with the flowing gas.

It can be concluded that all temperature transmitters can be used for measuring the temperature of gas with 100% hydrogen content, provided that a thermowell is used, installed according to the art, and ensuring a 100% sealed connection.

4.4 Volume converters

With regard to the use of natural gases with an admixture of hydrogen and pure hydrogen, the literature knowledge focuses on the algorithm for determining the compressibility factor as the most important issue of the volume conversion devices suitability for measuring such gases. According to the DVGW report G 3-02-12 [7, 8], the equations of state AGA8 and SGERG are basically intended to calculate the number of K for natural gases containing hydrogen up to 10% mol with an uncertainty of 0,1 %, provided that for the method SGERG pressure does not exceed 50 bar. The AGA8 equation can be used even for concentrations up to 30 % by volume. For admixtures up to 50 % H2 deviations using the AGA8 equation do not exceed 0,1 % over the entire pressure range (K number deviation).

According to the report [33], it is possible to modify the SGERG-88 model for calculating the compressibility factor of hydrogen-containing gas mixtures. To make this possible, one solution is to suppress the CO correction factor and create a so-called SGERG-mod-H2. The equation of state "SGERG-mod-H2" is suitable for the calculation of natural gases with hydrogen admixture even up to 100 % H2. An important observation is that at pressures up to 50 bar, deviations from the measured values as well as from the GERG-2008 equation are less than ±0,1 %. Deviations of up to ±0,5 % may occur at higher pressures up to 100 bar. While the equation can theoretically be applied to hydrogen concentrations up to 100 % mol, numerical problems can occur at very high hydrogen concentrations. Therefore, it is recommended to limit the application range to 30 % mol H2. The AGA8 equation and the GERG-2008 equation generally agree better than ±0,1 % on measured values for all data sets over the entire pressure range. It can therefore be expected that these equations of state can be applied to any desired fractions of hydrogen without significantly affecting the basic uncertainty of the equations of 0,1 %.

The density difference between the GERG-2008 and AGA8-DC92 models indicated in the Decarb project [57] is within ±0,03 % for a typical mixture of natural gas with a hydrogen concentration of up to 50 % and a pressure of 5 to 50 bar. Studies in the literature show that the calculations using the GERG-2008 method are in the range of ±0,05 % of the experimental density results for natural gas mixtures with a hydrogen concentration of up to 10 % and in the range of ±0,1 % up to a hydrogen concentration of 30 %. Further work is needed to evaluate the performance of GERG-2008 and AGA8-92DC against experimental data.

Analyzing the responses from producers to the submitted survey about volume conversion devices installed in DSO and TSO networks, it can be seen that the main limitation in the use of conversion devices for higher hydrogen content in gas are available validated calculation algorithms. Taking into account the currently produced devices covered by the MID Directive, they are limited to the concentration of hydrogen at the acceptable level and specified for gas pipeline quality gases and in a wider range of application compliant with SGERG-88 and AGA8-92DC. In addition to the MID, some of the conversion devices have other calculation methods implemented, which enable the determination of compressibility factors for gas mixtures with a much higher hydrogen content than 10%. For example, some already use the GERG-88-mod-H2 algorithm with a declaration of up to 100 % hydrogen. In the case of volume conversion devices, the second issue determining the suitability for hydrogen measurement are the construction requirements for the ATEX explosion-proof class. In the case of class IIB, it is considered that the device can work with hydrogen content from 25 % to 75 %, and above 75 % the construction should be classified as group IIC according to ATEX. Currently, only a few of the calculators have the ability to measure gases with a maximum content of 100 % H2, and some are under development. Subsequently, the technical documentation of devices for which no survey responses were received from manufacturers and whose number in the networks was shown above 1% was analyzed. After analyzing the documentation [113 - 128], it was found that the other conversion devices on the network are generally approved based on the EN 12405-1 standard with the SGERG and AGA8 algorithms, therefore with a limit of 10%. Some of them have IIB approval and some have IIC approval according to ATEX classification.

Summing up the barriers and limitations for conversion devices, it should be stated that up to 30 % hydrogen admixture in natural gas is a formal obstacle to the approval of the reference method (e.g. GERG 2008) which will allow for calculations in a wider range of hydrogen content. In the case of 100% hydrogen measurements, it is necessary to meet also the construction requirements due to ATEX, i.e. achieving the IIC classification and implementing the calculation method.

4.5 Gas Analyzers

There are no technical barriers to analyzing H2 and natural gas mixtures with required accuracy. All components that require measurement are present in refinery gases, and the gas chromatographic analysis of refinery gases is a well-established technique [36]. However, it should be noted that most devices currently installed in gas networks are not adapted to measure the composition of this type of mixtures. This limitation mainly arises because these devices are single-channel devices equipped with a TCD detector, for which the carrier gas is helium. Process gas chromatographs (PGC) that use helium as the carrier gas are unable to detect hydrogen due to the relatively close thermal conductivities of helium (151 W/mK) and hydrogen (180 W/mK) [38]. For this reason, the adaptation of gas networks to the transport of H2NG mixtures will require the replacement of most currently used gas chromatographs. Among the process gas chromatographs available on the market that enable the measurement of the composition of H2NG mixtures, the following can be mentioned:

- “MAN.12”, measuring range for hydrogen: 0 to 100%.
- “MAN.19”, measuring range for hydrogen: 0 to 1%.
- “MAN.20”, measuring range for hydrogen: 0 to 100%.

From a review of technical datasheet of commercial devices of manufacturers that do not answer the survey.

- Danalyzer™ Model 500 and Danalyzer™ Model 700, applications marked with 570HH and 6HH codes, measuring range for hydrogen: 0-10%,
- Rosemount 370XA and Rosemount 700XA customer configurable models, measuring range for hydrogen: 0.1 to 100%,
- GEDRA - Gas Energy Density Raman Analyser, measuring range for hydrogen: 0.05 to 20%,

4.6 Trace water sensors

The presence of hydrogen in natural gas has a minimal impact on the water dew point temperature, lowering it by less than approximately 1°C below 80 bar. This slight reduction in the dew point temperature may become problematic if the natural gas is already very close to the dew point when hydrogen is added. In such cases, there is a risk that the water dew point may exceed the required standards (GS(M)R values). To address this potential issue, the following solutions are recommended:

To ensure reliable and accurate measurement of moisture content in the presence of hydrogen, modifications to sensor materials and designs are necessary.

By selecting materials that are resistant to hydrogen permeation and corrosion, such as specialized alloys or polymers, the integrity and performance of trace water sensors can be maintained. These adaptations allow for accurate monitoring of moisture levels in gas mixtures containing hydrogen.

In addition to material considerations, advancements in sensor designs and measurement techniques have played a significant role in adapting trace water sensors for hydrogen blends. Improved sensor designs, such as those incorporating specific coatings or barriers, help mitigate the effects of hydrogen diffusion and ensure accurate moisture measurements. Furthermore, the calibration and characterization of trace water sensors in the presence of hydrogen have been investigated to account for any potential cross-sensitivity or interferences caused by hydrogen.

Moreover, innovative measurement techniques have been employed to enhance the adaptability of trace water sensors for hydrogen blends. For instance, optical sensing techniques, such as absorption spectroscopy or tunable diode laser spectroscopy, offer high sensitivity and selectivity for water vapor detection. These techniques can be combined with specialized sensor designs to enable accurate and reliable measurement of moisture content even in the presence of hydrogen.

Overall, the adaptation of trace water sensors for hydrogen blends involves addressing hydrogen's permeability and selecting appropriate materials, optimizing sensor designs, and utilizing innovative measurement techniques. Through advancements in materials science, sensor technologies, and measurement techniques, trace water sensors can provide precise and reliable measurements of moisture content in gas mixtures containing hydrogen. This adaptation supports various applications, including hydrogen production, fuel cell technology, and the safe operation of hydrogen-related infrastructure.

Gas network operators already use water dew point transducers that enable the measurement of this parameter in the presence of hydrogen in gas mixtures. Such water dew point transducers includes, for example, but not limited to:

- Ametek: OLV 3050,
- Bartec: Hygrophil F5673,
- Endress & Hauser: Spectrasensor
- Michell Instruments: Condumax II Hydrocarbon Dew-Point Analyzer,
- Michell Instruments: Promet EExd Process Moisture Analyzer,

- Michell Instruments: Transmet IS Dewpoint Transmitter,
- Michell: TDL 600.

The following water dew point transmitters are also available on the market:

- Manufacturer: Alpha Moisture System, models: SADPmini2-Ex, AMT-Ex, SADPmini-Ex, ADHT-Ex, DSP-Ex and SADPμ,
- Manufacturer: Stork Instruments, model: DEWCom II Transmitter.

Water dew point transmitters manufactured by “MAN.21” and “MAN.22” allow for measuring the dew point of water in mixtures containing up to 100% hydrogen.

4.7 Leak detectors

Leak detectors play a critical role in maintaining the safety and integrity of gas systems, including those involving hydrogen blends.

One of the primary challenges in adapting leak detectors for hydrogen blends is the unique properties of hydrogen. These characteristics can affect the sensitivity, response time, and accuracy of traditional leak detection technologies. Therefore, special attention must be given to ensure that leak detectors can effectively detect and locate hydrogen leaks in the presence of other gases.

Acoustic-based leak detection systems, commonly used for natural gas leak detection, have been adapted to effectively detect and locate hydrogen leaks in H2NG mixtures. These systems utilize advanced signal processing algorithms and sensor configurations optimized for the unique acoustic signatures of hydrogen leaks.

Furthermore, advancements in data analysis and machine learning techniques have improved the capabilities of leak detectors for hydrogen blends. These techniques enable the differentiation between genuine leak signals and background noise or other sources of interference. By training the detectors with a diverse set of hydrogen leak data, the accuracy and reliability of hydrogen leak detection can be enhanced.

Moreover, the integration of real-time monitoring and remote notification features has been explored to improve the response time and effectiveness of leak detectors for hydrogen blends. These features allow for immediate alerts and prompt actions in the event of a hydrogen leak, minimizing potential risks and enhancing safety in H2NG systems.

Summarizing, the adaptation of leak detectors for hydrogen blends involves addressing the unique properties of hydrogen gas, modifying detection techniques, and incorporating advanced data analysis and notification capabilities. Through advancements in acoustic and optical detection methods, machine learning algorithms, and real-time monitoring, leak detectors can effectively detect and locate hydrogen leaks in H2NG mixtures. This adaptation ensures the safety and integrity of hydrogen-related infrastructure, supporting various applications such as hydrogen fueling stations, storage facilities, and industrial installations.

Gas network operators most often use portable leak detectors. Therefore, as long as H2NG mixtures are not transported through gas networks, there is no need for the services responsible for network operation to be equipped with hydrogen leak detectors. However, it’s worth noting that leak detectors are available on the market that allow the determination of the hydrogen content in the air in the range from 0 ppm to the lower explosive limit.

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