European Metrology Network for Energy Gases

Strategic Research Agenda
Version 2.0 (09/2022)

EURAMET

ENERGY GASES

Authorship and Imprint

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The EMN members with support from stakeholders have confirmed that version 1.0 of the Strategic Research Agenda remained relevant and up to date with no new measurement challenges identified. There have been minor changes to include new or revised National reports.

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Further information

This is the first version of the Strategic Research Agenda for EMN Energy Gases, which provides guidance towards industrial metrology needs and the technical challenges that need to be solved as a priority through collaborative efforts between National Metrology Institutes (NMIs), Designated Institutes (DIs) and stakeholders. This document will be revised annually in accordance with priority changes from the energy gas community.

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Foreword

“We are witnessing a period of great change. The European Green Deal and related policies are paving the way towards a decarbonised economy and a climate neutral continent. In order to achieve this by 2050, the energy sector, production, transport, storage and use, should be decarbonised and converted into a smart system that integrates clean energies such as wind and photovoltaic as well as renewable energy gases such as hydrogen.

Research and innovation, focussed on creating new and safe key technologies for our energy future, are playing a crucial role and need to be supported by robust and reliable measurement data.

The European Metrology Network (EMN) for Energy Gases, under the European Association of National Metrology Institutes (EURAMET), has identified measurement needs and technical challenges in the field of energy gases that should be solved as a matter of priority through collaborative efforts between National Metrology Institutes, Designated Institutes and industry. The results are formulated in this document: the second edition of the Strategic Research Agenda for EMN Energy Gases.

We believe it is a valuable and comprehensive document and we hope that it will be the reference point for metrological research in the field of energy gases.

This document will be revised annually in accordance with priority changes from the energy gas community.

We wish you good reading and are happy to collaborate with you to make the EU’s energy transition happen!”

Dr Annarita Baldan
On behalf of European Metrology Network for Energy Gases

CONTENT

Acronyms and Abbreviations

BECCS	Bioenergy with carbon capture and storage
BEIS	United Kingdom's Department for Business, Energy and Industrial Strategy
CBM	Compressed Biomethane
CCC	United Kingdom's Committee on Climate Change
CCS	Carbon capture and storage
CCUS	Carbon capture, usage and storage
CHP	Combined heat and power
DI	Designated Institute
EMN	European Metrology Network
EU	European Union
GHG	Greenhouse gas
HENG	Hydrogen Enriched Natural Gas
HGV	Heavy goods vehicle
LBG	Liquified Biogas
LBM	Liquified Biomethane
LNG	Liquefied Natural Gas
NDC	Nationally Determined Contribution
NMI	National Metrology Institute
NPL	National Physical Laboratory
SMR	Steam methane reformation/reformer
SNG	Synthetic Natural Gas
SRA	Strategic Research Agenda
UK	United Kingdom

Executive Summary

There will be a significant transformation of the energy mix across Europe as we work towards meeting climate change targets by 2050. Whilst there are some uncertainty and differing predictions regarding the outlook of the supply mechanism for energy, it is clear that the electricity grid alone cannot support the user demands for energy. It is also clear that energy gases will play a key role during the transitional phases pre 2050 and the future energy mix post 2050.

Natural gas is expected to remain a significant part of the energy mix in short to midterm projections and may also be utilised to replace coal and oil in countries going through a phase out. It may also be utilised as part of the energy gas mix alongside low carbon gases during the transitional period (whilst the technologies that introduce low carbon gases are being developed and upscaled). For example, several deployment projects in Europe are investigating the possibility of blending hydrogen alongside natural gas termed 'Hydrogen Enriched Natural Gas (HENG)' in conventional natural gas networks. This is done with the view of reducing carbon emissions and slowly replacing natural gas with hydrogen. Furthermore, natural gas might also remain as part of the energy mix in Europe in the form of liquefied natural gas (LNG), which is promoted as a transport fuel to replace diesel across the continent.

Nevertheless, it is expected that a mix of low carbon gases such as biomethane, biogas, synthetic methane and hydrogen will eventually be utilised to replace natural gas. These low carbon gases can be used to decarbonise several sectors in Europe, such as the heating, transport, industrial with high energy intensive consumption and chemical production sectors. At the same time, these low carbon gases will be critical to achieving emissions targets. Not less relevant, these gases and in particular of hydrogen are expected to play an important role in the power sector, filling the gap when intermittent renewable energy does not deliver sufficient electricity. It is also clear that carbon capture, usage and storage (CCUS) will be a necessary technology to employ alongside the introduction of low carbon gases in Europe. Whilst each nation may have different approaches to decarbonising their energy system, they will all rely on the deployment of these low carbon gases to achieve this. Ultimately, Europe's strategy towards climate neutrality foresees establishing an integrated energy system, that is a coordinated planning and operation of the energy system as a whole across energy carriers, infrastructures and consumption sectors [1].

A notable criterion to ensure a smooth and accelerated energy transition in Europe will be a coordinated collaboration amongst countries in Europe with respect to research and development. This is to ensure that vital information, resources, best practices, and lessons learnt are shared, but also to continue to import and export energy between each other.

The change in the energy outlook and the addition of low carbon gases will lead to several new measurement challenges and needs. The European Metrology Network (EMN) for Energy Gases was formed as a nucleus of measurement expertise and measurement science activities to support the implementation of the energy transition to renewable gaseous fuels. It incorporates National Metrology Institutes and Designated Institutes across Europe who are working together to highlight and solve these important measurement challenges and supporting standardisation for renewable gases.

This report discusses current and future trends for these energy gases; it identifies and prioritises the measurement needs and challenges that may have the potential to create hurdles and bottlenecks in their utilisation. These challenges have been explored across natural gas, hydrogen, biogas and CCUS and include for example flow metering, physical properties, gas composition, gas metrology, materials characterisation, combustion, leak detection and storage.

Based on consultation with European stakeholders and drawing on the expertise of the European Metrology Network (EMN) for Energy Gases, some measurement challenges were perceived to be of high priority in short to mid-term scenarios. These challenges include flow metering for hydrogen refuelling stations, flow metering, gas quality measurements and energy metering of hydrogen enriched natural gas, validation of online purity analysers (hydrogen and biomethane) and representative sampling of gas. Some of these challenges are already being addressed in existing European projects such as the EMPIR MetroHyVe/MetroHyVe 2, Biomethane SIP and the EMPIR NEWGASMET (Flow metering for hydrogen enriched natural gas).

The identified measurement needs from this report will be taken forward by the EMN members as research priorities to ensure they are addressed appropriately.

1 INTRODUCTION

Gas plays a primary role across most of Europe's energy systems. It supplies more than 20% of the overall energy demand in Europe, with the major share of this coming from fossil fuel derived gas or 'natural gas' [2, 3]. Overall, the demand for gas in the energy sector is set to grow within Europe, with the International Energy Agency (IEA) predicting that 162 billion cubic metres of additional supply will be required by 2025 to meet demand [4]. This projected increase in demand is propelled by the need to move away from other non-sustainable and less environmentally friendly sources of energy in Europe such as coal and oil. As such, alongside the need to identify secure and reliable sources of domestic energy supply, European countries are also tasked with the urgent need to find cost cost-effective and scalable ways to decarbonise their energy systems. Many European countries have set ambitious emission reduction targets through Nationally Determined Contributions (NDCs) in accordance with the ratification of the Paris Agreement in 2016. This was done with the aim to keep 'global temperature rise this century well below 2° C above pre-industrial levels' and to pursue best efforts towards limiting to 1.5° C warming [5]. Some European countries have set a further ambitious legislative target of achieving net zero emissions by 2050 or earlier, with the United Kingdom (UK) being the first European country to announce this in June 2019 [6]. The UK has also stated that they would be adopting a 'Sixth Carbon Budget' as recommended by the Committee on Climate Change; this sets a new GHG emission reduction commitment that includes emissions from international aviation and shipping [7]. It aims to limit GHG emissions over a 5-year period starting in 2033 and cut UK's GHG emissions by 78% by 2035 compared to 1900 levels [7, 8]. As a collective, the European Commission (EC) has set out the European Green Deal for the European Union that aims to be the world's first climate-neutral continent by 2050 [9].

The substitution of coal and oil with gas - predominantly natural gas - in the short to medium term (2020 - 2035) will lead to a significant reduction in emissions from the energy sector [3]. However, with domestic supplies of natural gas in deficit in several countries across Europe and reliance on imports increasing [10], countries are required to explore the potential of alternative energy gases, such as non-conventional natural gas (natural gas derived from other sources such as shale reservoirs), hydrogen and biogas. The utilisation of these alternative energy gases could lead to increased domestic energy security and reduced reliance on gas imports. In the long term, these alternative gases could lead to a further reduction of emissions derived from the energy sector [11].

For many countries, meeting these emission reduction targets by 2050 will require a transition towards low or zero-carbon alternatives alongside carbon capture and storage (CCS), both of which have the potential to bring about new or unforeseen technical challenges. It is the role of National Metrology Institutes (NMIs) to develop a robust and reliable measurement infrastructure to tackle the priority measurement needs and challenges that often underpin these technical challenges, and it is the ambition of the European Metrology Network (EMN) for Energy Gases to work collaboratively and harmoniously in addressing them.

1.1 Current and Future European Trends for Energy Gases

Currently, the leading energy gas utilised in the European energy mix is **natural gas**. In 2018, EU countries imported a total of 401 billion cubic meters of natural gas [12], with around 66% of the EU's gas supply coming from two countries alone: Russia and Norway [12]. Reports suggest that the demand for natural gas in the energy mix will remain stable or may decrease very slightly until 2030 - 2035 [13]. Looking to the future, Exxon Mobil predicts that 'natural gas production is expected to grow in every region except Europe' [14] whilst according to BP, 'the importance of the gas trade notably natural gas will continue to grow… driven by robust expansion of LNG supplies which [will] account for more than 15% of total gas demand in 2040' [15]. Whilst there is still some uncertainty about the role of natural gas and LNG in the long term, alongside some other non-conventional natural gas sources such as shale gas, they will still play a role in the energy mix for decades to come. As such, it is necessary that we understand and address any measurement challenges or needs that arise from their continued use; these challenges are discussed in Chapter 2 of this report.

Hydrogen is being promoted as a potential replacement to natural gas in the future energy mix across Europe. The Hydrogen Roadmap Europe report published by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) in 2019 stated that there is 'the potential for generating approximately 2,250 terawatt hours (TWh) of hydrogen in Europe in 2050, representing roughly a quarter of the EU's total energy demand' [16], and as such hydrogen is viewed as a promising candidate to support the transition away from fossil fuel derived energy gases. However, depending on the process for producing hydrogen – whether from reformation (requiring CCS), electrolysis or as a by-product of other processes – issues for its end use applications and as such its commercialisation can arise. Hydrogen will be crucial in decarbonising several emission-intensive sectors including domestic heat, transport and industry. This importance has prompted a number of research activities and European projects (see Chapter 7) to investigate the best means for its large-scale deployment as an energy gas. Further detail around the utilisation of hydrogen as an energy gas in Europe as well as measurement challenges and needs are explored in Chapter 3.

Several countries across Europe have already begun to introduce biogas into their energy mix from a variety of sources including: energy crops, agricultural and household or industrial waste [17]. At the end of 2019, there were almost 19000 biogas plants across Europe with Germany, Italy and France leading the efforts in their deployment [18]. It is believed that biogas will be prominent in the future energy gas mix in Europe; its increased demand might lead to its production being quadrupled in 2050 in Europe [18, 19]. A high percentage of the biogas currently produced in Europe is used for heating and electricity generation. Additionally, biogas can also be upgraded to biomethane which can then be injected into conventional gas distribution networks to replace natural gas. As such, this option makes biomethane a readily available natural gas substitute as it could easily replace natural gas in the existing gas network without the need for any major technical modifications to Europe's gas grid infrastructure. Currently there are over 700 biomethane plants in Europe with a high share of that present in Germany France and the UK [18]. Nevertheless, the cost of producing biogas and biomethane is not competitive with that of natural gas at present, however continued policy support alongside 'a much higher price of CO_2 on the EU carbon market' could allow for further growth in its uptake [20]. In addition, the utilisation of biomethane or biogas from multiple varying sources is likely to create several challenges. Some of these challenges relate to the necessary purity levels of the gas, as well as the ability to trace the origin of the gas to ensure quality assurance. The challenges and measurement needs surrounding biomethane and biogas are explored further in Chapter 4.

In most cases, the production and utilisation of the leading gases that make up a significant part of present and future energy gas systems in Europe lead to the production of large amounts of carbon dioxide (CO_2). To achieve climate targets, the resulting CO_2 produced from these processes needs to be captured, permanently utilised or stored to prevent an increase in atmospheric CO_2 levels and its subsequent climate impacts. This can be achieved via **carbon capture, usage and storage (CCUS)** where CO_2 can be removed and either stored or utilised in closed-loop industrial processes. There is an extensive existing gas infrastructure across Europe, including a significant storage capacity of 1131 TWh across EU countries [21], which is well suited to the large-scale storage of new, decarbonised energy gases such as hydrogen and biogas, or for storing captured CO_2. The EC has stated that CCUS is necessary to achieve emission reduction targets across Europe in line with the Paris Agreement but must be carried out in a cost-efficient manner [22]. This stance is also currently supported by many but not all European countries [23]. The UK's Committee on Climate Change (CCC) refer to CCS as 'a necessity not an option' [24] which is a position maintained by the UK Government. Furthermore, there are CCUS projects planned or already underway in several European countries including Norway, the UK and the Netherlands. The potential for the usage of the CO_2 captured via CCS has made the business case for CCUS more tangible for some European countries, however depending on how the CO_2 is then utilised – such as within the food and drink industry – challenges around ensuring the purity of the gas may arise. Further challenges and measurement needs relating to CCUS are explored in Chapter 5.

Although there is some uncertainty around the prevalence of natural gas within Europe's energy mix by 2030, it is likely that it will continue to be used in some capacity to provide flexibility for renewable intermittency [13]. As such, gas as an energy vector will remain an integral part of Europe's energy mix, alongside renewable electricity and nuclear power generation for the foreseeable future. Therefore, it is vital that any current or future planned gas infrastructure projects account for the potential phase out of natural gas and introduction of these clean energy gases, to avoid the risk of Europe's current gas infrastructure becoming stranded assets as it decarbonises.

1.2 Energy Gas Policies and Strategies

Many European countries have set out their plans for current and future energy gases through published strategies, policies or legislative targets (summarised in Table 1). The EU member states also adhere to shared directives for renewable energy, energy efficiency and the management of their energy systems. The EU energy policy details measures to be deployed to ensure an integrated energy market in Europe whilst promoting energy diversity, energy security and renewable resources. A key aspect of these measures includes decarbonising and transitioning from fossil fuels to low carbon gases [25]. Another key component is to investigate cost effective means to deploy energy gases to ensure competitiveness, affordability and energy sustainability.

Some countries also have policy directives that seek to raise the ambition on the shared directives around particular energy gases. Some examples are the '*National Innovation Programme for Hydrogen and Fuel Cell Technology*' in Germany, the '*Plan for the Deployment of Hydrogen for the Energy Transition*' in France, and the '*Hydrogen Infrastructure for Transport*' (HIT) project in Sweden – more can be found in Chapter 7 of this report.

Table 1 collects the range of energy gas policies and strategies that were identified by the EMN members.

Table 1: Energy gas policies and strategies by EMN member country government's and the European Commission

Country	Cross cutting	Natural Gas	Hydrogen	Biogas /Biomethane	CCUS
Bosnia and Herzegovina	Action Plan for the Use of Renewable Energy in Bosnia and Herzegovina				
Denmark	Denmark's Integrated National Energy and Climate Plan				
France	PPE: Programmation Pluriannuelle de l'Energie		Hydrogen deployment plan	Heat Fund	
Germany		Gas 2030 – Auf dem Weg in die Zwei-Energieträger-Welt			
		Mit Gas in die Zukunft: Die Energiewende effizient und bezahlbar gestalten	National Strategy for Hydrogen National Innovation Programme Hydrogen and Fuel Cell Technology Fuel cells and hydrogen		
Hungary	Energy and Climate Plan of Hungary				
Italy	Italy's National Energy Strategy 2017		Tavolo sull'idrogeno		
Netherlands	Dutch Climate Agreement (2019) and Climate Law 2020 Dutch Energy Agreement (2013)	Gas Law	Dutch Hydrogen Programme (2021)		
Norway	New emission commitment for Norway for 2030 – towards joint fulfilment with the EU The Energy Act (1990)	Petroleum Act	The Norwegian hydrogen strategy The National Transport plan (2018-2029)		Carbon Capture and Storage Strategy
Spain			Spanish Climate Change and Clean Energy Strategy (EECCEL)		
Sweden	Klimatklivet (Climate Change support)		Hydrogen infrastructure for transport	Biomethane National Biogas Strategy Biogas Support 2018 Biogas plants	
United Kingdom	Energy Act 2008	Guidance on fracking: developing shale gas in the UK	Domestic Renewable Heat Incentive Carbon Price Floor		UK law of EU Directive 2009/31/EC
	Climate Change Act (2008): Net-Zero amendment (2019)		Decarbonisation of Heat Next steps for the Gas Grid		
	Clean Growth Strategy	UK Gas Generation Strategy 2012	Hydrogen Transport Programme	Anaerobic Digestion Strategy and Action Plan	
EU Member States	Renewable Energy Directive (EU)				
	Energy Efficiency Directive (EU)				
	Energy Union Strategy (COM/2015/080)				
	The Alternative Fuels Infrastructure Directive 2014/94/EU				
	Management Regulation (EU)				
			Directive 2009/31/EC (EU)		

1.3 European Metrology Network for Energy Gases

In striving towards environmental sustainability and a reliable and diverse energy network, it is vital to address unresolved fundamental challenges that may otherwise hinder the introduction of renewable gases as fuel sources and as energy vectors. These technical challenges can include, for example, the ability to perform required physical and chemical measurements to meet gas grid entry requirements, or to quantify the amount of hydrogen supplied to a fuel cell vehicle through accurate flow metering.

ENERGY GASES

To ensure the safety and reliability of renewable gaseous fuels, it is important to have robust, accurate measurements that are traceable to established standards. The European Metrology Network (EMN) for Energy Gases is a network of European national measurement institutes (NMIs) that provide measurement science expertise for energy gas measurements. Their role is to bridge the gap between research and end-user communities and act as a central nucleus for measurement science activities, as well as to provide a platform for industrial companies across Europe to easily identify the relevant products, services and consultancy offered by EMN members in support of their decarbonisation efforts.

EMN member NMIs and designated institutes (DIs) include:

Institutes	Country
IMBiH - Institute of Metrology of Bosnia and Herzegovina	Bosnia and Herzegovina
FORCE - FORCE Technology	Denmark
MIKES - VTT Technical Research Centre of Finland Ltd, Centre for Metrology MIKES	Finland
LNE-LADG - Laboratoire Associé de Débitmétrie Gazeuse	France
LNE - Laboratoire National de métrologie et d'Essais	France
BAM - Bundesanstalt für Materialforschung und -prüfung	Germany
PTB - Physikalisch-Technische Bundesanstalt	Germany
BFKH - Government Office of the Capital City Budapest	Hungary
VSL – Dutch Metrology Institute	Netherlands
JV - Justervesenet - Norwegian Metrology Service	Norway
GUM - Central Office of Measures/Glówny Urzad Miar	Poland
IPQ - Instituto Português da Qualidade	Portugal
CEM - Centro Español de Metrología	Spain
RISE - RISE Research Institutes of Sweden AB	Sweden
UME - Ulusal Metroloji Enstitüsü	Turkey
NPL - National Physical Laboratory	United Kingdom
NEL - National Engineering Laboratory	United Kingdom

1.4 Purpose of this Document

This document is a 'Strategic Research Agenda' (SRA) that will be used by EMN Energy Gases for formulating and sharing harmonised and sustainable European measurement strategies and infrastructure. The document is intended to facilitate the energy transition by highlighting where accelerated measurement activities are required as of 2021 (the year this version of the SRA was authored). The document will be updated annually to reflect progress made towards the measurement needs and challenges highlighted throughout – this is the 2nd version following the original SRA's publication in 2020. This document has been developed by EMN members taking into consideration input from industry stakeholders in the original SRA's publication in 2020. It focuses on topics considered under the theme of 'energy gases'.

2 NATURAL GAS

Natural gas is a fossil fuel that primarily consists of methane (CH_4), along with some other gases including nitrogen (N_2), carbon dioxide (CO_2), helium (He), hydrogen sulphide (H_2S), and noble gases; the composition will vary depending on its origin [26]. Natural gas consumption represents over 20% of the total primary energy consumed in Europe [13]. In 2018, it was predominantly supplied from Russia, Norway, Belarus and Ukraine [27]. The demand for natural gas in most applications is expected to decline in several countries in Europe due to a growing consensus that we must replace natural gas with renewable or low carbon sources in line with the shared ambition of tacking climate change. Taking the UK as an example, UK production of natural gas expanded in the early 1970s and its demand grew rapidly, reaching a record high in 2004 of 1125 TWh. Since then, demand has seen an overall decline and in 2017, demand was around a fifth of the 2004 peak at 868.6 TWh [28].

Nevertheless, it is estimated in mid-term projections that natural gas will remain a crucial energy gas across Europe, particularly in heat, transport and industry. Natural gas is viewed as a key transitional energy gas because it produces less CO_2 emissions than coal or oil and these emissions can be captured and utilised or stored through carbon capture, usage and storage (CCUS) either pre or post combustion. Furthermore, the decline in natural gas utilisation in several sectors might also be somewhat offset by a new demand to produce other gases such as hydrogen (through steam methane reformation). It is projected that the transition to hydrogen and other low carbon energy gases in most sectors will not be a quick process, for example in the heat sector, replacing natural gas with hydrogen in natural gas grids is likely to be carried out step-wise in most cases, by injecting hydrogen at low concentrations alongside natural gas and making incremental increases, known as 'hydrogen enriched natural gas' (see section 2.2).

2.1 Natural Gas Production

Most of Europe's natural gas supply comes from conventional sources however, non-conventional stores such as the natural gas that is stored in shale reservoirs and extracted through a process known as hydraulic fracturing or "fracking" are growing in utilisation within the continent. Bio-synthetic natural gas may also have an increasing prevalence in future low carbon energy gas mixes.

2.1.1 Shale Gas

The exploitation of non-conventional sources to supply natural gas is being investigated by several countries in efforts to improve energy security. Shale gas has been identified as one such non-conventional source with a high development potential within Europe. Shale gas is primarily natural gas that is released from dense clay rocks or shale reservoirs. Whilst it has several advantages over coal and other fossil fuels, there are environmental concerns relating to the utilisation of shale gas, mainly due to how the gas is released from the shale. The extraction process relies upon artificial fracturing caused by drilling and pumping water at high pressure [29] – commonly called 'fracking' – which can lead to increased emissions, as well as causing an increase in the frequency of earthquakes [30]. Several EU countries have differing stances on the utilisation of shale gas, with a full or partial ban or cease on shale gas fracking activities in countries such as Germany, the Republic of Ireland, the UK and France [31-35]. Furthermore, the

EU has issued guidance to ensure any utilisation or extraction is carried out with proper environmental and climate safeguards [36, 37].

2.1.2 Bio-Synthetic Natural Gas (Bio-SNG)

Bio-Synthetic Natural Gas (Bio-SNG) is a promising natural gas substitute due to its comparable properties and composition. It is produced from gasification of secondary biomass resources and an upgrading of the resulting syngas [38]. This differentiates Bio-SNG from ‘biogas’, which is produced via the biological process of anaerobic digestion (see section 4). Bio-SNG has an advantage over some other energy gases such as hydrogen as a replacement for natural gas, as it could easily do so with no technical modifications to current gas infrastructures in Europe [39].

2.2 Natural Gas Utilisation in Europe

It is likely that natural gas and its associated infrastructure will continue to play an important role in energy systems across Europe. Even in Europe’s mid-long term projections for decarbonisation, natural gas will continue to be deployed as part of the gas mix [13], as hydrogen enriched natural gas in natural gas systems and as liquefied natural gas (LNG).

2.2.1 Hydrogen Enriched Natural Gas (HENG)

Hydrogen deployment at scale could play an important role in achieving decarbonisation targets across Europe. One of the major challenges in meeting these targets is decarbonising heat which will require replacing natural gas with hydrogen or other low-carbon energy gases. However, network modifications and retrofitting are required before the conventional gas networks can be repurposed to carry 100 % hydrogen. Whilst these network upgrades are undertaken, hydrogen could be injected alongside natural gas into the gas network in a blend, to facilitate the phasing out of fossil-fuel derived energy gases. This blending is termed ‘hydrogen enriched natural gas’ (HENG).

Utilising HENG can lead to a reduction of GHG emissions and decreases the carbon intensity of natural gas use. It is particularly promoted for the decarbonisation of heat but recent projects

EMPIR LNG III

The European Metrology Programme for Innovation and Research (EMPIR) LNG project is in its third phase - EMPIR 'LNG III'. Its aims were to establish new test capabilities and develop measurement traceability for LNG and Liquefied Biogas (LBG) for quantity (flow) and quality (composition, density) to enable their large-scale roll-out as transport fuels.

Its main objectives are outlined as follows:

- Reduce uncertainty of onsite flow measurement for LNG applications,
- Undertake feasibility study to develop a flow calibration facility for typical flows (small and midscale) in LNG applications,
- Develop and validate technique for validation of LBG and LNG measurement systems,
- Improve methods and in-line sensors for the measurement of the composition of gas and sensors for the measurement of the methane number for LNG engine development.

Outcomes of this project have been added to relevant standards to facilitate LNG and LBG utilisation as transport fuel

NMI partners include VSL, Cesame CMI, INRIM, JV, NEL, NPL, PTB. Other partners include Mestrelab, Reganosa, RUB, TNO, TUBS, University of Coventry, Naturgy

including the 'Hydrogen Grid to Vehicles' (HG2V) project in the UK is looking into the feasibility of utilising the distributed gas from the network for decarbonising transport.

Whilst hydrogen and natural gas can be mixed in any proportion, studies indicate that up to 20 % hydrogen (volume) can be injected alongside natural gas without any modifications to most natural gas grids, reducing the immediate requirement for expensive infrastructure investments. The threshold for permitted concentrations of hydrogen in the grid varies in different countries across Europe and depends upon the network infrastructures in place, as well as the end uses of the distributed gas. In domestic use, the type and age of connected appliances plays an important role in the allowable limits for hydrogen. There are strict national regulations in most European countries with regards to permissible volume of hydrogen allowed in the gas grids; for example, the UK and Belgium presently allows a maximum blend level of 2 % molar volume of hydrogen in its natural gas grids whist France, Germany and the Netherlands allows a maximum of 8 %, 12 % (in some cases) and 14 % molar volume of hydrogen in their gas grids [40]. Nevertheless, several deployment projects (further information is provided in Chapter 7) have begun in several European countries with the view of reviewing this set blending limits and also promote HENG as part of the energy gas mix.

2.2.2 Liquified Natural Gas (LNG)

Due to the EU's large import demand for natural gas, there is a crucial need for diversification of its sources in order to meet energy demand, improve energy security, diversify gas supply, and to promote competitiveness. Liquefaction of natural gas (LNG) – achieved by cooling natural gas to approximately -162 °C – is primarily carried out as a more efficient means of transporting natural gas without the need of pipelines [41]. This is due to the volume of LNG being 600 times less than in its gaseous form. Utilising LNG also increases safety during transportation due to it being non-flammable in this state (until it begins to vaporise) [42]. It is projected that LNG imports to Europe will increase by 20 % in 2040 compared to 2016 levels and its LNG import capacity could provide approximately 45 % of the continent's total gas demand [43, 44]. As a result, the EU's 'Energy Union Strategy' has highlighted a key objective of ensuring that all members states have access to LNG markets.

In most cases in Europe, LNG is re-gasified and the corresponding gas utilised to meet the peak demand of natural gas. The associated measurement challenges are related to custody transfer, either when used as a transportation fuel (small to mid-scale applications) or in the large-scale application (LNG carrier (un)loading).

LNG is increasingly being used as transportation fuel [45]. In some countries, it is utilised as fuel in heavy duty trucks and lorries due to lower emissions when compared to diesel. It is also promoted as a good alternative to heavy oil as a marine or shipping fuel particularly in short to mid-term projections due to stringent environmental regulations [46]. The European Metrology Programme for Innovation and Research (EMPIR) 'LNG III' project is working on addressing measurement challenges associated with LNG utilisation as transport fuel.

2.3 Measurement Needs for Natural Gas

The utilisation of non-conventional sources of natural gas could lead to new measurement challenges and needs due to the varying production processes. Additionally, there are also challenges derived from liquifying natural gas and the addition of other low carbon gases, notably hydrogen, to natural gas distribution systems in Europe. We are also starting to accept different forms of natural gas (for example natural gas from different sources) and that will affect its composition and properties. This will affect metering, online gas monitoring and the composition of gas. It will also affect measurement of physical properties such as calorific value and Wobbe index.

Table 2 details the key measurement needs that arise from different natural gas sources/production process and particularly for HENG and LNG utilisation.

Table 2: Measurement needs for natural gas including HENG and LNG

<table>
<tr><th colspan="2">Measurement needs</th></tr>
<tr><td>HENG</td><td>

Metering and Gas Composition

- A fundamental challenge to be addressed for HENG is the measurement of the gas flow. Accurate flow metering is crucial as it gives an indication of the volume of gas and helps in custody transfer and in billing of energy. Also, the gas quality plays a critical role, in particular when intermittent renewable gases are added to the gas grid. Therefore, accurate measurement of calorific value (CV), physical properties and gas composition of the hydrogen-natural gas blend are priority needs.
- Techniques for metering these new compositions in a cost-effective way must also be developed and validated at varying concentrations.
- Equation of State of HENG for energy metering; volume conversion devices for natural gas are equipped with an algorithm that computes the real gas factor as a function of gas composition, pressure and temperature. These algorithms must also be tested with natural gases containing a wide range of hydrogen concentrations and the performance of these algorithms under these conditions is unclear.
- Accurate measurement of moisture content

Online Gas Monitoring and Leak Detection

- Reconfiguring conventional leak detections systems to detect leaks in HENG might be problematic due to interference between hydrogen and the carbon monoxide (CO) alarms. This might lead to false positives at the end user. New Leak detection and online monitoring techniques needs to be developed and validated

</td></tr>
<tr><td>LNG</td><td>

Metering and Gas Composition

- While the EMRP and EMPIR LNG metrology projects (LNG, LNGII, and LNGIII) have resulted in key metrological infrastructure for the traceable measurement of LNG flow, composition, and density, further measurement challenges exist such as:":
    - Metrology for LNG and LBG at larger flow rates (range 200 – 1000 m3/h and > 1000 m3/h),
    - Development of reference standards (primary reference standards and secondary reference standards) for LBG/LNG flow and composition measurements,
    - Development of reliable LNG methane number and methane slip measurement.
    - Accurate measurement of moisture content

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</table>

3 HYDROGEN

Hydrogen is being explored by many European countries as a zero or low carbon alternative to natural gas that can be produced domestically, thus improving energy security and resilience. Hydrogen is abundant in nature, however, to obtain pure hydrogen gas (H_2), energy is required [47]. Depending on the method of production, hydrogen has the potential to be a climate-friendly replacement for fossil fuels at the point-of-use. The '*Hydrogen Roadmap Europe*' report from the 'Fuel Cells and Hydrogen Joint Undertaking' (FCH JU) estimates the potential of generating 2 250 TWh of hydrogen in Europe by 2050 in an ambitious scenario [48]. This would lead to a significant reduction of carbon and NOx emissions and as such play a crucial role in achieving emission reduction targets in Europe [16].

The produced hydrogen can be utilised across the energy supply chain; for power generation, as well as in the transport and heat sectors [49]. The EC through its 'European Industrial Strategy' has also initiated a 'Clean Hydrogen Alliance'; this initiative will aim to identify technological needs and barriers towards production of clean hydrogen in Europe [48]. The Alliance will bring together investors, government and industrial partners to identify technological needs, regulatory barriers and investment opportunities for clean hydrogen in Europe [48]. A hydrogen strategy for a climate neutral Europe has also been released by the EC; the main key actions from the strategy is to have and support coordinated strategic investment into clean hydrogen, boost demand and scale up hydrogen production, design an enabling and supportive framework for hydrogen, and promote research and innovation in hydrogen technologies [50]. The 'Hydrogen Energy Network' (HyENet) in Europe is also supporting member countries on policies that could lead to upscaling and deployment of hydrogen. The network will act as a platform for the exchange of information, good practice and developments amongst EU member states [51]. The EMN for Energy gases looks to work in a similar function but with a specific focus on metrology across all types of energy gases.

3.1 Hydrogen Production

The means of producing hydrogen will be key to its potential role as a low-emission alternative to natural gas in Europe. Hydrogen can be produced through several different means:

1. Steam reforming of natural gas (or other hydrocarbons) – During the steam methane reforming (SMR) reaction, natural gas is mixed with steam, heated to over 815 °C and reacted in the presence of a nickel catalyst to produce hydrogen (H_2) and carbon monoxide (CO), which is then converted to CO_2 via a water gas shift reaction [52]. The reforming of fossil fuels could also be carried out in an authothermal process; this process is projected to also play a key role in the production of hydrogen in Europe [16]. Other hydrogen production methods include its production from biomass; this could be a thermochemical process where the biomass is gasified or pyrolyzed at elevated temperatures.
2. Electrolysis of water – Electrolysers are used to split water (H_2O) into H_2 and oxygen (O_2) gas with electricity (Power-to-Hydrogen). This process is particularly important for the generation of green hydrogen due to the significant reduction in emissions if the energy input used to power the electrolyser comes from a renewable source.
3. Hydrogen could also be produced in the future through the extraction of 'bio-hydrogen' from biogas through fermentation of organics or cyanobacteria.

The thermochemical production of hydrogen either through reformation or gasification processes like SMR is termed "grey hydrogen". This method leads to the release of CO_2 and hence has little impact on reducing emissions and meeting climate targets. However, an emissions reduction can be realised when CCUS is deployed alongside thermochemical hydrogen production processes – this is known as "blue hydrogen". Further emission reduction benefits can be achieved when hydrogen is produced from renewable sources such as wind, hydro power and solar, termed "green hydrogen".

Projections in Europe indicate that blue hydrogen will be deployed in the short to mid-term whilst technologies for the green hydrogen continue being developed [13]. At present, hydrogen produced via the SMR process is considered to be the lowest cost option for the production of bulk volumes of the gas [24]. For hydrogen refuelling stations where the gas will be used in a fuel cell electric vehicle (FCEV), electrolysers can be utilised onsite to produce hydrogen, primarily due to the demands for high purity hydrogen to be used in fuel cell systems to avoid degradation of these technologies [49] (challenges related to these are explored further in Table 3.

3.2 Hydrogen Utilisation in Europe

Hydrogen is an important industrial chemical and is utilised in several applications. It is also well suited as a low carbon energy fuel for use in energy-dense applications such as long-distance HGV and ship transportation, as well as for electricity and heating generation during peak periods [24]. Hydrogen is projected as the best choice in Europe for at scale decarbonisation of several sectors particularly transport, industry and buildings [16]. However, a European hydrogen infrastructure is required for hydrogen to effectively play a huge part in the climate and energy objectives in Europe. The European hydrogen backbone report demonstrates repurposing existing gas distribution networks in Europe alongside investments in new dedicated hydrogen pipeline is crucial for efficient distribution and utilisation of Hydrogen in Europe [53]. The potential for repurposing the conventional gas networks to carry 100% hydrogen is already being investigated in several European countries, notably Germany, the Netherlands, the UK and France. Hydrogen can also act as both a short and long-term energy store to balance supply and demand of renewable energy at different scales, geographies and weather conditions. It can therefore meet the need for a low-cost, 'on-demand' power supply that only fossil-fuelled power plants can currently satisfy [54].

Within Europe, there are several projects as well as ongoing research activities that look to support the development and deployment of hydrogen technologies. The 'Hydrogen for Europe' pre study was undertaken by SINTEF to evaluate the current potential of hydrogen in Europe; it took into consideration different production mechanisms proposed for upscaling activities [55]. The findings indicate that hydrogen has the potential to reduce GHG emissions in several sectors in Europe by 2050 and can provide one quarter of the total energy demand in Europe by 2050.

3.2.1 Hydrogen for Decarbonising Heat

The majority of the forecasted scenarios and projections of the energy mix in Europe indicate that hydrogen will make a significant contribution to the decarbonisation of heat [16]. In the buildings sector, post-2050 projections indicate that hydrogen boilers could be deployed alongside heat pumps in a fully decarbonised system [56]. Hydrogen boilers would be effective in buildings with poor insulation and in colder climates where the use of heat pumps is unfeasible. Projections indicate that the utilisation of hydrogen for domestic heating and in buildings could supply 15 % of the total energy demand in buildings across Europe [57]. The hydrogen roadmap for Europe report also estimates that hydrogen can cover the heating demand of more than 11 million households in Europe in 2040 and could heat more than the equivalent of 52 million households in Europe by 2050 [58].

Hydrogen is projected to contribute to the decarbonisation of non-process heat in industries which could be heat utilised in energy intensive industries [59]. Hydrogen can also be used in several production processes for industries including steel, plastic and ceramic production [60]. Furthermore, hydrogen can be utilised to produce synthetic methane in a process called ‘methanation’, which could function as a replacement for conventional natural gas in existing gas grids.

3.2.2 Hydrogen for Decarbonising Transport

Hydrogen could play a crucial role in decarbonising transport as it can be used as fuel in passenger and heavy-duty vehicles that utilise fuel cell technologies. It is particularly well-suited as a low carbon fuel in freight such as commercial vehicles, heavy goods vehicles (HGVs), trains and ships where the use of electric vehicles might not be sustainable. Hydrogen might also be used to produce synthetic fuels for aviation transport; this is being investigated in Europe currently [16].

There is a high interest in the development of infrastructure and techniques to ramp up the deployment of hydrogen in the transport sector in Europe. Several European countries including Germany, the UK, France, Scandinavia and the Netherlands have begun to invest in hydrogen infrastructure such as refuelling stations for transport applications [61] with projections indicating an additional 750 HRS by 2025 [58]. However, the deployment and uptake of FCEVs will depend very strongly on the interactions between vehicle costs, fuel costs and the cost of alternatives alongside policy drivers and evolving habits in different European countries [62]. Nevertheless, there could be a fleet of 3.7 million fuel cell passenger vehicles, 500,000 fuel cell light commercial vehicles and about 45,000 fuel cell trucks in Europe in 2030 [58].

The increased deployment of hydrogen in the transport sector could lead to myriad measurement challenges; the EMPIR ‘Metrology for Hydrogen Vehicles’ (MetroHyVe) project is addressing some of these challenges associated with hydrogen use in transport. The project includes four main work packages:

- Developing traceable methods for calibrating hydrogen flow meters under refuelling conditions (700 bar and fluctuating temperatures);
- Creating new methods and gas standards for hydrogen purity analysis in the laboratory in accordance with ISO 14687 and ISO 21087;
- Validating online purity analysers used for hydrogen quality control at the station;
- Formulating best practice guides for taking representative samples of hydrogen at stations.

Project partners include other European National Metrology Institutes (including EMN members CEM, FORCE, NEL, VSL, RISE, JV and LNE) in addition to hydrogen producers such as Air Liquide, ITM Power, Linde and Shell. Further development of solutions to challenges from hydrogen in transport will be continued in a follow-up project ‘MetroHyVe II’.

3.2.3 Hydrogen in Power

Hydrogen could allow for long term energy storage from renewable electricity, which can then be used in the power sector", and as such play a vital role in Europe’s energy mix. The utilisation of hydrogen in the power sector could provide grid balancing for intermittent renewables, which will help to provide load balancing for times that there is insufficient wind or solar energy. Projections indicate that this could account for up to 15% of the electricity utilised in 2050 across Europe [57]. Hydrogen is also used for cooling as it is much more efficient as a cooling medium compared to dry air [63].

EMPIR MefHySto

The EMPIR project 'Metrology for advanced Hydrogen Storage solutions' (MefHySto) coordinated by the BAM focuses on a metrological assessment of the reliability of the energy supply chain for hydrogen storage. MefHySto will assess the quality of hydrogen produced and improve the reference equations of state, it investigates the sustainability and reliability of fuel cells (FC) looking at impurities in hydrogen and tackles metrological issues in the large-scale storage of hydrogen incl. conversion of existing ones from natural gas to hydrogen.

The project will include five technical work packages:

- Metrology for hydrogen quality during rapidly imposed transient use periods, from power-to-hydrogen;
- Thermophysical properties of hydrogen obtained from electrolysis, hydrogen injected in the gas grids, and hydrogen under geological storage conditions;
- Metrology for hydrogen quality from electrical energy storage (HEES) by hydrogen back conversion (gas-to-power);
- Metrology for reversible hydrogen storage technologies;
- Large-scale storage of gases in geological storage facilities.

The project is calling on expertise from partners of other European NMI's (including NPL, PTB, CMI) in addition to external experts (CEA, DBI, DVGW, ERIC, FHA, MAHYTEC, MPG, Reganosa, UDC, UVa).

3.3 Hydrogen Distribution and Storage

Cost effective and sustainable transport and storage mechanisms are key to the deployment of hydrogen as an energy gas. Hydrogen can be transported as a liquid or gas; liquid hydrogen can be loaded in insulated cryogenic tanks which are then transported via lorries, trailers or other means of transport. Hydrogen can also be transported as a gas in compressed gas containers or tube trailers, which can then be transported via lorries. Another means to distribute hydrogen, particularly for energy gas utilisation over long distances, is through pipelines. Pipelines may be the best option for large scale distribution for energy use in Europe [64]. At present, there are several hydrogen pipelines globally; the longest pipelines in Europe are situated in Belgium and Germany and can transport hydrogen for 613km and 276km respectively.

Storing hydrogen will provide a crucial solution for grid balancing and ensuring adequate and sustainable energy supply, particularly during periods of renewable intermittency. There are several techniques being investigated for hydrogen storage in Europe:

1. Hydrogen can be stored in natural spaces including underground in salt caverns, natural gas stores and depleted gas reservoirs or aquifers.

2. The gas distribution network itself can serve as a storage mechanism whilst distributing hydrogen.

3. Hydrogen gas can be stored using physical methods through compression, cryo-compression or a combination of both methods. Cryogenic hydrogen could also be stored in the liquid state; storing hydrogen as a liquid is promoted due to its higher energy density.

4. Hydrogen can also be stored in solids, liquids and on surfaces; this includes hydride storage systems based on metals such as palladium, lanthanum and aluminium. It also includes surface storage in sorbent materials such as zeolites or carbon nano tubes. Storage in liquid can be done with chemical compounds with high hydrogen absorption capacities such as N-ethyl carbazole and toluene.

5.Hydrogen can also be converted to ammonia, which as a liquid, is very easy to store and transport.

The technology readiness level (TRL) of some of the storage mechanisms for hydrogen are in the development range, and the EMPIR 'Metrology for Hydrogen Storage' (MefHySto) project is poised to support advancement of these hydrogen storage technologies by addressing several metrology challenges that might arise during the process.

3.4 Measurement Needs for Hydrogen

There are various ways by which hydrogen can be adopted into Europe's energy gas systems, which could lead to several measurement needs and challenges that will require addressing before its deployment at scale. For example, these needs can include new requirements for gas quality measurements, determining material compatibility and ensuring storage mechanisms are fit for purpose.

Table 3 summarises some of the key measurement needs and challenges of hydrogen as it is introduced to the European energy mix.

Table 3: Measurement needs of hydrogen

	Measurement needs
Metering	• Accurate metering is crucial for billing end users of hydrogen and, for custody transfer, to enable financial and fiscal transactions. ○ It is essential to investigate and compare performance of various types of flow meters when utilised in hydrogen gas grids to ensure accuracy and precision. ○ Traceable and independent flow calibration equipment must also be developed for use in European gas networks with hydrogen. • Specifically for transport; Precise online hydrogen flow meters need to be developed and validated for use at refuelling stations. ○ It is also essential to measure the mass flow rate and operational variations (temperature and pressure) during refuelling at stations and provide reference standards for validation of the dispenser measurements. ○ Accurate, traceable metering will be required for all forms of transport refuelling, be they light or heavy road vehicles, trains, ferries, ship or aviation. • Accurate, traceable metering will be required for custody transfer measurement when hydrogen (be that blue from reformers, or green from electrolyser farms) is sold from producers into a supply network (e.g. gas network) or directly to a customer (be that by pipeline or by tanker) • Metering, flow monitoring and measurement of efficiency is also needed for underground storage of hydrogen.

Quality	● There will be a need for the development of primary reference standards and materials for different applications of hydrogen. Inter-comparison and validation of these reference materials is also required to provide traceability. ● Quality analysis of hydrogen through online analysers is critical for ensuring the fuel is compatible with the end use application. This will be necessary particularly for emerging production technologies where there is uncertainty around contamination and the possible impurities. ○ Fuel cell systems can be particularly sensitive to hydrogen purity and therefore it is essential to develop rapid novel in situ measurement techniques, modelling tools and standard test methods to characterise critical degradation mechanisms during fuel cell and electrolyser operation. ○ The distribution of hydrogen particularly through pipelines might also lead to additional contamination; the quality of gas must be determined and monitored before point of use to ensure compliance. ○ When storing hydrogen, the storage mechanism itself may add impurities into the hydrogen and this must be investigated.
Materials and Safety	● Precise detection of leaks during the distribution of hydrogen will be important, particularly if its distribution will be carried out via pipelines. The ability to measure hydrogen leaks will be required for distribution networks, storage mechanisms (salt caverns, depleted gas fields etc) and at end use. ○ Existing leak detection equipment and sensors must be recalibrated and validated for use with hydrogen. ● Odorisation of the gas might be carried out during distribution, and the odorant must be compatible with hydrogen and not affect the different end-use applications (i.e. the impact of odorants during distribution and fuel cell performance must be understood). ● Other critical measurement challenges such as flame detection (as hydrogen is invisible) and measurement of combustion properties in domestic combustion of hydrogen must be established. ● Assessment of the impacts of hydrogen on distribution infrastructure must be carried out and there should be further development of measurement techniques and modelling to support the development of better performing materials for fuel cells and electrolysers.

Fuel Cell and Electrolysers	• Measurement and prediction of performance and lifetime for new materials, new devices and existing devices under new operating conditions. This is difficult due to the very long lifetimes required of devices (~10 000's h) and because testing an individual fuel cell or electrolyser short stack requires complicated and expensive equipment. There is a need for both increased testing capacity at the device level that mimics real life operation accurately and for detailed measurements of the degradation processes occurring inside operating devices, so that lifetime limitation can be understood and modelled. • Quality control of produced materials and devices and making measurements on devices throughout their lifetime. • Development of improved methods to rapidly assess performance and durability of new materials to support high throughput materials discovery. • Development of advanced ex situ and in situ materials characterisation techniques to understand processes at a fundamental level including measurements of intermediates on catalysts, investigation of catalytic mechanisms and corrosion processes etc. • Measurements to support very accurate parameterisation of performance and degradation models. • Development of methods to give an improved understanding of degradation mechanisms operating inside of cell, for example EIS with spatial resolution. • Development of techniques for rapid, or online, optimisation of operating conditions and assessment of new materials and cell architectures. • Development of more accurate accelerated stress tests for devices used in new applications or with new operating conditions. • Measurements to support models and control systems of hybrid battery and fuel cell systems. • Techniques for online and end of line testing of components. • More rapid device factory acceptance tests and break in procedures. • Diagnostics methods and prognostics for devices operating in the field.

4 BIOGAS

Biogas is an energy vector and sustainable fuel which has the potential to play a huge role in the energy transition in Europe; it could have a role in the present and future energy mix scenarios for heat application, power and transport, as well facilitating the reduction of emissions from waste and agriculture. Biogas is composed of varying levels of CH_4 and CO_2 as well as water vapour, and small amounts of H_2S, nitrous oxide (N_2O) and ammonia (NH_3) [65]. The biogas market in

EMPIR Metrology for Biomethane

The EMPIR "Metrology for Biomethane" project is working on improving measurement standards for contaminants alongside the development of standardised robust and efficient test methods. These will be applied to parameters that need to be monitored for the application of biomethane either as a replacement of natural gas in the gas grid or whilst using it as a vehicle fuel.

The primary objectives of the project include developing and improving:

- Measurement standards for volatile organic compounds (VOCs),
- Measurement standards for corrosive components and compressor oil,
- Standardised test methods for biomethane.

A further objective is to facilitate the uptake of developed standardised test methods and standards within the measurement supply chain. The results from this project will enable end users to meet contractual obligations, quality and safety requirements.

Internally funded project partners include VSL, IMBiH, NPL, PTB, RISE and VTT, in addition to external partners such as Air Liquide, ITM Power, Linde and Shell.

Europe varies for different individual countries with regards to maturity, method of production and its overall development and deployment. It is utilised in most countries across Europe due to its ability to support increased energy security alongside its environmental benefits, as it aligns with many renewable energy and climate policies. It is generally accepted that the utilisation of biogas alongside other low carbon energy gases such a hydrogen will be essential in meeting the targets for renewable energy in the energy mix in Europe (target of 27% renewable energy in the energy mix in 2030) [66].

4.1 Biogas Production

Biogas is generally produced through anaerobic digestion using agricultural waste, manure, and energy crops in Europe. It can also be produced from landfill gas recovery and wastewater treatment [13, 66] and from the gasification of biomass. Biogas production represented 8 % of renewable energy production in Europe in 2015 with a major share of this produced in Germany [67]. In 2017, there were over 17 000 biogas plants across Europe primarily used to generate heat and electricity [66]. Biogas is also upgraded in some cases through the removal of CO_2, moisture and other contaminants to produce 'biomethane', which is growing in popularity across Europe as a direct replacement to natural gas in several applications, particularly in the natural gas grids and transport.

4.2 Biogas as an Energy Gas

Biogas can either be utilised directly for heat and electricity or it can be upgraded to biomethane which could replace natural gas in gas distribution networks. Over 9 0% of biogas produced in Europe is utilised directly for bio-power generation and capacity, which is utilised in 'electricity only' plants, or combined heat and power (CHP) plants [67]. The electricity realised from biogas plants in Europe amounted to over 11 GW in 2018, with an average electrical efficiency between 35 – 40 % [66, 68, 69]. Heat generated from the combustion of biogas can be used for local heat demand or distributed into district heating networks or off-grid installations.

There is a growing belief shared by several European countries that biogas should be upgraded to biomethane as opposed to its utilisation for direct heat and electricity generation. This belief is due to a combination of factors including low demand at present for heat generated from biogas, and poor economics of electricity biogas plants [17]. The high quality of the upgraded gas or biomethane also means that boilers and other appliances do not need modification or increased maintenance.

4.2.1 Biomethane

The utilisation of biomethane in the gas grid might be an energy efficient solution to decarbonising the gas networks in Europe. Biogas can be upgraded to biomethane (> 96 % CH_4) through the removal of CO_2, H_2S, H_2O and other trace contaminations. There are more than 600 biomethane plants in operation across Europe and similarly to biogas, it can be utilised for heat and electricity generation in CHP's. However, more focus is being placed in Europe on its use as a substitute for natural gas in existing natural gas grids due to the similar gas composition and physical properties.

Similarly, to natural gas, biomethane can be compressed or liquified to compressed biomethane (CBM) or liquefied biomethane (LBM), which facilitates its transportation and storage as existing facilities and vehicles can be utilised. CBM and LBM can also be used as fuel in natural gas-powered vehicles, thus supporting some emissions reductions along the fuel supply chain for a large section of the transport market (namely HGVs).

Biomethane can also be reformed to produce 'blue hydrogen', and if combined with CCS would lead to negative carbon emissions (net removal of CO_2 from the atmosphere) [70]. The negative emissions might also be realised if the biogas digestate is used as agricultural fertiliser [70]. Aiming for these types of negative emission technologies might be crucial across Europe to meet its future emission targets due to the scale of the task at hand. There are several projects being undertaken by individual member countries in Europe with the view of deploying biogas and biomethane as an energy gas, one example of which is the EMPIR Biomethane project, which is working on improving test methods for purity analysis for biomethane before its injection in the gas grid or use as a vehicle fuel. Other projects related to biogas and biomethane are listed in section 7.

4.3 Measurement Needs for Biogas and Biomethane

The addition of biogas and biomethane into the European energy mix leads to additional measurement needs that require addressing. It is paramount that the introduction of these novel energy gases do not lead to any adverse material or environmental effects during utilisation. Table 4 details some of the key challenges related to the utilisation of biomethane and biogas as energy gases.

Table 4: Measurement needs for biogas and biomethane

	Measurement needs
Quality	● A critical measurement need for biogas and biomethane utilisation is measurement of trace impurities that might be present in the gas before upgrading. ● Reference methods and reference materials must be developed for gas composition measurements of biogas, digestate, bio-CNG, bio-LNG and biomethane. New methods and gas reference standards for monitoring low level impurities such as siloxanes in biomethane must also be developed and the applicability of natural gas standards when injecting biomethane must be reassessed. ● Standardised sampling strategies and protocols must also be developed for biogas and biomethane to ensure a true representation of the gases. ● Testing the performance of commercial biomethane purity testing laboratories to ensure they provide traceable and accurate results will be necessary. ● Development and validation of online monitors and analysers for quality control of biomethane and biogas is also critical for its applications notably in the case of its distribution via the gas grids. ● Standards for biomethane utilised in LNG and CNG applications must be developed to provide guidance on required quality specifications to suppliers. ● Analysis of the effects of terpenes in biomethane and considerations of health and safety – as terpenes can mask the smell of natural gas odorants – will require further investigation.
Metering	● Accurate flow measurements will be needed for biogas and biomethane in their applications; this will be required particularly for biomethane being injected into the gas grids where it is essential to monitor amount of biomethane being injected. ● Energy metering of biomethane and the determination of energy content required will also ensure the right amount of gas is being distributed to the end user. ● Efficient means of calibration and validation of developed flow meters for biogas and biomethane should also be investigated to understand flow properties of the distributed gas.

5 CARBON DIOXIDE (FROM CARBON CAPTURE, USAGE AND STORAGE)

MefCO$_2$

The primary aim of the EU funded 'Methanol fuel from CO2' (MefCO$_2$) project was to encompass flexible methanol synthesis from CO_2 and hydrogen. The CO_2 is captured from thermal power stations and the hydrogen utilised is produced from renewable energy surplus.

The major benefits realised from the project are;

- Providing valorisation alternative for captured CO_2 to promote CCU applications,
- Utilisation of hydrogen from surplus renewable generation contributes to a more efficient operation of electric grid, and;
- Produced methanol can be used as a fuel in gasoline blends or used in fuel cells.

The MefCO$_2$ pilot plant is one the largest in Europe, capturing more than 1.5 tons of CO_2 a day.

Project partners include i-deals (Spain), National institute of Chemistry (Slovenia), Mitsubishi Hitachi Power systems Europe (Germany), Cardiff Catalysis Institute (UK), Carbon recycling International (Iceland), DIME-University of Genoa (Italy), Hydrogenics Europe (Belgium) and the University of Duisburg Essen (Germany).

It is important to note that not all emissions will be abated if only the above strategies outlined in Sections 3 and 4 are followed, as several of these novel energy gas production methods produce CO_2. Some of the suggested low carbon sources including blue hydrogen and biogas production, still lead to the emission of CO_2 and as such, carbon capture and storage (CCS) and carbon capture and usage/utilisation (CCU) technologies are required. These technologies are likely to be crucial in the decarbonisation of energy intensive sectors like power, transport and industry. CCS is a technique for capturing and trapping CO_2 emitted in processes and transporting it after compression to a safe and suitable storage mechanism (both long and short to mid-term storage), whilst CCU involves the use of the trapped CO_2 in other processes, for example food and drink production. CO_2 can also be recycled as a reactant for the production of chemicals, synthetic fuels and industrial processes. Furthermore, CO_2 is utilised in the production of Urea but can also be used to produce synthetic methane through reversed water gas shift reactions or methanation. The synthetic methane can thereafter be utilised as an energy gas.

It is important to note that the varying methods for the removal and capture of CO_2 are likely to impact the gas quality and therefore could prevent potential further usage of the gas itself.

5.1 CCUS Deployment in Europe

The deployment of CCUS has been identified as a crucial part of the long-term strategy in Europe for achieving their climate ambitions [9]. There is the potential that CCUS may be the only option in reducing emissions from several hard to decarbonise industrial processes including forging of steel and iron, natural gas processing, cement and ammonia production. It is also a viable means of reducing emissions from the production of low carbon sources and fossil fuel combustion in the short to mid-term.

In Europe, CCU deployment is being carried out in some industrial applications; this includes the fertiliser industry, where CO_2 trapped from ammonia production is used for different chemical production processes. An example of a CCU demonstration project is the 'Power to Methane' project in Germany, where CO_2 captured from bioethanol plants is utilised in producing synthetic methane. The synthetic methane produced can then be used as an energy gas in several sectors including heating, power, transport and industry.

5.2 Measurement Needs for CCUS

CCUS is a developing area in Europe and is poised to be an important part of the energy transition. There are several measurement challenges that could be realised at different phases of CCUS, this includes ensuring a high capture and storage efficiency and also safety concerns with storage and transport of CO_2. As this is also a developing area, several novel measurement challenges might also arise futuristically as technologies evolve and are developed. Table 5 identifies some of the key measurement needs associated with the deployment of CCUS.

Table 5: Measurement needs for CCUS

	Measurement needs
Safety	• Leak detection during utilisation, storage and distribution is paramount; identifying process leaks accurately and understanding dispersion rates of CO_2 will be required to ensure no gas is escaping and thus negating the climate benefits of its capture. • It is also crucial to investigate and measure the effect, if any, of CO_2 on infrastructure during transport, utilisation and storage.
Quality	• The quality of CO_2 is key to the safe operation of the CCS and CCU process; it is essential to identify and monitor impurities that will arise from different stages of the process. This is important to ensure quality compliance of CO_2 for its different end applications.
Process control and Metering	• There must be accurate flow metering from CO_2 capture to storage. It is also necessary to ascertain the carbon capture efficiency; this entails energy efficiency measurements, ensuring capture processed are closed processes and comparing efficiencies of different capture processes. • Carbon accounting and inventories must also be considered; this involves measuring what is being captured, ensuring traceability, and identifying associated processing emissions from capture, which is important if it is to be considered as a negative emission technology. • Accurate, traceable flow measurement will be essential not just from a carbon accounting and reservoir management perspective, but for enabling fiscal and financial transactions which will be directly based upon these measurements. CCS will be monetised in some way (be that taxation or a credit-based system) and so a fiscal grade measurement will be required.

6 SUMMARY OF MEASUREMENT NEEDS

There is a consensus in Europe that it will require a combination of energy solutions, many of which have been outlined in this report, to decarbonise Europe's future energy mix. The shift towards lower carbon energy gases in Europe will ultimately lead to several metrology challenges and needs as discussed in previous chapters, which will require addressing to ensure a sustainable transition. Whilst there are several European and EU-scale projects as well as national projects (highlighted in Chapter 7) looking to address some of these measurement needs, there is still a long way to go in terms of research and development (R&D), to fully identify, understand and proffer solutions in support of the energy transition underway in Europe.

6.1 Measurement Needs for Energy Gases Table

The measurement needs as detailed throughout this report differ for each energy gas. Nevertheless, a key proponent for all energy gas to be utilised as part of the energy mix is to ensure that the characteristics (both physical and chemical) of the gas do not have any adverse effects on its eventual end-use application. Table 6 highlights key measurement needs that will need to be addressed for future energy gases.

Table 6: Key measurement needs for energy gases in Europe

<table>
<tr><th colspan="2">Measurement Challenge/Need</th><th>Description</th></tr>
<tr><td colspan="3">Energy Metering & Process Control</td></tr>
<tr><td>Calorimetry</td><td>Biomethane calorimetry</td><td>- Measurement of biomethane energy content by calorimeter</td></tr>
<tr><td rowspan="2">Chemical Metrology</td><td>Gas measurements for biogas</td><td>- Measurement of water content of biomethane
- Enhancement factor of biogas for moisture content
- Reference methods for component analysis in the digester</td></tr>
<tr><td>Standards for biomethane analysis</td><td>- Assess applicability of natural gas standards when injecting biomethane</td></tr>
<tr><td>Chemical Metrology</td><td>Quality assurance for biogases</td><td>- Reference methods and sampling protocol for impurities in Bio-CNG and BIO-LNG
- Reference methods for CH_4 percentage at the outlet of purification: precision <1%
- Reference methods for online biogas composition analysis: precision <2% for CH_4 and CO_2
- Reference methods for CH_4 in CO_2 (off gas emission)
- Reliable sampling methods</td></tr>
</table>

	Purity measurement for carbon capture and storage	- Effect of impurities (combustion products) on efficiency or storage capacity
	Gas analysis for LNG shipping	- Reliable LNG methane number and methane slip measurement
	Carbon usage methods	- Measurement challenges around pumping captured CO2 into greenhouses
Flow metering	Flow metering for hydrogen refuelling stations	- Measuring mass flow rate of hydrogen dispensed from refuelling stations as required by OIML R 139-1 - Primary and secondary standards for metering at hydrogen refuelling stations are required on different scales for light and heavy-duty transport - Measurement of the temperature and pressure variation during the refuelling process, for testing of compliance to the SAE J2601 refuelling protocol
	Smart metering for hydrogen	- Improved accuracy for customer billing
	Distribution and transmission scale gas grid metering	- Distribution and transmission scale gas grid metering be required for both pure hydrogen and HENG scenarios
	Flow metering for custody transfer	- From either reformers (for blue hydrogen production) or electrolyser farms (for green hydrogen production) a custody transfer grade flow measurement will be required
	Flow metering for hydrogen storage	- Metering of hydrogen in underground storage for transmission network
Flow metering	Flow metering for biogas	- Flow metering for gas grids making use of biomethane injection. Calibration of flow meters for biogas (with various composition) will also be required
	Flow monitoring of CO_2 for carbon usage	- Flow metering of pure carbon dioxide produced from energy processes
	Energy metering for gas grids making use of biomethane injection	- Flow metering to monitor storage of carbon dioxide in sites
Flow	Flow metering of CO_2 storage	- Storage capacity (flow metering)

	Flow metering and gas analysis for LNG	- Metrology for LNG and LBG at larger flow rates (range 200 - 1000 m3/h and > 1000 m3/h) - Improved primary and secondary standards for LBG/LNG flow and composition measurements to achieve reduced measurement uncertainty of calculated energy to within 0.5%
Water content	Water measurements	- Measurements to determine water content in the gas
Storage	Hydrogen storage for intraday use	- Measuring efficiency of the storage mechanism on a national scale
	Carbon capture process efficiency	- Understanding if capture techniques are fully closed processes - Measure/compare the efficiency of different techniques for capture (demonstration facilities) - Energy efficiency measurement - Amine scrubbing efficiency
	Efficiency of compression for storage of CO_2	- Monitoring compression efficiencies when storing carbon dioxide and require energy usage
	Measurement of storage capacity	- Storage capacity of material g CO2 / X g
	Physical properties	- Physical properties (phase changes)
Safety & Quality		
Chemical Metrology	Validation of online purity analysers	- Assessing accuracy and performance of commercial online analysers capable of performing continuous and fast monitoring of harmful impurities in energy gases
	Validation of online analysers for non-conventional gases added to natural gas in gas grid	- Assessing accuracy and performance of commercial online analysers capable of measuring the rapid changes of composition of energy gas in the gas grid due to intermittent addition of non-conventional gases and hydrogen

	Impurities from air for hydrogen use	- Determination of effect of air permeation, for example, through plastic tubing, on hydrogen composition
	Hydrogen purity for storage	- Measurement of hydrogen purity changes as a result of long-term storage in geological storage locations - Measurement of potential impurities from converting back liquid organic hydrogen
	Gas analysis for biogas	- Standardised methods for conformity assessment are necessary - Reference methods for biogas purity analysis - Reference methods for digestate analysis
	Impact of impurities from biogas on appliance lifetime	- Testing the impurities and levels that can affect home appliances and collected robust data required to set threshold levels in standards such as EN 16723
	Traceability of biomethane quality	- Evaluating performance of commercial biomethane purity testing laboratories to ensure they provide traceable and accurate results
	Biogas quality assurance	- Investigate the purity analysis and quality checks that are performed for the upgraded biomethane, and who does them
	Gas measurement of impurities in biomethane	- Develop new methods and gas reference standards for monitoring low level impurities, such as siloxanes, in biomethane
	Biogas odorant for leak detection	- Develop new methods and gas reference standards for monitoring low level impurities, such as siloxanes, in biomethane
Chemical Metrology	Biogas odorant for leak detection	- Testing the effects of terpenes in biomethane and considerations to health and safety (terpenes can mask the smell of natural gas odorants which are injected to help users quickly identify a leak)
	Quality control of CO_2	- Process control – real time measurements
	New pollutants caused by CO_2 capture	- Identification of new impurities that can be present in carbon dioxide due to the capture process

	CO_2 leakage from storage	- Purity (reactivity, harmful impurities in leaks) - Online analysis
Combustion	Flame detection and visibility for hydrogen combustion	- Methods for detecting hydrogen flames and the ability to measure how acceptably ‘visible’ the hydrogen flame is
	Combustion properties of hydrogen	- Measurement of flame propagation, temperature and NOx emissions for hydrogen
Electrochemistry	Materials development for fuel cells and electrolysers	- Novel measurement and modelling techniques for characterisation of performance at micro and nanoscale to support development of next-generation materials
	Quality control for fuel cells and electrolysers	- Online techniques for real-time quality control of manufactured components, for example, membrane electrode assemblies, diffusion media, current collectors and bipolar plates
	Hydrogen odorant	- Measurement of the impact of odorants on fuel cell performance and lifetime
Leak detection and monitoring	Hydrogen leakage	- Ensuring portable leak detectors can accurately measure and differentiate between natural gas, pure hydrogen and HENG - Ability to quantify hydrogen leaks and impacts of release into the atmosphere - Validation of network leakage models and their accuracy - Accurate measurement of capacity, and leak rate for all storage mechanisms - Discharge for cryogenic storage - Accurate leakage measurements to provide safety assurance and establish the efficiency of ammonia storage
	CO_2 leakage from storage	- Process leaks
Materials	Material compatibility	- Assessment of susceptibility to hydrogen embrittlement of materials used in construction of distribution infrastructure, including existing pipeline network

	CO_2 purity	- Materials integrity challenges with moving high-pressure CO2 and impurities - Assess impact of impurity on the corrosivity of CO2 at high pressure
Materials	Impact of CO_2 on infrastructure	- Porosity of materials - Corrosion and cracking of metal pipelines and pressure vessels
Storage	Physical properties, impacts and processes for CO_2 storage	- Erosion, Reaction with rocks / geology - Detecting movement of CO2 sub surface
	Hydrogen leakage	- Measurement techniques and standard test methods for hydrogen capacity and absorption/desorption rate for solid-state storage - Measurement of capacity, and efficiency
Regulation & Other Challenges		
Chemical Metrology	Quality regulation for biogas in vehicles	- Producing the robust scientific data required to set a purity specification for biogas used in vehicles
	CO_2 purity for secondary use	- Requirements for usage in difference industries (impurities) - Food and beverage industry (CO2 purity) - CO2 as feedstock for many industries (market cost, where is CO2 currently coming from, what CO2 purity is needed for different industries)
	Traceability of CO_2	- Providing traceable reference materials and gas analysis measurement to determine isotopic composition of CO2 - Developing method for tracing loss of CO2 from storage to the atmosphere
Combustion	Combustion properties of hydrogen	- Measuring free oxygen/unburnt hydrogen in very wet combustion products

Emissions	Carbon accounting and inventories for CCUS	- Carbon accounting and inventories – measuring what is being captured, traceability, associated processing emissions from capture (important if considered as a negative emission technology)
	CO_2 emissions trading	- CO2 emissions trading – reduced uncertainties
Leak detection	CO_2 leakage	- Understanding CO2 leak dispersion - Subsea storage – leak detection, PH, acoustic (for safety and meeting EU ETS) - Online analysis of CO_2 leakage
Modelling	Life cycle analysis of CCUS	- Life cycle analysis (Modelling of fuel use, to+ all subcategories – storage usage transport capture, every input might emit more than capture) - Modelling of whole system approaches and life cycle analysis of energy use and processes

Fehler! Verweisquelle konnte nicht gefunden werden. illustrates that there are numerous m easurement needs presented by the energy transition, however it is essential to reiterate that the urgency to address these needs will vary for different energy gas to be introduced. A key factor in determining the urgency or priority of the different measurement needs and challenges will be in consideration of the policy drivers and as such the timescales for deployment of the future energy gases. This strategy differs between countries across Europe; nevertheless, it is expected that each energy gas described in this document will play some role in the future European energy mix.

6.2 Stakeholder Input on Measurement Needs

The European Metrology Network (EMN) for Energy Gases was established to share best practice in the field of metrology across several European countries in one collective effort (a list of measurement organisations that participate in the EMN can be found in section 1.3). It supports government, academia and industry by providing measurement science expertise with the view of facilitating a safe, reliable, and diverse energy network in Europe.

The EMN agreed that to be able to effectively prioritise measurement needs and produce an impactful strategic research agenda, it was essential to understand the perception of external stakeholders working in the field of energy gases in Europe. A workshop was held, and a survey undertaken to gain stakeholder input into measurement needs and opportunities as we move towards decarbonised energy systems in Europe. These activities were carried out to establish input regarding how measurement, specifically NMIs and DIs represented by the EMN for Energy Gases, could assist in the energy transition. Input from stakeholders was used to validate trends in energy gas utilisation, country strategies and policies, as well as progression within the R&D landscape in relation to energy gases.

6.2.1 European Energy Gas Workshop

The EMN for Energy Gases held a stakeholder workshop on 22nd January 2020, which offered attendees the opportunity to discuss and prioritise future energy gas measurement needs as Europe moves towards decarbonised energy systems. Topic areas such as decarbonising natural gas, as well as hydrogen, biogas and CCUS were presented and discussed, and attendees were given the chance to identify new measurement services and products that they felt needed to be offered by European laboratories through the EMN.

Table 7 summarises the measurement needs identified by attendees of the workshop as highest priority. For some of the areas, projects are already underway that look to address these needs, however during this workshop it was identified that more work needs to be done and/or the findings of these projects need to be more widely shared with relevant stakeholders.

Table 7: Measurement needs with highest priority from EMN workshop

Measurement need	Existing Project(s)
Flow metering for hydrogen refuelling stations	EMPIR MetroHyVe/ MetroHyVe 2
Energy metering of hydrogen enriched natural gas: • Flow metering • Calorific value • Gas quality	EMPIR NEWGASMET (Flow metering for hydrogen enriched natural gas)
Validation of online purity analysers (hydrogen and biomethane)	EMPIR MetroHyVe/MetroHyVe 2 Biomethane SIP
Representative sampling of gas	EMPIR MetroHyVe/MetroHyVe 2 Biomethane SIP

6.2.2 European Energy Gas Survey

A survey was conducted to gain industry and stakeholder insight concerning current policies and emerging energy gas trends in Europe. Most of the organisations who responded to the survey were involved with several energy gases being utilised or researched in Europe. Some key statistics from the survey are that:

1. Over 90% of the organisations were involved with hydrogen and/or hydrogen enriched natural gas,
2. Around 70% were involved with natural gas,
3. Over 45% of the organisation were involved with biogas and/or, biomethane, LNG and CO_2 from CCUS, and;
4. A great number of these organisations (>70%) are also involved with European-wide or EU national research-based projects on energy gases. Many of the organisations stated that current national policies related to energy gases directly affected organisational decisions, and there was a consensus that the major barriers facing the deployment and commercialisation of decarbonised energy gases in Europe could be attributed to the following factors;

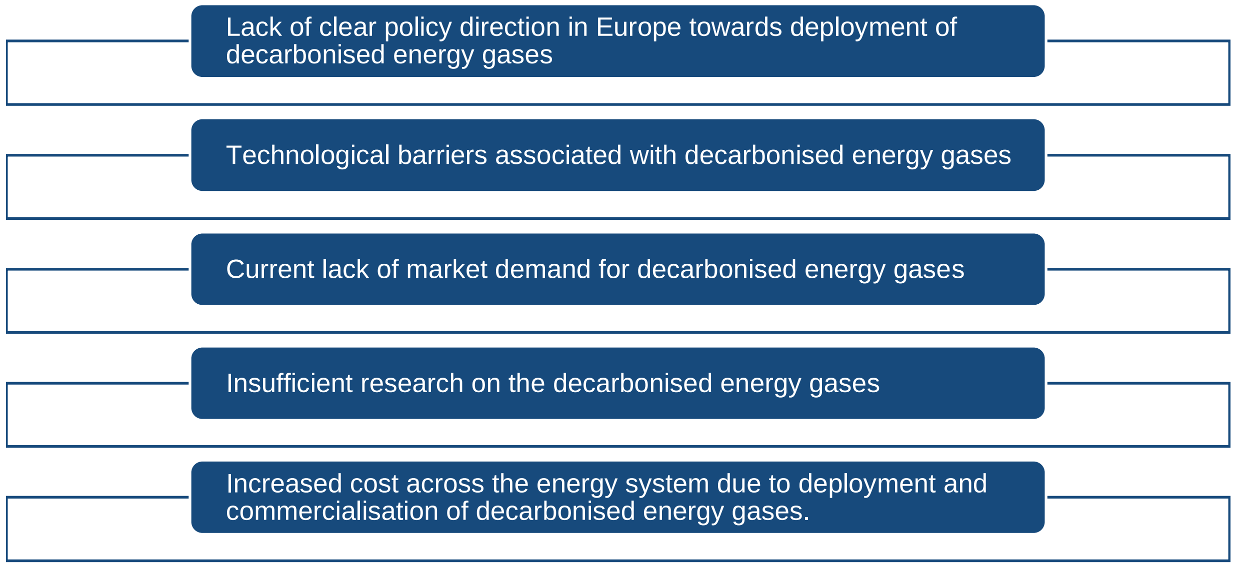

Figure 1: Factors affecting deployment and commercialisation of decarbonised energy gases in Europe according to survey respondents

6.3 Priority Measurement Needs

There was no clear distinction from the survey on which of the aforementioned factors (Figure 1) carry more precedence. However, there was a great agreement between the respondents at the workshop and the survey carried out with respect to the priority of the measurement challenges (Table 8). Some respondents also specified that other factors, such as lack of incentives and political will and lack of supply of decarbonised energy gases, will act as a barrier to the deployment and commercialisation of decarbonised energy gases in their view. Another respondent stated that another challenge to the deployment of decarbonised energy gases will be due to fear of failure from national governments in setting policies and deploying decarbonised energy gases.

Table 8: Priority of measurement needs from survey and workshop

Measurement needs	Priority at workshop	Priority from survey	Timescales
Flow metering for hydrogen refuelling stations	High	Medium - High	2020- 2025
Energy metering of hydrogen enriched natural gas - Flow metering	High	Medium	2020- 2025
Energy metering of hydrogen enriched natural gas - Calorific value	High	Medium	2020- 2025

Energy metering of hydrogen enriched natural gas - Gas quality	High	High	2020- 2025
Validation of online purity analysers (hydrogen and biomethane)	High	High	2020- 2030
Representative sampling of gas	High	Medium - High	2020- 2025

It is the role of NMIs and DIs to support government in evidence-based decision making, and the EMN for Energy Gases is well placed to provide advice and undertake R&D on behalf of their representative country, or as part of an international consortium.

7 PROJECTS

Table 9: Selection of key domestic and European-wide projects linked to energy gases

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
H21 North of England	Cadent, Equinor and Northern Gas Networks; UK	The H21 project is developing a detailed engineering solution for converting the gas networks across the North of England to hydrogen between 2028 and 2034.	Further information
Hydrogen Mobility Europe	Element Energy; UK	The H2ME project will significantly expand the European hydrogen vehicles fleet and in doing so, aims to confirm the technical and commercial readiness of vehicles, fuelling stations and hydrogen production techniques.	Further information
The Future of Gas Networks	SGN; UK	SGN believe low carbon solutions which utilise our existing gas network infrastructure will allow for the decarbonisation of heat at the lowest cost and least disruption to customers. This could be in the short-term by blending green gas such as biomethane and bioSNG into the network, the medium-term adding hydrogen to that blend and in the longer term the potential to	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
		move towards 100% hydrogen networks.	
HyDeploy	Cadent; UK	The project will demonstrate that natural gas containing levels of hydrogen beyond those in the GS(M)R specification can be distributed and utilised safely & efficiently for the first time in a section of the UK distribution network.	Further information
Oban Project	SGN; UK	A trial in Oban – a resort town on the South West coast of Scotland, which has its own isolated gas network – was undertaken by Scotia Gas Networks (SGN) to investigate the supply of gas outside the current UK specification legislated for by GSMR. Funded by the Network Innovation Competition, it sought to provide evidence to support a cost-effective new gas supply solution for the Scottish Independent Undertakings (SIU's) – isolated local distribution networks – following the closure of the LNG storage facility at Avonmouth. It was also foreseen as providing a potential roadmap for the UK adoption of a widened gas-quality (Wobbe Index) specification, subject to the project findings.	Further information
Hy4Heat	Department for Business, Energy and Industrial Strategy (BEIS); UK	Hy4Heat is a programme commissioned by BEIS, the Department for Business, Energy & Industrial Strategy to explore whether replacing natural gas (methane) with hydrogen for domestic heating and cooking is feasible and could be part of a	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
		plausible potential pathway to help meet heat decarbonisation targets.	
MetroHyVe & MetroHyVe 2	NPL; Europe	The EMPIR Metrology for Hydrogen Vehicles project is in great demand by the hydrogen industry as can be evidenced by the 41 letters of support received from hydrogen vehicle manufacturers (including BMW, Daimler and Toyota), hydrogen refuelling station (HRS) operators, gas producers and standardisation bodies. A large hydrogen infrastructure is currently in development across Europe however the industry faces the dilemma that they are required to meet certain measurement requirements (set by European legislation) that cannot currently be followed due to the lack of available methods and standards. The EMPIR Metrology for Hydrogen Vehicles will be the first large scale project of its kind that will tackle these measurement challenges.	Further information
Northern Lights	Equinor, Norske Shell and Total E&P Norge; Norway	The Northern Lights project is part of the Norwegian full-scale CCS project. The full-scale project includes capture of CO_2 from industrial capture sources in the Oslo-fjord region (cement and waste-to-energy) and shipping of liquid CO_2 from these industrial capture sites to an onshore terminal on the Norwegian west coast. From there, the liquified CO_2 will be transported by pipeline to an offshore storage	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
		location subsea in the North Sea, for permanent storage.	
Biomethane	VSL; Europe	The overall objective of this project is to develop standardised test methods for the parameters (mainly impurities) to be monitored when injecting biomethane into the natural gas grid and when using it as a vehicle fuel. A further objective is to develop or improve the measurement standards for these parameters, in order to enable SI traceable calibration and measurement results. This project will closely liaise with the biogas producing and upgrading industry, regulators and biomethane testing laboratories to ensure that the developed test methods are robust and efficient and can readily be implemented.	Further information
Metrology for LNG	VSL; Europe	"Metrology for LNG" refers to a group of European research projects that aim to improve and develop the metrology for LNG custody transfer measurements, leading to smaller measurement uncertainties, reduction of financial risks of transactions and more transparency in the trade of LNG. projects are defined as so-called Joint Research Project (JRP) and carried out as a part of the European Metrology Research Program (EMRP) that is jointly supported by the European Commission and the participating countries within the European Association of National Metrology Institutes (EURAMET e.V.).	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
NEWGASMET	LNE; Europe	This project will assess renewable gas flow measurements using commercially available meters already validated for use with natural gas. Instrumentation will be assessed under typical renewable gas usage, to investigate the effects on measurement accuracy, costs and meter lifetime, with gas composition suitably defined for test purposes. SI-traceable type testing and verification procedures will be developed to demonstrate flow meter accuracy and durability for MID compliance. Standards bodies will be offered the use of the results to improve gas measurement harmonisation, to build confidence in the accuracy of metered transactions for the European energy gas market.	Further information
ACORN ERA-NET ACT http://www.actacorn.eu/	Pale Blu Dot; Europe	Acorn is a low-cost, low-risk carbon capture and storage project specifically designed to make best use of existing oil and gas infrastructure and a well understood offshore CO2 storage site to quickly unlock large-scale CO2 transport and storage solutions for the east coast of the UK and beyond. The project, being developed by Pale Blue Dot Energy, is recognised as a European Project of Common Interest and is located at the St Fergus Gas Terminal in North East Scotland – an active industrial site where around 35% of all the natural gas used in the UK comes onshore, and a perfect site for an early CCUS catalyst project.	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
HyNet	Cadent; UK	HyNet North West is a hydrogen energy and Carbon Capture, Usage and Storage (CCUS) project. The goal of HyNet is to reduce carbon emissions from industry, homes and transport and support economic growth in the North West of England. HyNet is based on the production of hydrogen from natural gas. It includes the development of a new hydrogen pipeline; and the creation of the UK's first CCUS infrastructure.	Further information
GRHYD	ENGIE; France	The GRHYD demonstration project tests the injection of hydrogen produced from renewable electricity into the natural gas distribution network as HENG for NGV buses operating in Dunkirk.	Further information
Porthos project	Port of Rotterdam Authority, Gasunie, EBN; Netherlands	Porthos is a project of common interest to the EU, its aim is to transport CO2 from various companies in the Port of Rotterdam and store this in empty gas fields beneath the North Sea. The CO2 will be pressurised and transported through an offshore pipeline to a platform in the North Sea, approximately 20 km off the coast. From this platform, the CO2 will be pumped in an empty gas field. The empty gas fields are situated in a sealed reservoir of porous sandstone, more than 3 km beneath the North Sea.	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
EvEmBi	DBFZ; Europe	The EvEmBi project is funded in the 11th Joint Call for Research and Development Proposals of the ERA-NET Bioenergy. It aims to evaluate methane emissions from European biogas plants to develop a European voluntary system for greenhouse gas (GHG) emission mitigation. The expected outcomes of the project will be the determination of the methane emission factors, emission reduction strategies, European and national (country specific) position papers on GHG emissions and emission mitigation strategies.	Further information
DECARB	NPL; Europe	The use of natural gas as a primary energy source represents a major issue to global warming. Decarbonisation of the gas grids is a possible solution, alongside electrification, to meet the climate change targets and reduce carbon dioxide emissions. This project will be the first large scale project of its kind that will tackle four measurement challenges that the gas industry need to solve before they can decarbonise the gas grid through introduction of biomethane, hydrogen-enriched natural gas, 100 % hydrogen, and carbon capture and storage (CCS). The project will cover the priority challenges within flow metering, gas composition, physical properties and safety (including monitoring of gas leaks).	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
MetHyInfra	PTB; Europe	This project is the first large scale industry project that will provide the required metrological infrastructure (and traceability) that is needed to tackle the measurement challenges that are currently faced by the hydrogen industry. This will promote growth in several sectors (mobility, fuel cells, liquified hydrogen). The aim of this project is to ensure measurement traceability in the hydrogen distribution chain. Therefore, critical flow Venturi nozzles will be established as standards for use with high pressure gas and a traceability route will be established for liquified hydrogen. Without this, verifiable measurements will not be possible and hydrogen will not be accepted for use as an environmentally friendly fuel.	Further Information
Influence of renewable gases on gas flow meters	DNV; Europe	DNV is initiating a joint industry project (JIP) to investigate the influence of renewablel gases on the measurement uncertainty of flow meters. More frequent occurrence of high- CO2 biogas and hydrogen in natural gas grids demands the verification of gas flow meters under various gas compositions. Scaling rules between different gas compositions exist and depend on the metering technology used. However, these rules have not been tested systematically. The aim of this JIP is to investigate the theoretical response of different metering technologies to the introduction of non-conventional gases and validate the outcome to high-pressure, large-scale	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
		calibration with different gas compositions.	
Met4H2	VSL; Europe	The EU Green Deal sets ambitious targets for the transformation towards a climate neutral continent. Hydrogen plays a key role as an energy in this ambition, yet the metrological infrastructure to support the entire hydrogen supply chain is underdeveloped. Research addressing this SRT should focus on key aspects of determining quality and quantity of hydrogen, monitoring and regulatory conformity, providing the necessary measurement standards, methods, models and best practices for the production, storage, transmission, and distribution of hydrogen	Further information
MetCCUS	NPL; Europe	As part of the European Green Deal, the European Commission proposed to raise the 2030 greenhouse gas emission reduction target, including emissions and removals, to at least 55 % compared to 1990. Carbon capture, utilisation and storage (CCUS) has been identified as a priority topic to reach this target and to enable the EU to become carbon neutral by 2050. The aim of this proposal is to develop the metrology infrastructure that will allow monitoring and leak detection of CO2 within energy/industrial processes and transportation networks, promote the use of CO2	Further information

Project with reference link	Leading or coordinating organisation & country/region	Aim of project and measurement challenge focus	Reference links
		removal such as CCUS, and support a better understanding of the CO2 lifecycle. Providing metrology support in these areas will help industry to properly assess their CO2 emissions to operate within the EU Emissions Trading System (EU ETS) and allow the use of CCUS to reduce carbon emissions	
Normative Biomethane	NPL; Europe	Biomethane is a renewable energy gas that can be injected into natural gas networks, and used as a vehicle fuel, if it conforms with the specifications of EN 16723. To ensure conformity, the industry requires measurement standards that contain both SI-traceable levels of targeted impurities and other possible interferents. Therefore, methods should be developed for the dynamic preparation of these gas standards, which should be validated for use in biomethane conformity assessment. In addition, a comprehensive protocol should be developed for the validation, and performance evaluation, of the analytical instruments and measurement methods that are used. It should be suitable for both onsite and offsite analysis using commercially available industrial gas analysers. The protocol, gas standard preparation methods and use cases should be provided as a contribution to the standards development work of technical committees, including ISO/TC193/SC1/WG25 “Biomethane”.	Further information

8 REFERENCES

1. European Commission, *Powering a climate-neutral economy: An EU Strategy for Energy System Integration* 2020.
2. Lebelhuber, C. and H. Steinmüller, *How and to which extent can the gas sector contribute to a climate-neutral European energy system? A qualitative approach.* Energy, Sustainability and Society, 2019. **9**(1): p. 23.
3. International Energy Agency, *The Role of Gas in Today's Energy Transitions*, in *World Energy Outlook special report* 2019, International Energy Agency.
4. International Energy Agency. *Commentary: A long-term view of natural gas security in the European Union*. 2019 05/08/2019]; Available from: https://www.iea.org/newsroom/news/2019/march/a-long-term-view-of-natural-gas-security-in-the-european-union.html.
5. United Nations Framework Convention on Climate Change. *What is the Paris Agreement?* 2016 05/08/2019]; Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement.
6. HM Government. *UK becomes first major economy to pass net zero emissions law*. 2019 20/08/2019]; Available from: https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law.
7. Committee on Climate Change, *The Sixth Carbon Budget - The UK's path to Net Zero.* 2020, Committee on Climate Change (CCC): London.
8. BEIS, P.M.s.O., 10 Downing Street, The Rt Hon Kwasi Kwarteng MP, The Rt Hon Alok Sharma MP, and The Rt Hon Boris Johnson MP, *UK enshrines new target in law to slash emissions by 78% by 2035. 2021.*
9. European Commission, S.-G., *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Green Deal*, SGN, Editor. 2019.
10. International Energy Agency, *Gas 2018 - Analysis and Forecasts to 2023: Executive Summary*. 2018.
11. ENTSOG. *Ten Year Network Development Plan*. [cited 2020 August 10]; Available from: https://www.entsog.eu/tyndp#entsog-ten-year-network-development-plan-2020.
12. McKinsey. *How did the European natural gas market evolve in 2018?* 2019 05/08/2019]; Available from: https://www.mckinsey.com/industries/oil-and-gas/our-insights/petroleum-blog/how-did-the-european-natural-gas-market-evolve-in-2018.
13. Mihnea Cătuţi, C.E.M.E., *The future of gas in Europe: Review of recent studies on the future of gas* 2019, CEPS Energy Climate House.
14. ExxonMobil, *2019 Outlook for Energy: A perspective to 2040*. 2019.
15. BP, *BP Energy Outlook: 2019 edition*. 2019.
16. Fuel Cells and Hydrogen 2 Joint Undertaking, *Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition*. 2019.
17. Laurent Geerolf, *The biogas sector development: Current and future trends in Western and Northern Europe*, in *Division of Heat & Power*. 2018, KTH School of Industrial Engineering and Management: Stockholm, Sweden.

18. European Biogas Association, *Annual Report 2020- European Biogas Association.* 2021, European Biogas Association,: Belgium.
19. European Biogas Association, *EBA Statistical Report 2018*. 2018.
20. EURACTIV & Engie, *Biomethane in the EU*. 2019.
21. Gas Infrastructure Europe, * *PRESS RELEASE * Existing gas storage capacity in Europe exceeded one petawatthour in 2018, shrinked against 2016*. 2018.
22. United Nations, *Paris agreement*. 2015.
23. European Commission IOGP, *The potential for CCS and CCU in Europe*, in *Report to the thirty second meeting of the European gas regulatory forum 5-6 June 2019*. 2019, IOGP.
24. Committee on Climate Change, *Net Zero: The UK's contribution to stopping global warming*. 2019.
25. Wettengel, J., *Germany must put CCS back on the table, says Merkel*. 2020, energy post.
26. Parliament, E., *Energy policy: general principles*, in *Fact Sheets on the European Union* 2020.
27. S.Faramawy, T.Z., A.A.-E.Sakr,, *Natural gas origin, composition, and processing: A review.* Journal of Natural Gas Science and Engineering, 2016. **Volume 34**: p. 34-54.
28. Eurostat, *Natural gas supply statistics-Statistics Explained*. 2019.
29. BEIS, *UK ENERGY IN BRIEF 2018*, Business Energy & Industrial Strategy, Editor. 2018: Crown copyright
30. British Geological Survey. *Shale gas*. 2019 20/08/2019]; Available from: https://www.bgs.ac.uk/shalegas/.
31. Aksyutin, O.E., A.G. Ishkov, and V.A. Grachev, *Prospects and Challenges of Shale Gas Recovery in Europe.* Studies on Russian Economic Development, 2019. **30**(5): p. 578-583.
32. Priestley, S., *Shale gas and fracking*, in *BRIEFING PAPER*, House of Commons Library, Editor. 2020.
33. Government of France, *France, the first country to prohibit exploitation of hydrocarbons*. 2017.
34. Northern Ireland Assembly, *Hydraulic Fracturing (fracking) Motion*. 2014.
35. Morris, C. and M. Pehnt, *Energy Transition The German Energiewende*. 2014, Heinrich Böll Foundation: Berlin.
36. National Parliament of Ireland, *Fossil Fuel Divestment Act 2018 (Act 29 of 2018)*. 2018.
37. THE EUROPEAN COMMISSION, *COMMISSION RECOMMENDATION of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing.* Official Journal of the European Union, 2014. **2014/70/EU**(39): p. 72-78.
38. Stokes, E., *New EU policy on shale gas.* Environmental Law Review, 2014. **16**(1): p. 42-49.
39. European Technology and Innovation Platform. *Bio-SNG (Synthetic Natural Gas) and Gasification Technologies*. 2019 20/08/2019]; Available from: http://www.etipbioenergy.eu/value-chains/products-end-use/products/bio-synthetic-natural-gas-biosng.
40. Policy Connect, *Next Steps for the Gas Grid - Future Gas Series: Part 1*. 2018.

41. Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2JU), *Hydrogen injection into the natural gas grid*, in *Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities*. 2017, Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2JU), Roland Berger GmbH,: Brussels.
42. Chevron. *What is LNG – liquefied natural gas?* 2019 20/08/2019]; Available from: https://www.chevron.com/operations/liquefied-natural-gas-lng.
43. Shell. *What is LNG and how can we use it?* 2019 20/08/2019]; Available from: https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng.html.
44. European Commission. *Liquefied Natural Gas and gas storage will boost EU's energy security*. 2016; Available from: https://ec.europa.eu/commission/presscorner/detail/sv/MEMO_16_310.
45. European Commission. *EU-U.S. Joint Statement: Liquefied Natural Gas (LNG) imports from the U.S. continue to rise, up by 181%*. 2019; Available from: https://ec.europa.eu/commission/presscorner/detail/nl/IP_19_1531.
46. LNG Blue Corridors. *Demonstration of heavy duty vehicles running with liquefied methane*. Available from: https://lngbc.eu/.
47. Sharples, J., *LNG Supply Chains and the Development of LNG as a Shipping Fuel in Northern Europe*. 2019, University of Oxford: Oxford Institute for Energy studies.
48. International Energy Agency, *Technology Roadmap; Hydrogen and Fuel Cells*. 2015.
49. EUROPEAN COMMISSION, *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS- A New Industrial Strategy for Europe*. 2020 Brussels.
50. National Physical Laboratory, *Energy transition: Measurement needs within the hydrogen industry*. 2017.
51. European Commission, *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN*

    PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL

    COMMITTEE AND THE COMMITTEE OF THE REGIONS-A hydrogen strategy for a climate-neutral Europe, EUROPEAN COMMISSION, Editor. 2020, EUROPEAN COMMISSION,: Brussels.
52. European Commission. *Hydrogen Energy Network*. Hydrogen 2019 29 May 2020 [cited 2020 16th of June]; Available from: https://ec.europa.eu/energy/topics/energy-system-integration_en/energy-storage/hydrogen_en#hydrogen-energy-network.
53. Air Products, *Energy: Hydrogen steam methane reformer datasheet*. 2013.
54. Wang, A., et al., *European hydrogen backbone: How a dedicated hydrogen infrastructure can be created.* 2020.
55. Energy Technologies Institute, *Hydrogen - The role of hydrogen storage in a clean responsive power system*. 2015.
56. Sintef and IFPEN, *Hydrogen for Europe- Final report of the pre-study*. 2019, SINTEF Energy Research,: NORWAY.
57. POYRY, *Fully decarbonising Europe's energy system by 2050*. 2018.

58. Lambert, M., *Hydrogen and decarbonisation of gas: false dawn or silver bullet?* , in *Energy Insight: 66*. 2020, Oxford Institute for Energy Studies University of Oxford. p. 23.
59. FUEL CELLS AND HYDROGEN JOINT UNDRTAKING, *Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition*. 2019: Luxembourg: Publications Office of the European Union.
60. POYRY, *Hydrogen from natural gas –The key to deep decarbonisation*. 2019.
61. Bhaskar, A., M. Assadi, and H.N. Nikpey Somehsaraei, *Decarbonization of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen.* Energies, 2020. **13**(3): p. 758.
62. Hydrogen Mobility Europe. *H2ME*. 2019 31/10/19]; Available from: https://h2me.eu/.
63. International Energy Agency, *The Future of Hydrogen*. 2019.
64. Hydrogen Europe. *Hydrogen transport and distribution*. [cited 2020 16/06]; Available from: https://hydrogeneurope.eu/hydrogen-transport-distribution.
65. Ola Eriksson, *Environmental Technology Assessment of Natural Gas Compared to Biogas.* Natural Gas, Primoz Potocnik, 2010.
66. Scarlat, N., J.-F. Dallemand, and F. Fahl, *Biogas: Developments and perspectives in Europe.* Renewable Energy, 2018. **129**: p. 457-472.
67. IFPEN. *Economic outlook Biogas in Europe: future prospects?* 2017; Available from: https://www.ifpenergiesnouvelles.com/article/biogas-europe-future-prospects.
68. EBA, *Annual report 2019*. 2019, European Biogas Association, .
69. Gas for Climate and Guide house, *Gas Decarbonisation Pathways 2020–2050*. 2020, Guide house: Netherlands.
70. Antonini, C., et al., *Hydrogen production from natural gas and biomethane with carbon capture and storage – A techno-environmental analysis.* Sustainable Energy & Fuels, 2020. **4**(6): p. 2967-2986.

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