HIGGS
Hydrogen in Gas Grids

A systematic validation approach at various admixture levels into high-pressure grids

D2.3
Final document review on specific technical, RCS barriers, enablers and innovations

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RE Restricted to a group specified by the consortium*

CO Confidential, only for members of the consortium*

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Table of Contents

List of Figures

List of Tables

Executive Summary

The report “Final document review on specific technical, RCS barriers, enablers and innovations” has attempted to provide an overview on the European high-pressure gas transmission grid with its current infrastructure as well as on the legal and technical framework regarding hydrogen in the European Union and its member states.

Regulation on the injection and transport of hydrogen in the gas grid, transmission or distribution networks, is in the responsibility of the European Commission and the governments of the member states of the European Union. This applies to the United Kingdom of Great Britain after leaving the European Union as well. The topic hydrogen energy system and the linked transmission of hydrogen through the European gas networks reached a big momentum, having its initiation at the time of the speech of Executive Vice-President Frans Timmermans at the Fuel Cells and Hydrogen Joint Undertaking’s stakeholder forum on November 21, 2019. Already then, the workplan of the HIGGS project was submitted and the project was in the Grant Preparation phase with the FCH JU offices. During the definition of the HIGGS work scope in spring 2019 the actual rapid and extensive take-up of activities were not expected as well as that there will be so fast so many activities around the gas infrastructure dealing with the transmission of hydrogen. Following to the national drafting of the National Energy and Climate Plans, by end of the year 2019, the member countries have started to release their specific national hydrogen strategies.

In parallel, many projects on hydrogen infrastructures using the existing gas grid were started at national level. This led to the effect, that some transmission system operators decided not to disclose information on their gas networks to the HIGGS consortium. Nevertheless, the partners in HIGGS work package 2 could compile an as comprehensive as possible report mapping the European gas infrastructure and the legal and technical framework for the European high-pressure transmission gas grid. Basis of both are two separate surveys, complemented by literature research and consultations of the partner’s employees working in technical committees (e.g. CEN/CENELEC, MARCOGAZ, DVGW etc.) at European and national levels.

Infrastructure

The conduction of the infrastructure survey has given a descriptive picture of the European natural gas transmission grid and its facilities. The information has been provided by the European TSOs and gas operators associations. It has been verified that the information obtained is consistent with that collected in previous reports (EGIG, MARCOGAZ, etc.), where applicable. Complementing these reports, additional information on infrastructures has been obtained that completes the available ones in these reports obtaining a good knowledge of the European infrastructures for the

transmission of natural gas. The analysis of the information has made it possible to identify the most representative facilities of the natural gas transmission network, and specifically those in contact with gas and which, therefore, will be exposed to hydrogen when it is injected into the network. The main components and characteristics of these representative facilities have been identified, establishing those that could be especially sensitive to hydrogen.

Generally, the quality of the steel used in the pipes is associated with the operating pressure of the network: higher pressures force the use of higher quality steels (grade) to avoid the use of pipelines with higher thickness. As result of the survey, five main steel types (API 5L Gr. B / X42 / X52 / X60 / X70) were identified in installed pipelines in the European high-pressure gas transmission grid, having together a share of about 88 %. As literature suggests that these steels, except for X70, are considered to be hydrogen-ready and considered to be able to handle hydrogen and blends of hydrogen and natural gas without major adjustments. These steel grades have been recommended for the testing campaign in HIGGS' WP4. For the remaining part of the grid (about 12 %) mainly another five steel grades are used (API 5L Gr A / X46 / X56 / X65 / X80). Referring to literature, there might be limitations in regards of blends of natural gas and hydrogen and with pure hydrogen using the latter two, while the first three steel grades are considered to be hydrogen-ready as well.

From the data available on infrastructures in previous reports, and from the information obtained from the European TSOs through the infrastructure survey, it is observed that the most common installations in the high-pressure transmission gas grids are valves positions (valves nodes or cut-off stations) and stations designed to measure the gas flow and regulate its pressure (metering stations and pressure reduction stations).These facilities are mainly composed of sections of pipes and valves, regulators, meters and instrumentation. These components are usually installed using flanged joints, using gaskets made of elastomeric materials. According to the literature, most of these materials are compatible with hydrogen. However, the diffusion and permeability of hydrogen through these materials is greater than for methane, so we consider it advisable to carry out specific tests on gaskets and components of this material in the WP4 test campaign.

The TSOs that contributed to the survey could not provide much information about the impact that hydrogen may have on their facilities because the impact is mostly still unknown. Regarding gas meters, some TSO suggested that ultrasonic devices can operate with a hydrogen content up to 20 %, while diaphragm (bellows-type) gas meters have no hydrogen content restrictions.

European legal framework

The European Commission's work programme foresees a transition of the Green Deal and the related strategies to action. Although the current European legal framework does not yet cover hydrogen and hydrogen admixtures in natural gas in the European high-pressure gas transmission grid, the European Commission is working intensely on the preparation of proposals of legislation (gas package), which is awaited to be published during 2021. With the first package of the "Fit for 55"-programme, revision proposals have been released in July 2021. The second package e is awaited to include hydrogen and the decarbonisation of gas markets in the current gas legislation and to be released by the end of 2021. Especially the second package will define the basis for the future uses of the gas grid for hydrogen.

European technical framework

Concerning the European technical framework of standardisation, currently the relevant standards are subject to investigation on revision needs or are already under revision with respect to hydrogen readiness. The challenge of the current adaptation of standards for the use of hydrogen is the content interaction between the standards and the co-ordination between the standardisation committees. Especially regarding the adaptations for hydrogen blends, it is not yet clear, which hydrogen concentrations the provisions in the European standards need to cover, as there are no strategic commitments yet. Referring to the current knowledge, most of the technical committees are investigating their standards for up to 20 Vol-% hydrogen. For the coordination of European hydrogen standardisation between the technical committees, the direct liaisons work between the groups, but also the consultations and investigations in the CEN and CENELEC Sector Fora, i.e. Sector Forum Gas infrastructure, Sector Forum Gas utilisation and Sector Forum Energy Management and energy transition – play a key role.

Fostering the coordination and coherent approach, the intended European Commission's Standardisation Request on hydrogen to CEN and CENELEC is highly appreciated. The current proposal includes four uses of hydrogen:

- hydrogen in repurposed natural gas infrastructure and application
- hydrogen as a blend in natural gas infrastructure and application,
- hydrogen in dedicated infrastructure and application
- methanation

European sector initiatives

Full support of the decarbonisation needs and targets for the energy system is given in the gas sector. A high awareness is notable that the transition to a decarbonised hydrogen system will only be possible with all parts along the gas chain being involved in the architecture and the realisation of the transition. Thus, many initiatives in the gas sector between companies or European stakeholder within and across the parts of the gas chain are working on the appropriate solutions to finally enable the intended broad use of hydrogen.

The European hydrogen backbone initiative comprehensively describes how a hydrogen backbone in Europe can be created and which knots and existing pipelines can be redesignated or have to be built from scratch in order to secure a large-scale hydrogen market. The H2 Gas Assets Readiness (H2GAR) is a project of the seven transmission system operators Enagas, Fluxys, Gasunie, GRTgaz, Nationalgrid, OGE and SNAM. It specifically aims at sharing technical knowledge on the hydrogen readiness of the gas assets (blends and pure) among the project partners, building a joint view on the findings and contributing them to the standardisation process for a robust future hydrogen-ready gas system. The Prime movers' group on gas quality and hydrogen handling set up in 2020 functions as the open exchange platform between stakeholders from gas production to the various gas applications and including organisations and representatives of the Commission.

National frameworks

Concerning the national legal and technical framework in regards of hydrogen throughout the member states of the European Union a quite diverse picture is perceived. Generally, the European gas sector is very active and shows big efforts to achieve and enable the use of hydrogen, especially in Czech Republic, Denmark, France, Germany, Italy, Spain and the Netherlands. For the establishment of the national legal framework and the further development of the national strategies the European proposals for the revision of the gas package will be a major guideline.

The National Energy and Climate Plans (NECPs) of the member countries of the European Union are publicly available and administered by the European Commission. A similar approach in regards of the national hydrogen strategies could help to raise the availability and transparency of the strategies. All member countries, Switzerland and UK have published or announced a national hydrogen strategy. 14 countries allow the presence of hydrogen in the transmission natural gas grid. Yet, the allowed concentrations in some of these countries are very low.

Countries like Germany, Austria, France, Spain have allowed concentrations between 5 to 10 Vol-% and in some of these countries further adjustments to raise this limit to up to 20 Vol-% are ongoing. In other countries there is no opportunity for the injection or the transport of hydrogen reported.

Certification / testing methods

In terms of certification and of the approval of hydrogen readiness of the gas transmission grid first developments of suitability and/or certification procedures respectively programs can be observed based on technical assessments and manufacturers declarations. Certification programs are requested to offer reliable approval procedures for pilot projects and further gas transmission grid development until formal certification based on European or national standards are available. It is recommended to use bilateral and European networks to learn from the parties that are already working on certification and approval of suitability in order to be efficient and to come to a European framework as soon as possible.

There are appropriate test methods like dynamic or static load test or non-mechanical tests available to determine hydrogen embrittlement in pipelines and facilities materials of the high-pressure gas transmission grid. These test methods should be anchored in the European standards of CEN and CENELEC.

Conclusion remark

The research and analysis carried out for the present report leads to following findings:

> The high-pressure transmission gas grid is substantially hydrogen-ready. Some parts of the gas grid still need additional monitoring and approval through single tests and observations. Especially, facility equipment like compressors, gas meters etc. are to be checked on their capabilities to handle certain hydrogen concentrations, avoiding damages or major incidents. A general assertation on their hydrogen readiness cannot be stated.
>
> Acknowledging that many countries and organisations are already comprehensively preparing the technical and legal framework for the national and European level, especially the standardization, certification and legislation require expedite adaptions to build an appropriate and reliable basis for the safe use of hydrogen in the gas grid and to ensure the secure environment for the investment needed for an accelerated upgrading of the hydrogen energy system at gas transmission and distribution level. The proposals of the European Commission for the revision of gas package will give the development a significant orientation.

1 Objective

Work Package 2 “Legal, regulatory and technical aspects: identification and follow-up” of the HIGGS project provides updated information on present regulations, standards and certifications for the equipment and infrastructure of the high-pressure natural gas grid in the European Union. The present report summarises the work carried out and the achieved results.

The work programme of work package 2 consists of two main parts. The first part is the inventory and quantification of existing assets in the European gas transmission grid, giving a comprehensive overview of the existing pipelines and their properties (length, material, diameter, maximum operating pressure, welding material, coating and age) as well as the existing facilities (gas quality control systems, LNG terminals, underground storage, cross-border interconnection points and odorization systems) and compare it with similar investigations. The information gathered shall be used to identify the most representative facilities of the European high-pressure gas transmission grid that get in contact with hydrogen. The data will serve as a basis for the work packages 3 (Design, preparation and commissioning of testing facilities) and 4 (Systematic and experimental validation) in the HIGGS project. The contained inventory of the European transmission gas grid is presented in section 3. The second part is the current legal and technical framework in regards of hydrogen in the EU and its member countries. The national legal and technical frameworks of the European member countries are investigated as well as the ones of the European Union. Furthermore, the status of certification and testing methods in regards of hydrogen is outlined as well. The resulting information is presented in section 4.

2 Introduction

The HIGGS project aims to pave the way to the decarbonisation of the gas grid and its usage. Achieving this top goal demands knowledge on the impact high levels of hydrogen could have on the gas infrastructure, its components and its management and the identification the existing gaps. It requires target-oriented activities, including mapping of technical, legal and regulatory barriers and enablers, testing and validation of systems and innovation, techno-economic modelling and the preparation of a set of conclusions as a pathway towards enabling the injection of hydrogen in high-pressure gas grids.

The present deliverable report's scope is to provide an inventory of the European high-pressure transmission gas grid and its components, as well as an assessment of the European legal and technical framework applicable to the injection, blending and transport of hydrogen. The hereby linked barriers and enablers are considered as well. Tackling this challenging task, two surveys were prepared and sent out to the corresponding stakeholders. The first survey, being the inventory of the infrastructure in the European transmission grid, addresses those stakeholders who operate the gas transmission system (TSO – Transmission System Operators) as well as the national gas associations of the European Union's member states. The second survey, the questionnaire on the current legal and technical framework in the European member states, is targeted towards national gas associations and TSOs, who were contacted therefore. The data gathered was processed and analysed to create the results, draw conclusions and detect the main gaps. Latter have been filled through direct meetings with the corresponding stakeholders or seconded through additional inquiries. The HIGGS consortium conducted a stakeholder workshop to bring unclear points of the surveys into light and to answer potential questions, the stakeholder might have.

3 European gas transmission grid – capability of the high-pressure gas infrastructure and applied equipment to handle hydrogen concentrations up to 100 Vol-%

Chapter 3 outlines the data on the current European gas transmission grid gathered from TSOs (Transmission System Operators) throughout the European Union and draws a picture of the current high-pressure transmission gas grid and its components. It starts with an introduction to the technical basic information on high-pressure transmission gas grids, and the methodology used to gather the data. The second section describes the data analysis and the current state of the European gas transmission network. Chapter 3 finishes with the evaluation of the gas network's state and the discussion on the capability of the gas transport grid infrastructure in regards of handling hydrogen.

3.1 The transmission natural gas pipelines and implication of hydrogen injection

3.1.1 Basics on transmission grid pipelines

The current European transmission network of natural gas pipelines, the one dedicated to connecting the system's gas entry points with the distribution networks and consumption points, transporting large volumes of gas, at high pressure and long distances, has a length of around 220,000 km and more than 23,000 stations to measure the gas circulating the network and reduce its pressure to distribution conditions, as a step prior to its use by end consumers [1].

Natural gas as energy source is not a discovery of the industrial age. The first natural gas deposits appear in Iran in the year 2,000 B.C., when the earliest civilizations discovered its existence and gave constant flames a divine origin. It wasn't until about 500 B.C. that the Chinese discovered the potential to use these fires to their advantage, finding places where gas was seeping to the surface. The Chinese formed pipelines out of bamboo to transport the gas, where it was used to boil sea water, separating the salt. Later, in 125 B.C. drilling of the first known natural gas well was carried out in China.

In Europe, the first mentions of natural gas are found in England in the 17th century, but it was still not known how to transport it from its deposits. This missing knowledge was the reason why it remained displaced from industrial development by oil, coal and its derivatives. The first uses of piped gas date back to the late 18th century and refer to the use of gas produced from coal (town gas) to illuminate the Britannic houses, as well as streetlights.

During most of the 19th century, natural gas was used almost exclusively as a source of light. Without a pipeline infrastructure, it was difficult to transport the gas very far, or into homes to be used for heating or cooking.

In 1821 in a small town in New York, natural gas was transported by a small diameter copper pipe, but the great advances in gas transport technology did appear before 1890, with the invention of the joints that prevented leaks, and allowed to carry the gas 150 km away.

Near the end of the 19th century, with the advent of electricity, natural gas lights were converted to electric lights. This led producers of natural gas to look for new uses for their product, which was a new impulse for its development.

In the 20th century, in 1927 pipe technology has evolved and in the United States large gas transmission pipelines of more than 51 centimetres in diameter and 320 kilometres were built for the first time. In 1970 in Russia, there was a construction of the longest pipe for the transport of natural gas, 5,470 kilometres long, crossing the Urals joining Eastern Europe with Siberia. In Europe, the growth of natural gas transmission grid has been continuous from the 1970s to the first decade of the 21st century, in which the length of the network has stabilized.

The natural gas transmission grids are complex infrastructures connecting the system entry points (local production facilities (wells), LNG terminals within territory or pipeline connections to outer producing countries) with the exit points (regional networks, storage infrastructures and key consumer areas) that are typically located away from the entry points.

The natural gas transmission system consists of physical units such as pipelines, compressors, processing or extraction terminals, stations, and valves. Three important properties of natural gas must be considered for the design of the network: pressure, flow, and quality. The different elements of gas transmission networks are closely linked, and changes in gas flow, pressure, or composition (quality) in a part of the network can also affect the flow or capabilities of the downstream network. In addition, production and demand will also vary.

The classic gas transport facility between two points is the pipeline, either buried in the ground, mounted on the ground surface or laid the bottom of the seas. The dispatching capacity of the pipeline depends on the pressure difference between the pipe ends and the tube diameter (larger diameter involves higher transport capacity). The transmission pipelines are operated at high-pressure (up to 85 barg onshore, and up to 225 barg for some offshore applications), large-diameter (up to 60 in.) pipes running long distances. They are designed to handle large volumes of gas between system entry and exit points, and they are built with high-elasticity carbon steels.

Natural gas flowing through transmission lines is subject to pressure losses due to friction. Circulating gas through the pipelines requires an increase of the gas pressure at certain points of the grid. The pressure increase is regulated by compression stations, which ensure the correct circulation of gas flows and the maintenance of system capacity.

In metering stations and in pressure reduction stations, the flow of the gas circulating through the installation is measured and its pressure is adjusted to suit the conditions of the downstream networks.

At certain points in the gas network, such as system entry points and major inter-network connection points, gas quality control equipment is available to ensure that the gas meets the parameters set out in the system. As natural gas is a colourless and odorless medium, odorization equipment is also applied to add an odorizing compound to natural gas making leaks easily recognizable and mitigating the risks of toxicity and explosion.

Gas flows are controlled from facilities of the gas network operators, that receive pressure measurements, temperatures, flow rates and other physical and chemical gas parameters (heating value, composition, etc.), called control centers.

3.1.2 Production of hydrogen

Hydrogen is used as base material in many chemical processes and the EU's estimated annual demand accounts to about 325 TWh [2], from which a total of 96 % originates from fossil sources, mainly natural gas [3]. In the next decades until 2050 an increase to about 2250 TWh/a is expected because of the increasing need of carbon-neutral energy supply throughout the European Union [2]. Production processes of hydrogen can be classified into thermo-chemical/thermal processes, electrochemical and biological processes [4].

The most relevant thermo-chemical process in the hydrogen production is steam reforming of hydrocarbons. Hydrocarbons like methane, fed together with high temperature steam at pressures between 15 and 25 bar over a catalytic bed results in hydrogen and CO_2 (this is the complete or ideal conversion reaction).

$$CH_4 + 2\,H_2O \rightarrow CO_2 + 4\,H_2$$

Biogas, which consists of methane (renewable) as well, especially after purification to natural gas grade quality, can also be used as fuel for the steam methane reforming.

Other processes are the partial oxidation of natural gas using oxygen, high temperatures and pressures as well as pyrolysis, also referred to as thermal cracking, where hydrocarbons are cracked at high temperatures using catalysts in the absence of oxygen to create hydrogen [4]. There are new developments trying to use plastic waste and create hydrogen with the by-product of carbon dioxide or, in a very recent process, instead of carbon dioxide, carbon nanotubes (waste-to-hydrogen).

A different approach is the electrochemical separation of water, using (renewable) electricity to decompose water into its components - oxygen and hydrogen. Depending on the temperature of operation low temperature water electrolysis (LTWE) or high temperature steam electrolysis (HTSE) technologies are distinguished. Additionally, depending on the used electrolyte there are three main LTWE technologies: alkaline electrolysers (AEL), proton exchange membrane electrolyser (PEMEL) and those based on Anion Exchange Membranes (AEMEL). Regarding HTSE, electrolysers including solid oxide anionic conducting electrolyte (SOE) or proton conducting electrolyte (PCE) are considered.

3.1.3 Hydrogen technologies and functions in the energy system

Hydrogen can be utilised to **decarbonise** the industry sector, such as the steel or cement production, but also other industries, with high demand of heat during the production process. Most of the required heat is currently produced using natural gas and thus generating CO_2-emissions, which can be avoided using renewable hydrogen. In the power sector hydrogen can be used to generate electrical power in the same manner as natural gas is used already today, but without the CO_2-emissions, when renewable hydrogen is used. Hydrogen can also be used in the transport sector, either for passenger cars or for heavy-duty vehicles in a combustion engine or using fuel-cell-based powertrains. In the heat market hydrogen can replace the current natural gas fired heating systems using burners that are suitable for hydrogen (or blends of renewable methane and hydrogen) or by fuel-cell heating systems as well. In addition, hydrogen fuelled combined heat and power systems (CHP) at different size are suitable for the decentralised energy transmission – electrical power and short distance district heating. In this way, hydrogen can act as a stabilization medium for the electrical distribution networks, especially, when renewable electricity combined with electromobility is concerned.

In terms of the **transport** of energy hydrogen can be transported and distributed from centralised or decentralised production to its point of use by using pipelines, by road transport, by rail transport or via transportation by ship.

The energy carrier hydrogen and more general **storing** energy in the form of renewable gas bears several fruitful implications. Large amounts of energy can be converted and long-term stored, thus enabling the seasonal shift by storing energy from intermittent renewable energy production, such as solar and wind, in times of surplus production. In times when the production of intermittent renewable energy does not meet the demand, the gap can be filled by the stored gas. By utilising the existing transmission natural gas pipelines where possible and creating an European hydrogen backbone vast amounts of energy can be stored in form of hydrogen.

3.1.4 Hydrogen and its potential implications on the gas grid

The main component of the high-pressure transmission gas grid currently is methane (CH_4). The materials that are used for pipelines or equipment of the gas grid today are fine-tuned for the use in combination with methane. By introducing hydrogen (H_2) into the gas grid there is less experience on the interaction between the pipeline material and the transport product. Quite well known is, that hydrogen atoms can interact with the steel material of pipelines or equipment, which can have a negative effect on the mechanical behaviour of the steel. Generally, this phenomenon is addressed as hydrogen embrittlement and depends on the pipeline material's steel grade, stress level, microstructure, mechanical loading conditions, presence of crack-like defects, the temperature, on the shape or pattern of the hydrogen (molecular, ion) as well as on the presence of an oxide layer [5].

3.2 The infrastructure equipment and hydrogen

The HIGGS project considers a report on the equipment and infrastructure of the European high-pressure transmission gas network. Since the available data in the literature is not complete enough to serve as a sufficient database and achieve a full overview, a survey on the equipment and infrastructure of the European gas transmission network was established and described in the not public project deliverable report D2.1 “First update report on equipment and infrastructure”.

This survey queries information about the different pipeline materials (tubes, welding), lengths and diameters. Furthermore, the age and planned renewal time of the pipelines and the frequency of the pressure drop fluctuations, which occur in the transmission gas grid, are of interest, too. Other infrastructure elements, like LNG terminals, underground storages and cross-border interconnections are essential parts of the survey as well. The HIGGS transmission gas network survey has been sent to several stakeholders - the transmission system operators (TSO) and European natural gas associations, such as Sedigas in Spain and MARCOGAZ. After the reception and analysis of the new and updated data on the high-pressure transmission grid the results are discussed in the following subsections.

3.2.1 Creation and content of the infrastructure survey

Most of the facilities in the transmission grid are quantified in sectoral reports. However, they do not include a detailed classification of each type of facility, so the information provided is limited. A new survey has been created to collect and to complete the information already available in MARCOGAZ, with other relevant data, by consulting the European TSOs.

Table 1 and Table 2 show the elements and parameters considered, and the evaluation of criteria established. Once the main transmission facilities are identified, it is necessary to establish criteria to determine which information is considered relevant for the project. Therefore, it is necessary to include and focus on elements sensitive to the addition of hydrogen, and the significant cost of modification or renewal.

The following criteria are set:

> **Relevance criterion**. The elements of the gas transmission system and its main characteristics are valued from 0 to 5, where 0 is not relevant, and 5 is very relevant, depending on its usefulness in the later stages of the HIGGS project (for estimation of the renewal cost, for defining the test loop, etc.)

Availability criterion. Depending on what availability is expected for transmission facilities information, elements of the transmission system and its main features are valued from 0 to 5, where 0 represents an unlikely availability and 5 a very likely availability. The evaluation is made based on the information collected annually by SEDIGAS (Spanish Gas Association) and the information available from the Spanish Gas System Technical Manager (ENAGAS).

Table 1: Pipeline parameters table

Parameter	Relevance criterion	Availability criterion	Utility
Length (km)	4	5	Renewal costs estimation
Diameter (inches)	4	5	Test loop definition and renewal costs estimation
Pipe material / Steel quality	5	3	Test loop and test tubes definition. Renewal costs estimation
Welding material	5	2	Test loop and test tubes definition
Pipe coating / painting materials	3	3	Test loop and test tubes definition
Operating pressure (bar)	3	2	Test loop definition
Pressure drop allowed	3	3	Test loop definition

Table 2: Facilities, installations and equipment table

Facilities, installations and equipment	Relevance criterion	Availability criterion	Utility
Transmission valves positions	3	4	Renewal costs estimation
Transmission compressor stations	3	5	Renewal costs estimation
Transmission network pressure reduction stations	3	5	Renewal costs estimation
City Gate pressure reduction stations	3	5	Renewal costs estimation
Odorization systems	4	4	Test loop definition and renewal costs estimation
Odorant type	5	4	Test definition
Gas quality control systems	4	3	Test loop definition
Flow control systems	4	4	Test loop definition

Data of LNG terminals, Underground storages and Cross border interconnection are collected in order to update and complete the natural gas reception, transmission and storage information available in MARCOGAZ Statistics.

For all these elements data of installation year and expected year of renewal are collected, being important information to estimate the impact on the renewal of gas networks.

Since the developed survey has been sent to several TSOs in different countries (see section 3.2.2), a huge amount of gross data was, and still is, expected to be received. To transform all this input in useful information for the project, the suitable data treatment is necessary. This section explains how the data received from the survey was planned (and was conducted) to be processed, transforming it into useful information to achieve an extrapolation to the European situation. The processed data is shown in several tables. Table 3 refers to the validation of the data received by stakeholders. Table 4 to Table 8 refer to pipelines; and Table 9 and Table 10, to auxiliary components. They may be divided by countries depending on the table size for a more understandable reading. The quantity of elements related to the total length of pipelines is often used to achieve a more accurate comparison.

Table 3 contains a list of the operators that have sent back an answer to the survey, classified by the countries they provide information for. It is also decided whether the number of answers received constitute sufficient quality to achieve reliable information for each country.

Table 4 shows the total length of transport pipelines for each European country. The kilometers of pipelines are classified according to i) the kind of steel, ii) the pipeline diameter, iii) the maximal operating pressure, iv) the welding materials and v) the outer and inner coatings. The percentage of each case, with regard to the total length, is also calculated. The data is extrapolated to the whole of Europe by adding the kilometer amounts for each country.

Table 5 is based on the steel grades and how they are used in the different counties. It will help to identify the most used diameters and welding materials for each of them. The extrapolation to Europe is made as for Table 4.

Table 6 gathers the operation conditions, in terms of maximal pressure drop, minimum pressure and frequency of pressure variations, as function of the maximum operating pressure for each country. These results will help to define allowance intervals in the European transmission gas grid.

Table 7 deals with the renewal times of the installed pipelines. The installed length for several installation periods is shown for each country. This allows the calculation of the percentage of the total length, they represent, considering total length values of Table 4. The expected renewal time is also provided. The data from this screening allows to build a general overview for Europe in Table 8, where the percentage of grid length according to its installation time that is going to be replaced before a certain year is provided.

Table 9 contains the number, installed power, gas energy content to handle and hydrogen tolerance of transmission facilities, odorization systems and gas quality control systems of each country that takes part in the survey. Considering the pipeline length for the different countries (see Table 4), the amount of each element per kilometer of pipeline can be calculated. The addition of all of them or the average calculation, depending on the variable studied, provides the European general overview.

Table 10 deals with the renewal issues of auxiliary elements, considering the year of installation, the estimated time for their renewal and the cost it would imply. This will help to calculate average values for the whole European grid.

Table 3. List of TSOs ordered by country

	Country									
	DE	UK	IT	FR	NL	ES	PL	CR	LV	Other
Operators										
Number of operators										
Representative degree[1]										

[1] Is the number of operators enough to achieve relevant conclusions for this country?
A- Excellent
B- Sufficient
C- Not enough

Table 4. Length of pipeline depending on steel quality, diameter, maximum operating pressure, welding materials and coating

Category		Country									
		DE		ES		UK		...		Europe	
		Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Total country length											
Steel (API 5L)	Gr B										
	X42										
	X60										
	X70										
	X80										
	Other										
Diameter	2"										
	3"										
	4"										
	6"										
	8"										
	10"										
	12"										
	Other										
Maximun operating pressure	<59 bar										
	<80 bar										
	Other										
Welding material	E 6010										
	E 7016										
	E7018										
	E XX15-X										
	E XX16-X										
	E XX18-X										
	ER 70S-X										
	ER 70S-1B										
	ER XXS-X										
	E XXC-X										
	E X1T-XG-J										
	Other										
Outer coating	Type 1										
	Other										
Inner coating/painting	Type 1										
	Other										

Table 5. Length of pipeline for each steel quality according to its diameter and welding materials

API 5L Gr B		Country									
		DE		ES		UK		...		Europe	
		Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Total country length											
Diameter	2"										
	3"										
	Other										
Welding material	E 6010										
	Other										
API 5L Gr X42		Country									
		DE		ES		UK		...		Europe	
		Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Total country length											
Diameter	2"										
	3"										
	Other										
Welding material	E 6010										
	Other										
API 5L Gr X60		Country									
		DE		ES		UK		...		Europe	
		Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Total country length											
Diameter	2"										
	3"										
	Other										
Welding material	E 6010										
	Other										
...		Country									
		DE		ES		UK		...		Europe	
		Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Total country length											
Diameter	2"										
	3"										
	Other										
Welding material	E 6010										
	Other										

Table 6. Operating parameters for the gas grid according to the maximum operating pressure

Country	Parameters	Maximum operating pressure		
		≤ 59 bar	≤ 80 bar	Other
DE	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
UK	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
IT	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
FR	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
NL	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
ES	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
...	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			
Europe	Max. pressure drop (%)			
	Minimum pressure (bar)			
	Frequency of pressure variation			

Table 7. Length of pipeline depending on the date of installation and the expected renewal time

Installation period (year)	Country											
	DE			ES			UK			...		
	Length (km)	Length (%)	Expected year of renewal	Length (km)	Length (%)	Expected year of renewal	Length (km)	Length (%)	Expected year of renewal	Length (km)	Length (%)	Expected year of renewal
2016 to 2020												
2011 to 2015												
2006 to 2010												
2001 to 2005												
1996 to 2000												
1991 to 1995												
1986 to 1990												
1981 to 1985												
1976 to 1980												
before 1975												
Total length installed												

Table 8. Europe overview of the expected pipeline renewal time

Installation period (year)	Europe overview											
	Before 2025		Before 2030		Before 2035		Before 2040		Before 2045		Before 2050	
	km pipe renewed	Length (%)	km pipe renewed	Length (%)	km pipe renewed	Length (%)	km pipe renewed	Length (%)	km pipe renewed	Length (%)	km pipe renewed	Length (%)
2016 to 2020												
2011 to 2015												
2006 to 2010												
2001 to 2005												
1996 to 2000												
1991 to 1995												
1986 to 1990												
1981 to 1985												
1976 to 1980												
before 1975												

Table 9. Quantification of transmission facilities

Category			Country N						
			Type	Number	Number/km pipeline length	Installed power	Power/km pipeline length	Energy content to handle in MW	H2 tolerance in Vol%
Transmission facilities	LNG terminals								
	Transmission valves positions								
	Transmission compressor stations								
	Transmission network pressure reduction stations								
	Transmission network metering stations								
	City Gate (transmission/distribution) pressure reduction stations								
	Underground storage	Cavern							
		Porous							
		Other							
		TOTAL							
	Cross border interconnection points								
	Other (to be defined)								
	TOTAL								
Odorization systems	System	Laminar System							
		Drip system							
		Injection pump system							
		Other							
		TOTAL							
	Odorant type	THT							
		TMB							
		DMS							
		MES							
		IPM							
		TOTAL							
Gas quality control systems	Quality control Systems	Process Gas Cromatographs							
		Mass Spectrometers							
	Flow Control Systems	Gas Pressure Control							
		Gas Meter							
	TOATL								

Table 10. Estimated renewal time for the transmission facilities

Category			Country								
			DE			...			Europe		
			average installation year	estimated renewal time (years)	estimated renewal cost	average installation year	estimated renewal time (years)	estimated renewal cost	average installation year	estimated renewal time (years)	estimated renewal cost
Transmission facilities	LNG terminals										
	Transmission valves positions										
	Transmission compressor stations										
	Transmission network pressure reduction stations										
	Transmission network metering stations										
	City Gate (transmission/distribution) pressure reduction stations										
	Underground storage	Cavern									
		Porous									
		Other									
		TOTAL									
	Cross border interconnection points										
	Other (to be defined)										
	TOTAL										
Odorization systems	System	Laminar System									
		Drip system									
		Injection pump system									
		Other									
		TOTAL									
	Odorant type	THT									
		TMB									
		DMS									
		MES									
		IPM									
		TOTAL									
Gas quality control systems	Quality control Systems	Process Gas Cromatographs									
		Mass Spectrometers									
	Flow Control Systems	Gas Pressure Control									
		Gas Meter									
	TOATL										

The data received is processed country by country following the methodology explained above. However, this data is kept confidential and for internal use only. The final results shown in this report are gathered in clusters to protect the confidentiality of the TSOs that have contributed, as it will be explained in section 3.2.2.

3.2.2 Stakeholder and gathered surveys

After creating the survey and determining the data that is needed and therefore desired to be collected, the next step is to identify the stakeholders, who can give this information. This has been done by using the existing networks of the partners. By contacting the national gas operators' associations as well as European gas associations a list of suitable stakeholders has been identified.

The stakeholders have been allocated to one of the three HIGGS partners involved (DVGW, FHa, REDEXIS) to ensure an efficient communication. After getting first feedback from the contacted stakeholders, the deadline has been extended, since the initial timeframe has turned out to be not viable. 13 out of the 21 entities consulted have given some feedback to the survey. The other 8 have not answered yet.

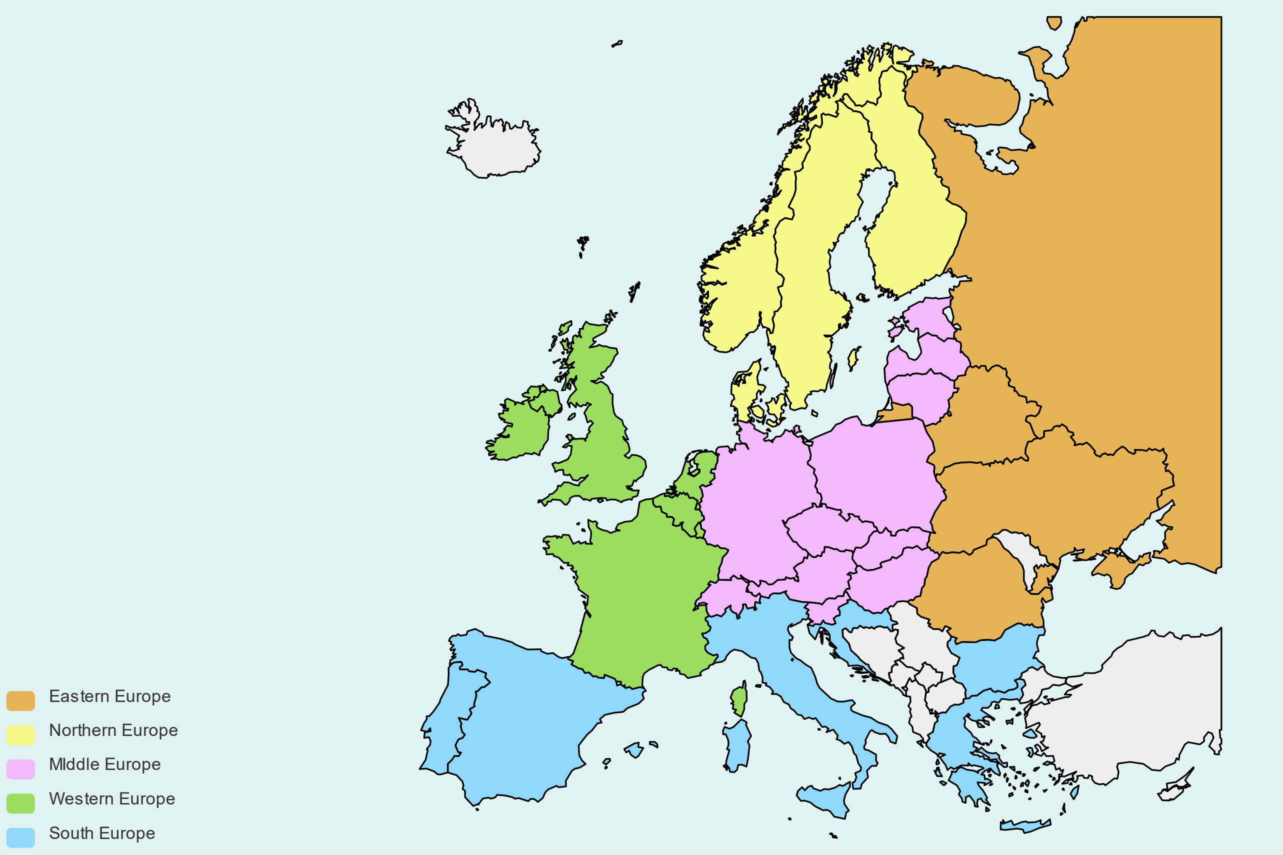

Figure 1: European map showing the clustering for the evaluation of the survey

The country specific data gathered with the infrastructure survey has been aggregated into five clusters. Figure 1 and Table 11 show the allocation for each of the European member countries and the United Kingdom. The data had to be clustered in a way, that conclusions about the single countries cannot be drawn, since this could affect the companies that have provided the data in a negative way. By clustering the provided datasets, the concerns of the data providers can be dispelled, without affecting the benefits for the analysis of the European gas transport network in this report. In addition to that the clusters have been defined by the authors for reasons of proper analysis of the survey and do not reflect any other motives.

Table 11: Clustering for the evaluation of the infrastructure survey

South Europe	Western Europe	Middle Europe	Northern Europe	Eastern Europe
Spain	France	Germany	Norway	Russia
Portugal	UK	Poland	Denmark	Belarus
Italy	Ireland	Czech Rep	Finland	Ukraine
Croatia	Luxembourg	Austria	Sweden	Romania
Serbia	Belgium	Switzerland		
Greece	The Nether-lands	Lithuania		
Bulgaria		Latvia		
		Slovakia		
		Estonia		
		Slovenia		
		Hungary		

3.2.3 Results of the inventory of the European transmission gas grid

As aforementioned, the survey has two different parts. Part one is focused on information about pipelines and part two on facilities, installation and equipment. Both are described in depth in the following sections. Noteworthy, the discussion of results has been done using the data received. The representativity of the conclusions stated may not be completely accurate for those clusters in which size of the grid is bigger than the data achieved with the survey.

3.2.3.1 Pipelines

Within the work developed in WP2, detailed information about around 65,000 km of the European transmission gas grid has been collected (see Figure 2). As a reference, this length means almost half of the length reported by EGIG in their last report about incidents in the European transmission gas grid in 2019 [6] and almost a third of the length reported by MARCOGAZ in their Technical Statistics for the countries considered in WP2 [1]. The main part corresponds to Middle Europe with more than 45,000 km, followed by South Europe (near 14000 km). Western Europe and Northern Europe contribute to these numbers with over 4,800 and 600 km, respectively. Unfortunately, no information about Eastern Europe could be gathered during this period. The information collected about the pipelines considers their size, material, coating used, installation period and operating pressure. All these properties will be discussed in the following subsections.

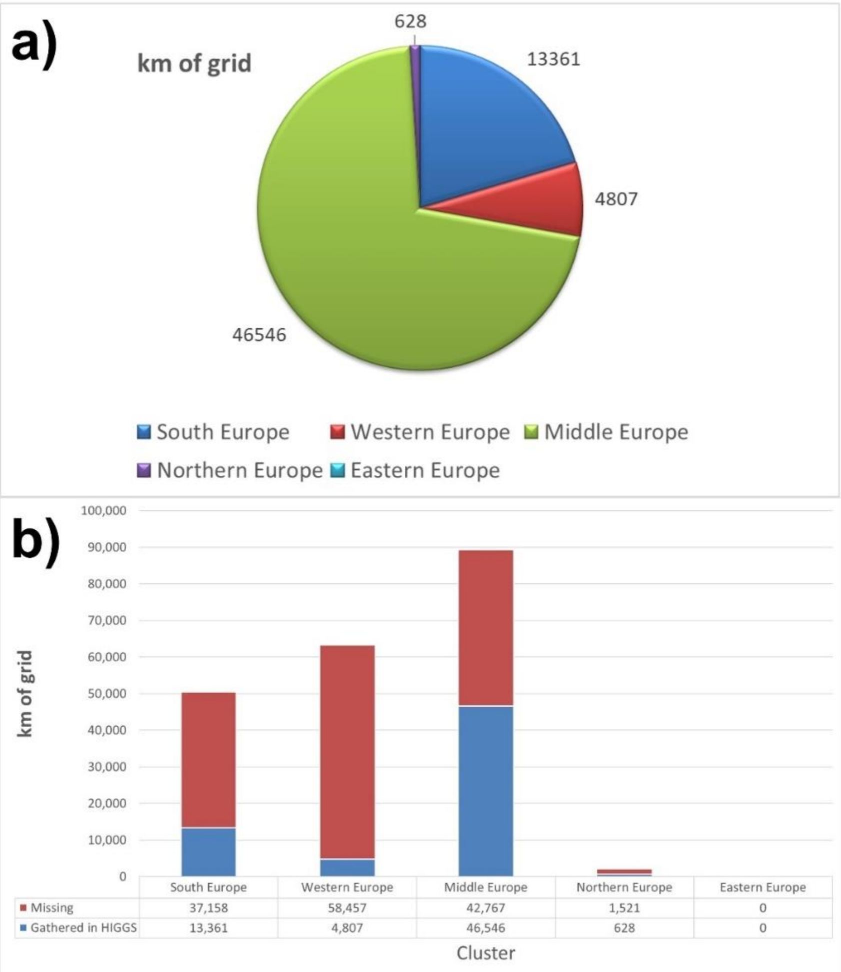

Figure 2. Total length of transmission pipelines collected in WP2 (a) and its comparison with the data reported by MARCOGAZ in 2013 (b) [1]

Within the work developed in WP2, detailed information about around 65,342 km of the European transmission gas grid has been collected (see Figure 2). As a reference, this length means almost half of the length reported by EGIG in their last report about incidents in the European transmission gas grid in 2019 [6] and almost a third of the length reported by MARCOGAZ in their Technical Statistics for the countries considered in WP2. [1] The main part corresponds to Middle Europe with more than 45,000 km, followed by South Europe (near 14,000 km). Western Europe and Northern Europe contribute to these numbers with over 4,800 and 600 km, respectively. From Eastern Europe no data could be gathered during this period (see above). The information collected about these pipelines considers their size, material, coating used, installation period and operating pressure. All these properties will be discussed in the following subsections. The part of the grid missing is also depicted in Figure 2b, by direct comparison between the data collected and those reported by MARCOGAZ in its technical statistics of 2013. [1] This comparison may not be completely accurate because this report is 8 years old, but it is the only reference in the literature that can be used as baseline.

Steel material

The information collected from the different institutions that contributed to the survey was converted into the American nomenclature (API 5L), when necessary, to achieve comparable results. Figure 3 depicts the steel quality used in the different European clusters. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 22). According to this information, a wide range of steel qualities from API 5L Gr A to Gr X80 are being used in Europe.

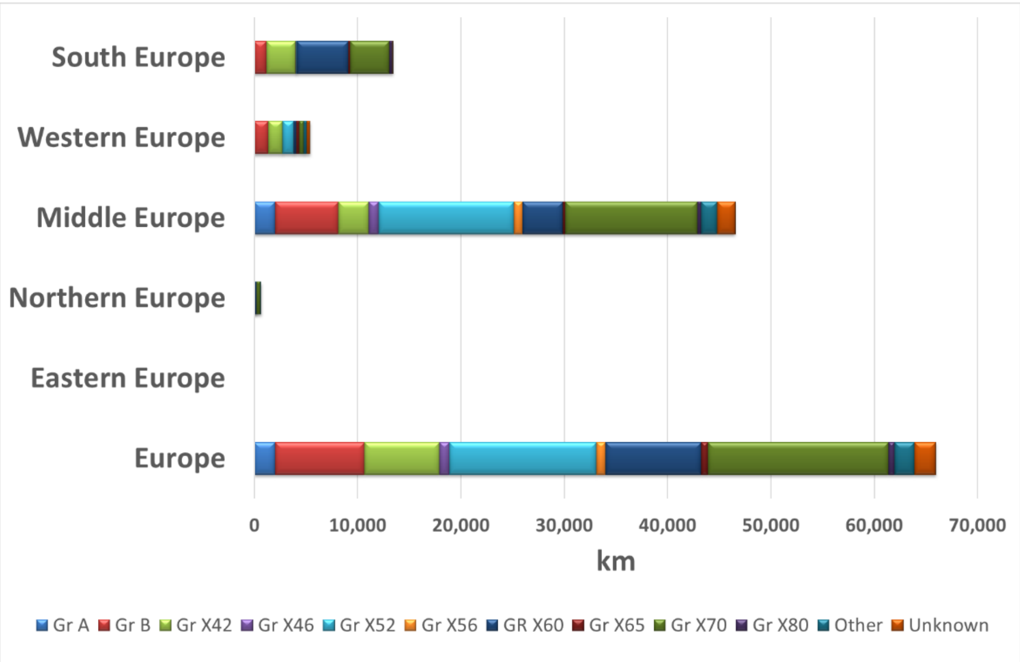

Figure 3. Distribution of the steel quality for the different clusters studied.

From the diagram, as depicted in Figure 3, it is obvious that some of the steel materials are more relevant, i.e. API 5L Gr B (13,5 % of the grid collected), X42 (11,1 %), X52 (21,8 %), X60 (14,2 %) and X70 (27,2 %), although with no clear predominance. Focusing on the different clusters, different tendencies in each region can be observed. For example, while API 5L Gr B and Gr X42 are the most common steels in Western Europe (28 and 29 % of the length collected for this cluster, respectively), Gr X60 becomes more relevant in Northern Europe and South Europe (27 and 37 % of the cluster grid, respectively) and Gr X 52 and X70 is the most predominant steel in Middle Europe, being each 28 % of the cluster's grid. On the whole, the results of D 2.3 are coherent with those given by EGIG in their report about incidents in the European transmission gas grid [6] (see Table 12), when comparing them as percentage of grid with a certain steel quality. This implies that the scope of HIGGS' survey had the right approach.

Table 12. Comparison between data collected in WP2 for D 2.3 and those reported by EGIG in their last incident report. [6]

Steel quality	**Percentage of length in EGIG report** [6]	**Percentage of length in D 2.3**
API 5L Gr A	3.0 %	3.1 %
API 5L Gr B	16.3 %	13.5 %
API 5L Gr X42	7.7 %	11.3 %
API 5L Gr X46	3.6 %	1.5 %
API 5L Gr X52	22.2 %	21.9 %
API 5L Gr X56	1.2 %	1.3 %
API 5L Gr X60	19.2 %	14.2 %
API 5L Gr X65	7.3 %	1.1 %
API 5L Gr X70	14.4 %	27.2 %
API 5L Gr X80	0.0 %	1.0 %
Other	2.3 %	4.1 %

Diameter

The length of the pipelines collected where also classified according to their outer diameter (OD) in inches, which is the typical measuring unit for pipelines, not only in the U.S., but in Europe as well. The results are displayed in Figure 4 as total length and percentage of length for each South Europe and the whole of Europe. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 22). Considering the whole European Union, the most representative diameter values are below 40 in. 37 % of the pipes in the European transmission grid have diameters between 11 and 20 in OD, while around 20 % of them are below 10 in or between 21 and 30 in. Finally, 13,5 % of the pipes collected are between 31 and 40 in.

Looking into each specific cluster, it can be seen how South Europe and Middle Europe follow a similar tendency than the whole of Europe. However, in Western Europe almost 60 % of the pipes have diameters below 10 in and in Northern Europe, the great majority of pipes (63 %) have an outer diameter of 11-20 in.

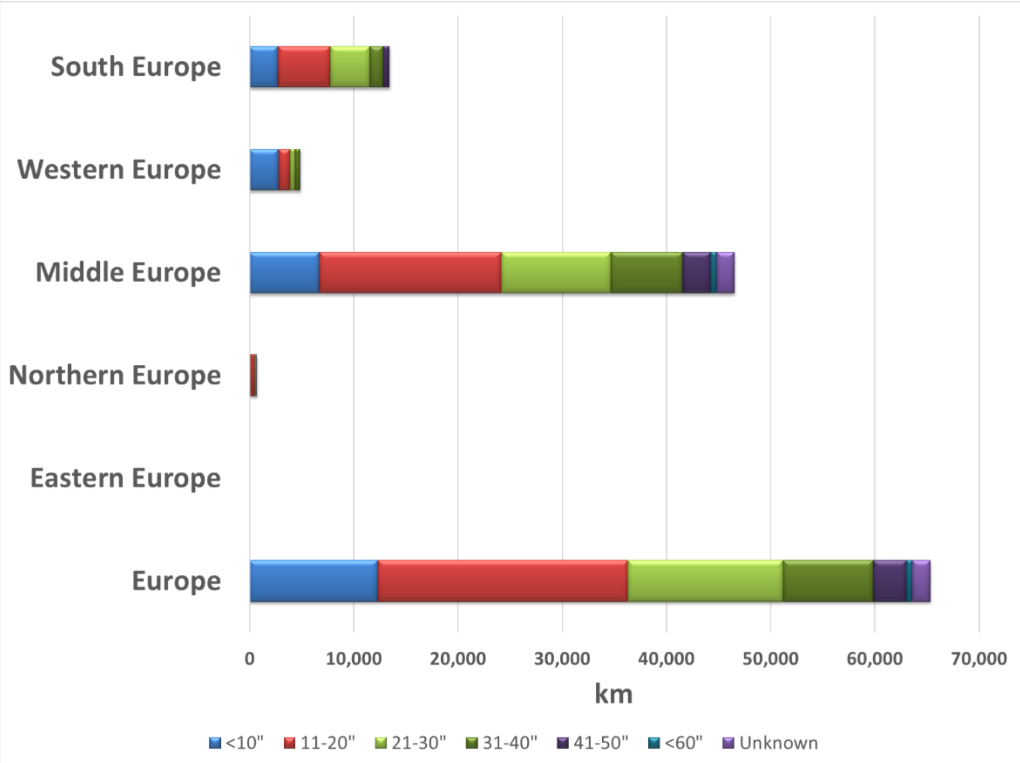

Figure 4. Diameter of the European transmission grid pipelines

Maximum Operating Pressure - MOP

The pipelines collected in the different countries have also been classified in accordance to their maximum operating pressure (MOP) in service. The results for each South Europe and the whole of Europe can be seen in Figure 5. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 22). When considering the European Unionas a whole, it can be seen how there are two different pressures dominating, since MOP <59 bar and <80 bar share one third of the length of the grid collected. The next important MOP would be below 70 bar, with 17 % of the grid length. The "equilibrium" between <59 bar and <80 bar is imposed by Middle Europe, which leads the tendency due to the major contribution to the total grid length in Europe. However, other clusters do not show this symmetry. In the case of South Europe, MOP <80 bar is predominant with 80 % of the grid length, followed by <59 bar with 16 %. Something similar occurs with Western Europe, but in this case the MOPs are shifted to <66 bar and <85 bar. In Northern Europe, MOP<80 bar is also dominant.

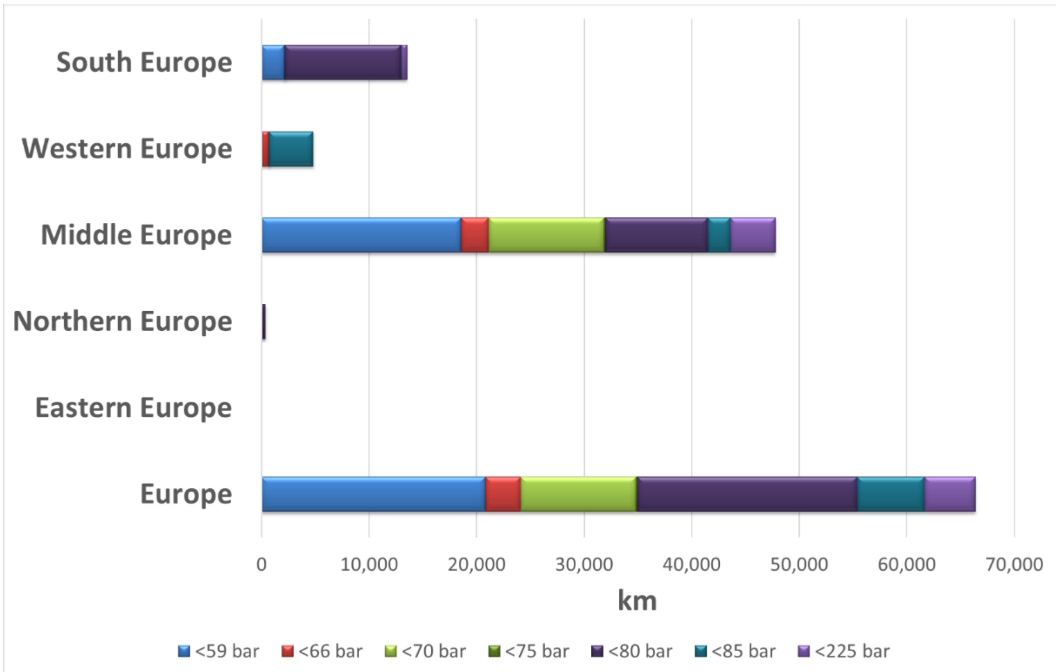

Figure 5. MOP of the transmission European grid pipelines

Welding material

For the case of welding materials, it has not been possible to prepare a quantitative review because of the lack of accurate numerical values of the length of pipes welded with a certain PQR (i.e. Procedure Qualification Record). Nevertheless, the information gathered allows to show in a qualitative way the most common materials used in each cluster when available (see Table 13).

Table 13. Welding materials used in each cluster. When indicated with an "X" this material is used

Welding material	South Europe	Western Europe	Middle Europe	Northern Europe	Eastern Europe
AWS A 5.1-E 6010	X	X	X		
AWS A 5.1-E 7010			X		
AWS A 5.1-E 7016		X	X		
AWS A 5.1-E7018	X	X	X		
AWS A 5.5-E XX10-X	X				
AWS A 5.5-E XX15-X	X				
AWS A 5.5-E XX16-X		X			
AWS A 5.5-E XX18-X	X	X	X		
AWS A 5.5-E XX18M-X	X	X	X		
AWS A 5.17-EH12-X		X			
AWS A 5.18-ER 70S-X		X	X		
AWS A 5.18-ER 70S-1B		X			
AWS A 5.28-ER XXS-X	X		X		
AWS A 5.28-E XXC-X		X			
AWS A 5.28-ER XXS-X			X		
AWS A 5.20-E X1T-XG-J		X			
AWS A 5.20-E X1T-XM-J	X				
AWS A 5.29-EXT1-XM-X		X			
AWS A 5.36-EXT1-MX-Ni1J		X			

Outer coating

The coating procedures were also collected with the survey on the inventory of the transmission grid. The most relevant coating materials found are shown in Figure 6 and the numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 22).

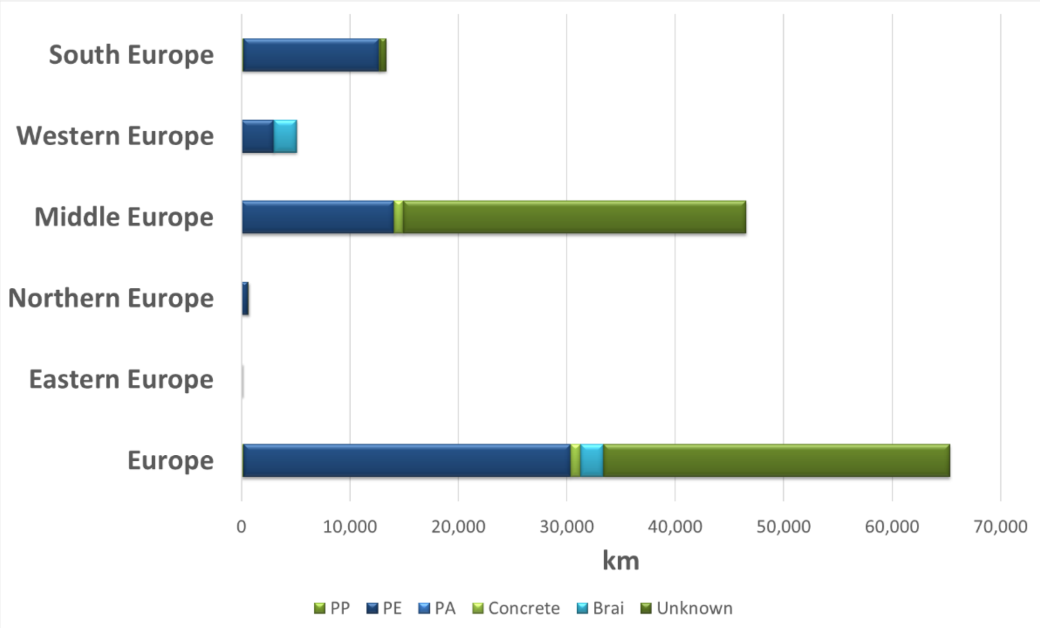

Figure 6. Outer coating materials used in the European transmission grid pipelines.

Basically, there are six materials used for external coating of the pipelines: polymers (such as polyethylene, polyamide and polypropylene), concrete or brai. The use of polyethylene is clearly dominant in each of the clusters, and therefore, in Europe as a whole. Besides, in Western Europe there is an important part of the pipes that are coated using Brai (44 % of the pipe length in this cluster). Unfortunately, the coating material of 68 % of the pipes in Middle Europe was not able to be acquired, meaning that there is no information about the material of the external coating of almost half the pipes in Europe.

Inner coating

Similar to the outer coating, the materials used for the inner coating of pipelines in Europe was also collected. The results are depicted in Figure 7. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 22).

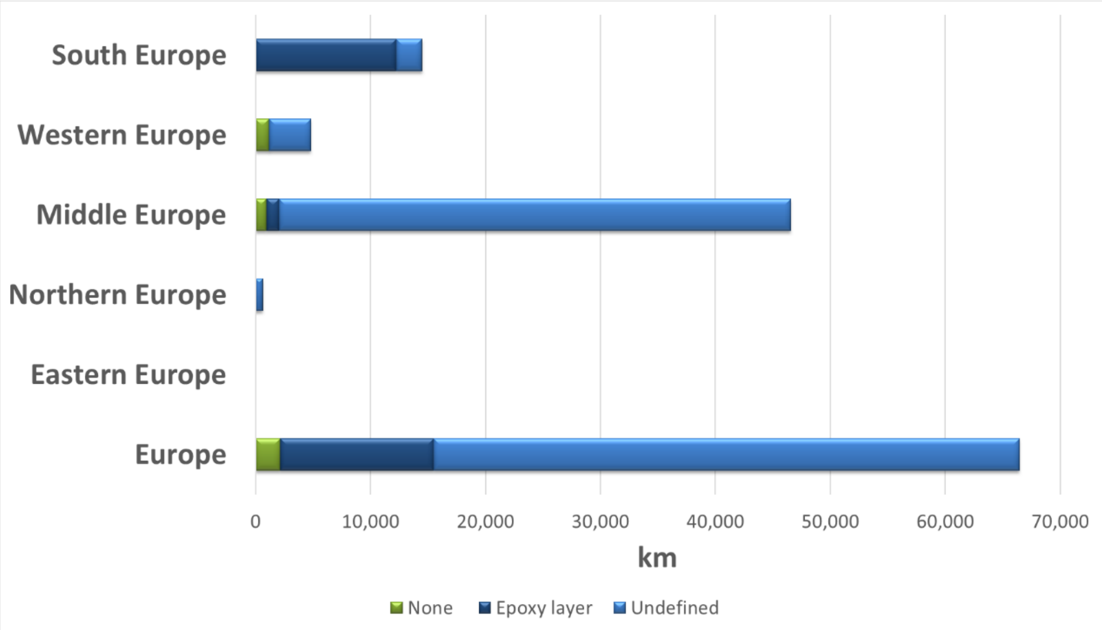

Figure 7. Inner coating materials used in the European transmission grid pipelines.

There are two option available:

- using epoxy resin as coating material
- no coating at all.

20 % of the pipes in Europe are coated internally with Epoxy, while 3 % remain uncoated, according to the data collected. There is, however, 78 % of the length in Europe of which no data could be collected. The predominance of the use of epoxy is also clear in South Europe, in Middle Europe is more equilibrated and in Western Europe, the lack of coating seems more popular.

Installation period

The last goal of the inventory of the gas grid regarding pipelines was tracking the installation period of the different grids in each cluster.

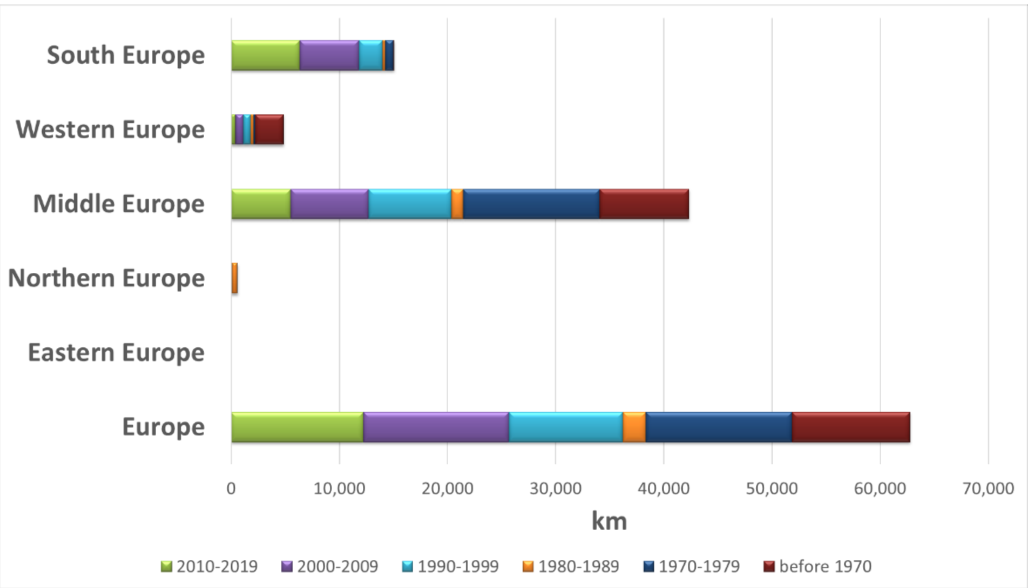

Figure 8. Installation period of pipelines in the European transmission gas grid

The results gathered are shown in Figure 8 as well as in in Annex I: Numerical data of the inventory of the European grid (Table 23). Looking onto Europe as a whole the installation periods are quite distributed over the last decades. It can be considered that around 20 % of the grid length has been installed every decade, except for the 1980-1989 period, where only 3 % of the pipes were installed. While Middle Europe follows basically this tendency, the behaviour is different in the other clusters. In South Europe, the grid is relatively new, with 78 % of the pipes installed after 2009. In Western Europe, however, half of the pipes were installed before 1970, consequently the grid is much older. The age of Northern Europe with 80 % of its grid installed 1980-1989 falls in between.

The expected year of renewal of the pipelines was also asked in the survey. However, the amount of information gathered was insufficient to draw proper conclusions. It can only be stated that i) 53 % of grid installed in Western Europe before 1975 will be replaced by 2030, ii) 76 % of the pipes in Northern Europe will be replaced between 2060 and 2070 and 8 % by 2080 and iii) 5 % of the pipes in Middle Europe will be replaced by 2080.

3.2.3.2 Facilities

The information gathered about the facilities available in the European transmission grid is divided into six categories: transmission facilities, LNG terminals, underground storages, cross-border interconnection points, odorization systems and gas control systems. The results for each of them will be developed in the following.

Transmission facilities

As shown in Figure 9, over 6,300 facilities have been collected for the European transmission gas grid, of which 3,492 correspond to valve positions (also known as valve placements or valve nodes), 155 to compressor stations, 166 to Pressure Reduction Stations (PRS), 182 to Metering Stations (MS) and 2,306 City Gates (transmission/distribution pressure reduction stations). While PRS and MS can be found with a frequency of around 2,5 items per 1,000 km of grid, that of City Gates is 12 times higher, being the most common facility in the grid. Regarding compressor stations, 2,4 stations can be found every 1,000 km of grid. Valve positions are the second most common facilities, with over 50 items per 1,000 km of grid. This frequency is calculated dividing the number of items collected by the kilometers of grid according to the data depicted in Figure 2.

Having a close look into each cluster, the proportion of compressor stations is higher in Northern Europe with almost 5 stations per 1,000 km of grid. Middle Europe has the same proportion as the whole continent and South Europe and Western Europe show 1 unit less per 1,000 km of grid. Only South Europe, Western Europe and Middle Europe contribute to valve positions data. The frequency found in Western Europe doubles the European, with over 100 positions per 1,000 km of grid. In the case of South Europe, the frequency is also superior, but drops to over 70 positions per 1,000 km of grid. And it is slightly inferior in Middle Europe (43.7 positions/1000 km grid). The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 24).

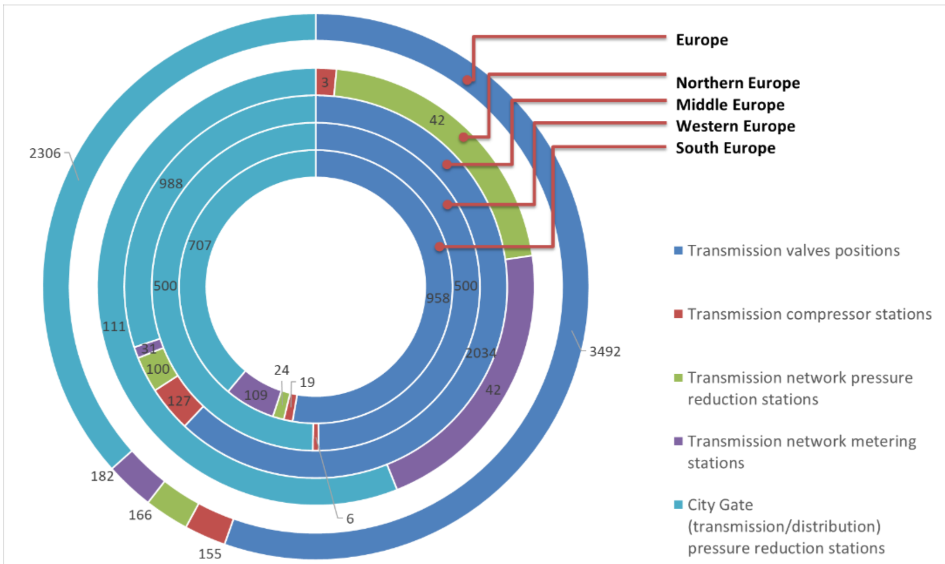

Figure 9. Transmission facilities in the European gas grid

The proportion of metering stations and regulation stations is also very dependent on the cluster. City gates are the more common facilities with frequencies between 20 and 180 positions/1000 grid. The heterogeneity in the data for the different clusters may be due to a poor response to some aspects of the survey.

No relevant general conclusions about the hydrogen content these devices can handle could be achieved from the answers to the survey.

LNG terminals

Table 24 in Annex I: Numerical data of the inventory of the European grid contains information about LNG terminals that are operational in Europe. This data was processed from the information available in the last Gas Infrastructure Europe (GIE) report released in 2020. [7] This information can be gathered into clusters, the same way it has been done in previous sections (see Table 14).

Table 14. LNG terminals in the different European clusters

Cluster	Number LNG terminals	NOMINAL ANNUAL CAPACITY (billion m3(N)/year)	LNG STORAGE CAPACITY (m3 LNG)	Average Start-up year
South Europe	12	98.2	4,719,000	1996
Western Europe	10	113.6	4,576,000	2001
Middle Europe	2	9.0	490,000	2015
Northern Europe	6	1.2	2,185,900	2013
Eastern Europe	1	3.7	174,000	2019
Europe	31	225.7	12,144,900	2003

It is obvious that South Europe and Western Europe are the zones in Europe where the entrance of natural gas in the grid is more important via LNG terminals then by other means, since these two clusters possess 70 % of the LNG terminals in Europe. This translates to nearly 10 million m^3 of LNG storage capacity.

Managing H_2NG blends in LNG terminals is considered as impossible due to the different boiling point of gas species (-162 °C for LNG, -253 °C for hydrogen).

Underground storages

The number of underground storages was also reported by GIE in 2019. [8] The facilities per country are listed in Table 26 in Annex I: Numerical data of the inventory of the European grid basing on the data found in this document. All these data can be gathered in clusters (see Table 27-Annex I: Numerical data of the inventory of the European grid), where Hungary and Romania have been added to Middle Europe, and are depicted in Figure 10.

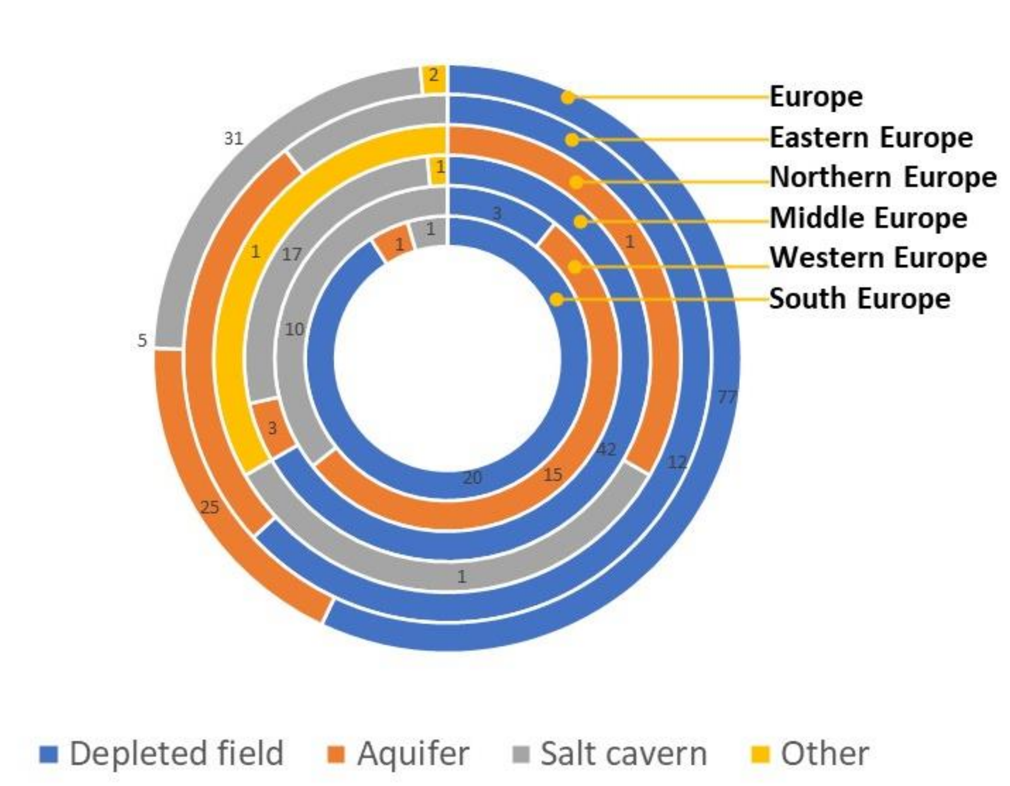

Figure 10. Underground storages in the different European clusters

From the figure above one can see that Europe possesses 139 storages and the year 1976 being the average installation year. 77 of them are depleted fields, 25 are aquifers, 31 salt caverns and 2 of them are not defined. This means a total working gas volume of over 1,300 TWh and a withdrawal and injection capacity of around 20,000 and 13,000 GWh/day, respectively. Middle Europe contributes to around 40 % of each of these values, while the contribution of Northern Europe is rather low (below 1 % of the total working gas volume and injection or withdrawal capacity). The contribution of South Europe and Western Europe is basically equilibrated, and the numbers of Eastern Europe double the former, especially in working gas volume.

Depleted fields are more common in South Europe, Middle Europe and Eastern Europe, with 20, 42 and 12 storages, respectively. Aquifers can be specially found in Western Europe (15 storages) and salt caverns are basically distributed between Western Europe and Middle Europe, with 10 and 17 storages, respectively.

Finally, Switzerland has also reported to HIGGS 15 underground storages, without defining their nature.

A more recent report from GIE states, however, a higher number of storages in Europe, with 80 depleted fields, 27 aquifers, 63 salt caverns and 1 hard rock cavern. [9]

Cross border interconnection points

According to the most recent ENTSOG report that quantifies the number of cross-border connections in Europe, [10] there are a total of 115 cross-border points within the EU and with non-EU countries. 86 of them work as export points and the other 29, as import points. Besides, there are also 34 intra-country balancing zone interconnection points within Europe. This means a total technical physical capacity in Europe over 42,600 GWh/d. Specific detail can be found in Table 28, Table 29 and Table 30 of Annex I: Numerical data of the inventory of the European grid.

Odorisation systems

The information about odorization systems that was collected with the survey is displayed in Figure 11. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 24).

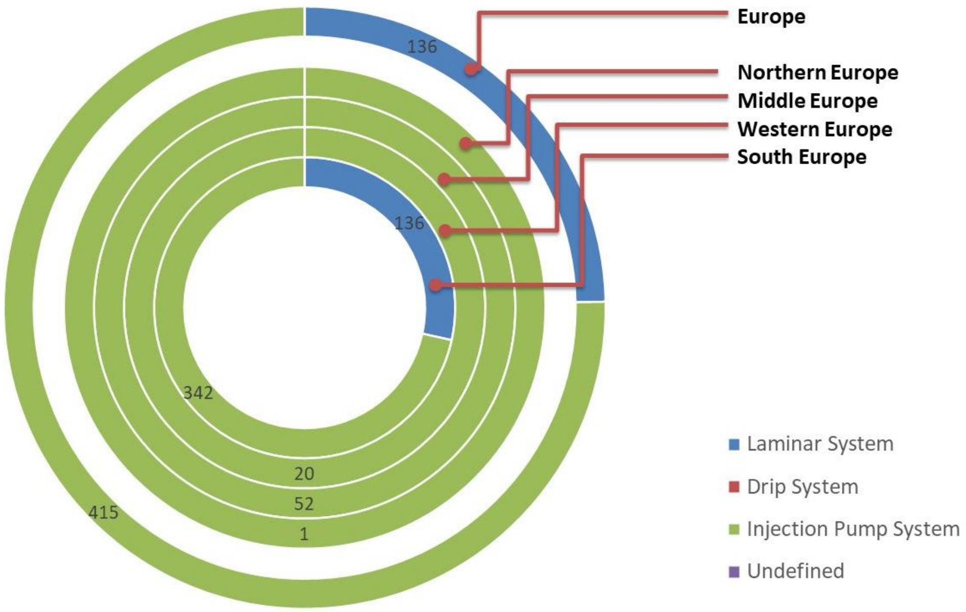

Figure 11. Odorization systems used in the European transmission grid.

A total of 415 injection pump devices and 136 laminar systems were gathered for the whole continent. Most of them belong to South Europe (91 % of the injection pumps and 100 % of the laminar systems). And no drip system was quantified.

Noteworthy THT (tetrahydro-thiophene) was identified as the most common odorant used by European TSOs according to the answers to the survey collected, since South Europe, Western Europe and Northern Europe only report this odorant for their devices. DMS (dimethyl sulfide) and IPM (isopropyl mercaptan) are also occasionally used. A quantitative assessment can, however, not be given.

The hydrogen content these devices can handle could not be achieved from the answers to the survey. The information provided about odorization devices is not much because some of the countries that contribute with the highest length to the total transmission grid do not odorize at transmission level but at distribution level, such as Germany.

Gas quality control systems

Gas quality control systems were divided into quality control systems itself and flow control systems. The units collected for the former are depicted in Figure 12. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 24).

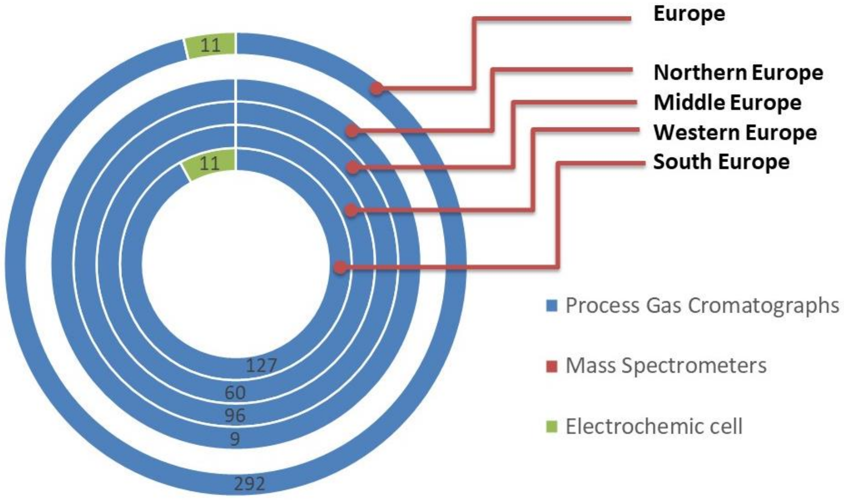

Figure 12. Type of quality control systems used in the European transmission grid.

A total of 303 devices were gathered for whole Europe. This means a concentration of 4.6 devices per each 1,000 km of grid. Most of them correspond to process gas chromatographs, while only 11 are electrochemical cells. No mass spectrometers were recorded with the survey. Process gas chromatographs are dominant in all clusters and electrochemical cells could only be found in South Europe.

The concentration of quality control systems is higher in South Europe, Western Europe and Northern Europe (10-15 units per 1,000 km of grid), while in Middle Europe is around 2. This means that the information gather for the last cluster is poor and makes the European average decrease to 4.6 devices per each 1,000 km of grid and may not be representative.

Flow control systems were divided into gas metering systems and gas pressure control systems. The information gathered about both of them is shown in Figure 13 and Figure 14, respectively.

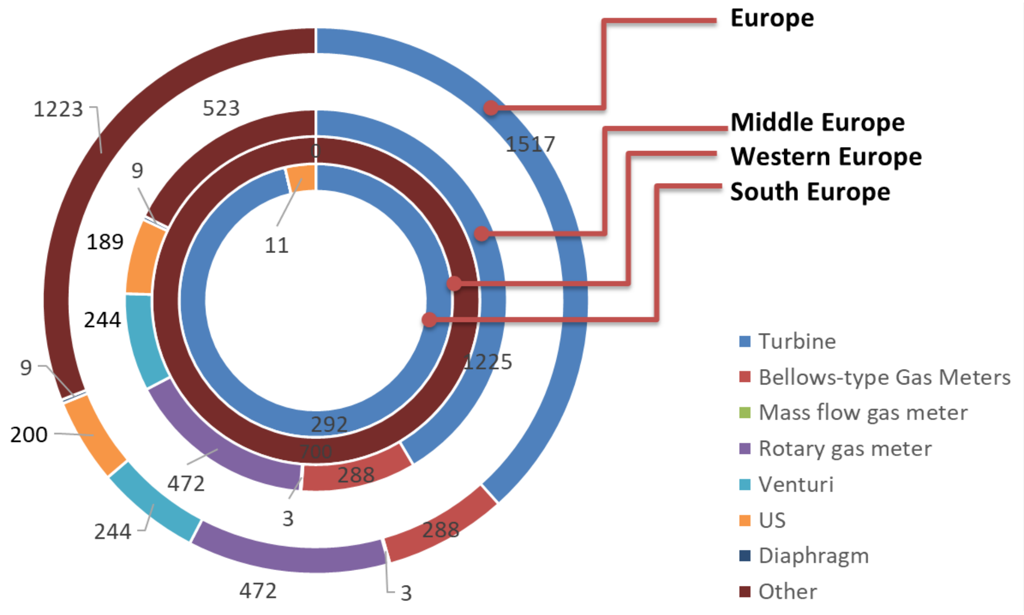

Figure 13. Type of gas meters used in the European transmission grid.

As seen in Figure 13, there are different gas metering systems available in Europe, among which turbine, bellows-type, mass flow, rotary, Venturi and ultrasonic gas meters can be highlighted. 2,287 devices where gather in the whole continent. This is a concentration of almost 35 gas meters per 1,000 km of grid. Turbine gas meters are the most commonly used devices, with 1,517 units available in the European grid. The second most commonly gas meters are rotary gas meters with 472 devices. Bellows-type, Venturi and US gas meters are equally used (between 5-7 % of the units collected). The technology of almost half of them is, however, not defined. This uncertainty is particularly high in Western Europe and Middle Europe, since the technology used for over 700 and 371 devices reported, respectively, is unknown.

Looking into each cluster in detail, turbine gas meters are the most common devices in South Europe and Middle Europe. Besides, Middle Europe shows the greater variety of devices. Regarding the frequency of gas meters in the grid, Middle Europe shows a similar value to that European (60 gas meters per 1,000 km of grid). However, this amount is the half in South Europe and three times greater in Western Europe.

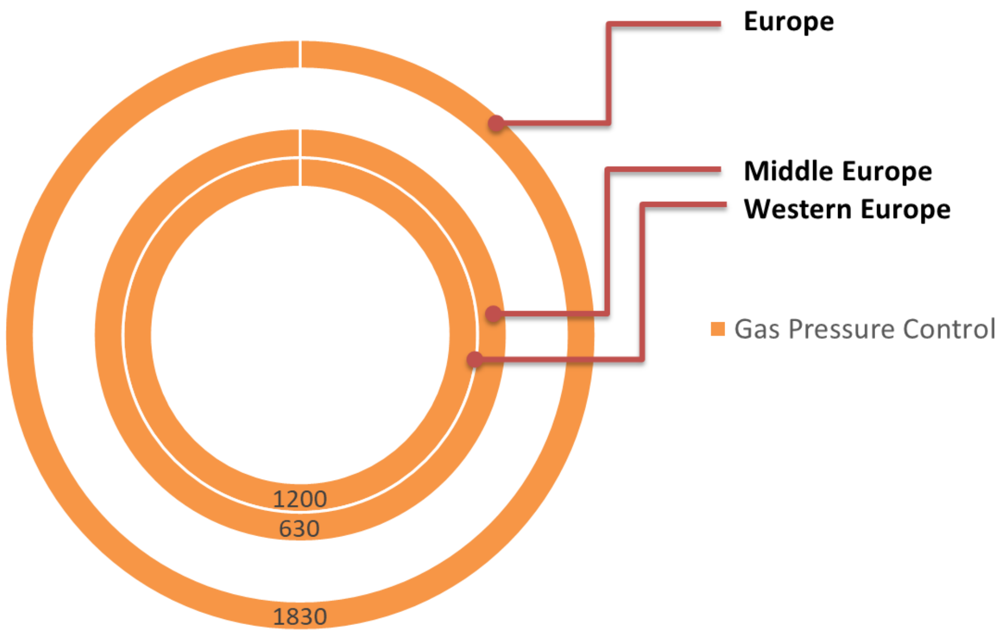

Figure 14. Gas pressure control systems used in the European transmission grid.

Finally, the number of gas pressure control systems gathered for Europe can be seen in Figure 14. Only data for Western Europe and Middle Europe could be collected, resulting in a poor overview of the whole European grid. In Western Europe, 1,200 devices were reported, i.e. a frequency of 250 units per 1,000km of the cluster's grid, of which the most part are membrane regulators. In Middle Europe, the numbers drop to 630 devices (13.5 units per 1,000km of the cluster's grid). The use of flow control systems in the Western Europe cluster seems more popular than in other regions in Europe according to the information gathered. The numerical data can be found in Annex I: Numerical data of the inventory of the European grid (Table 24).

No relevant general conclusions about the hydrogen content these devices can handle could be achieved from the answers to the survey.

3.3 Evaluation of the survey results in comparison with available information from literature and recommendations for the test campaign in work package 4

Via the conduction of the infrastructure survey a descriptive picture of the European natural gas transmission grid and its facilities has been compiled. The information has been provided by the European TSOs and gas operators associations. It has been verified that the information obtained is consistent with that collected in previous reports (EGIG, MARCOGAZ, etc.), where applicable. Complementing these reports, additional information on infrastructures has been obtained that completes the available ones in these reports obtaining a good knowledge of the European infrastructures for the transmission of natural gas. The analysis of the information has made it possible to identify the most representative facilities of the natural gas transmission network, and specifically those in contact with gas and which, therefore, will be exposed to hydrogen when it is injected into the network. The main components and characteristics of these representative facilities have been identified, establishing those that could be especially sensitive to hydrogen.

The quality of the steel used in the pipes is associated with the operating pressure of the network, higher pressures force the use of higher quality steels (grade) to avoid the use of pipelines with higher thickness.

The backbone of the European network, which connects the main gas entry points to the system with the main consumption points, must allow greater transmission capacity and therefore works at higher pressure. This is the reason why it is made up of higher quality pipes. Those clusters that due to their location or their demand for gas, have a greater presence in the basic network, therefore have a greater proportion of higher quality pipes.

Thus, and as can be seen in Figure 3 and Figure 5, countries such as the ones in the cluster South Europe, which include a high number of gas inlets to the system, have a higher percentage of networks that operate at high pressures (close to 80 bar) compared to those with lower pressure (up to 66 bar). Therefore, these clusters proportionally are using higher quality steels (X60 to X80) in its pipes.

Based on the infrastructure survey (see section 3.2.1), the resulting inventory of the European transmission gas grid (see section 3.2.3) derives a distribution of the different pipeline materials throughout the grid, as far as the data is available. As illustrated in Figure 3 there are five steel types used for about 88 % of the European transmission gas grid. These steel types are API 5L Gr B (~13.5 %), API 5L Gr X42 (~11.3 %), API 5L Gr X52 (~21.9 %), API 5L Gr X60 (~14.2 %), API 5L Gr X70 (~27.2 %). The first four of these steel types are considered to be suitable for 100 % hydrogen and blends of hydrogen and natural gas according to the following reports internally analysed by DVGW in 2021 (see also chapter 4.5) [11] [12] [13] [14] [15] [16]. However, more research is necessary to assure that these materials are suitable for blends of natural gas and hydrogen, especially at high pressure level (i.e. transmission level). For API 5L Grade X70 there are limitations in regards of 100 % hydrogen and blends of hydrogen and natural gas with higher portions of hydrogen [11] [15] [16]. Therefore, all these steel grades have been recommended for the selection of the test campaign in WP4 in the testing platform prepared in WP3.

The remaining steel types in the transmission pipeline grid according to the survey are API 5L Gr A (~3.1 %), API 5L Gr X46 (~1,5 %), API 5L Gr X56 (~1.3 %), API 5L Gr X65 (~1.0 %), API 5L Gr X80 (~1.0 %). The first three of these steel types are also considered suitable for natural gas, 100 % hydrogen and blends of hydrogen and natural gas according to the following reports internally analysed by DVGW in 2021 (see also chapter 4.5) [11] [12] [16] [17]. According to that, API 5L Gr X65 and X80 might have limitations in regards of 100 % hydrogen and in regards of blends of hydrogen and natural gas.

Derived from that according to the data gathered in the survey, about two thirds of the transmission gas grid are, very likely, suitable for transporting blends of natural gas and hydrogen and 100 % hydrogen if the suggestions from the cited reports are accepted. Due to the incomplete data, as discussed in section 3.2.3, the actual share of these steels throughout the European transmission gas grid might differ. Nevertheless, a guideline indicating that vast parts of the pipelines in the grid might be hydrogen-ready today can be derived. If the uncertainties of the X70 steel type can be dispelled, almost all pipelines in the grid can be viewed as hydrogen-ready. The same predication applies to the steel types X65 and X80, even though their shares are much lower. However, this assessment must be contrasted by more experimental research. From this perspective, WP2 advices to focus the testing in the HIGGS project on the aforementioned steel grades, that still have uncertainties and limitations in regards of hydrogen and blending of hydrogen and natural gas.

Furthermore, pipelines made of cast iron and steel types that contain a minimum of 2,25 % Nickel and more are not suitable as transport pipelines, neither for hydrogen nor for blends of natural gas and hydrogen [14].

From the data available on infrastructures in previous reports, and from the information obtained from the European TSOs through the infrastructure survey, it is observed that the most common installations in the high-pressure transmission gas grids are valves positions (valves nodes or cut-off stations) and stations designed to measure the gas flow and regulate its pressure (metering stations and pressure reduction stations).

These facilities are mainly composed of sections of pipes and valves, regulators, meters and instrumentation. These components are usually installed using flanged joints, using gaskets made of elastomeric materials. Most of these materials are compatible with hydrogen [18]. However, the diffusion and permeability of hydrogen through these materials is greater than for methane, so we consider it advisable to carry out specific tests on gaskets and components of this material in the WP4 test campaign.

The TSOs that contributed to the survey could not provide much information about the impact that hydrogen may have on their facilities because the impact is mostly still unknown. Regarding gas meters, some TSO suggested that ultrasonic devices can operate with a hydrogen content up to 20 %, while diaphragm (bellows-type) gas meters have no hydrogen content restrictions. MARCOGAZ, indicates that for percentages of hydrogen in natural gas lower than 10 %, no significant issues have been reported in the studies available for the usual metering equipment (turbine, rotatory displacement, ultrasonic and diaphragm gas meters), but conflicting references are found for higher percentages [19].

A better understanding of the effect of hydrogen admixtures in transmission conditions on gas meters and associated volume convertors and flow computers is necessary. Based on Figure 13, the most common gas meters in the European transmission network are the turbine meters, followed by the membrane meters and the rotary ones. Considering the high number of metering equipment in the transmission network, it is foreseeable that the cost of adapting these systems will be significant when the percentage of hydrogen in the mixture with natural gas exceeds 10 %.

For odorization systems, if grid hydrogen is being provided to devices that demand a high hydrogen purity, such as fuel cells, the odorant is an impurity that would need to be removed to meet ISO 14687 specifications. For instance, THT is completely incompatible with fuel cells, while they may be compatible with non-sulphur odorants, although more research on fuel cell degradation is still necessary. [20] In the same way, complementary studies are needed on the combined effect of hydrogen and sulfur on the usual materials of gas transmission networks, in order to analyzse the use of alternative odorizers that avoid these possible negative effects [21].

In the case of LNG terminals, they are incompatible with blends of natural gas and hydrogen due to the different boiling point of hydrogen and natural gas.

Regarding underground storages, so far salt caverns are the only proven underground hydrogen storage technology since they are inert and impermeable to hydrogen. Hydrogen has been successfully stored in three salt caverns at Teesside (UK), with a total capacity of 1,000,000 m³. The total estimated working gas capacity of salt caverns in Europe according to GIE is 50 TWh of hydrogen [9]. Pure hydrogen has not been stored in depleted gas fields yet but there are investigations ongoing regarding this topic. The first operational pure hydrogen storage in a depleted gas field is expected in 2030, operated by RAG Austria. The main problem in this kind of storages is the reactivity of hydrogen, since in the presence of sulphate-reducing bacteria and certain minerals it reacts to hydrogen sulphide. Case-by-case studies are necessary to assess which storages are compatible with hydrogen. Besides, H_2NG blends are less likely to develop this reaction than pure hydrogen, and therefore, depleted fields storing blends could be a useful solution in the short term, as long as the hydrogen demand is still low. In the case of aquifers, besides the problems with bacteria, their tightness to hydrogen has still to be proven [9].

Finally, cross-border interconnection points should have no additional restrictions to hydrogen compatibility than those considered for other transmission facilities. However, the different legal framework in terms of maximum allowed hydrogen content among the countries connected (more details in section 4) may hinder the flow of gas. This can affect most of the cross-border points in Europe.

The analysis of the information has made it possible to identify the most representative facilities of the natural gas transmission network, and specifically those in contact with gas and which, therefore, will be exposed to hydrogen when it is injected into the network. The main components and characteristics of these representative facilities have been identified, establishing those that could be especially sensitive to hydrogen. For its consideration in the development of the HIGGS Project, and in particular in work packages number 3 (Design, preparation and commissioning of testing facilities) and 4 (Systematic and experimental validation), it has been suggested which components and materials may be of interest for its representativeness and sensitivity to hydrogen.

For its consideration in the development of the HIGGS Project, and, especially, in work packages number 3 (Design, preparation and commissioning of testing facilities) and 4 (Systematic and experimental validation), it has been suggested which components and materials may be of interest for its representativeness and sensitivity to hydrogen.

4 Legal and technical framework – enablers and barriers for hydrogen injection into the gas grid

Chapter 4 describes the current legal and technical framework of the European Union and its member states. The European gas transmission system is historically grown on national level based on different national legal and technical framework. However, with the establishment of the common European market, the corresponding market regulation and the increasing role of European and international standards, the European framework is more and more leading the national frameworks.

4.1 European legal framework and EC strategies

The European framework, as it has been illustrated in the HIGGS deliverable report D2.2 from June 2020, was subject to the following new developments, that have been investigated [22].

As part of the Green Deal [23], the European Commission developed further strategies on hydrogen and sector integration. Interested parties were invited to contribute their knowledge and to share their views during several public consultations, the Madrid Forum and workshops on related aspects in 2020.

The **EU Hydrogen Strategy**, which has been released in July 2020, emphasises the essential role of hydrogen for the EU to lower greenhouse gas emissions and to reach its climate goals by 2050. Hydrogen can be used across the industry, transport, power and buildings sector and is therefore suitable to help to decarbonise certain sectors, where decarbonising is both urgent and difficult to achieve. The strategy formulates three phases, how to scale-up hydrogen production until 2050. In a first step, until 2024, 6 GW of renewable water electrolyser capacity for the production of renewable hydrogen shall be deployed. Corresponding to that, electrolyser manufacturing shall be increased accordingly. The aim is to reduce emissions in a short and medium term. Simultaneously, the legal framework for hydrogen will be developed and the planning of a backbone transmission infrastructure will be started. The second step from 2025 to 2030 foresees an electrolyser capacity of at least 40 GW of renewable hydrogen and aims to achieve cost parity of renewable hydrogen to other forms of hydrogen production. Therefore, an EU-wide logistical infrastructure will be needed and the plans for the European hydrogen backbone are to be finalised. In the final step from 2030 to 2050 hydrogen technologies have matured and deployed large-scale to all hard-to-decarbonise sectors [24].

The **EU Sector Integration Strategy** has been launched simultaneously to the EU Hydrogen Strategy. Its main goal is to integrate the energy system by establishing a coordinated way of planning and operating the energy system and all its different energy carriers, infrastructures and end-use sectors in order to create a more effective and affordable energy system and thus to achieve the decarbonisation goals of the EU. The strategy sets energy efficiency as its highest priority and points out that higher efficiency shall be achieved by utilising all potential for the avoidance of energy consumption and the purposeful re-use of processes with a surplus of waste energy. Further improvement is to be reached by more direct electrification and the use of renewable and low-carbon fuels [25].

The European Commission's work programme foresees a transition from strategy to action. For the European Green Deal this means the revision or amendment of the relevant directives and regulations for climate, energy and transport in such a way, that the adjusted reduction goals for 2030 of minus 55 % compared to 1990 and the climate neutrality of 2050 will be reached. The European Commission calls this package **"Fit for 55"** [26]. It includes two steps related to the decarbonisation of the energy system:

1. Mid-June the Commission adopted the first package of revision proposals for the following seven interlinked legal EU documents which will be subject to discussion by the EU Council:

    - renewable energy directive (RED), promoting the use of renewable hydrogen (certification system, decarbonisation industry and heavy-duty/long-distance transport)
    - energy efficiency directive (EED)
    - energy taxation directive (ETD), setting preferential tax rates for renewable and low-carbon hydrogen for end-users.
    - EU emissions trading system (EU ETS) and related directive, including hydrogen production
    - alternative fuel infrastructure directive (AFID), including hydrogen refuelling points
    - land use, land use change and forestry (LULUCF) and agriculture regulation
    - regulation on setting CO_2 emission standards for cars and vans (technology neutral targets, with hydrogen as a part of the solution)

2. A second package – which is highly significant for the gas transmission sector – is awaited by end of 2021 with proposals for hydrogen and the decarbonisation of gas markets

- Directive concerning common rules for the internal market in natural gas (2009/73/EC)
- Regulation for conditions for access to the natural gas transmission network 715/2009/EC
- Directive concerning the energy performance of Buildings Directive (EPBD)

As an input for the European Commission's proposal, public consultations on the gas package roadmap, on a dedicated detailed questionnaire and several workshops took place in 2021, involving all interested parties in the preparation process.

Especially the second package will define the basis for the future uses of the gas grid for hydrogen.

The European Commission informs through its online platform explicitly on the progress of their activities and planning. For the different areas illustrative fact sheets are available for download, e.g. for Energy System or Hydrogen [26] [27].

In this context the regulation Trans-European Networks for Energy (TEN-E; [28]) and its revision should be noted. TEN-E focusses on an effective and accelerated grid development to achieve the EU's energy policy goals including the linking of the energy infrastructure of the EU member states. It lays down the criteria for as necessary identified expansion projects, i.e. the Projects of Common Interest (PCIs). A role of this regulation is also seen for the built-up of the future European hydrogen infrastructure. The draft was presented in December 2020 and is presently in consultations between the EU institutions while drafting this report.

4.2 European technical framework by standardisation

4.2.1 Standards for gas transmission grids

The basic prerequisite for the use of hydrogen in the existing gas grids is the technical suitability of the system. Taking the similarities and differences of hydrogen and natural gas properties into account, the standards for gas infrastructure, for their components and equipment can generally also be applied for the use of hydrogen in natural gas transmission grids and for the construction of new hydrogen grids. However, it is particularly important to thoroughly consider the possible changes caused by hydrogen on materials such as embrittlement of steel, permeation through materials, suitability of elastomers and sealing materials, on safety aspects such as purging/venting, gas tightness, leakage, detection as well as on the technical system such as compression, metering, requires precise evaluation and testing. It represents the basis for transporting hydrogen in gas grids to identify the required adaptations of the technical requirements in the standards. Therefore, the relevant standards are currently subject to investigation on revision needs to make them hydrogen-ready; some are already in revision where the relevant hydrogen aspects are already identified. Several additional standards and standardisation deliverables are also already identified and partly started.

The challenge of the current adaptation of standards for the use of hydrogen is the content interaction between the standards and the co-ordination between the standardisation committees. Referencing is needed to other complementary standards, which are not yet adapted for hydrogen or are still in the process. For example, the functional standard for gas transmission pipelines refers to standards for valves. Yet, the valve standard is not yet available. Here, at least for a transition period, specific responsibility is given to the standard applying parties who need to ensure the fitness for purpose in cooperation with the competent parties (e.g. manufacturers of valves).

Especially regarding the adaptations for hydrogen blends, it is not yet clear, which hydrogen concentrations the provisions in the European standards need to cover, as there are no strategic commitments yet. Referring to the current knowledge and according to the exchange in the Sector Forum Gas infrastructure (April 2021), most of the technical committees are investigating their standards for up to 20 Vol-% and nominal 100 Vol-% hydrogen.

For the coordination of European hydrogen standardisation between the technical committees, the direct liaisons work between the groups, but also the consultations and investigations in the CEN and CENELEC Sector Fora, i.e. Sector Forum Gas infrastructure, Sector Forum Gas utilisation and Sector Forum Energy Management and energy transition – play a key role (see 4.2.2).

Fostering the coordination and coherent approach, the intended EC Standardisation Request on hydrogen to CEN and CENELEC is highly appreciated. (see 4.2.4)

Table 15 focuses on the European standards for onland gas transmission network including standards for the pipelines, components, equipment and the connection to other grids and facilities.

There are also few offshore transmission pipelines in Europe for which EN 14161 (Petroleum and natural gas industries - Pipeline transportation systems (ISO 13623:2009 modified) and related reference standards apply. These are not specifically included in this table.

As far as evident, the relevance for hydrogen is indicated by an asterix behind the standard reference number and the status of hydrogen inclusion is indicated as text below the document title.

Additionally, the available standards on hydrogen that can be applied for gas adaptation of the transmission grids for the transport of blends or conversion for pure hydrogen are integrated in Table 15 below. Table 15 does not claim to be exhaustive.

Table 15: European standards for gas transmission grids

Standard reference	Title	Current version	Responsible TC
Gas quality standards			
EN 16723-1	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network	2016	CEN/TC 408
EN 16726*	Gas infrastructure - Quality of gas - Group H	2015/ 2018	CEN/TC 234
prEN xxxx WI 00234096*	Gas infrastructure – Quality of gas – Hydrogen used in converted/rededicated gas systems	project stage	CEN/TC 234
EN ISO 6145*, parts 1, 4 to 11	Gas analysis - Preparation of calibration gas mixtures using dynamic volumetric methods	2008-2019	CEN/TC 238 – ISO/TC 158
EN ISO 6974* parts 1 to 5	Natural gas – Determination of composition and associated uncertainty by gas chromatography	2001-2014	CEN/TC 238 – ISO/TC 197
EN ISO 6975	Natural gas — Extended analysis — Gas-chromatographic method (ISO 6975)	2005	CEN/TC 238 – ISO/TC 197
EN ISO 6976	Calorific value, density, relative density and wobbe indices from composition	2016	CEN/TC 238
EN ISO 13443*	Natural gas — Standard reference conditions	2005	CEN/TC 238 – ISO/TC 197

Standard reference	Title	Current version	Responsible TC
EN ISO 13734*	Natural gas – Organic components used as odorants – Requirements and test methods	2013	CEN/TC 238 – ISO/193
ISO 14687*	Hydrogen fuel quality – Product specification	2019	ISO/TC 197
ISO 19229*	Gas analysis — Purity analysis and the treatment of purity data	2019	ISO/TC 158
ISO/TR 16922:	Natural gas – Odorization	2013	ISO/TC 197

Functional standards for design, construction and operation of onland gas transmission infrastructure with maximal operation pressure over 16 bar			
EN 1594*	Gas infrastructure - Pipelines for maximum operating pressure over 16 bar - Functional requirements	2013	CEN/TC 234
EN 12327*	Gas infrastructure - Pressure testing, commissioning and decommissioning procedures - Functional requirements	2012	CEN/TC 234
EN 12732*	Gas infrastructure - Welding steel pipework - Functional requirements	2014	CEN/TC 234
EN 16348*	Gas infrastructure - Safety Management System (SMS) for gas transmission infrastructure and Pipeline Integrity Management System (PIMS) for gas transmission pipelines - Functional requirements	2013	CEN/TC 234
prEN 17649*	Gas infrastructure – Safety Management (SMS) and Pipeline Integrity Management System (PIMS) - Functional requirements (replacing EN 16348)	2022	CEN/TC 234
EN 14161*	Petroleum and natural gas industries - Pipeline transportation systems (ISO 13623:2009 modified) Note: applicable for offshore gas transportation system	2015	CEN/TC 12 – ISO/TC 67 SC 2
Functional standards for components and equipment			
EN 1776*	Gas infrastructure - Gas measuring systems - Functional requirements Revision intended as soon as the necessary technical findings are available for hydrogen-ready gas meters and other related issues.	2015	CEN/TC 234
EN 12186*	Gas infrastructure - Gas pressure regulating stations for transmission and distribution - Functional requirements	2014	CEN/TC 234

	Revision intended to start in 2021		
EN 12583*	Gas Infrastructure - Compressor stations - Functional requirements Revision in process;	2014	CEN/TC 234

Product standards for components and equipment			
EN 334*	Gas pressure regulators for inlet pressure up to 10 MPa (100 bar)	2019	CEN/TC 235
EN 682*	Elastomeric seals - Materials requirements for seals used in pipes and fittings carrying gas and hydrocarbon fluids	2005	CEN/TC 208
EN 1012-3	Compressors and vacuum pumps — Safety requirements — Part 3: Process compressors	2013	CEN/TC 232
EN 12261*	Gas meters - Turbine gas meters	2018	CEN/TC 237
EN 12266-1*	Industrial valves - Testing of metallic valves - Part 1: Pressure tests, test procedures and acceptance criteria - Mandatory requirements	2012	CEN/TC 69
EN 12266-2*	Industrial valves - Testing of metallic valves - Part 2: Tests, test procedures and acceptance criteria - Supplementary requirements	2012	CEN/TC 69
EN 12405-1*	Gas meters - Conversion devices - Part 1: Volume conversion	2018	CEN/TC 237
EN 12405-2*	Gas meters - Conversion devices - Part 2: Energy conversion	2018	CEN/TC 237
EN 12405-3*	Gas meters - Conversion devices - Part 3: Flow computer	2018	CEN/TC 237
EN 13463-1	Non-electrical equipment for use in potentially explosive atmospheres — Part 1: Basic method and requirements	2009	CEN/TC 305
EN 13774*	Valves for gas distribution systems with maximum operating pressure less than or equal to 16 bar - Performance requirements	2013	CEN/TC 69
EN 13942*	Petroleum and natural gas industries - Pipeline transportation systems - Pipeline valves (ISO 14313:2007 modified/Cor 1:2009)	2009	CEN/TC 12
EN 14141	Valves for natural gas transportation in pipelines — Performance requirements and test	2013	CEN/TC 69

EN 14382*	Gas safety shut-off devices for inlet pressure up to 10 MPa (100 bar)	2019	CEN/TC 235
EN 14505	Cathodic protection of complex structures	2005	CEN/TC 219
EN ISO 4126*, parts 1 to 6	Safety devices for protection against excessive pressure - no need to be revised, applicable to all applications	2013-2019	CEN/TC 69 – ISO/TC 185
EN ISO 10437	Petroleum, petrochemical and natural gas industries — Steam turbines — Special-purpose applications (ISO 10437)	2003	CEN/TC 12 – ISO/TC 67/SC 6
EN ISO 10439 parts 1 to 5	Petroleum, chemical and gas service industries — Centrifugal compressors (ISO 10439)	2015	CEN/TC 12 – ISO/TC 67/SC 6
EN ISO 13849-1	Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design (ISO 13849-1)	2021	CEN/TC 114 – ISO/TC 199
EN ISO 17292	Metal ball valves for petroleum, petrochemical and allied industries	2015	CEN/TC 69 (ISO/TC 153)
ISO 3977* (all parts)	Gas turbines — Procurement	1997-2004	ISO/192
ISO 5168	Measurement of fluid flow — Procedures for the evaluation of uncertainties	2005	ISO/TC 30
ISO 13707	Petroleum and natural gas industries — Reciprocating compressors	2000	ISO/TC 118

Standards for pipes and coating			
EN ISO 3183*	Petroleum and natural gas industries — Steel pipe for pipeline transportation systems (ISO 3183:2019) Including the normative reference to API 5L: pipe(46th Edition Updated on 2020):	2020	CEN/TC 459/SC 10
prEN 751-3	Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water - Part 3: Unsintered PTFE tapes (Document in comments treatment after Public Enquiry)	2021 (1998)	CEN/TC 208
EN 10168	Steel products - Inspection documents - List of information and description	2004	CEN/TC 459/SC 12
EN 10204	Metallic products — Types of inspection documents	2004	CEN/TC 459/SC 12
EN 10288	Steel tubes and fittings for onshore and offshore pipelines — External two layer extruded polyethylene based coatings	2002	CEN/TC 459/SC 10
EN 10289	Steel tubes and fittings for onshore and offshore pipelines — External liquid applied epoxy and epoxy-modified coatings	2002	CEN/TC 459/SC 10
EN 10290	Steel tubes and fittings for onshore and offshore pipelines — External liquid applied polyurethane and polyurethane-modified coating	2002	CEN/TC 459/SC 10
EN 10301*	Steel tubes and fittings for on and offshore pipelines — Internal coating for the reduction of friction for conveyance of non-corrosive gas	2003	CEN/TC 459/SC 10
EN 12068	Cathodic protection — External organic coatings for the corrosion protection of buried or immersed steel pipelines used in conjunction with cathodic protection — Tapes and shrinkable materials	1998	CEN/TC 219
EN 12954	General principles of cathodic protection of buried or immersed onshore metallic structures	2019	CEN/TC 219
EN ISO 11114-4	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement (ISO 11114-4:2017)	2017	CEN/TC 23 (ISO/TC 58)
EN ISO 12944	Paints and varnishes — Corrosion protection of steel structures by protective paint systems — parts 1-8	2017	CEN/TC 139
EN ISO 15589-1	Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems — Part 1: On-land pipelines Revision in process	2017	CEN/TC 219 – ISO/TC 67 SC 2

EN ISO 21809-1	Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 1: Polyolefin coatings (3-layer PE and 3-layer PP)	2018	CEN/TC 459/SC10 – ISO/TC 67

Other relevant standards for the gas transmission grid			
EN 837-1	Pressure gauges — Part 1: Bourdon tube pressure gauges — Dimensions, metrology, requirements and testing	1996	CEN/TC 141
EN 837-2	Pressure gauges — Part 2: Selection and installation recommendations for pressure gauges	1997	CEN/TC 141
EN 837-3	Pressure gauges — Part 3: Diaphragm and capsule pressure gauges — Dimensions, metrology, requirements and testing	1996	CEN/TC 141
EN 1127-1	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology	2019	CEN/TC 305
EN 1998-4	Eurocode 8 - Design of structures for earthquake resistance -Part 4: Silos, tanks and pipelines	2006	CEN/TC 250
EN IEC 31010	Risk management - Risk assessment techniques	2010	CLC/SR 56
EN ISO 15112	Natural gas - Energy determination	2018	CEN/TC 238
EN IEC 60079-10-1,	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres	2021	CLC/TC 31
EN IEC 60079-14	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	2014	CLC/TC 31
EN 60079-17	Explosive atmospheres — Part 17: Electrical installations inspection and maintenance (IEC 60079-17)	2014	CLC/TC 31
EN 60079-20-1	Explosive atmospheres — Part 20-1: Material characteristics for gas and vapour classification — Test methods and data (IEC 60079-20-1)	2010	CLC/TC 31
EN 60079-29-1*	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases Amendments are in process	2016	CLC/TC 31
EN 60079-29-2	Explosive atmospheres - Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen	2015	CLC/TC 31
EN 60079-29-3	Explosive atmospheres - Part 29-3: Gas detectors - Guidance on functional safety of fixed gas detection systems	2014	CLC/TC 31

EN 60079-29-4	Explosive atmospheres - Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases	2010	CLC/TC 31
EN ISO 80079-36	Explosive atmospheres - Part 36: Non-electrical equipment for explosive atmospheres- Part 1: Basic method and requirement	2016	CEN/TC 305
EN 61000-6-2	Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity for industrial environments (IEC 61000-6-2)	2019	CLC 210
EN 61000-6-4	Electromagnetic compatibility (EMC) — Part 6-4: Generic standards — Emission standard for industrial environments (IEC 61000-6-4)	2019	CLC 210
EN 61508 (all parts),	Functional safety of electrical/electronic/programmable electronic safety-related systems (IEC 61508 (all parts))	2010	CLC/TC 65X
EN 61511 (all parts)	Functional safety — Safety instrumented systems for the process industry sector	2019	CLC/TC 65X
ISO 26142*	Hydrogen detection apparatus – Stationary applications	2010	ISO/TC 197
ISO/TR 15916*	Basic considerations for the safety of hydrogen systems	2004	CEN/TC 305 (ISO/TC 197)
prEN ISO 24078*	Hydrogen in Energy Systems – Vocabulary In elaboration; Public enquiry forecasted for in November 2021	project stage	CEN/CLC/JTC 6 (ISO/TC 197)
prTR xxx* (JT006002)	Safe use of hydrogen in built constructions In elaboration	Project stage	CEN/CLC/JTC 6

Standards to ensure compatibility with the connection to equipment and grids, where available

EN 1473*	Installation and equipment for liquefied natural gas — Design of onshore installations	2021	CEN/TC 282
EN 1918-5*	Gas supply systems — Underground gas storage — Part 5: Functional recommendations for surface facilities	2016	CEN/TC 234
EN 12007 series*	Gas infrastructure — Pipelines for maximum operating pressure up to and including 16 bar (parts 1 to 4) Under revision; hydrogen inclusion intended after publication of current revision.	2012	CEN/TC 234
EN 15001-1*	Gas Infrastructure — Gas installation pipework with an operating pressure greater than 0,5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations — Part 1: Detailed	2009	CEN/TC 234

	functional requirements for design, materials, construction, inspection and testing Under revision; hydrogen inclusion intended after publication of current revision.		
EN 15001-2*	Gas infrastructure — Gas installation pipework with an operating pressure greater than 0,5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations — Part 2: Detailed functional requirements for commissioning, operation and maintenance Under revision; hydrogen inclusion intended after publication of current revision.	2008	CEN/TC 234
prEN xxxx* (00234087)	Gas infrastructure - Injection stations - Part 1: General requirements In elaboration; Public enquiry forecasted for 2022/01	project stage	CEN/TC 234
prEN xxxx* (00234088)	Gas infrastructure - Injection stations - Part 2: Specific requirements regarding the injection of biomethane In elaboration; Public enquiry forecasted for 2022/01	project stage	CEN/TC 234
prEN xxxx* (00234090)	Gas infrastructure – Injection stations - Part 3: Specific requirements regarding the injection of hydrogen fuel gas In elaboration; Public enquiry forecasted for 2022/01	project stage	CEN/TC 234
ISO/TS 19883*	Safety of pressure swing adsorption systems for hydrogen separation and purification	2017	CEN/TC 197

Note: For the adaption of the gas transmission grid for the use of hydrogen, several further documents are currently used by standardisers and operators such as:

- ASME B 31.12-2019 - Hydrogen piping and pipelines
- EIGA Doc. 121/14 - Hydrogen Pipeline Systems
- EIGA Doc. 122/11 - Environmental Impacts of Hydrogen Plants
- EIGA Doc. 210/17 - Hydrogen Pressure Swing Adsorber (PSA) Mechanical Integrity Requirements
- NASA SAFETY STANDARD, NSS 1740.16,: Hydrogen and hydrogen systems, Guidelines for hydrogen system design, materials selection, operations, storage, and transportation (12 FEB 1997) [S/S BY ANSI/AIAA G-095-2004].

* The standards marked with an asterix behind the standard reference have been already identified as relevant for the use of hydrogen in gas systems in the context of the potential EC Standardisation Request.

The following standards are available and are referenced in section 4.6 for the test methods regarding hydrogen embrittlement in High pressure hydrogen gas transmission systems:

Table 16: Standards available for testing of hydrogen embrittlement (see section 4.6)

Standard reference	Title	Current version	Responsible TC
EN ISO 7539-7:	Corrosion of metals and alloys. Stress corrosion testing - Part 7: Method for slow strain rate testing (ISO 7539-7:2005).	2018	
EN ISO 12737	Metallic materials - Determination of plane-strain fracture toughness (ISO 12737:2010)		CEN/TC 459/SC 1
EN ISO 11114-4	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement (ISO 11114-4:2017)	2017	CEN/TC 23 (ISO/TC 58)
EN ISO 17081	ISO 17081. Method of measurement of hydrogen permeation and determination of hydrogen uptake and transport in metals by an electrochemical technique	2014	
ISO 12135	Metallic materials - Determination of plane-strain fracture toughness *Publication new version announced.*	2016	ISO/TC 164/SC 4

Note: Additional to the CEN and ISO standards the corresponding technical voluntary consensus standards of ASTM International (formerly American Society for Testing and Materials) are applied:

- ASTM 1820 Standard test method for measurement of fracture toughness.
- ASTM E647 Standard text method for measurement of fatigue crack growth rates
- ASTM E1681 Standard test method for determining threshold stress intensity factor for environment-assisted cracking of metallic materials
- ASTM F1459 Standard test method for determination of the susceptibility of metallic materials to gaseous hydrogen embrittlement
- ASTM G 38 Standard practice for making and using C-ring stress-corrosion test specimens
- ASTM G129: Standard practice for Slow Strain Rate Testing to evaluate the susceptibility of metallic materials to environmentally assisted cracking
- ASTM G142 Determination of susceptibility of metals to embrittlement in hydrogen containing environments at high pressure, high temperature or both.

ASTM G142 Determination of susceptibility of metals to embrittlement in hydrogen containing environments at high pressure, high temperature or both.

4.2.2 Relevant CEN and CENELEC Technical Committees and Sector Fora

Referring to section 4.2.1, the technical committees providing standards for the gas transmission grid are described in Table 17. It focusses on standardisation related to gas transmission grids. In this respect it narrows down and supplements the listing given in report D.2.2.

The majority of the listed technical committees provide standards on products and/or procedures that are used to build and extend a gas transmission grid. Some committees elaborate so called functional standards that describe the requirement for a part or an overall system. For the functional standards for the gas grid, CEN/TC 234 Gas infrastructure is key defining requirements "in the field of gas infrastructure* from the input of gas into the onshore transmission network up to the inlet connection of gas appliances […] including transmission, distribution, storage, compression, regulation and metering, installation, injection of non-conventional gases, gas quality issues and others." The term "gas" refers to combustible gas, which is gaseous at 15°C and 1013 mbar, eg natural gas including CNG, LNG, LPG, biomethane, synthetic gases and hydrogen as a blending and used in converted natural gas infrastructure.
Due to the functional standardisation for the overarching system of gas infrastructure, CEN/TC 234 standards in a way determines the gas infrastructure aspects in the technical work dealt with by other CEN/TCs related to gas infrastructure. Regarding the standardisation for hydrogen in the gas infrastructure, CEN/TC 234 investigated the consequences of hydrogen and the related need for adaptation and completion of its set of standards based on the predominant similar properties of hydrogen compared with natural gas. (see Table 15).

Based on the investigations of hydrogen in European energy system in CEN CENELEC SFEM WG Hydrogen, the CEN/CLC/JTC 6 Hydrogen in energy systems has been formed in 2016. It is in charge of "standardization in the field of systems, devices and connections for the production, storage, transport and distribution, measurement and use of hydrogen from renewable energy sources and other sources, in the context of the European strategy for the development and acceptance of the hydrogen market. The scope includes cross cutting items such as: terminology, Guarantee of Origin, interfaces, operational management, relevant hydrogen safety issues, training and education. Excluded are: - Storage and transport of liquid hydrogen which is covered in the scope of CEN/TC 268. - Storage and transport of compressed hydrogen which is covered in the scope of CEN/TC 23. - Vehicle refuelling stations and associated equipment and procedures as related to the standardization Request M/533. - The injection of hydrogen and the mixture of hydrogen with natural gas (H2NG) in the gas infrastructure, which is covered in the scope of CEN/TC 234. - The use of mixtures of natural gas with hydrogen (H2NG)." CEN/CLC/JTC 6 also mirrors the standardisation activities of

ISO/TC 197 Hydrogen technologies and carries out projects under the Vienna agreement as far as falling into its scope.

From the today's point of view there is a significant interface between CEN/TC 234 and CEN/CLC/JTC 6 regarding the standardisation of infrastructural aspects especially regarding the repurposing of the existing gas infrastructure and also dedicated hydrogen infrastructure especially regarding to storage, connection to production, transport, distribution, measurement). Therefore, the TCs are working in close and formal cooperation according to the CEN-CENELEC Internal Rules (Mode 5) combining the expertise in both committees for the best benefit of the decarbonisation of the energy system.

The standardisation work is supported by so called Sector for a. They are composed of representatives of technical committees, interested national standardisation bodies, European/international stakeholders and the European Commission. They offer the appropriate place to exchange on subjects of joint and overarching relevance, e.g. coordination of standardisation and standardisation strategies or realisation of pre-normative studies. They support of the CEN and/or CENELEC Boards including exchange with the European Commission where appropriate.

The relevant Sector Fora for the gas (transmission) grid and the use hydrogen in the grid are:

- CEN Sector Forum Gas infrastructure (SFG-I): focussing on standardisation related to the gas chain from the input of gas into the gas transmission system until the inlet of the gas appliances.
- CEN Sector Forum Gas utilisation (SFG-U): focussing on standardisation related to gas applications
- CEN/CENELEC Sector Forum Energy Management and Energy transition (SFEM)

SFG-I and SFG-U together build the CEN Sector Forum Gas. Prominent actions of the Sector Forum Gas are currently the pre-normative study on H-gas quality parameter, specifically the Wobbe index. Furthermore, the exchange on the actual adaptation of the standards for the use of hydrogen. They both have a specific focus on the cooperation among the related CEN and CEN/CLC TCs that are member of the committees and the support of their standardisation work including the interested stakeholder organisations.

The CEN/CENELEC Sector Forum Energy Management and Energy transition (SFEM) focuses horizontal issues in support of an optimised and aligned standardisation energy efficiency and energy transition. Current issues are behaviour change, hydrogen, blockchain and DLT in energy sector and multiple benefits of energy efficiency. In the scope of the HIGGS project emphasise is given to the WG on hydrogen that elaborated the comprehensive mapping of hydrogen research and standardisation (see report D2.2) and is currently investigating the standardisation need for hydrogen in aviation and maritime transport.

Due to the interface of the Sector Fora specific issues are dealt with jointly. For this a joint task force has been built between SFEM WG H2, SFG-I and SFG-U. A first subject is the investigation of the needs of hydrogen quality/purity by (industrial) end-users.

All the three Sector Fora are actively supporting the potential EC Standardisation request on hydrogen and also the standardisation policies for a decarbonised energy system outlined in the policies of the European Commission and transposed in the CEN and CENELEC policies.

The listing of the technical standardisation committees providing standards applicable (Table 17) in the field of the gas transmission grid is including the committees which elaborating to the standards identified in Table 15. The major committees are printed fat. This listing is not exhaustive.

From the European perspective, in first line the CEN and CENELEC committees and standards are of major interest as the national standardisation bodies of the European countries, all CEN and CENELEC members, committed themselves to implement the European standards nationally. The CEN and CENELEC Technical Committees are mirroring the work of the corresponding ISO and IEC Technical Committees and take-over the relevant international standards as CEN respectively CENELEC standards. This relation is expressed in Table 15 in the far-right column.

Table 17: Technical committees providing standards for the gas transmission grid as indicated in Table 15 [29]

Technical Committee	Title and scope
CEN/TC 12	Materials, equipment and *offshore* structures for petroleum, petrochemical and natural gas industries
CEN/TC 69	**Industrial valves**
CENTC 139	Paints and varnishes
CEN/TC 141	Pressure gauges - Thermometers - Means of measuring and/or recording temperature in the cold chain
CEN/TC 208	**Elastomeric seals for joints in pipework and pipelines**
CEN/TC 219	**Cathodic protection**
CEN/TC 232	Compressors, vacuum pumps and their systems
CEN/TC 234	**Gas infrastructure**

Technical Committee	Title and scope
CEN/TC 235	**Gas pressure regulators and associated safety devices for use in gas transmission and distribution**
CEN/TC 236	**Non-industrial manually operated shut-off valves for gas and particular combinations valves-other products**
CEN/TC 237	**Gas meters**
CEN/TC 238	**Test gases, test pressures, appliance categories and gas appliance types**
CEN/TC 250	Structural Eurocodes
CEN/TC 262	Metallic and other inorganic coatings, including for corrosion protection and corrosion testing of metals and alloys
CEN/TC 282	Installation and equipment for LNG
CEN/TC 305	Potentially explosive atmospheres - Explosion prevention and protection
CEN/TC 399	**Gas Turbines applications - Safety**
CEN/TC 408	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid
CEN/TC 459/SC 10	**(Metallic products) Steel tubes, and iron and steel fittings**
CEN/TC 459/SC 12	**(Metallic products) General issues**
CEN/CLC/JTC 6	**Hydrogen in energy systems**
CLC/TC 31	Electrical apparatus for potentially explosive atmospheres
CLC/TC 57	Power systems management and associated information exchange
CLC/TC 65x	Industrial-process measurement, control and automation
CLC/TC 210	Electromagnetic Compatibility (EMC)
CLC/TC 216	Gas detectors
CLC/SR 56	Dependability
ISO/TC 30	Measurement of fluid flow in closed conduits
ISO/TC 58	Gas cylinders
ISO/TC 67/SC 2	(Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries) Pipeline transportation
ISO/TC 67/SC 6	(Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries) Processing equipment and systems
ISO/TC 70	Internal combustion engines
ISO/TC 118	Compressors and pneumatic tools, machines and equipment
ISO/TC 153	Valves

Technical Committee	Title and scope
ISO/TC 158	Analysis of gases
ISO/TC 185	Safety devices for protection against excessive pressure
ISO/TC 192	Gas turbines
ISO/TC 193	Natural gas
ISO/TC 197	Hydrogen technologies
ISO/TC 199	Safety of machinery
IEC/TC 31	Equipment for explosive atmospheres

4.2.3 Standardisation support by EC-CEN Pre-normative study on hydrogen in natural gas networks and applications (EC-CEN PNR H2NG)

In support of the standardisation and complementary to the current European research projects such as HIGGS and THyGA, the European Commission allocated a pre-normative project *'Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users'* (SA CEN 2019-14) to CEN for analysis of available study reports and literature on hydrogen in natural gas systems (infrastructure and application) for the use of the technical findings in standardisation and for identification of knowledge gaps related to the following work packages (see Table 18).

The investigations include a comprehensive survey of knowledge sources and detailed elaboration on the state of the art on the impact of:

- hydrogen blends up to 20 % hydrogen concentration, looking also at the relevance of variations due to uncontinuous H_2 injection, and
- pure hydrogen.

Since the complete gas chain needs to be able to accept hydrogen blends and/or pure hydrogen and since there are significant and obvious interlinks between the topics, it is considered as being useful to show the full scope of the project even if not all of the work packages are related to the gas transmission grid.

Table 18: EC-CEN PNR work packages and identified subtopics

Work package	Subtopics
1. Safety	○ Behaviour H_2NG in existing natural gas pipework at high percentage up to 100 % in homes and households ○ Classification of leaks (ignition and leakage) ○ Safety-related sensors for detection of hydrogen and hydrogen mixtures ○ Gas tightness of installations and piping ○ Integrity management and inspection in a H_2 Pipeline
2. Gas quality	○ Impact of hydrogen addition in gas mixtures on physical properties ○ Hydrogen quality needed for injection in natural gas ○ Odorisation-effects of hydrogen on natural gas odorization ○ Sensors and measurement of varying hydrogen concentrations ○ Impact of billing, energy measurement and methods to overcome commercial constraints.

3. Underground storage	○ Surface equipment – Compressors ○ Surface equipment – Pre-heating, units, pressure release units, gas drying, gas treatment ○ Surface equipment – Well head and ESD ○ Surface equipment – Well completion ○ Storage formations ○ Safety and survey equipment ○ Material selection for piping and seals
4. Centralised and decentralised power generation	○ Turbines (in compressor stations or as cogeneration device) and CHP gas engines under varying H_2 input ○ Compressors ○ Engines ○ Adaptive control of power generation and CHP equipment
5. Industry (feedstock gas and industrial processes)	○ sensitive users identified in the HIPS report and ○ H_2 critical parameters, such as flash-back (safety), process efficiency, NOx emissions, process equilibrium, process control, but also economics (energy costs) and decision makers (H_2 acceptability), depending on the H_2 content

6. Steel pipes	○ Hydrogen embrittlement ○ Mitigation /inhibition of hydrogen effect ○ Corrosion and coating ○ Impact on repair ○ Conversion of gas network
7. Equipment and materials on gas network	○ Valves including, slam shut-, relief- and excess flow valves (long time effect on used polymer seals, materials, functionality comprising inner and outer tightness) ○ Meters and volume converter (material suitability and function for different types of meters as ultrasonic, turbine, diaphragm, etc.) ○ Filter (material suitability and function in context with system level effects as capacity/increased flow speed) ○ Seals and connections (material suitability and function) ○ Pressure regulators/ control diaphragms (material suitability and function) ○ Preheater (material suitability and function)
8. End-use applications	○ Domestic and commercial uses of gas including forced draught burners and NGVs (except tanks) and grid control (system level) ○ Safe operation (testing, service conditions, certification and regulatory framework) ○ Environmental impact (noise, comfort) ○ Energy efficiency

	○ Overall performances for the service it is designed for
9. Hydrogen purity needs of industrial end user	Possibly, depending on the availability of budget) ○ Sub-categories of industrial users (non-combustion/feed-stock application, combustion application) ○ H_2 purity needs of the different sub-categories ○ Relevance of other H_2 quality parameter and impurities, through repurposed pipelines and infrastructure ○ Mitigation/purification measures outlined

Source: GERG Expert Team reporting to the project supervisory board (CEN/TC 234 WG 13), July 2021

The project formally started in October 2020 and has been planned for 12 months. Due to a CEN request for extension, the reports of the project are expected in November 2021. These will also include a comprehensive list of knowledge sources which includes at the current project stage already more than 800 individual references.

This project is carried out under the umbrella of CEN/TC 234 Gas infrastructure (CEN/TC 234 WG 13 Supervisory Board) with involvement of all relevant CEN and CENELEC TCs and European stakeholder organisations. The studies themselves are carried out by GERG (The European Gas Research Group) in dedicated expert teams in regular exchange with CEN/TC 234 WG 13.

4.2.4 Preparations for an EC Standardisation Request (SReq) on hydrogen

The availability of standards for transmission, distribution and use of hydrogen on national and European level is limited at the moment. Some countries such as Austria, France, Germany, The Netherlands and UK have started first documents. With view to the EC strategies on the European hydrogen and sector integration, the establishment of a coherent set of European standards is preferable up from the beginning of the broad hydrogen introduction process. Application of European wide applicable technical principles and requirements allows the efficient building of a safe, reliable and compatible European hydrogen system and fosters the common European hydrogen market.

Bearing this in mind, the gas and hydrogen related CEN, CENELEC and ISO technical committees have started investigations on the standardisation need to use hydrogen in the existing gas infrastructure and applications and to build up dedicated hydrogen systems.

In support of a coherent approach and set of standards, a formal standardisation request by EC to the European Standardisation Organisation CEN and CENELEC is in preparation between the organisations. A CEN-CENELEC Ad Hoc Group (SRAHG), has been formed to reflect the necessities of the related sectors and standardisation bodies in the drafting process. This SRAHG is composed of representatives of the national standardisation bodies, technical committees and also the relevant Sector Fora for gas infrastructure (CEN SFG-I), for gas utilisation (CEN SFG-U) and for energy management and energy transition (CEN-CENELEC SFEM).

The current proposal of the standardisation request includes the following four uses of hydrogen:

- hydrogen in repurposed natural gas infrastructure and application,
- hydrogen as a blend in natural gas infrastructure and application,
- hydrogen in dedicated infrastructure and application
- methanation.

In the draft scope of the standardisation request, 38 CEN and CENELEC technical committees have been identified as relevant to contribute to the necessary European set of standards. Furthermore, 11 IEC and ISO technical committees are working in the areas and should therefore be involved in the process. These technical committees investigated the need of standards – adaptations and/or new standards - within their scope to facilitate the uses of hydrogen. A potential joint work program has been drafted.

It is currently not clear, when the standardisation request will be finalised and allocated as it is related to the revision of the European legislation for the common gas market and the implementation of the EC strategies on hydrogen and sector integration which are currently in process (see 4.1). Furthermore, the current comprehensive scope might be split in several work packages, even if interfaces are given between the areas which will make a complete separation of the work packages difficult (e.g. standardisation for blends in existing natural gas infrastructure, for the repurposing of natural gas infrastructure for pure hydrogen and also for the building of the dedicated hydrogen infrastructure or hydrogen underground storages are related to the same set of interrelated (existing) standards as the technical exigences are similar for all these areas and would not request a separate/parallel set of standards).

Note: Besides the draft EC Standardisation Request on hydrogen also further standardisation requests with relevance for the standards in the field of gas transmission grids need to be considered and possibly revised to include hydrogen. E.g.

- M/400 Gas Quality, currently requesting provision of a European standard for H-gas (EN 16726:2015), might need an extension for admixtures with hydrogen and possibly the inclusion of standardisation of hydrogen quality in repurposed gas grids. Depending on the revision of the related European gas legislation also this might need revision of the mandate.
- M 071 Pressure Equipment Directive (2014/68/EU) , relevant for the design, manufacture and conformity assessment of stationary pressure equipment such as pressure devices, pressure vessels or safety valves in the gas transmission grids.

Current related pre-normative activities on the harmonisation of Wobbe index requirements in CEN Sector Forum Gas also include investigations for renewable gases (e.g. hydrogen, biomethane).

4.3 European sector initiatives

Full support of the decarbonisation needs and targets for the energy system is given in the gas sector. A high awareness is notable that the transition to a decarbonised hydrogen system will only be possible with all parts along the gas chain being involved in the architecture and the realisation of the transition. Therefore, many **initiatives in the gas sector** between companies or European stakeholder within and across the parts of the gas chain are working on the appropriate solutions to finally enable the intended broad use of hydrogen.

The most of these initiatives are not directly linked to standardisation but they give valuable support to the process by dissemination of expertise which is fundamental for setting the appropriate normative requirements. A far from exhaustive number of which are presented in the following

In July 2020 an initiative composed of 11 European gas infrastructure companies introduced their vision to create a **European hydrogen backbone** until 2040. In the meantime, the initiative has grown to 23 European gas infrastructure companies and there have been several update reports, the latest one in June 2021. The initiative comprehensively describes how a hydrogen backbone in Europe can be established and which knots and existing pipelines can be redesignated or have to be built from scratch in order to secure a large-scale hydrogen market. The aim of the vision is to present a possible way how to connect hydrogen supply and demand over the whole of Europe, also taking the need for green electricity to produce green hydrogen into account [30] [31].

H2 Gas Assets Readiness (H2GAR) is a project of the seven transmission system operators Enagas, Fluxys, Gasunie, GRTgaz, Nationalgrid, OGE and SNAM. It specifically aims at

- sharing technical knowledge on the hydrogen readiness of the gas assets (blends and pure) among the project partners,
- building a joint view on the findings and
- contributing them to the standardisation process for a robust future hydrogen-ready gas system.

As such the project is very valuable for the adaptation and elaboration of new standards for the use of the gas transmission system for hydrogen blends and pure.

With six dedicated working groups and without overlapping with other ongoing works by other organisations, the project focusses on

1. existing and new pipelines (material compatibility s, technological and regulatory gaps),
2. compressor stations (hydrogen levels 10 % and 100 %, impact on gas turbines and compressors, involving manufactures),
3. separation systems for separating hydrogen from H_2NG blends (analysis of case studies for highest cost-effective and energy-efficient solutions;
4. metering of quantity and quality of H_2NG blends involving manufacturers (effects of hydrogen on unaccounted for gas, simulation of H_2NG blends in pipelines, accuracy of Z-calculation; odorization out of scope)
5. safety related to the transport of hydrogen for existing and new pipelines (safety data sheet for blend, risk analysis of H_2NG/hydrogen leakage, state of the art and gaps)
6. underground gas storage (impacts of 10 % and 90 % hydrogen in porous storages, , definition of risk assessment matrix, impact severity classification, definition of roadmap and data base of storage characteristics and study results)

Exchange especially with CEN/TC 234 Gas infrastructure is set by the nominated experts in the working groups; technical input has already been incorporated in the current revision of EN 1594 in CEN/TC 234.

The **Prime movers' group on gas quality and hydrogen handling** functions as the open exchange platform **between stakeholders** from gas production to the various gas applications and including organisations like CEN-CENELEC and representatives of the Commission. It currently involves more than 25 European stakeholder organisations.

The group was established in September 2020 on initiative of the European associations of gas network operators ENTSOG, EUROGAS, GEODE, CEDEC and GD4S and aims at

- creating a good understanding of the technical feasibility and challenges to cope with the future gas quality in the gas system, including renewable, decarbonised and low-carbon gases.

- developing a joint roadmap for a whole system approach allowing decarbonisation and at the same time safe and efficient end-use with least emissions as well as security of the gas supply. The roadmap will include the identification of solutions for the areas of concern.
- feeding the results in the consultations with the European Commission on the revision of the gas legislation implementing the EC hydrogen and sector integration strategies.

A specific focus is given to fluctuating hydrogen blends as well as pure hydrogen grids in the future gas system and to develop a joint roadmap.

Whilst in the plenary group the focus is set on open exchange on the hydrogen readiness, on challenges and strategies, two subgroups are installed for conceptual work:

SG 1 WI Framework has the specific task to consult with all stakeholders about the needs of a legal/regulatory framework facilitating the implementation of the proposal for WI standardization elaborated in the CEN Sector Forum Gas Working Group 'Pre-normative study on H-gas quality parameters'. This includes the description of pragmatic procedures but also recommendations for which aspects would need support by EU legislation/regulation, e.g. regarding liabilities and responsibilities. A first report is provided to the Commission in July 2021.

SG 1 is directly supporting the standardisation of gas quality as the current CEN Wobbe index proposal will only be acceptable for inclusion in EN 16726 on H-gas quality, if a framework is set which is appropriate for all parts of the gas chain.

SG 2 Value chain H_2 readiness roadmap & solutions for GQ&H_2 handling elaborates on the key challenges related to the current and future gas quality including hydrogen and biomethane to jointly assess possible solutions to overcome the challenges with the joint aiming of a decarbonised gas system.

In addition to this SG2 a first report was sent to the European Commission. Furthermore, a transparent list of projects and initiatives has been drafted to give evidence on the different parallel activities and to strengthen network.

A public website is available for external stakeholders on the ENTSOG website to be informed about the process: https://entsog.eu/prime-movers-group-gas-quality-and-hydrogen-handling.

4.4 National framework of the European member countries

Aiming at fast and efficient decarbonisation of the energy systems and in the context of the European climate targets and strategies, the countries are working on their national strategies and frameworks. Hydrogen is clearly recognised as an essential element of a decarbonised energy system. However, the view on the use of hydrogen in the gas grids and applications is diverging from country to country, also between national authorities and the gas sector. Furthermore, the velocity of planning and developments is very different in the EU member states.

The national approaches are already reflected in the national energy and climate plans from 2018/2019 but separately outlined in dedicated national hydrogen strategies of the EU member states mostly published in late 2020 and 2021. Some are not available, yet. The national hydrogen strategies are not centrally published.

The **national energy and climate plans (NECP) are** describing the 10-year planning aiming at the 2050 climate neutrality objectives including among others the reduction of emissions, increase of renewables, improving energy efficiency, raising cross-border infrastructure. A progress report must be delivered every 2 years. The NECPs for the period 2021 to 2030 are established in accordance with the EU Regulation on the governance of the energy union [32]. They are published on the European Commission's website for transparency and coordination [33] together with the EC's individual assessments.

For the creation of the state-of-the-art regulatory, standardisation and certification map of the EU, a questionnaire has been prepared on the basis of the HyLAW project and addressed mainly to national TSOs and related associations in the EU Member States, Switzerland and UK. The questions are addressing the general legal framework for hydrogen, the injection and transport of hydrogen in natural gas network (see Table 19). Background information on the setting of the questionnaire and the contacted stakeholders is referenced to the HIGGS deliverable report D2.2 [22].

Questionnaire replies and further information from bilateral exchange have been received for nineteen countries, i.e. Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Latvia, Poland, Romania, Slovenia, Spain, Sweden and Switzerland, The Netherlands.

The findings are summarised in the following clauses. The level of information detail is differing from country to country due to the obtained replies and availability of information.

Table 19: Content of questionnaire

Q	Subject of question (Q)
General national legal framework	
1	Responsible authority/legal entity for the permission of the connection/injection of hydrogen in the gas grid
2	Existing national legislation and/or regulation concerning the injection of hydrogen into the gas grid;
3	Existing legal provisions and responsibilities of the TSOs regarding the transport of pure hydrogen and mixtures of hydrogen and natural gas
4	Allowed maximum hydrogen concentration (0-100 %) to be transport as a TSO
5	Allowed maximum hydrogen concentration to be injected into the gas transmission grid
15	National intentions to revise the legal and technical framework to facilitate the transport of hydrogen – pure or as blends – in the natural gas transmission grid.
Operational aspects related to injection and connection practices	
6	Injection practice into the gas transmission grid in case of blending
	○ injection of pure hydrogen or pre-mixed blend of hydrogen with natural gas
	○ responsibility for pre-mixing, if any.
	○ TSO obligations to deliver natural gas for pre-mixing
7	Specific requirements for increasing or decreasing the admissible threshold of hydrogen concentration (upstream and downstream networks, infrastructure elements and appliances with lower tolerance)
8	Specific restrictions/permissions for the transport of hydrogen other than “concentration” and “quality”
9	Allowance for injection of off-spec gases if required gas quality specifications are met at entry to customer

Ownership of connection facilities of hydrogen into the grid (injection installation considered part of the connection facility)	
10	TSO ownership of or responsibility for connection facility of hydrogen into the grid
11	TSO consideration of legal and administrative restrictions with regard to the ownership of the connection facility of hydrogen into the grid (injection installation considered part of the connection facility)
Differences in provisions and requirements for connection of (blend/pure) **hydrogen to** the **gas grid compared to current** the **situation with natural gas and biomethane**	
12	Difference in legal and administrative restrictions between connections for hydrogen injection into TSO and DSO-networks
13	Specific national (add-on) restrictions for the connection/injection of hydrogen in TSO networks compared to the connection/injection of natural gas
14	Requirements for the injection of H_2NG-blends in TSO networks compared to pure Hydrogen
Further relevant information	
16	Further relevant information relevant for the transport of hydrogen in the natural gas grid.

The sections 4.4.1 to 4.4.24 aims at summarising the national legal framework for each of the EU countries according to the contributions to the questionnaire to the questions 1 to 5 and 15.

Considering parallel activities of other organisations on the same subject, the findings from the HIGGS investigations have been supplemented by information from complementary information sources, i.e. the studies carried out by ACER [34], THyGA [35] and MARCOGAZ [36] and also by press releases (see below).

Respecting the developments in the countries since the closure of the questionnaire, the information has been updated by bilateral exchange with the addressees of the questionnaire and integrated in the following descriptions of the countries' situations, as far as possible.

Note: If 'pure hydrogen' is mentioned in the text, it is referred to a fuel gas that is mainly composed of hydrogen, e.g. for more than 98 Vol-%.

The complementary information sources used for supplementing the general national framework are described in the following:

- **ACER survey report on hydrogen, biomethane and related network adaptations** [34]. The evaluated survey aimed at the identification of the current technical ability of the gas transportation system and the potential adaptation investments to accept hydrogen and biomethane in the gas transmission grid, not including the repurposing for the use of hydrogen. Thus, similar questions on hydrogen as those in the HIGGS questionnaire were put forward. The survey was carried out in parallel to the HIGGS project and was published in July 2020. The related survey was addressed to the national regulatory authorities and bundles the replies from up to 23 countries. It collects the information on the national legal situations and national approaches regarding dedicated hydrogen and hydrogen blended with natural gas including information on adaptation needs to enable the use of hydrogen in the existing gas infrastructure. It reflects the need of a European-wide or regional H_2 approach. Also, in this study a specific focus is given on gas transmission networks and particularly on cross-border points. It refers not only to hydrogen but also to biomethane. The report is publicly available on the ACER website and is recommended to read it.

- **THyGA project interim deliverable on current standardization & certification framework and the impact of H_2NG mixtures** [35]: THyGA (Testing Hydrogen admixture fore Gas Applications) is a project of the FCH-JU programme, too. It runs timely in parallel to the HIGGS project and is complementary to HIGGS as regards contents: It investigates especially the feasibility of the use of hydrogen in the residential and commercial end-use. Information on the national technical and legal framework was investigated as a basis for the project considerations as well. The interim deliverable has been published on the project website in the end of 2020.

- **MARCOGAZ study on hydrogen regulation/standards** [36]: The document was published in November 2020 and results from an internal enquiry among the members of the MARCOGAZ working group for gas quality. It covers the national legal and technical framework focussing on limits of hydrogen volumes injected into the natural gas transmission and distribution grids for Belgium, Denmark, France, Germany, Italy, Portugal, Slovakia, Spain, Sweden and The Netherlands.

Further publications and press-releases have been consulted, which are indicated as reference and listed in the bibliography.

4.4.1 Austria

The current legal framework in concern of the injection of hydrogen into the gas grid consists of several laws, including the Environmental Impact Assessment Law (UVP-G 2000), the Natural Gas Act (2011), the Trade Commerce and Industry Regulation Act as well as acts on land use in each of the federated states. Currently, this framework is under revision to include renewable and low-carbon gases as hydrogen. Additionally, the technical framework consists of the technical rules of the Austrian gas association ÖVGW (Österreichische Vereinigung für das Gas- und Wasserfach) as well as the national and nationally implemented European and international standards. Recently, the technical rule for gas quality, G B 210 [37], has come into force. It defines the gas quality for injection, transport, storage, retrieval and distribution of gases in gas pipeline systems in accordance with the Austrian gas law and is applied complementary to the ÖNORM EN 16726 and ÖNORM EN 16723-1. The former G 31 on gas quality and G B 220 on renewable gases have been transferred into the new G B 210. The gas market model ordinance (Gas-Marktmodell-Verordnung 2012) references to the respectively applicable technical rules for gas quality from the ÖVGW.

According to the ÖVGW G B210 a maximum concentration of 10 Mol-% of hydrogen can be injected into natural gas distribution grids. For some gas applications as for compressor stations, turbines, storages, high-tensile steel pipes, CNG tanks, individual examinations are needed.

In Austria the producer of hydrogen is responsible for the blending with natural gas; TSOs do not have the obligation to provide the necessary natural gas for the blending. Also, the TSO is not obliged to accept any other gas quality except the specified one. It is not allowed to inject pure hydrogen (100 %) into natural gas grids, although according to the ACER report, isolated industrial hydrogen networks with 100 % hydrogen exist [34]. Furthermore, it is not allowed to feed in hydrogen and natural gas blends with higher concentrations of hydrogen, than the maximum of 10 Mol-%, even if it can be guaranteed, that the required quality specification will be matched at the next exit point. Exemption builds, the use of higher concentrations for research purposes. In this case, special agreements for the use of higher concentrations between the relevant parties, e.g. the injecting network operator and the customers in the affected grid, are required.

Gas for the border-crossing gas transmission has to meet the requirements of ÖNORM EN 16726. When injecting into the transmission gas grid it is very likely, that the mixture will cross the borders to neighbouring countries, where other obligations might have to be fulfilled. According to the ACER report, current cross-border activities are not coordinated with the neighbouring member states [34].

The permitting party for the connection to and injection of hydrogen into the transmission gas grid is currently the corresponding TSO, since the TSO is responsible for a safe, cost efficient and reliable operation of the transmission system. The current maximum hydrogen injection concentration is determined because of technical restrictions, such as the embrittlement of pipeline and equipment material.

The Austrian TSOs Gas Connect Austria and Trans Austria Gasleitung GmbH (TAG) part of the European Hydrogen Backbone planning initiated by Gas for Climate [38].

4.4.2 Belgium

In Belgium, the Gas Law (Royal Decree) forms the framework for the hydrogen in natural gas systems. The updated version, published on 27 May 2021 and put into force on 6 June 2021, extends the authorisation for the transport of natural gas by the injection and transport of biogas, gas from biomass or other types of gas [thus also hydrogen], as well as mixtures of these gases with natural gas" in the natural gas network respecting the technical feasibility and safety and the required gas specification of the network [39]. The concentration of hydrogen in blends with natural gas is not yet stipulated.

Currently, a hydrogen concentration in blends with natural gas up to 2 % is in discussion. The hydrogen concentration of up to 2 Mol-% in the mid- and high-pressure gas networks is currently approved in the revision and extension of the technical prescription of Synergrid G8/01 [40] on the injection for biomethane in the Belgian gas grid, the Belgium federation of electricity and gas network operators. (This hydrogen concentration is in line with EN 16726-1 and -2.) G8/01 determines the pre-mixing with the methane gas prior to injection. For injection of pure hydrogen and for the specifications for the connection of a hydrogen injection facility, additional standards from Synergrid are required, as well as adequate agreements with the network operator.

Furthermore, a formal consultation on the Access Codes for Transmission and the Standard transmission agreement will be organised in Q3 2021 aiming at the usage of hydrogen blends from the natural gas grid; for injection, the formal consultation is expected during Q1 2022.

The earlier consultation on the G8/01, organised by Synergrid, [41] did not indicate major concerns regarding a 2 Mol-% blend, presuming that these blends are not crossing any interconnection point with other market or country nor be injected in underground storage facilities as not enough knowledge is available for aquifer storages at the time being. The view of the end-use market need to be completed by a dedicated consultation.

The legal entity facilitating the connection and injection of hydrogen into the transmission gas grid is currently the corresponding TSO, under the permission of the energy market regulator, the CREG. Taking into account end-users needs, a pro-active screening of the downstream customers regarding their gas quality requirements is considered necessary, especially in the field of feedstock.

Lately, the national hydrogen strategy is announced to be published in late summer 2021. A study on “The role of clean gas in a climate neutral Belgium” initiated by the BE Federal Public Service Economy (DG Energy) [42] was published recently which sees the strategic role of the existing gas infructure and the repurposing for hydrogen (and carbon dioxide). Other sources indicate a clear market trend and policy commitments can be seen already favouring green hydrogen pilot projects [43].

The Belgium TSO Fluxys is member of the Gas for Climate Initiative and therefore part of the European Hydrogen Backbone studies [38].

4.4.3 Croatia

In Croatia the legal framework for gas quality is defined by the Energy law on gas, which covers natural gas and other types of gas (e.g. biomethane, liquefied natural gas, …). The same law stipulates the responsibility of the TSO to receive and transmit these gases that must comply with the Table 3, Standard gas quality of 'General Gas Supply Conditions' rule. Currently, hydrogen is not covered by the gas legislation nor by another specific hydrogen law.

The injection of pure hydrogen (100 %) is not allowed; the production of the blend to be injected into the natural gas grid is in the responsibility of the hydrogen producer.

The current gas quality requirements do not explicitly exclude H_2NG blends, but the injected volume would be limited by the specified gas quality parameter such as NCV, GCV, upper and lower Wobbe index, relative density and dew point, temperature at a pressure of 70 bar of water and hydrocarbons. No statement is made on potentially possible injection volumes.

The Croatian regulator carried out a nation-wide study on gas quality, the result of which are not publicly available. However, it is awaited that the Standard gas quality of 'General Gas Supply Conditions' rule will be updated.

The development of a national hydrogen strategy started on initiative of the Croatian Government and especially of the Ministry of Economy and Sustainable Development, beginning of 2021 [44].

4.4.4 Cyprus

Cyprus has not yet established the national gas market and thus there is no transmission network and no quality standards defined yet [34].

4.4.5 Czech Republic

The current legal framework in concern of the injection of natural gas into the gas grid consists of several laws, including the Energy Act, the Decree on gas metering and on the method of determining compensation for damage (specifying the quality of gaseous fuels), as well as the Decree on requirements for biomethane (transmission, distribution, underground storage). Hydrogen is specified only in the latter, related to the injection of biomethane into the transmission system. Here the limits for H_2 concentrations are up to and including 0,01 Mol-%. Besides that, hydrogen is not defined as fuel gas and is therefore not subject to the gas legislation, yet. Consequently, the transport of pure hydrogen or as a blend in the natural gas network is not allowed. However, hydrogen will be defined as fuel gas in the new Energy Act.

The current National Climate and Energy Plan is focussing on the production and use of biomethane; it also indicates pilot projects in the area of power-to-gas.

The national H_2 strategy is currently being prepared and should be released in July 2021. The strategy was discussed in connection with the preparation of a new Energy Act and in a dedicated working group of the Ministry of Industry and Trade with the relevant associations [34]. The European development of hydrogen uses for decarbonisation is carefully monitored in order to gather information for the required adaptation of the legislation.

The Czech TSO NET4GAS participates in the European Hydrogen Backbone studies, initiated by the Gas for Climate initiative [38].

4.4.6 Denmark

Currently the legal gas quality requirements in Denmark do not specify hydrogen limits for blends or pure hydrogen in natural gas networks. However, the gas quality ordinance [45], §§ 27 to 29 + §§ 53 to 55, stipulates the hydrogen quality injected into the natural gas network as at least 98 Vol-% hydrogen by volume. The volume content of hydrogen in natural gas grids generally requires the approval of the Danish Safety Technology Authority. Continuous respectively periodical gas quality parameter measurements are obligatory. [36]

This ordinance also covers the hydrogen quality supplied to stationary fuel cells or in dedicated gas distribution networks where stationary fuel cells are connected. The required H_2 volume content is 98 Vol-%; the overall composition of the hydrogen is diverging of that to be injected in the natural gas grid. Deviations from the 98 Vol-% H_2 content needs authority approval.

Hydrogen in transmission networks is not yet defined in the ordinance nor in the Energinet requirements for gas quality and delivery specifications for shippers [46] which refer to the gas ordinance. Thus, for the moment, it is not allowed to inject any amount of H_2 or to transport pure hydrogen in the gas transmission network. Dialog between the parties is ongoing.

Denmark intends to launch a national hydrogen strategy. There are suggestions in Denmark to establish a hydrogen industry with surplus of production of hydrogen using wind and solar power. Since the Danish demand is regarded as limited, the export to e.g. Germany is viewed as potential export destination for surplus hydrogen [34] [47].

The Danish Safety Technology Authority is the competent authority to set hydrogen blending limits in Denmark [34].

The Danish TSO Energinet is member of the Gas for Climate Initiative and therefore part of the European Hydrogen Backbone studies.

4.4.7 Estonia

In Estonia currently no injection of hydrogen volumes into the natural gas network is allowed [34], so far. A hydrogen strategy is under development on proposal of the Estonian at the time of the writing of writing this report.

The Estonian TSO Elering is member of the Gas for Climate Initiative and therefore part of the European Hydrogen Backbone studies.

4.4.8 Finland

The current relevant legal framework relevant for hydrogen in the gas grid consists of the Act on Safety Handling of Hazardous Chemicals and Explosives [48] and the Decree on safe handling natural gas [49]. The latter stipulates the requirements for the natural gas grid but does not refer to the injection of hydrogen into the grid.

Also, for the transport of pure hydrogen no legislation is set, yet. However, a short-term need is seen with view to potential pilot projects with pure hydrogen and the possible need of other small grids within the next 5 to 10 years. Therefore, discussions between the TSO Gasgrid Finland Oy and the authorities have started.

The responsible party for the permission of the connection and injection of hydrogen into the transmission gas grid is currently the Finnish Safety and Chemicals Agency and the Finish TSO Gasgrid Finland Oy, owner of the gas transmission grid.

The TSO has set a maximum concentration limit of 1 Mol-% hydrogen as admixture in natural gas which is acceptable for all end-users. The TSO monitors the gas quality of the gas that enters the grid. Off-spec gases are not allowed.

The national energy and climate strategy of Finland includes hydrogen as a significant part of the decarbonisation. Instead of a national hydrogen strategy, a hydrogen roadmap [50] has been established on behalf of Business Finland (the Finnish government organization for innovation funding and trade, travel and investment promotion). This builds the basis for the Finish hydrogen policy and the build-up of the legal and technical framework. Finland aims to be carbon neutral by 2035 and carbon negative by 2050. The roadmap refers to the transport of gaseous hydrogen in tube trailers and dedicated hydrogen pipelines, as far as the volume is large enough to allow economic scale of hydrogen transport. For the latter the existing gas infrastructure could be used, but also dedicated hydrogen network newly built. Blending is not mentioned in the document.

However, the Finish TSO currently considers two pathways:

1) blending in the current grid – A study with the Baltic operators has been initiated to investigate the possibilities to increase the hydrogen content in the natural gas grid.

2) pure hydrogen infrastructure – the Finish TSO Gasgrid Finland Oy joined the Gas European Hydrogen Backbone [38]. to visualize the potential market needs regarding pure hydrogen grids in the future.

4.4.9 France

The French Energy code builds the legal basis for the gas grid in France [51].

According to the gas quality specifications in the technical requirements applicable to the connection of a third-party facility to the natural gas transmission grid natural gas transmission system from GRTgaz [52] and TERÉGA, a maximum of 6 Mol-% of hydrogen is allowed in the injected gas. This means that up to 6 Mol-% hydrogen is generally permitted, as long as the legally stipulated higher heating value (HHV) of the gas and the further TSO requirements are respected. The legal framework requests the gas system operators by law (Article R433-12 of the Energy code) to provide specification for the gas quality transported and distributed through their network. However, the network operator is not obliged to accept this maximum hydrogen concentration in the grid.

Regarding pure hydrogen at present there is no legal basis for the construction or operation of pure hydrogen networks; consequently, TSOs have no permission for that without exemption agreements by authorities in general and in specific terms of design and safety.

For R&D pilot projects with blends and pure hydrogen also specific agreements are necessary and possible, as for the project GrHyD.

Corresponding to the current responsibilities for natural gas, it is presumed that the natural gas grid operators will also be responsible for hydrogen transmission and distribution in future.

Regarding the injection modalities, TSO specifications do not allow the injection of pure hydrogen into the grid (comparable to biomethane injection). The injecting party is responsible for the blending with natural gas prior to injection.

The French Energy and Climate Act of 8 November 2019 [53] implements the national climate change policies and builds the basis for the energy transition in France. It allows the government to specify the different types of hydrogen according to their sources, to permit production, transport, storage and traceability of hydrogen and also to define the framework to facilitate the use of low-carbon and renewable hydrogen. First implementation is realised with the publication of the ordinance No. 2021-167 in February 2021 [54] [55]which build the frame for the renewable and low-carbon hydrogen market in the country. It defines the types of hydrogen (renewable, low-carbon, and fossil-based) including the related permissible CO_2 emission limits, the tools for traceability (Guarantee of Origin and Guarantees of traceability). Also, a subsidy mechanism for the production by electrolysers is part of the legal document. The ordinance also amends other legal documents to create the appropriate framework for the use of hydrogen.

As a basis for the further shaping of hydrogen in the energy sector, a specialised working group is working on the definition of the technical requirements for the connection and injection of hydrogen and first small-scale demonstration projects are carried out. There are private pipeline networks outside of the regulated network with 100 % hydrogen for industrial purposes [34].

The French national hydrogen strategy has been released in September 2020 and outlines three priorities:

1. decarbonisation of the French industry by developing a French electrolysis sector,
2. development of heavy-duty transport using hydrogen and the further investments into research and
3. development of hydrogen and corresponding technologies.

The ambition is to invest a total of 7 billion € until 2030. Several projects are already ongoing and planned in near future [56]. Regarding hydrogen concentrations in blends, a potential increase by 10 % is indicated. However, the main target sectors of the current strategy are the industrial, the power and the transport sector, while the buildings sector is considered as well with an expected overall annual hydrogen consumption of 41 TWh in 2028 [57].

The French TSOs GRTgaz and TERÉGA are members of the Gas for Climate Initiative and therefore part of the European Hydrogen Backbone studies [38].

4.4.10 Germany

The current legislative and regulative framework in concern of the injection of hydrogen into the gas transmission grid consists of the Energy Act (2021), complemented by the High-pressure Gas pipeline ordinance and the Gas Grid Access Ordinance.

The revised Energy Act has been published in the Official Journal on 26 July 2021. It includes hydrogen as a fuel gas and determines hydrogen systems as gas systems similarly to natural gas. The legal presumption clause that the gas system is designed, constructed and operated in a safe, economic and environmentally friendly manner if the Codes of Practice of the German scientific and technical association for gas and water – DVGW (Deutscher Verein des Gas- und Wasserfachs) are applied, is extended for hydrogen in expressis verbis (ENWG § 49). Accordingly, the application of DVGW Codes of Practice is extended for the field of hydrogen.

The German gas quality requirements for gas systems – complementary to EN 16726 – are defined in DVGW G 260 [58], DVGW G 262 [59] and DVGW G 472 [60]. Currently, as per DVGW G 262 from September 2011, clause 5.9, a hydrogen concentration in natural gas up to below 10 % is permitted with restrictions for some grid components such as gas turbines, underground gas storages and CNG stations that in many cases can are designed for hydrogen contents between 2 and 5 Vol-%. With the revised G 260, expected for end September 2021, hydrogen as such will become a gas for public gas supply. The new G 260, which also integrated DVGW G 262, presents the current state of the art with regard to the injection of more than 10 Vol-% hydrogen content. As a prerequisite, hydrogen injection requires grid-specific investigations that also include downstream structures and consumers to confirm the actual suitability. In blends, hydrogen is fed in as an augmentation gas; no processing or conditioning are requested. However, when feeding hydrogen into gas supply networks, it must be ensured that the requirements of DVGW Code of Practice G 260 are met in the base gas and that the natural gas-hydrogen mixture is homogenous by the next exit point and that inadmissible hydrogen enrichment, e.g. in shuttle zones, is avoided. In the case of cross-border gas transport, European technical requirements are to be respected.

Further, to comply with the requirements of the energy act, a new. 5th gas family is introduced in DVGW G 260, specifying hydrogen for grids, in two groups of different purity.

The DVGW has started the extension and completion of its Codes of Practice for hydrogen-containing gases and for pure hydrogen, including the generation, injection, blending, transport, distribution and storage of hydrogen in the natural gas infrastructure and use in gas applications. This includes rules for the conversion of existing gas grids for 100 % of hydrogen and the construction of dedicated hydrogen grids. The aim is to facilitate 10 Vol-% of hydrogen by 2030 for the whole gas system without restrictions, to enable 20 Vol-% further on and to provide in parallel the Codes of Practice for the conversion and new construction of the grids for 100 Vol-% of hydrogen.

DVGW Codes of practice including hydrogen aspects and with relevance for gas transmission grids are already available for:

- hydrogen injection stations (G 265-2 [61]+G 265-3, Guideline [62]; basis of the CEN/TC 234 WI 00234089 to 90 [63])
- a systematic approach for the assessment and conversion of existing gas transport pipelines with maximum operation pressure over 16 bar for operation with hydrogen (G 409, Guideline [64]) describing also technical aspects and the procedure for determining the material-mechanical suitability of a pipeline.

- qualification of experts for energy systems for pipeline-bound supply of the general public with gas including hydrogen (G 100 [65]), fulfilling also the criteria of the High-Pressure Gas Pipeline Ordinance)
- operation of metering points (G 687 [66])
- explosion protection (G 440, Guideline [67])

Furthermore, the update for gas transmission steel piping (G 463 [68] and G 466-1 [69]) is in progress; A guidance document is in elaboration complementing the DVGW codes of practice for the use of 'hydrogen-rich fuel gases' and hydrogen in the gas infrastructure where the available codes not yet cover the specific hydrogen aspects. The publication is expected in 2021.

In Germany, isolated hydrogen pipeline networks with 100 % hydrogen concentrations already exist for industrial purposes owned and operated by private network operators, mainly from the chemical industry. These are built according to another legal regime, the rules for gas transmission pipelines [70]. Furthermore, several pilot projects are in progress for which agreements with authorities and other involved parties are made and for which DVGW codes of practices and other relevant codes and standards are applied, as far as possible.

Regarding the German climate strategy, measures for CO_2 savings have been tightened again, aiming at climate-neutrality by 2045, and at reduction of greenhouse gases emission of 65 % (instead of 55 %) less than in 1990 until 2030. The new thresholds also build a significant challenge for the gas sector.

The national hydrogen strategy has been published in June 2020. The government recognises hydrogen as a chance to reduce greenhouse gases by developing a market for green hydrogen and sees a high potential for decarbonisation of sectors like steel and chemical industries, among others. Until 2030 a capacity of 5 GW hydrogen production shall be established [71].

This shall foster economic growth in the national economy and help to secure the energy supply in the future energy system. Germany as a country without sufficient resources for energy production (fossil and renewable), at least in the mediate future, sets a strategic bias towards the import of hydrogen from other member states in the North and Baltic Sea as well as southern Europe/North Africa. The main target sectors of the current strategy are the industrial and the transport sector, while the power and the buildings sector are considered as well with an expected overall annual hydrogen consumption of 90-110 TWh in 2030 and 110-380 TWh in 2050 [57].

The German TSOs Open Grid Europe and ONTRAS as well as the DSO Creos are members of the Gas for Climate Initiative and also part of the European Hydrogen Backbone studies [38].

4.4.11 Greece

In Greece there is presently no legal or technical framework in regards of hydrogen injection or transport, but the production of hydrogen and the use of hydrogen - among others - in coupled energy systems is included in the National Energy and Climate Plan (NECP) with longer term perspectives. No concrete targets are set by now. [72]

Ministry of Transportation has plans to establish legislation and eventually build hydrogen infrastructure up from 2025. As far as the gas grid is concerned Greek companies are planning to enable and realise the blending of hydrogen with natural gas in the future.

The Greek TSOs DESFA is member of the Gas for Climate Initiative and also part of the European Hydrogen Backbone studies.

4.4.12 Hungary

Currently, the Hungarian Natural Gas Law [73] does not mention the injection of hydrogen volumes into the transmission gas network but there is also no prohibition. The current legislation or gas quality standards do not mention blending H_2 in natural gas. Work is being done on a new regulation to allow H_2 blending in the natural gas infrastructure, which will most likely consider EU legislative developments.

The following two authorities are generally responsible for the permission of the connection and injection of hydrogen in the gas grid:

- Hungarian Energy and Public Utility Regulatory Authority (HEA, Magyar Energetikai és Közmű-szabályozási Hivatal)
- Mining Authority (responsible for establishment of any new injection point).

In May 2021, the Hungarian government published Hungary's National Hydrogen Strategy [74], with the aim to produce 36,000 t / year "green" hydrogen, other carbon-free and low-carbon hydrogen in 2030. As part of the strategy, it is considered that, in the foreseeable future, hydrogen may be introduced to natural gas networks in Hungary, with a min. 2 % per year volume blending ratio in the natural gas system (where appropriate) by 2030. The first projects for hydrogen production have been incentivised by the government [75].

The Hungarian gas TSO FGSZ is part of the European Hydrogen Backbone studies initiated by Gas for Climate [38].

4.4.13 Ireland

Currently, the legal as well as the technical framework in Ireland do not allow the injection of hydrogen volumes into the transmission gas network. However, a maximum concentration of 0,1 Vol-% hydrogen in natural gas is permitted by the TSOs.

The Irish Government set an ambitious Climate Action Plan in 2019 [76] with a revision in 2020 which foresees the reduction of emissions by 7 % per year by 2030. Government and Irish regulator CRU indicate in their strategies the increase of the share of gases from renewable sources [34]. Although, no specific strategy for hydrogen is set so far, the progress report, "Interim Climate Actions 2021" [77] determines the major steps for the decarbonisation of the natural gas grid (action 54) including sector integration between gas and electricity, the use of green hydrogen (pure and as blend), by Q4/2022, i.e.:

- assessment the potential for energy system integration between the electricity and gas networks including the production, storage and use of green hydrogen.
- development of a policy/regulatory roadmap for green hydrogen uses in the natural gas grid
- completion of the feasibility assessment on the use of green hydrogen blends in gas networks and end-use application regarding technical integrity and safety.

The Irish TSO Gas Networks Ireland supports the climate action with a clear vision for 2050 which intends to provide a net zero carbon network by 2050 with help of biomethane (37 %), hydrogen (13 %) and abated natural gas (50 %) by carbon capture and storage. It is intended to use hydrogen increasingly up from 2034, as blending and in its pure form. Research and co-operation with the authorities are ongoing [78].

The Irish TSO Gas Networks Ireland takes part in the European Hydrogen Backbone studies initiated by the Gas for Climate [38].

4.4.14 Italy

In Italy there is no specific legal or technical framework concerning the injection of hydrogen into the gas grid. So far, there is no allowance to inject pure hydrogen into the transmission network but natural gas with a maximum hydrogen concentration of 0,5 Mol-% is accepted [21] [35].

The Ministry of Economic Development of Italy published preliminary guidelines for the hydrogen strategy for public consultation in November 2020 [79]. It states the objective of 2 % hydrogen penetration into final energy demand by 2030, and up to 20 % by 2050.

The use of hydrogen in the natural gas grid will be part of the strategy but no details are given in the current document. The national hydrogen strategy has been announced for beginning of 2021 but is not available at the drafting of this report.

The Italian TSO Snam initialised experimental projects, that cope with the injection of hydrogen blends with hydrogen concentration of 5 respectively 10 % into defined parts of the grid, working collaboratively with industry customers. About 70 % of the gas transmission grid is already considered hydrogen-ready and internal technical procedures for hydrogen are already established within the company [80]. The concerns in regards of hydrogen limitations relate to underground gas storages, gas-fuelled vehicles, engines and turbines. In the context of power-to-gas projects planning, allowances for injection of hydrogen might be included [34].

The Italian TSO SNAM is member of the Gas for Climate initiative and participates in the European Hydrogen Backbone studies [38].

4.4.15 Latvia

Currently, there is no dedicated legal or technical framework for hydrogen in Latvia. The maximum concentration of hydrogen in natural gas in the transmission network is less or equal to 0,1 Mol-%.

National energy and climate plan foresees the evaluation of the hydrogen potential for Latvia and solutions for introduction of the H_2 into states energy mix, but no legislative process is started, yet. So far, no hydrogen strategy has been released [34].

The Latvian TSO Conexus considers a H_2 concentration up to 2 Mol-% as realistic, with the condition that the hydrogen has no deteriorating effects on aquifer underground gas storage reservoir part in operation.

4.4.16 Lithuania

In Lithuania, no national legislation or regulation for the injection of hydrogen into the gas transmission system is set by now. Respecting the current national gas quality specification, a hydrogen content of up to 0,1 Mol-% in natural gas is permitted. In the case of biomethane injection and in accordance with the conditions for connecting biogas installations to the transmission system (issues by the TSO), the concentration of up to and including 2 Mol-% in the biomethane is permitted. However, specific attention needs to be given to the location of the connection point, the technical safety criteria for the injection facilities in the gas transmission system and also the gas accounting standards.

The Ministry of Energy in the Republic of Lithuania, created in September 2020 the Lithuanian Hydrogen Platform composed of 19 Lithuanian organisations, including e.g. ministeries, institutes, associations and energy companies. The objective is to participate in the different national, regional and EU policies and to develop a Hydrogen Strategy and Hydrogen Development Action Plan. Also, the contribution to the legal framework setting and encouragement of joint research is aimed at [81].

The development of hydrogen technologies in Lithuania are also seen in the context of National Strategy for Energy Independence (NSEI) referring to aspects like climate change, air pollution, energy security.

So far, there is no national hydrogen strategy set. However, a support scheme might be developed to fulfill the national decarbonisation objectives [34].

4.4.17 Luxembourg

Currently, the legal as well as the technical framework in Luxembourg do not allow the injection of hydrogen volumes into the transmission gas network.

There is no published national hydrogen strategy so far, but the Ministry of Energy presented a working document for public consultation in February 2021 [82] [83]. It gives specific focus on the use of renewable hydrogen in industry.

4.4.18 Poland

Currently, the legal as well as the technical framework in Poland do not cover the injection of hydrogen volumes into the transmission gas network, yet. Hydrogen is legally not considered as a gaseous fuel but as technical gas. Consequently, hydrogen in natural gas would be considered as contaminant; the injection of hydrogen into and transportation through the gas transmission network are not allowed at the time being. The revision of the legal energy provisions is already decided to enable the use of hydrogen in the natural gas system. This includes revision of Polish Energy Law Act [84], Art.3 § 3a (definition of gaseous fuel) and art. 9d §1h (role of TSO). Furthermore, consideration of conversion and storage possibilities of energy in legislation is needed. Currently there is no definition and therefore permission in Polish Energy Law Act for storage of electrical energy.

A draft hydrogen strategy has been released, which defines six objectives until 2030 and foresees total investments of about 220 Mio. € until 2030. The main objectives are the implementation of hydrogen technologies in the energy and industry sector, hydrogen as fuel in the transport sector, implementation of new hydrogen production, implementing hydrogen-ready transport and update the regulatory framework [85].

The Polish TSO takes part in the European Hydrogen Backbone studies initiated by the Gas for Climate Initiative [38].

4.4.19 Portugal

Currently, the legal as well as the technical framework in Portugal do not cover the hydrogen volumes into the transmission gas network. It is up to the TSO to guarantee the quality of the gas [36].

In August 2020, the government has published an umbrella law, the Decreto-Lei n.°62/2020 [86] on the organisation and functioning of the gas system, which makes the adaptation of several legal documents necessary.

The national hydrogen strategy (EN-H_2) has been released in May 2020. It includes the intentions to develop the related regulation/legislation in concern of the injection and transport of hydrogen is in ongoing [87].

4.4.20 Romania

Currently, the legal as well as the technical framework in Romania do not cover the injection of hydrogen volumes into the transmission gas network.

The NECP includes plans for hydrogen in the national energy mix. The specific national hydrogen strategy is still in preparation by the Ministry of Energy [88].

4.4.21 Slovak Republic

The legal framework for the gas grid will generally apply for the use of hydrogen in the gas grid. Specific legislation for the injection of hydrogen is not yet set. The most relevant laws are:

- Energy Act No. 251/2012 Coll. and on Amendments to Certain Acts;

- Act no. 309/2009 Coll. on the Promotion of Renewable Energy Sources and Highly Efficient Cogeneration and on Amendments to Certain Acts; and
- Act no. 250/2012 Coll. on Regulation in Network Industries.

Currently, the legal as well as the technical framework in the Slovak Republic do not allow the injection of hydrogen volumes into the transmission gas network. The maximum concentration of hydrogen in natural gas in the transmission network is not defined. In imported natural gas a maximum of 2 % of hydrogen can be present [34].

For current research and pilot hydrogen projects, the legislation for natural gas is applied and interpretated, where needed.

A hydrogen strategy has been released in June 2021 [89]. For the further development Slovakia orients the further development at the hydrogen framework setting of other EU countries with view to injection limits of between 20 and 30 % hydrogen [90].

The Slovak Gas TSOs Eustream is part of the European Hydrogen Backbone studies initiated by Gas for Climate [38].

4.4.22 Slovenia

Currently, the legal as well as the technical framework in Slovenia for the injection and transport of hydrogen is not yet set. So, no explicit maximum concentration of hydrogen which is allowed to be transported in gas transmission network, is given.

So far, no hydrogen strategy has been released. But based on the Slovenian Energy and Climate Plans, investigations of the existing gas grids for H_2 readiness and adaptation needs are ongoing to facilitate the share of 10 % renewable gases in the system by 2030. First projects to develop towards green hydrogen production and the use of hydrogen especially in the transport sector, e.g the energy agency project (KSSENA), are in process [91].

The Slovenian TSO Plinovodi participates in the European Hydrogen Backbone studies, initiated by the Gas for Climate initiative [38].

4.4.23 Spain

The Spanish legal and technical framework in regards of the gas grid system is quite extensive. Law 34/1998 “The Regulation of the supply of combustible gases by canalisation” is the basis for the gas grid system and its regulation. Therefore, it mainly applies to natural gas, but also to other gas types, if it is technically possible and safe to inject and transport these gases into the gas grid. In June 2020 the Royal Decree 542/2020 modified the technical regulation of distribution and use of gaseous fuels including hydrogen in the gas phase as a fuel gas and including service stations for hydrogen vehicle in the gas phase.

The resolution from September 22, 2011 of the Directorate General of Energy Policy and Mines includes the protocol of detail PD-01 "Measurement" of the norms of technical management of the gas system. It specifies the current maximum concentration of hydrogen in natural gas that can be injected into the transmission gas grid is 5 Mol-%. Furthermore, the gas grid owner can reject gas, which is not according to the gas quality specifications and the owner of the injection facility is responsible for the gas quality. Currently, a revision of the PD-01 is ongoing and it is foreseen to reference to the UNE-EN16726 standard, which would change the permitted maximum hydrogen concentration.

The Spanish government published the Spanish national hydrogen strategy in October 2020 focusing on green hydrogen. The strategy establishes country targets until 2030 and provides visions for the development in 2030 and 2050. It sets the goal to scale up the electrolysis capacity to 4 GW with a total investment volume of about 8.9 billion € [92]. The main target sectors of the current strategy are the industrial, the transport and the export sector, while the power sector are considered as well [57].

The Spanish TSOs Enagas is member of the Gas for Climate Initiative and also part of the European Hydrogen Backbone studies.

4.4.24 Sweden

The legal framework for the natural gas grid is determined by the Swedish natural gas act [93] and the Natural gas regulations MSBFS 2009:7 [94]. These do not include requirements for hydrogen in the gas grid. At the time being, the responsible authority or legal entity for the permission of the connection/injection of hydrogen in the gas grid is not yet defined.

There is no maximum concentration of hydrogen in natural gas legally stipulated; levels up to 2 % are in discussion so far. There are no restrictions regarding gas composition as far as it is within the limits of the TSO quality specification and complying with the safety requirements [95]. There is no defined maximum concentration from authorities but for safety reasons a maximum of 2 Vol-% hydrogen is used in practice. Also, the EN 16726 is followed by the TSO. A hydrogen strategy is currently under development [96].

The Swedish TSO Swedegas is member of the Gas for Climate initiative; Nordion Energi participates in the Hydrogen Backbone studies [38].

4.4.25 Switzerland

Currently, the legal as well as the technical framework for the injection of hydrogen into the transmission gas network is not yet set for Switzerland. There are also no clear rules for the access to the gas transport network; a case-by-case decision is needed. The revision of the current Gas Supply Act (GasVG), subject to consultation from October 2019 until February 2020, stipulates a comprehensive set of rules to facilitate an efficient gas market. Hydrogen is not mentioned in the draft legal document.

The national gas quality specifications do not allow any hydrogen in the gas transmission grid, yet, whilst up to 2 % hydrogen is permitted in the distribution grid.

From the technical point of view, the Swiss TSOs consider that there are no limitations for the gas transmission grid to use hydrogen but for gas compression in the north/south pipeline (5 %), operated by Transitgas.

Switzerland, not member of the EU, supports the EU Hydrogen Strategy. The national hydrogen strategy is in preparation. As a basis, the National Council adopted a Parliamentary Initiative in June 2021 [97].

4.4.26 The Netherlands

The Dutch legal framework concerning gas grid issues is composed of two umbrella laws, the gas act [98] and the electricity act [99], version 2014 [100]. It is noted that the gas act is not including hydrogen by now. These laws are complemented by a set of Decrees for the construction of energy infrastructure (Besluit aanleg energie–infrastructuur), the security of supply gas (Besluit leveringszekerheid gaswet), the safety of low-pressure gas transportation (Besluit veiligheid lage druk gastransport) and the gas quality requirements (Regeling Gaskwaliteit). Also, the regulation of quality aspects of electricity and gas grid management and the regulation on notification of construction and extension investments are coming forth from the afore mentioned gas and electricity laws. Important codes provided by Netbeheer Nederland (the organisation of all Dutch electricity and gas grid operators) or NEDU (the organisation of all stakeholders in the regulated gas and electricity chain) in regard of the injection of hydrogen are the Measurement Code (Meetcode Gas) and the Injection Code (Ivoedcode Gas) both for the TSO. These codes are legally anchored to – among others – the gas act and electricity act.

In the Netherlands, the Decree on gas quality requirements (The Ministeriële Regeling Gaskwaliteit) specifies a maximum hydrogen concentration of

- 0,02 Mol-% for the high-pressure L- and H-gas transmission grid, at the entry and exit points.
- 0,5 Mol-% for the L-gas distribution grid and the low-pressure L-gas transmission grid, at entry and exit points.
- 40 Mol–% for a specific and small H-gas area (defined in the Decree), at the exit.

The Decree is maintained by the Dutch Ministry of Economic Affairs as responsible authority.

Generally, the TSO are accepting injected gases that are fulfilling the gas quality requirements. Provided that the main constituent is methane TSOs are permitted to accept gases with similar characteristics as natural gas and also to blend them with other gases to provide the legally stipulated exit quality. Thus, theoretically, TSO can accept gases with hydrogen concentrations in the natural gas less than 50 Mol-% under special arrangements and ensuring the required exit quality. (DSOs are not allowed to blend gases). Logically, the injection of pure hydrogen in the gas transmission grid is not allowed.

The Dutch government published the Dutch national hydrogen strategy in April 2020 focusing on green hydrogen but also considering blue hydrogen. The strategy sets three different milestones for the time periods of up to 2021, from 2022-2025 and from 2026-2030, setting the goal to scale up the electrolysis capacity to 3-4 GW with a total investment volume of about 325 Mio. € [101]. The main target sectors of the current strategy are the industrial and the transport sector, while the power and the buildings sector are considered as well with an expected overall annual hydrogen consumption of 94-215 TWh in 2050 [57].

The Dutch TSOs Gasunie is member of the Gas for Climate Initiative and also part of the European Hydrogen Backbone studies [38].

4.5 Certification – Proofing of H_2 readiness for high pressure piping and components

With view to the similarities between hydrogen and natural gas, natural gas networks are technologically suitable for the transport of hydrogen. Consequently, the same technical standards and codes of practice can principally be applied for the design, construction and operation of new hydrogen transmission networks. It is, furthermore, evident that the special properties of hydrogen and the resulting consequences for the gas transport grid, such as possible material embrittlement, pressure behaviour, higher upper explosion limit and energy content need to be taken into account by the appropriate measures and need to be anchored in the related technical standards and codes of practice. Finally, the hydrogen aspects need to be considered in the applicable conformity assessment procedures for the H_2-readiness of gas-related products and also for certification and (pre-)qualification schemes for networks and their components, companies and personnel.

Basically, also in the field of certification, the procedures for methane are considered adequate and applicable for hydrogen as well. For some hydrogen specifics, such as safety (ATEX and others), material specifications, gas behaviour (vibrations, turbulences in stations etc), grid integrity, a limited need for supplements might be needed. The detailed and internal approval procedures and certification need to reflect the necessities for use of H_2NG or the conversion to pure hydrogen as for natural gas (and other low-carbon and renewable gases). The learning process is still ongoing.

Thus, the European and national certification and qualification regimes are not yet formally set. At some TSOs and also certification bodies in the different countries, concrete hydrogen proofing activities and preparation of programs are in progress to facilitate pilot projects. These programs temporarily provide a pragmatic and reliable solution until the technical and regulatory framework is established. They are built on the available findings from completed and/or ongoing hydrogen research projects and the organisations' expertise. Finally, these temporarily certification programs will serve as starting point for the national and European conformity standards and regulations. However, in countries where hydrogen is not yet legally anchored as fuel gas, a formal certification setting is not yet possible, such as in the Czech Republic.

Prior to the use with hydrogen, the actual suitability of the existing network must be thoroughly assessed and proven by the network operators themselves and also – for some major aspects – by third party involvement.

The conclusions in this section are basically resulting from informal exchange with responding members of MARCOGAZ Working Group Gas transmission.

Thus, TSOs as well as gas associations and certification bodies are very committed to identify the hydrogen specifics and appropriate solutions to ensure the H_2 readiness of the transmission grid regarding H_2NG blends and pure H_2. According to current information, first informal European exchange is taking place among companies and/or certification bodies. The activity findings are rather company internal and informal and thus not yet available for use in this report. This hinders to draw a representative picture. However, an insight is given.

On one hand the technical suitability and pilot projects are offering necessary findings, on the other hand substantial test and certification projects are carried out, also to already prepare (as TSOs) the potential future conversion projects. The following aspects are addressed (not exhaustive):

- investigation of the technical asset readiness

  A related project of the German TSO Open Grid Europe (OGE) showed the readiness of the transmission asset for 2 Vol-% admixtures, and necessary technical changes for 10 Vol-% admixtures and proofed, which parts can be reused for hydrogen transport applications.

- prioritization and identification of pipeline components necessary to certify.

  OGE for example clustered the components with help of components' material data (KI-aided).

- evaluation of the requirements for dedicated procedures, partly in cooperation with third party organisations,

  Testing programs within GRTgaz are known; Procedures for valves are in process on TSO level: Gascade, Gasunie Deutschland, OGE, Ontras and Thyssengas; also requirements for valves in stock are in development on organisations' level: DVGW experts committee.

First development of suitability and/or certification procedures respectively programs can be observed based on technical assessments and manufacturers declarations:

- verification of natural gas system for hydrogen suitability of transmission grid with expertise of internal expertise, independent institutes and audit company,
  e.g OGE for relevant parts of the grid, including pipes, sealing materials but also components like compressor stations. [102]; The Czech TSO Net4Gas together with DNV on possible retrofitting of existing gas pipeline DN1400 to H2 – both blend and 100 % H_2 scenarios.
- certification procedures for gas measurement and regulation plants for up to 10 Vol-% H_2 admixture (OGE/TÜV)

- certification program for valves (DVGW CERT),
- Individual certificates for network equipment based on technical assessments and manufacturers declarations (DBI/TÜV)

Certification and approval programs are requested to offer reliable approval procedures for pilot projects and further gas transmission grid development until formal certification on the basis of European or national standards is available; Companies such as Energinet (DK), OGE (DE), Gasunie (NL) are currently establishing the engineering basis for the conversion and are establishing new hydrogen pipelines

The concrete operational inspection schemes are already under development in some companies but not yet at larger scale. Some network operators are already adapting a part of their pigs for hydrogen; some companies are seeing the need for specialized ILIs, e.g. considering crack-like features, geometry anomalies, hard spots as an important precondition for qualification especially of older assets. Evaluation of potential hydrogen specifics in in-line-inspection (ILI) (e.g. crack-like features, geometry anomalies, hard spots) are part of current projects and initiatives, such as EC-CEN PNR H_2NG (4.2.3), European Pipeline Research Group (EPRG) on the use of existing natural gas transmission pipelines for transporting hydrogen, Pipeline Research Council International (PRCI), H2GAR (0), HyDelta, Westküste 100, Marcogaz, GERG and internal company projects. Most of the results are project internal and not (yet) publicly available.

Not directly linked to certification or approval procedures but interesting as basis for the suitability proof, in Germany a DVGW internal document has been established as a kind of reference book with verified knowledge on the suitability of the gas transmission networks with hydrogen admixture and pure hydrogen. It contains short listings of the most important data for the gas transmission pipe material and gas transmission network components (piping, compressor station, gas pressure control, energy metering) and system aspects. The document also builds a source for the adaption of the DVGW codes of practice for hydrogen. At the time being, the mode of publication is not yet clear. (A similar reference book is existing for the distribution grid which will be transposed in an IT driven data base. The Swiss SVGW, involved in the DSO study, is following a similar approach for the register of certification.)

It is recommended to use bilateral and European networks to learn from the parties that are already working on certification and approval of suitability in order to be efficient and to come to a European framework as soon as possible.

4.6 Testing methods

In general, hydrogen embrittlement (HE) in hydrogen gas is evaluated by mechanical testing in high-pressure H_2 gas with two types of test methods: Dynamic load tests and static load tests.

Examples for “dynamic” load tests are:

- Tensile tests: SSRT method
- Fracture toughness test
- Fatigue test
- Disk rupture test

Example for a “static” load test is:

- Constant load/constant displacement test

Further an example for a non-mechanical test is:

- Hydrogen permeation test

In HE the combination of several testing techniques is usually recommended. The different test methods are outlined below. Additionally, results from the open technical literature are given.

4.6.1 Tensile tests: SSRT method

Tensile testing requires straining a specimen until rupture to determine the effects of hydrogen on ductility and strength (yield and ultimate tensile strength) of the material. Reduction of area and elongation are often used as a measure of the ductility. For example, for elongation the following index is used:

$$I_{EF}(\%) = \frac{E_F^{N_2} - E_F^{H_2}}{E_F^{N_2}} \times 100$$

Where E_F^{N2} is the elongation to failure in N_2 gas and E_F^{H2} is the elongation to failure in H_2 gas.

The Slow Strain Rate Test (SSRT) is a particularly important method to measure susceptibility to HE. Specimens are tensile strained to failure with “slow” strain rates commonly in the range 10^{-6} - $10^{-4}s^{-1}$. The results of the SSRT are evaluated comparing the results obtained in the inert environ-ment (air/N_2/ argon/helium) and in H_2 gas. Common specimen designs are based on cylindrical ten-sile specimens, but they could be modified by including a circumferential notch.

Standards:

- ASTM G142: Determination of susceptibility of metals to embrittlement in hydrogen containing environments at high pressure, high temperature or both.
- ISO 7539-7: Corrosion of metals and alloys. Stress corrosion testing - Part 7: Method for slow strain rate testing.
- ASTM G129: Standard practice for Slow Strain Rate Testing to evaluate the susceptibility of metallic materials to environmentally assisted cracking.

Figure 15 shows typical load vs strain SSRT curves obtained for API X80 steel in 30MPa of H_2 gas at different strain rates. Ductility increases with decreasing strain rate.

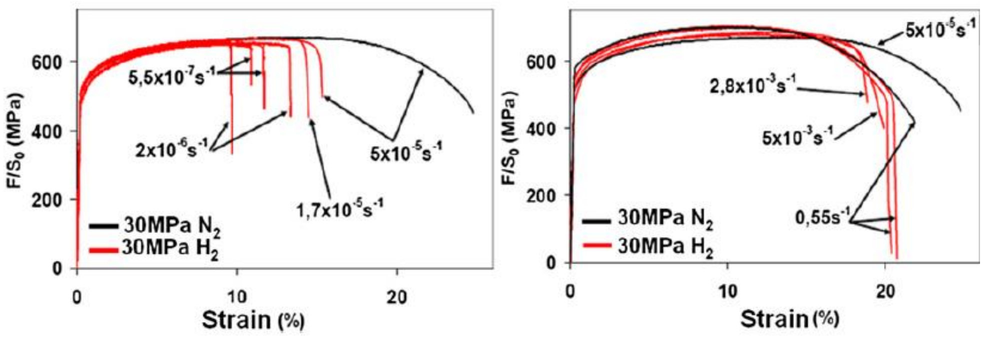

Figure 15: Tensile tests for API X80 steel tested in 30MPa of H_2 or N_2 gas for various strain rates [103]

Table 20 summarizes properties measured in 6.9 and 69 MPa H_2 gas for a wide range of carbon steels. Measurement of smooth tensile properties of carbon steels in high-pressure H_2 gas demonstrates that hydrogen degrades reduction of area, but not the ultimate tensile strength (S_u).

Table 20: Smooth tensile properties of carbon steels in 69 MPa H_2 gas at room temperature. Properties in air or He gas are include for comparison [104]

Steel	Test environment	Strain rate* (s^{-1})	S_y (MPa)	S_u (MPa)	El_t (%)	RA (%)	Ref.
1042	69 MPa He 69 MPa H_2	$3.3x10^{-5}$	400† -	621 614	29 22	59 27	[7]
1020‡	Air 69 MPa He 69 MPa H_2	$3.3x10^{-5}$	373† 283† 276†	490 435 428	— 40 32	65 68 45	[7]
A515	Air 69 MPa He 69 MPa H_2	$3.3x10^{-5}$	338† 276† 297†	504 448 442	— 42 29	66 67 35	[7]

* strain rate in elastic range
† defined at deviation from linearity on load *vs* time plot
‡ prestrained under tension in air immediately prior to testing

Hydrogen embrittlement in terms of ductility generally increases when pressure increases up to a threshold pressure, as it can be seen in Figure 2.

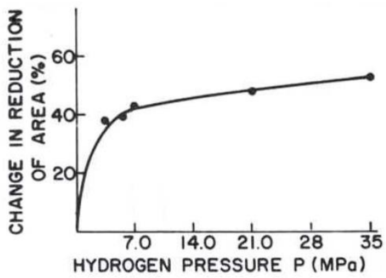

Figure 16: Influence of hydrogen pressure on reduction in area losses for steel similar to X42. Tensile tests with double notched grade X42 specimens were used [105]

4.6.2 Fracture toughness

Hydrogen has a significant influence on the crack initiation and growth behaviour, particularly when reasonably large surface flaws exist on a susceptible material exposed to H_2 gas. Therefore, fracture mechanics is usually required to assess the maximum allowable stress and service life of a component, based on the surface flaw sizes and crack growth rates, in high-pressure H_2 environment. Two common types of fracture properties are evaluated: the threshold stress intensity factor (KTH), and the associated crack growth rates. The threshold stress-intensity factor for sustained-load cracking is a measure of a material's resistance to hydrogen-assisted crack propagation under static loading. Two types of test configurations are commonly used: the compact tension (CT) specimen (Figure 17) and the and WOL (Wedge Opening Load) also known as modified bolt load compact specimen (Figure 18). For these two types of specimens an initial stress intensity factor less than KIEAC is applied before placing the pre-cracked specimen in the environment of interest, in this case H_2 gas. If susceptible to environment assisted fracture, the pre-crack will extend under decreasing stress-intensity factor until the crack arrests at the threshold value.

Standards:

- ASTM 1820: Standard test method for measurement of fracture toughness.
- ISO 12737: Metallic materials. Determination of plane-strain fracture toughness.
- ISO 12135: Metallic materials. Unified method of test for the determination of quasistatic fracture toughness.

- ASTM E1681:2020: Standard test method for determining threshold stress intensity factor for environment-assisted cracking of metallic materials.

- ISO 11114-4: Transportable gas cylinders. Compatibility of cylinder and valve materials with gas contents- Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement.

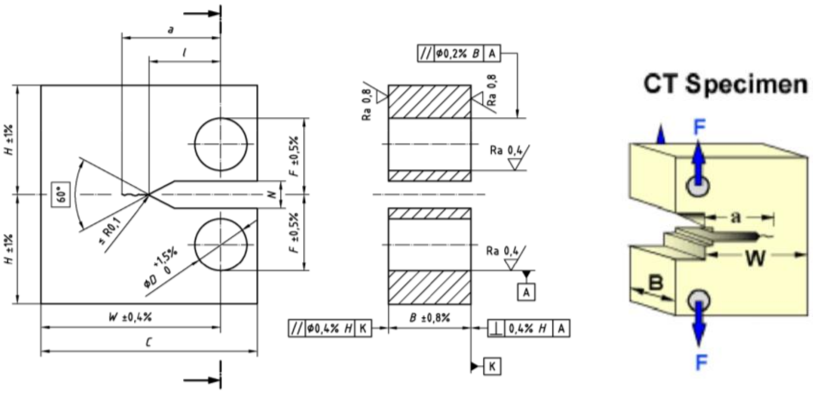

Figure 17: Typical geometry of compact specimen (CT) for fracture toughness test according to ISO 1114-4

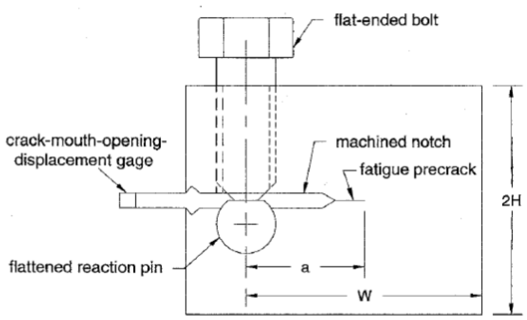

Figure 18: Typical arrangement for constant displacement KIEAC tests with modified bolt-load compact specimen according to ASTM E1681 standard

The fracture toughness and crack propagation resistance of carbon steels are lower in high pressure H_2 gas compared to properties measured in air or inert gas (Figure 19).

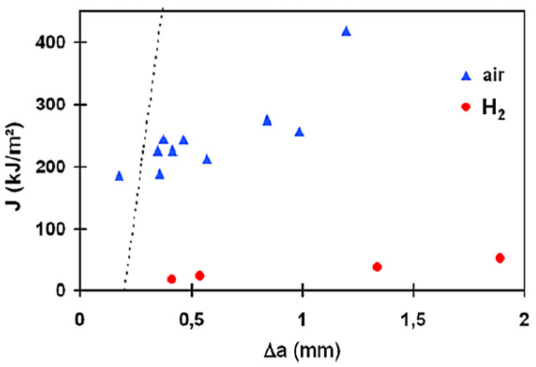

Figure 19: Fracture toughness results realized on x80 CT specimens in H_2 gas at 30 MPa and in air [103]

Table 21: Fracture toughness for carbon steels in H_2 gas at room temperature. The fracture toughness in air, N2 or He is included for comparison [104]

Steel	S_y † (MPa)	RA † (%)	Test environment	Displ. rate (mm/s)	K_{Ic} (MPa ·m$^{1/2}$)	K_{IH} ‡ (MPa ·m$^{1/2}$)	dJ/da (MPa)	Ref.
A516	375	69	Air 3.5 MPa H_2 6.9 MPa H_2 20.7 MPa H_2 34.5 MPa H_2	$8.5x10^{-3}$	166*	 131 113 98 90	516 47 55 54 57	[8, 9]
1080	414	16	6.9 MPa N_2 6.9 MPa H_2	$2.5x10^{-4}$ - $2.5x10^{-3}$	111	 81	42 13	[5]
X42	366	56	6.9 MPa N_2 6.9 MPa H_2	$2.5x10^{-4}$ - $2.5x10^{-3}$	178*	 107	70 63	[5, 6, 10]
X42	280	58	Air 2.0 MPa H_2 4.0 MPa H_2 6.5 MPa H_2 7.0 MPa H_2 8.0 MPa H_2 10.0 MPa H_2 12.2 MPa H_2 16.0 MPa H_2	$\leq 3.3x10^{-4}$	147*	 101-128 85 69 73# 59# 53# 57# 46#	111 — 36 31 — — — — —	[11]
X60	473	62	6.9 MPa He 6.9 MPa H_2	$8.5x10^{-3}$	142	 104	123 43	[8]
X70	584	57	6.9 MPa N_2 6.9 MPa H_2	$2.5x10^{-4}$ - $2.5x10^{-3}$	197	 95	251 23	[6]
X60	434	88	5.5 MPa H_2 21 MPa H_2	$8.3x10^{-5}$ - $8.3x10^{-4}$	—	85 82	—	[18]
X80	565	81	5.5 MPa H_2 21 MPa H_2	$8.3x10^{-5}$ - $8.3x10^{-4}$	—	105 102	—	[18]

† yield strength and reduction of area of smooth tensile specimen in air
‡ calculated from relationship $K = \sqrt{JE/1-\nu^2}$
* reported fracture toughness may not be valid plane strain measurement
# measured from burst tests on pipes with machined flaws

Table 21 lists fracture toughness and crack propagation resistance results for a range of carbon steels tested in H_2 gas up to 35 MPa pressure. As it can be seen, hydrogen has a more pronounced effect on crack propagation resistance. The dJ/da values measured in H_2 gas can be 90 % lower than the values measured in air or inert gas. The fracture toughness measured in H_2 gas is sensitive to both, the loading rate and gas pressure.

Figure 20 displays the fracture toughness vs H_2 gas pressure data for X42 and A516 steel from Table 21. For both sets of data, fracture toughness decreases as gas pressure increases, but appears to be approaching a lower limiting value.

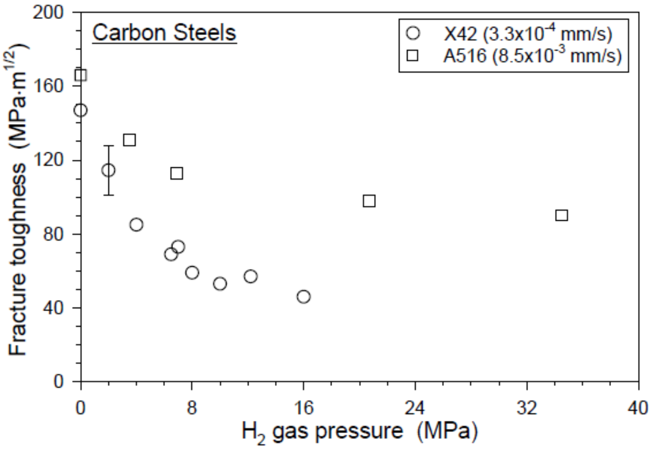

Figure 20: Effect of H_2 gas pressure on fracture toughness for carbon steels grade X42 and A516 [105]

4.6.3 Fatigue test

Fatigue is a material failure mode particular to cyclic loading. The effects of H_2 gas on fatigue properties have not been extensively investigated for most alloy classes. Fatigue is possibly the most important failure mechanism in metallic structures subjected to cyclic stress, therefore this failure mechanism must be considered in the design of components in contact with H_2 gas, subjected to pressure cycling. Materials fatigue performance is commonly characterized by the S-N curve and the crack growth rate. The S-N curves are often plotted with the cyclic stress (S) against the cycles to failure (N) on a logarithmic scale. The crack growth rate is a very important fatigue property because most of the fatigue life is generally consumed in the crack growth phase. Frequency of the load cycle and the ratio of minimum load to maximum load (R-ratio) are two important variables that have been shown to affect fatigue properties measured in H_2 gas. In general, H_2 gas enhances the fatigue crack growth rate of carbon steels and reduces the number of cycles to fracture.

4.6.3.1 Fatigue crack propagation

Pre-cracked specimens are tested using fracture mechanics methods to generate plots of fatigue crack growth rate (crack extension per load cycle, da/dN) as a function of the stress-intensity factor range (ΔK). Fatigue crack growth rate testing is usually conducted following procedure in ASTM E647 using the compact tension (CT) specimen shown in Figure 17.

Standards:

- ASTM E647: Standard test method for measurement of fatigue crack growth rates.

Figure 21 shows the crack growth rate (da/dN) vs ΔK relationship for carbon steels SA 105 and 1020 steel tested in H_2 gas at different pressures. Fatigue crack growth rates generally increase as H_2 gas pressure increases. At lower ΔK, crack growth rates can increase by more than a factor of 10 as gas pressure increases from 0.02 MPa to 100 MPa. It can be seen also that the fatigue crack growth rates in H_2 become increasingly greater relative to crack growth rates in air or inert gas as ΔK increases. In the higher range of ΔK, fatigue crack growth rates are at least ten-fold greater than crack growth rates in air or inert gas.

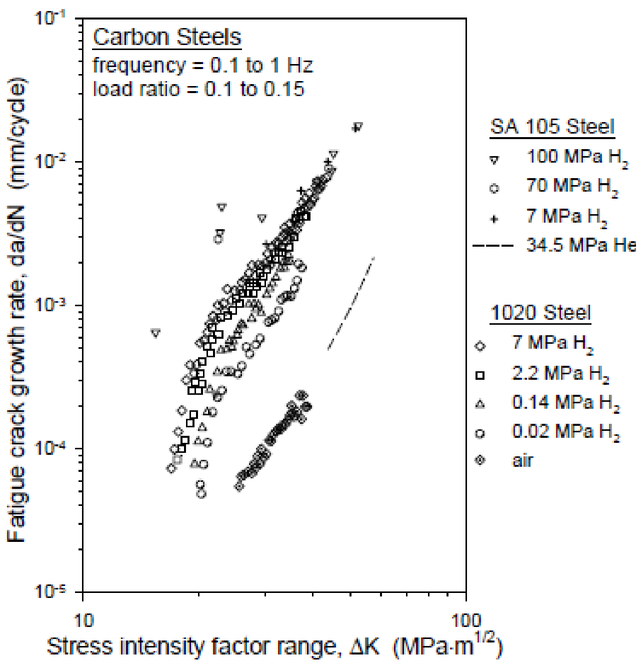

Figure 21: Effect of H_2 gas pressure on fatigue crack growth rate vs stress-intensity factor range relationships for carbon steels. Fatigue crack growth rate data in air or helium gas are included for comparison [104]

Fatigue crack growth rates in H_2 gas generally increase as the load cycle frequency decreases. This trend is illustrated in Figure 8.

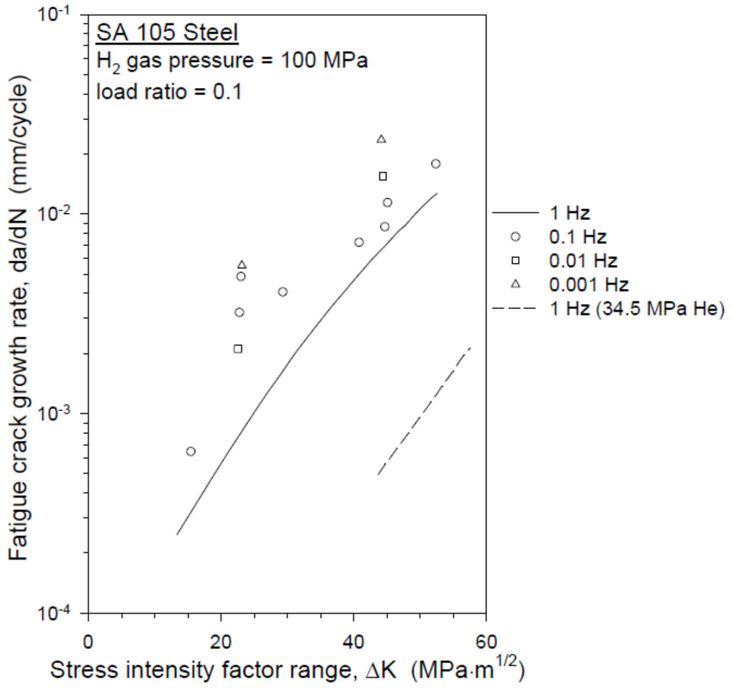

Figure 22: Effect of load cycle frequency on fatigue crack growth rate vs stress intensity factor range relationships for SA 105 steel in H_2 gas. Fatigue crack growth rate data in helium gas are included for comparison [104]

4.6.3.2 S-N curves

The most common fatigue testing method involves smooth cylindrical specimens used in low-cycle (LCF) and high-cycle fatigue (HCF) to generate the so-called S-N curves. The S-N curves are plots of alternating stress amplitude (S) vs number of cycles to failure (N). The number of cycles to failure includes both crack initiation and propagation.

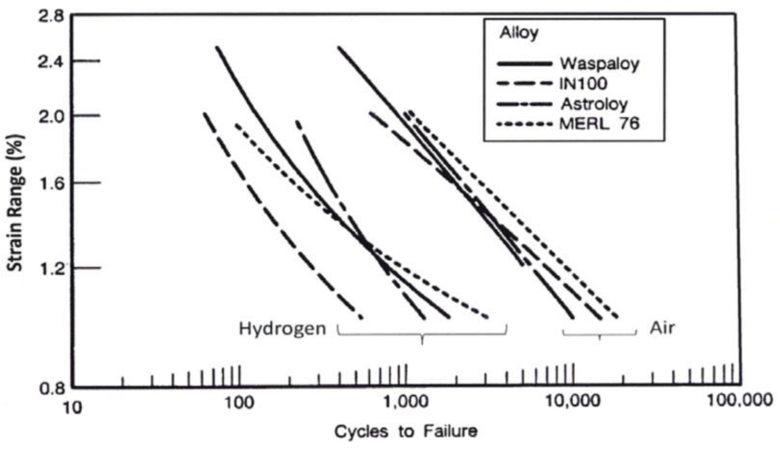

Figure 23: Effect of hydrogen on strain controlled LCF of several superalloys [106]

4.6.4 Disk pressure (rupture) test

The disk rupture test is a qualitative assessment of susceptibility to hydrogen-assisted fracture. This method involves pressurizing identical membranes of material with H_2 gas and with inert gas (usually He) until the membranes fail. Specimens typically 58 mm diameter and 0,75 mm thickness are clamped between two steel flasks and pressurized at a specific pressure rate until fracture (Figure 24). The ratio IE of failure pressures in He and in H_2 gas at a given pressure rate is calculated.

$$I_{E=} P_{He}/P_{H2}$$

An index equal to or less than 1 indicates that the material is not susceptible to embrittlement by H_2 gas. If the index is greater than 2, the material is considered sensitive, so it should not be exposed to hydrogen. If the index is comprised between 1 and 2, probably a certain hydrogen embrittlement should be expected after a long time of exposure.

An advantage of using disk testing over other methods is that a triaxial stress state is created which more closely replicates the stresses of a pressurized storage vessel. These tests do not provide data that are used to quantify the safety margins of components in H_2 gas systems; however, disk rupture tests can be used as a simple screening tool for evaluating the relative susceptibility of materials to HE.

Standards:

- ASTM F1459: Standard test method for determination of the susceptibility of metallic materials to gaseous hydrogen embrittlement.
- ISO 11114-4. Method A: Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement. Method A: disc rupture test. This standard is specific for hydrogen pressure vessels constructed with steel having ultimate tensile strength greater than 950 MPa.

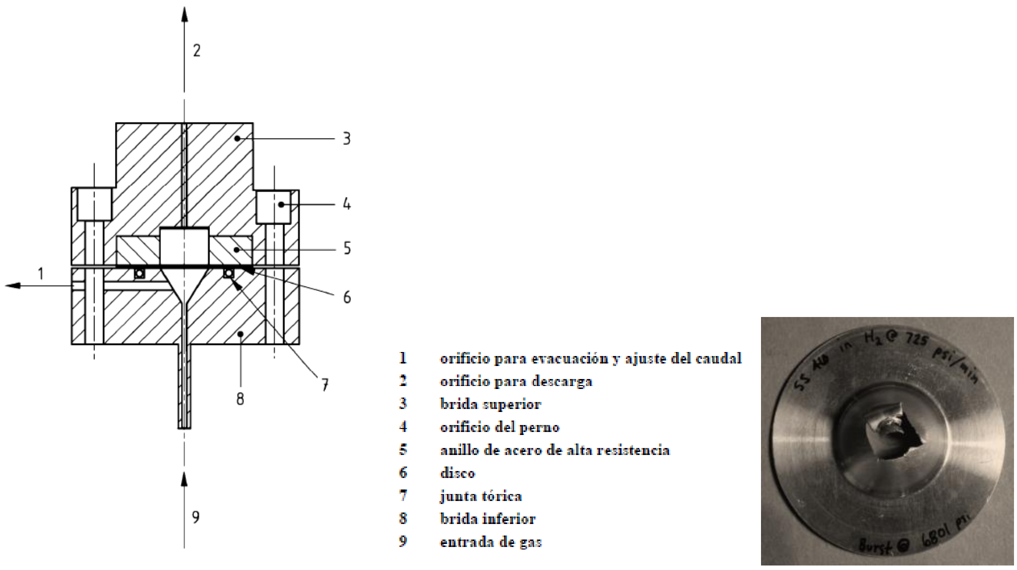

Figure 24: Disk testing method indicated in standard ISO 11114-4-Method A

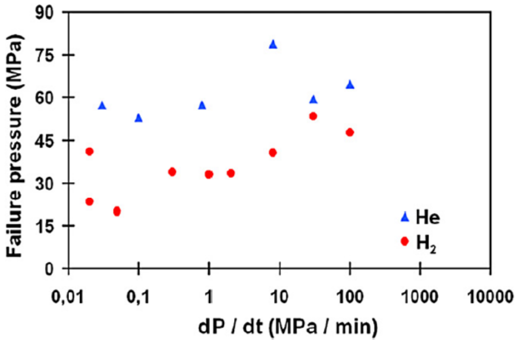

Figure 25: Disk pressure test results realized on X80 specimens [103]

4.6.5 Constant load/constant displacement tests

An important benefit of using stressed specimens is that once the deformation has been applied to the specimen, the self-loading assemblies may be inserted into loops or closed test vessels and exposed to the H_2 gas environment. Several types of normalized stressed specimens can be used for evaluating hydrogen embrittlement sensibility.

4.6.5.1 C-Ring specimens

C-rings specimens (Figure 26) are made from tubular products and are bolt loaded to the desired stress level (constant strain), usually reported as a percentage of the yield strength. Deflections should be limited to stresses comprised between 75 and 100 % of the elastic limit. Specimens are examined metallographically at the conclusion of the tests for evidence of cracking.

Standards:

- ASTM G 38: Standard practice for making and using C-ring stress-corrosion test specimens
- ISO 7539-6: Corrosion of metals and alloys. Stress corrosion testing. Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement.

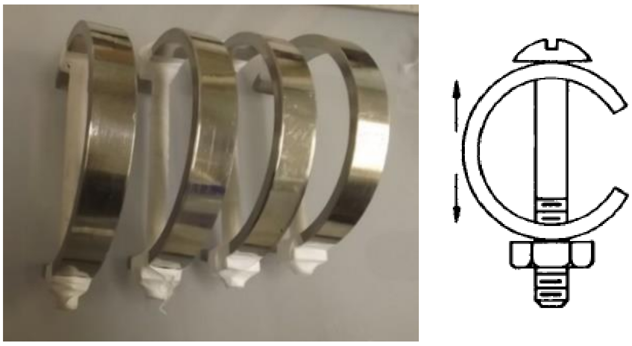

Figure 26: C-ring specimens (constant strain)

4.6.5.2 4-point bend specimens

The four-point bend specimen (4pb, Figure 27) is subjected to a constant tension that is performed by supporting the beam specimen on two loading rollers and applying a load through two other rollers. Deflections should be limited to stresses below the material elastic limit, usually comprised between 75 and 100 % of the elastic limit. The evaluation of the material resistance to the environment is realized by examining the tested specimen in the tensile stressed region for the detection of cracks.

Standards:

- ISO 16540: Corrosion of metals and alloys. Methodology for determining the resistance of metals to stress corrosion cracking using the four-point bend method.
- NACE TM0316: Four-point bend testing of materials for oil and gas applications.
- ISO 7539-6: Corrosion of metals and alloys. Stress corrosion testing. Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement.

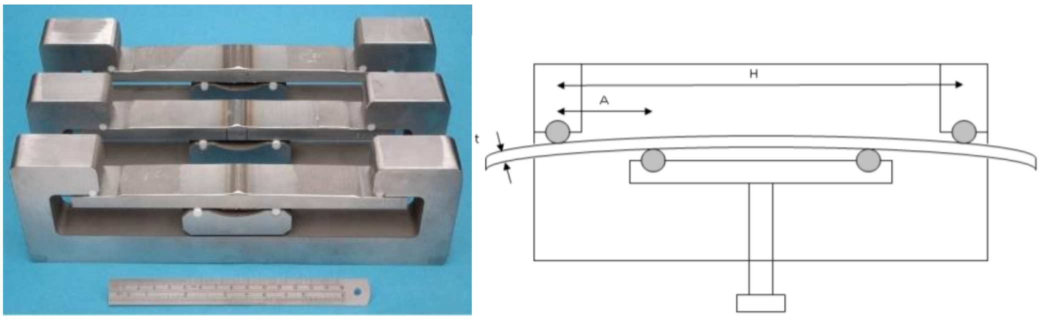

Figure 27: Four-point bend testing of welded specimens

4.6.5.3 Pre-cracked compact tension specimen

Compact tension (CT) specimens (Figure 17) may be loaded with equipment for application of a constant load or can incorporate a device, for example a taper pin, to produce a constant displacement at the loading points. Preparation and use of pre-cracked specimens for tests under constant displacement or under constant load are dealt with ISO 7539-6 and ISO 1114-4 (method C).

Standards:

- ISO 7539-6: Corrosion of metals and alloys. Stress corrosion testing. Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement.

ISO 1114-4-Method C: Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement. Method C: Test method to determine the resistance to hydrogen assisted cracking of steel cylinders.

4.6.6 Non mechanical tests: Hydrogen permeation test

This permeation test can be used to measure the diffusible hydrogen in metals and coatings, for example. This permeation test is basically a double cell set up in which one chamber is entry cell also called a charging cell and the another is oxidation cell (exit cell). These two chambers are separated by a steel membrane. The electrochemical process has used to hydrogen charging. This hydrogen is firstly introduced in charging the cell and then goes to oxidation cell with the help of membrane.

Standards:

- ISO 17081. Method of measurement of hydrogen permeation and determination of hydrogen uptake and transport in metals by an electrochemical technique

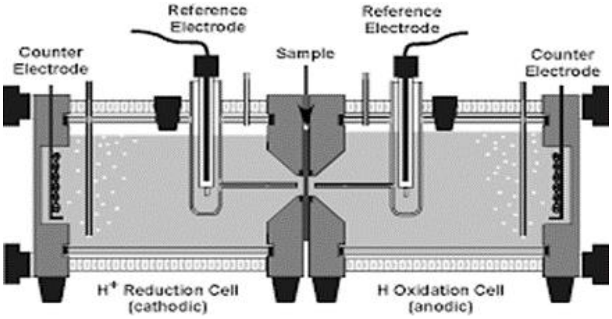

Figure 28: General scheme of the hydrogen permeation (DEVANATHAN) cell

5 Summary

This report “Final document review on specific technical, RCS barriers, enablers and innovations” provides an overview on the European high-pressure gas transmission grid with its current infrastructure as well as on the legal and technical framework regarding hydrogen in the European Union and its member states.

5.1 European gas transmission grid inventory

Via the conduction of the infrastructure survey a descriptive picture of the European natural gas transmission grid and its facilities has been compiled. The information has been provided by the European TSOs and gas operators associations. It has been verified that the information obtained is consistent with that collected in previous reports (EGIG, MARCOGAZ, etc.), where applicable. Complementing these reports, additional information on infrastructures has been obtained that completes the available ones in these reports obtaining a good knowledge of the European infrastructures for the transmission of natural gas. The analysis of the information has made it possible to identify the most representative facilities of the natural gas transmission network, and specifically those in contact with gas and which, therefore, will be exposed to hydrogen when it is injected into the network. The main components and characteristics of these representative facilities have been identified, establishing those that could be especially sensitive to hydrogen.

5.1.1 Pipes and materials in the transmission network

Around 65,000 km of the European transmission gas grid has been collected in this report. This length constitutes almost half of the length reported by EGIG in their last report about incidents in the European transmission gas grid in 2019 [6] and almost a third of the length reported by MARCOGAZ in their Technical Statistics in 2013 [1]. Having the latter as reference, the quantity of grid covered for each cluster is quite asymmetrical. While in South and Northern Europe more than ¼ of the grid has been achieved (26.0 % and 29.2 %, respectively), this amount rises up to 52.7 % in Middle Europe. However, in Western Europe only 7.6 % of the grid has been collected. The information given in this report is therefore more reliable for those clusters where the grid is better covered.

The quality of the steel used in the pipes is associated with the operating pressure of the network, since higher pressures force the use of higher quality steels (grade) to avoid the use of pipelines with higher thickness.

The backbone of the European network, which connects the main gas entry points to the system with the main consumption points, must allow a large transmission capacity and therefore works at high pressure. This is the reason why it is made up of higher quality pipes. Those clusters that due to their location or their demand for gas, have a greater presence in the basic network, therefore have a greater proportion of higher quality pipes.

Thus, countries such as the ones in the cluster South Europe, which include a high number of gas inlets to the system, have a higher percentage of networks that operate at high pressures (close to 80 bar) compared to those with lower pressure (up to 66 bar). Therefore, these clusters proportionally are using proportionally higher quality steels (X60 to X80) in its pipes. X60 to X80 steels represent almost 70 % of the total grid length in South Europe and 78 % in Northern Europe. On the other hand, in the countries in Middle Europe, which are the main consumption centres in Europe, this proportion drops to 44 %, being still significant.

Five steel types (API 5L Gr. B / X42 / X52 / X60 / X70) are currently used for about 88 % of the installed pipelines in the European high-pressure gas transmission grid. Existing literature (see 3.3) suggests that these steels, except for the latter, are considered to be hydrogen-ready and handle hydrogen and blends of natural gas and hydrogen without major adjustments. To assure this, more research is necessary and it has therefore been recommended to the HIGGS consortium to select these steel grades for the testing campaign in WP4. For the remaining part of the grid (about 12 %) mainly another five steel grades are used (API 5L Gr A / X46 / X56 / X65 / X80). Referring to literature (see 3.3) there might be limitations in regards of blends of natural gas and hydrogen and with pure hydrogen using the latter two, while the first three steel grades are considered to be hydrogen-ready as well. As discussed above, a broad part of the grid is composed by high-grade steels (over X60) and these are the materials with the highest probability to suffer degradation issues when hydrogen enters the system, since steels with high ultimate tensile strength or hardness are considered more susceptible to hydrogen embrittlement. This situation is more critical for those countries that build the door for natural gas to enter Europe.

Regarding the size of the pipes, most of the European grid diameter is below 40 in OD and nearly equally distributed in ranges of 10 in, with no clear predominance of any of them. The size of the pipes is important when estimating the cost of transporting gas through the grid and an individual analysis for each grid section would be necessary because of this heterogeneity.

The internal coating of the pipelines is crucial when retrofitting the natural gas grid for the transport of hydrogen. In uncoated pipes, the steel is directly exposed to hydrogen, while in coated pipes, hydrogen diffusion through the steel inner surface could be minimized, preventing degradation by hydrogen embrittlement. 20 % of the pipes collected in Europe are coated internally with Epoxy, while 3 % remain uncoated. The uncoated pipes are especially popular in Western Europe. There is however a 78 % of the pipes of which no information could be gathered. The external coating of pipelines is quite heterogeneous and should have no impact on hydrogen transport.

5.1.2 Facilities in the transmission network

From the data available on infrastructures in previous reports, and from the information obtained from the European TSOs through the infrastructure survey, it is observed that the most common installations in the high-pressure transmission gas grids are valves positions (valves nodes or cut-off stations). These facilities can be found in the grid with a frequency of 50 items per 1,000 km of grid. Also stations designed to measure the gas flow and regulate its pressure (metering stations and pressure reduction stations) are very common. They can be found with a frequency around 2.5 items per 1,000 km of grid (valves positions). All these facilities are mainly composed of sections of pipes and valves, regulators, meters and instrumentation. These components are usually installed using flanged joints, using gaskets made of elastomeric materials. According to the literature, most of these materials are compatible with hydrogen (see 3.3). However, the diffusion and permeability of hydrogen through these materials is greater than for methane, so we consider it advisable to carry out specific tests on gaskets and components of this material in the WP4 test campaign.

The TSOs that contributed to the survey could not provide much information about the impact that hydrogen may have on gas quality control systems because the impact is mostly still unknown. Over 300 devices were identified in Europe. Regarding gas meters, some TSO suggested that ultrasonic devices can operate with a hydrogen content up to 20 %, while diaphragm (bellows-type) gas meters have no hydrogen content restrictions.

Finally, 139 gas storages have been identified in Europe. 55 % are depleted fields, around 40 % either aquifers or salt caverns. This means a total working gas volume of over 1,300 TWh and a withdrawal and injection capacity of around 20,000 and 13,000 GWh/day, respectively.

5.2 European and national legal and technical framework for hydrogen injection into the gas grid

Chapter 4 draws a state-of-the-art map of the RCS in the EU and its member countries and shows, that there is a quite diverse picture on the current status of hydrogen implementation in the European Union and its member countries.

5.2.1 European legal framework

The current European legal framework does not yet cover hydrogen and hydrogen admixtures in natural gas in the European high-pressure gas transmission grid. The European Commission's work programme foresees a transition of the Green Deal and the related strategies, e.g. the EU Hydrogen and the EU Sector Integration Strategies, to action. For this, the European Commission has proclaimed the Fit for 55 initiative, including the increased reduction goals for 2030, i.e. 55 % less CO_2 emission than 1990, and climate neutrality by 2050. .The first package of the “Fit for 55”-initiative has been released in July 2021. It includes revision proposals for RED, EED, ETD, EU ETS, AFID, LULUCF, CO2 ES for car. The second package (gas market package) is announced for 14 December 2021. It includes revision proposals for the European gas market legislation and thus defines the basis for future uses of the gas grid for hydrogen and its possible regulation.

The ‘FitFor55’ initiative proposals will be subject of public consultation to collect the broad view of all interested parties. These consultations allow to bring the policies and the expertise of all relevant fields together. This is crucial to come to a suitable and sustainable framework for the transition of the natural gas via a low-carbon to a climate-neutral gas market based on renewable hydrogen and other renewable gases.

In regards of the intense activities concerning the possibilities of utilising hydrogen and hydrogen blends as well as the European gas grids to support the decarbonisation of the European Union, the early establishment of a clear European framework builds the basis for the facilitation of the take-off of the use of hydrogen in energy systems.

5.2.2 European technical framework by standardisation

Concerning the European technical framework by standardisation, currently the relevant standards for gas infrastructure, gas application, gas quality and hydrogen technologies are subject to investigation on revision needs or are already under revision with respect to hydrogen readiness. Noting the numerous similarities between hydrogen and natural gas, special attention is given to the impact of hydrogen on materials such as embrittlement of steel, permeation through materials, suitability of elastomers and sealing materials, on safety aspects such as purging/venting, gas tightness, leakage, detection as well as on the components of the technical system and on applications/appliances.

The challenge of the current adaptation of standards for the use of hydrogen is the content interaction between the standards and the co-ordination between the standardisation committees. Especially, regarding the adaptations for hydrogen blends, it is not yet clear, which hydrogen concentrations the provisions in the European standards need to cover, as there are no strategic commitments yet. Referring to the current knowledge, most of the technical committees are investigating their standards for up to 20 Vol-% and nominal 100 Vol-% hydrogen. For the coordination of European hydrogen standardisation between the technical committees, the direct liaisons work between the groups, but also the consultations and investigations in the CEN and CENELEC Sector Fora, i.e. Sector

Forum Gas Infrastructure, Sector Forum Gas Utilisation and Sector Forum Energy Management and Energy Transition – play a key role.

The current European standards for high-pressure gas transmission grids are listed in a non-exhaustive list in Table 15.

Fostering the coordination and coherent approach, the intended European Commission Standardisation Request on hydrogen to CEN and CENELEC is highly appreciated. The current proposal includes four uses of hydrogen:

- hydrogen in repurposed natural gas infrastructure and application,
- hydrogen as a blend in natural gas infrastructure and application,
- hydrogen in dedicated infrastructure and application,
- methanation.

38 CEN and CENELEC technical committees and 11 IEC and ISO technical committees have been considered in the draft work programme.

Verifications are ongoing to put a further focus of the Standardisation Request on production technologies for renewable and low-carbon hydrogen in line with the EU Hydrogen Strategy. Furthermore, alignment with parallel Standardisation Requests' drafting (GAR and AFID) is intended.

Under the umbrella of CEN/TC 234 Gas infrastructure (CEN/TC 234 WG 13 Supervisory Board) with involvement of all relevant CEN and CENELEC TCs and European stakeholder organisations the European Commission allocated a pre-normative project *'Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users'* (SA CEN 2019-14) to CEN for analysis of available study reports and literature on hydrogen in natural gas systems (infrastructure and application) for the use of the technical findings in standardisation and for identification of knowledge gaps.

The investigations include a comprehensive survey of knowledge sources and detailed elaboration on the state of the art on the impact of:

- hydrogen blends up to 20 % hydrogen concentration, looking also at the relevance of variations due to uncontinuous H_2 injection, and
- pure hydrogen.

for the following key aspects:

1. Safety
2. Gas quality
3. Underground storage
4. Centralised and decentralised power generation
5. Industry (feedstock gas and industrial processes)
6. Steel pipes
7. Equipment and materials on gas network
8. End-use applications
9. Hydrogen purity needs of industrial end user.

5.2.3 European sector initiatives

Full support of the decarbonisation needs and targets for the energy system is given in the gas sector. A high awareness is notable that the transition to a decarbonised hydrogen system will only be possible with all parts along the gas chain being involved in the architecture and the realisation of the transition. Therefore, many initiatives in the gas sector between companies or European stakeholder within and across the parts of the gas chain are working on the appropriate solutions to finally enable the intended broad use of hydrogen. Only a very few are specifically mentioned in this report.

The European hydrogen backbone initiative comprehensively describes how a hydrogen backbone in Europe can be created and which knots and existing pipelines can be redesignated or have to be built from scratch in order to secure a large-scale hydrogen market. The H2 Gas Assets Readiness (H2GAR) is a project of the seven transmission system operators Enagas, Fluxys, Gasunie, GRTgaz, Nationalgrid, OGE and SNAM. It specifically aims at sharing technical knowledge on the hydrogen readiness of the gas assets (blends and pure) among the project partners, building a joint view on the findings and contributing them to the standardisation process for a robust future hydrogen-ready gas system. The Prime movers' group on gas quality and hydrogen handling set up in 2020 functions as the open exchange platform between stakeholders from gas production to the various gas applications and including organisations like CEN-CENELEC and representatives of the Commission. It currently involves more than 25 European stakeholder organisations. It aims at aims at

- creating a good understanding of the technical feasibility and challenges to cope with the future gas quality in the gas system, including renewable, decarbonised and low-carbon gases.
- developing a joint roadmap for a whole system approach allowing decarbonisation and at the same time safe and efficient end-use with least emissions as well as security of the gas supply. The roadmap will include the identification of solutions for the areas of concern.
- feeding the results in the consultations with the European Commission on the revision of the gas legislation implementing the EC hydrogen and sector integration strategies.

5.2.4 National framework of the European member countries

Concerning the national legal and technical framework in regards of hydrogen throughout the member states of the European Union a quite diverse picture is perceived. Generally, the European gas sector is very active and shows big efforts to achieve and enable the use of hydrogen. For the establishment of the national legal framework and the further development of the national strategies the European proposals for the revision of the gas package will be a major guideline.

Some countries such as Austria, France, Germany, The Netherlands and UK have started first revisions of their standards documents.

The National Energy and Climate Plans (NECPs) of the member countries of the European Union are publicly available and assessed on a website of the European Commission. A similar collection of the national hydrogen strategies could help to raise the availability and transparency of the national strategies and facilitate European cooperation.

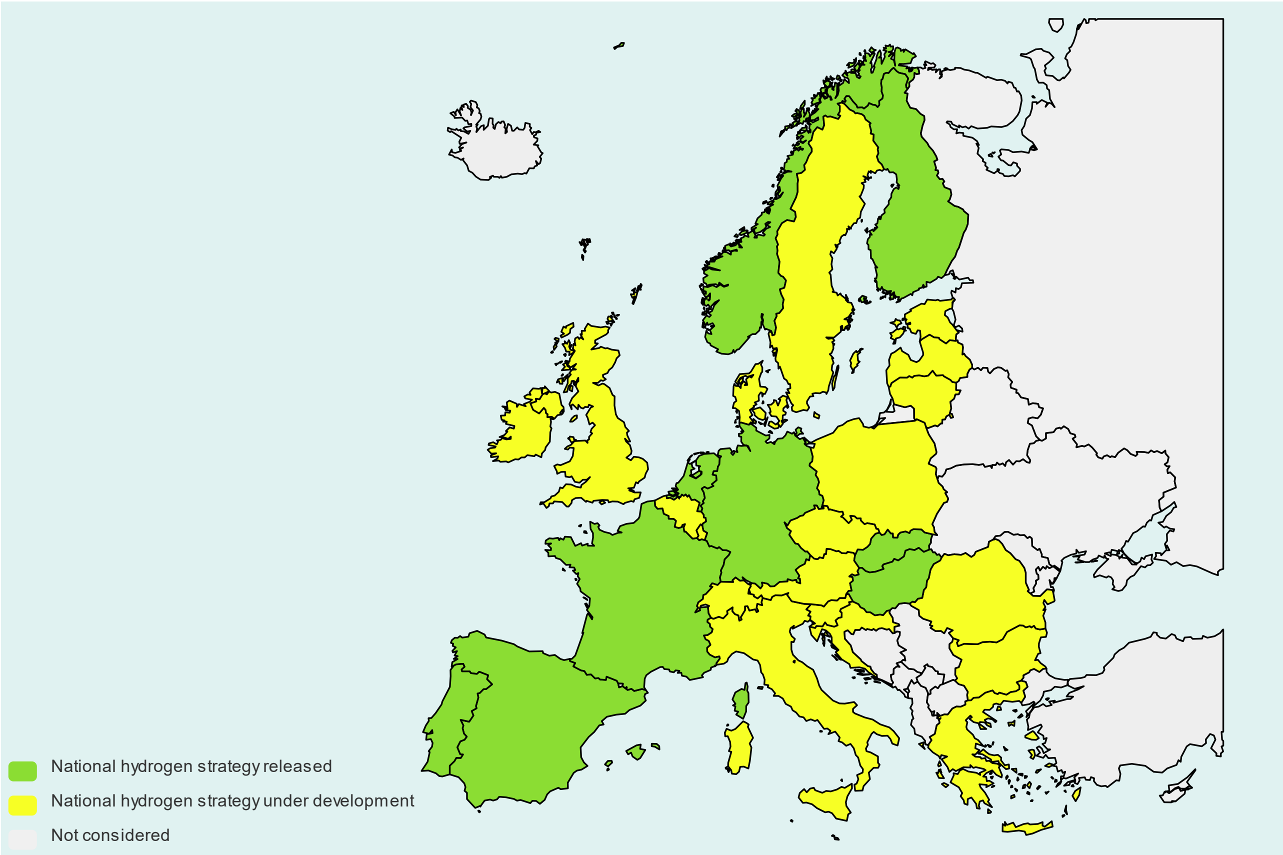

Figure 29: Status of hydrogen strategies in the European countries (the figure might not be exhaustive and new development might have occurred during the finalisation of this document)

<u>Notes to figure:</u>

1. The map reflects the situation of the EU member countries, Switzerland and UK. The other countries shown in the figure are not considered.
2. Some of the countries that have not published a dedicated hydrogen strategy yet, covered the national strategic objectives for hydrogen already in more detail in the NECP, e.g. Bulgaria, Greece, Latvia, Slovenia.
3. Ireland: Hydrogen is part of the Climate Action Plan (action 54) foreseeing feasibility assessments and development of a regulatory roadmap by 2022.

All member countries, Switzerland and UK have published or announced a national hydrogen strategy. Figure 29 shows the status of the national hydrogen strategies throughout the EU member countries, as far as reported in the HIGGS questionnaire, the other considered reports or according to publicly available information.

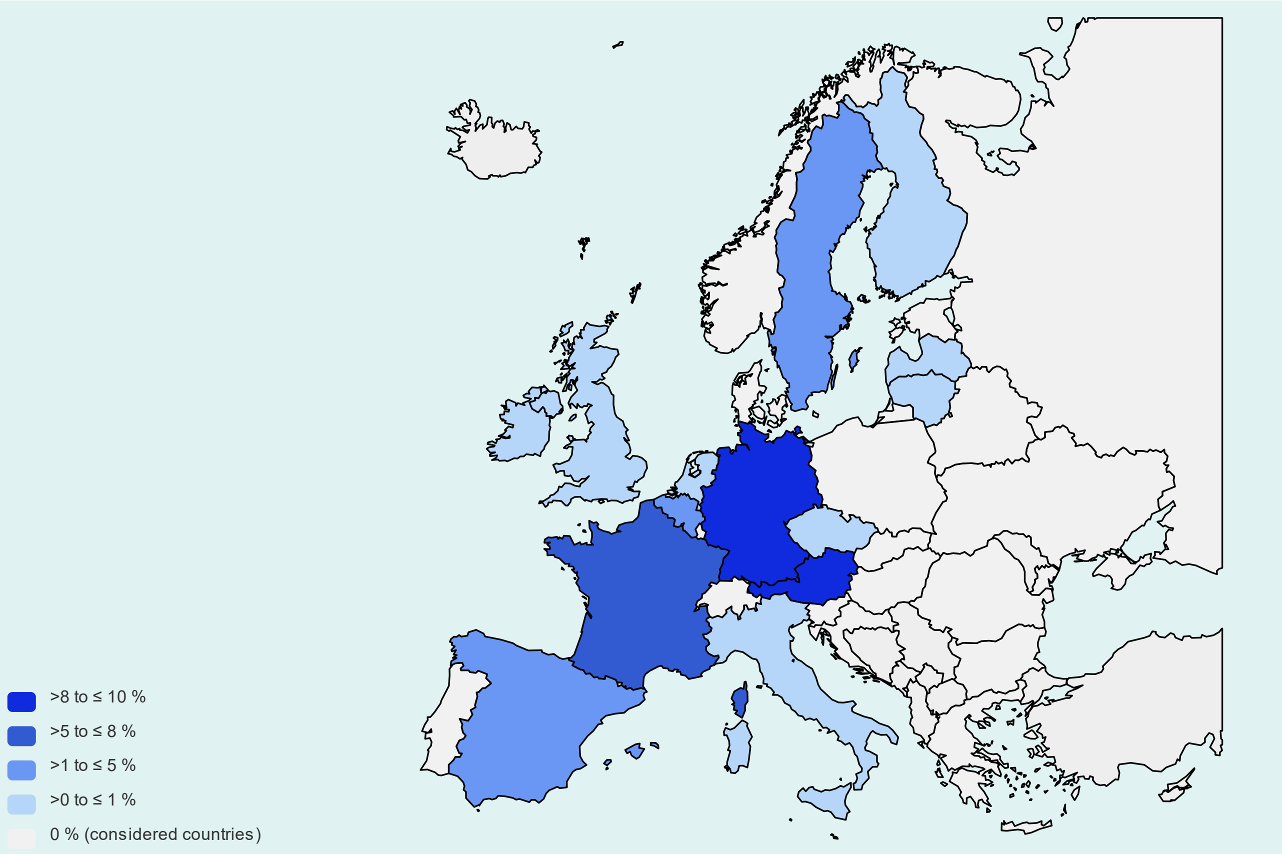

Figure 30: Allowed hydrogen concentration for blends with natural gas in the transmission gas grid of the European countries (the figure might not be exhaustive and new development might have occurred during the finalisation of this document)

<u>Notes to figure:</u>

1. The map reflects the situation of the EU member countries, Switzerland and UK. Other countries are not considered.
2. As the nominal difference between the indication of the hydrogen concentration in Vol-% or Mol-% under pressure is very small, for this figure no difference is made.
3. Austria: for sensitive components and applications in the grid individual examinations are required.
4. Germany: Restrictions for sensitive components and applications need consideration; concentrations over 10 % require specific investigation and suitability confirmation of concerned parties.
5. Lithuania: in the context of biomethane injection into the gas transmission grid 2 % is possible under certain circumstances.
6. Slovak Republic: The maximum concentration of hydrogen in natural gas in the transmission network is not defined. In imported natural gas a maximum of 2 % of hydrogen can be present.
7. United Kingdom: Gas Safety (Management) Regulations 1996 [107].

Figure 30 shows the currently allowed hydrogen concentrations in blends with natural gas in the different EU member countries. It can be seen, that in 14 countries it is possible to have hydrogen in the transmission natural gas grid. On the other hand, the allowed concentrations in some of these countries are very low. Countries like Germany, Austria, France, Spain have allowed concentrations between 5 to 10 Vol-% and in some of these countries further adjustments to raise this limit to up to 20 Vol-% are ongoing. In other countries there is no opportunity for the injection or the transport of hydrogen reported at all.

5.2.5 Certification – proofing of H2 readiness for high pressure piping and components

The hydrogen aspects need to be considered in the applicable conformity assessment procedures for the H_2-readiness of gas-related products and for certification and (pre-)qualification schemes for networks and their components, companies and personnel.

In general, also in the field of certification, the procedures for methane are considered adequate and applicable for hydrogen as well. For some hydrogen specifics, such as safety (ATEX and others), material specifications, gas behaviour (vibrations, turbulences in stations etc), grid integrity, a limited need for supplements might be needed. The detailed and internal approval procedures and certification need to reflect the necessities for use of H_2NG or the conversion to pure hydrogen as for natural gas (and other low-carbon and renewable gases). The learning process is still ongoing. Thus, the European and national certification and qualification regimes are not yet formally set.

Prior to the use with hydrogen, the actual suitability of the existing network must be thoroughly assessed and proven by the network operators themselves and – for some major aspects – by third party involvement. Temporary assessment programs provide pragmatic and reliable solutions until the technical and regulatory framework is established. They are built on the available findings from completed and/or ongoing hydrogen research projects and the organisations' expertise.

Finally, these temporary assessment programs will serve as starting point for the national and European conformity standards and regulations.

5.2.6 Testing methods

Dynamic or static load tests or non-mechanical tests are available as test methods to determine hydrogen embrittlement in pipelines and materials of the high-pressure gas transmission grid. The described test methods in this report are built on ISO, ASME and NACE standards. Some of these documents are covering hydrogen aspects others are dedicated to other gas technologies but are properly transposed to these tests with hydrogen. The indicated ISO standards are not all transferred to European standards (EN ISO).

These test methods should be anchored in the European standards of CEN and CENELEC by integrating them in existing or new standards respectively by take-over of ISO standards, where appropriate.

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Annex I: Numerical data of the inventory of the European grid

Table 22. Numerical information gathered about European pipelines for each cluster

Property		South Europe (km)	Western Europe (km)	Middle Europe (km)	Northern Europe (km)	Eastern Europe (km)	Europe (km)
Total cluster length		13,361	4,807	46,546	628	-	65,342
Steel	API 5L Gr A	0	0	2,010	0	-	2,010
	API 5L Gr B	1,197	1,339	6,103	24	-	8,662
	API 5L Gr X42	2,822	1,398	2,988	25	-	7,233
	API 5L Gr X46	18	0	947	0	-	966
	API 5L Gr X52	74	1,097	13,088	7	-	14,266
	API 5L Gr X56	0	0	849	0	-	849
	API 5L Gr X60	4,978	2,31	3,891	170	-	9,270
	API 5L Gr X65	202	266	207	0	-	675
	API 5L Gr X70	3,799	476	12,828	328	-	17,431
	API 5L Gr X80	269	0	343	0	-	611
	Other	2	301	1,536	74	-	1,914
	Unknown	2	301	1,755	0	-	2,059
Diameter	<10"	2,697	2,774	6,705	121	-	12,297
	11-20"	5,027	1,107	17,470	395	-	23,999
	21-30"	3,827	485	10,470	103	-	14,885
	31-40"	1,257	441	6,941	0	-	8,639
	41-50"	551	0	2,651	0	-	3,202
	<60"	0	0	576	0	-	5,76
	Unknown	4	0	1,735	9	-	1,749
Maximum operating pressure	<59 bar	2,166	0	18,570	81	-	20,817
	<66 bar	0	7,03	2,574	0	-	3,277
	<70 bar	0	0	10,731	0		10,731
	<75 bar	0	0	132	0	-	132

Property		South Europe (km)	Western Europe (km)	Middle Europe (km)	Northern Europe (km)	Eastern Europe (km)	Europe (km)
	<80 bar	10,750	0	9,464	238	-	20,452
	<85 bar	62	4,086	2,102	0	-	6,250
	<225 bar	526	0	4,202	0	-	4,728
	Other	0	0	0	0	-	0
	Unknown	7	0	0	0	-	7
Welding material	AWS A 5.1-E 6010	x	x	332	-	-	332
	AWS A 5.1-E 7010	-	-	382	-	-	382
	AWS A 5.1-E 7016	-	x	-	-	-	-
	AWS A 5.1-E7018	x	x	76	-	-	76
	AWS A 5.5-E XX10-X	x	-	-	-	-	-
	AWS A 5.5-E XX15-X	x	-	-	-	-	-
	AWS A 5.5-E XX16-X	-	x	-	-	-	-
	AWS A 5.5-E XX18-X	x	x	-	-	-	-
	AWS A 5.5-E XX18M-X	-	-	-	-	-	-
	AWS A 5.17-EH12-X	-	x	-	-	-	-
	AWS A 5.18-ER 70S-X	-	x	-	-	-	-
	AWS A 5.18-ER 70S-1B	-	x	-	-	-	-
	AWS A 5.28-ER XXS-X	x	-	-	-	-	-
	AWS A 5.28-E XXC-X	-	x	-	-	-	-
	AWS A 5.28-ER XXS-X	-	-	-	-	-	-
	AWS A 5.20-E X1T-XG-J	-	x	-	-	-	-
	AWS A 5.20-E X1T-XM-J	x	-	-	-	-	-
	AWS A 5.29-EXT1-XM-X	-	x	-	-	-	-
	AWS A 5.36-EXT1-MX-Ni1J	-	x	-	-	-	-
	Other	-	-	-	-	-	-

Property		South Europe (km)	Western Europe (km)	Middle Europe (km)	Northern Europe (km)	Eastern Europe (km)	Europe (km)
Outer Coating	PP	210	0	0	0	0	210
	PE	12,468	2,979	14,082	606	0	30,135
	PA	0	0	0	0	0	0
	Concrete	90	0	835	0	0	925
	Brai	0	2129	0	0	0	2,129
	Unknown	593	0	31,629	22	0	31,944
Inner coating/painting	None	0	1,190	947	0	-	2,137
	Epoxy layer	12,244	0	1,118	0	-	13,362
	Other	0	0	0	0	-	0
	Undefined	2,235	3,617	44,481	628	-	6,480

Table 23. Numerical information gathered about the renewal time of European pipelines

Intallation period (year)	South Europe (km)	Western Europe (km)	Middle Europe (km)	Northern Europe (km)	Eastern Europe (km)	Europe (km)
2010-2019	6,321	417	5,485	1	-	12,223
2000-2009	5,492	692	7,209	57	-	13,450
1990-1999	2,169	676	7,680	42	-	10,567
1980-1989	272	297	1,082	439	-	2,090
1970-1979	763	155	12,605	0	-	13,523
before 1970	47	2,609	8,266	0	-	10,921
Unknown	-	-	4,220	89	-	4,309

Table 24. Numerical information gathered about transmission facilities in the European gas grid

Category				South Europe		Western Europe		Middle Europe		Northern Europe		Eastern Europe		Europe	
				Number	Number/ 1000 km pipe length	Number	Number /1000 km pipe length	Number	Number/ 1000 km pipe length	Number	Number /1000 km pipe length	Number	Number/ 1000 km pipe length	Number	Number/ 1000 km pipe length
ransmission facilitie	Transmission valves positions			958	71.7	500	104.0	2034	43.7	0	0.0	-	-	3492	53.4
	Transmission compressor stations			19	1.4	6	1.2	127	2.7	3	4.8	-	-	155	2.4
	Transmission network pressure reduction stations			24	1.8	0	0.0	100	2.1	42	66.8	-	-	166	2.5
	Transmission network metering stations			109	8.2	0	0.0	31	0.7	42	66.8	-	-	182	2.8
	City Gate (transmission/distribution) pressure reduction stations			707	52.9	500	104.0	988	21.2	111	176.6	-	-	2306	35.3
Odorization systems	System	Laminar System		136	10.2	0	0.0	0	0.0	0	0.0	-	-	136	2.1
		Drip System			0.0	0	0.0	0	0.0	0	0.0	-	-	0	0.0
		Injection Pump System		342	25.6	20	4.2	52	1.1	1	1.6	-	-	415	6.4
		Undefined			0.0	0	0.0	0	0.0	0	0.0	-	-	0	0.0
	Odorant type	THT (tetrahydro-thiophene)			0.0		0.0	12	0.3	1	1.6	-	-	13	0.2
		S-free		-	-	-	-	0	0.0	-	-	-	-	0	0.0
		TBM			0.0	0	0.0	1	0.0	-	-	-	-	-	-
		DMS			0.0	0	0.0	0	0.0	-	-	-	-	-	-
		MES			0.0	0	0.0	0	0.0	-	-	-	-	-	-
		IPM			0.0	0	0.0	1	0.0	-	-	-	-	-	-
quality control syst	Quality control Systems	Process Gas		127	9.5	60	12.5	96	2.1	9	14.3	-	-	292	4.5
		Mass Spectrometers		0	0.0	0	0.0	0	0.0	0	0.0	-	-	0	0.0
		Electrochemic cell		11	0.8	0	0.0	0	0.0	0	0.0	-	-	11	0.2
	Flow Control Systems	Gas Pressure Control	Undefined	0	0.0	1200	249.6	630	13.5	0	0.0	-	-	1830	28.0
		Gas Meter	Turbine	292	21.9	0	0.0	1225	26.3	0	0.0	-	-	1517	23.2
			Bellows-type Gas Meters	0	0.0	0	0.0	288	6.2	0	0.0	-	-	288	4.4
			Mass flow gas meter	0	0.0	0	0.0	3	0.1	0	0.0	-	-	3	0.0
			Rotary gas meter	0	0.0	0	0.0	472	10.1	0	0.0	-	-	472	7.2
			Venturi	0	0.0	0	0.0	244	5.2	0	0.0	-	-	244	3.7
			US	11	0.8	0	0.0	189	4.1	0	0.0	-	-	200	3.1
			Diaphragm	0		0		9		0		-	-	9	
			Other	0	0.0	700	145.6	523	11.2	0	0.0	-	-	1223	18.7

Table 25. Operational LNG terminal in Europe from GIE report. [7]

Country	Number LNG terminals	NOMINAL ANNUAL CAPACITY (billion m3(N)/year)	LNG STORAGE CAPACITY (m3 LNG)	Average Start-up year
Belgium	1	9.0	566,000	1987
France	4	44.2	1,370,000	1995
Finland	2	0.5	78,500	2017
Greece	1	7.0	225,000	2000
Italy	3	14.7	487,500	1998
Lithuania	1	4.0	170,000	2014
Malta	1	0.7	125,000	2017
Norway	2	0.1	12,400	2009
The Netherlands	1	12.0	540,000	2011
Poland	1	5.0	320,000	2016
Portugal	1	7.6	390,000	2004
Rusia	1	3.7	174,000	2019
Spain	7	68.9	3,616,500	1994
Sweden	2	0.6	2,095,000	2014
UK	4	48.3	2,100,000	2009

Table 26. Operational underground storages in the different countries in Europe from GIE report [8]

Country	Type of storage					Woking gas volume TPA (TWh)	Withdrowal capacity TPA (GWh/day)	Injection capacity TPA (GWh/day)	Average Start-up year
	Depleted field	Aquifer	Salt cavern	Other	TOTAL				
Austria	11	0	0	0	11	131,5	1543	1224	1999
Belarus	1	1	1	0	3	15,5	318	0	1995
Belgium	0	1	0	0	1	9,0	170	88	1985
Bulgaria	1	0	0	0	1	6,3	36	34	1974
Croatia	1	0	0	0	1	5,6	61	45	1988
Czech Republic	6	1	0	1	8	34,4	608	420	1991
Denmark	0	1	1	0	2	10,4	194	101	1991
France	1	13	3	0	17	133,1	2507	1226	1974
Germany	3	1	15	0	19	112,0	2888	1721	1994
Greece	0	0	0	0	0	0,0	0	0	-
Hungary	5	0	0	0	5	67,5	837	478	1989
Italy	12	0	0	0	12	194,5	2877	1657	1983
Latvia	0	1	0	0	1	24,2	315	179	1968
The Netherlands	0	1	0	0	5	48,6	1057	726	2003
Poland	7	0	2	0	9	32,7	522	176	1995
Portugal	0	0	1	0	1	3,6	86	24	2003
Romania	7	0	0	0	7	33,6	348	262	1993
Russia	0	2	1	0	3	23,8	408	367	1984
Serbia	3	0	0	0	3	10,1	50	35	-
Slovakia	3	0	0	0	3	35,6	479	415	1995
Spain	3	1	0	0	4	32,0	215	126	2002
Sweden	0	0	0	1	1	0,1	12	4	2004
UK	2	0	7	0	9	16,5	1332	760	2005
Ukraine	11	2	0	0	13	333,4	2790	2968	1986

Table 27. Operational underground storages in Europe gathered in clusters.

Cluster	Type of storage					Woking gas volume-TPA (TWh) L	Withdrowal capacity TPA (GWh/day)	Injection capacity TPA (GWh/day)	Average Start-up year
	Depleted field	Aquifer	Salt cavern	Other	TOTAL				
South Europe	20	1	1	0	22	252,01	3323,97	1922,39	1988
Western Europe	3	15	10	0	32	207,17	5065,16	2799,66	1988
Middle Europe	42	3	17	1	63	506,98	8020,09	5289,08	1962
Northern Europe	0	1	1	1	3	10,45	205,92	105,12	1995
Eastern Europe	12	5	2	0	19	372,68	3515,56	3335,65	1987
TOTAL	77	25	31	2	139	1349,29	20130,7	13451,9	1976

Table 28. Cross-border IP within EU and with non-EU (export) from ENTSOG report [10]

Point name	*Technical physical capacity (GWh/d)*	*From Operator*	*From CC*	*To Operator*	*To CC*
Zeebrugge IZT	651.7	Interconnector	UK	Fluxys Belgium	BE
	803.4	Fluxys Belgium	BE	Interconnector	UK
Zelzate	271.0	Fluxys Belgium	BE	GTS	NL
	407.0	GTS	NL	Fluxys Belgium	BE
Zelzate (Zebra Pijpleiding)	122.0	Fluxys Belgium	BE	Zebra Pijpleiding	NL
Zandvliet H-gas	47.0	GTS	NL	Fluxys Belgium	BE
Hilvarenbeek	642.0	GTS	NL	Fluxys Belgium	BE
	340.8	GTS	NL	Fluxys Belgium	BE

Point name	*Technical physical capacity (GWh/d)*	*From Operator*	*From CC*	*To Operator*	*To CC*
Eynatten 1 (BE) // Lichtenbusch / Raeren (DE)	132.2	GASCADE Gas-transport	DE	Fluxys Belgium	BE
	129.5	Fluxys Belgium	BE	GASCADE Gas-transport	DE
Eynatten 2 (BE) // Lichtenbusch / Raeren (DE)	268.3	Open Grid Europe	DE	Fluxys Belgium	BE
		Thyssengas	DE	Fluxys Belgium	BE
		Fluxys TENP	DE	Fluxys Belgium	BE
	160.0	Fluxys Belgium	BE	Open Grid Europe	DE
				Thyssengas	DE
				Fluxys TENP	DE
Remich	38.4	Open Grid Europe	DE	Creos Luxembourg	LU
Blaregnies L (BE) / Taisnières B (FR)	230.0	Fluxys Belgium	BE	GRTgaz	FR
Bocholtz	395.8	GTS	NL	Open Grid Europe	DE
				Fluxys TENP	DE
Bocholtz-Vetschau	5.1	GTS	NL	Thyssengas	DE
Zevenaar	327.6	GTS	NL	Open Grid Europe	DE
				Thyssengas	DE
Winterswijk	178.6	GTS	NL	Open Grid Europe	DE
Vlieghuis	72.0	GTS	NL	RWE	DE
Epe (DE) (Eneco) / Enschede (NL)	93.6	Eneco	DE	GTS	NL
	43.3	GTS	NL	Eneco	DE

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
Epe (DE) (Nuon) / Enschede (NL)	77.9	GTS	NL		
	117.2			GTS	NL
Epe (DE) / Enschede (NL)	103.5			GTS	NL
	47.5	GTS	NL	innogy	DE
Bunde (DE) / Oude Statenzijl (H) (NL) (GASCADE)	298.1	GASCADE Gas-transport	DE	GTS	NL
Bunde (DE) / Oude Statenzijl (H) (NL) (GUD)	42.9	Gasunie Deutsch-land	DE	GTS	NL
	63.1	GTS	NL	Gasunie Deutsch-land	DE
Bunde (DE) / Oude Statenzijl (H) (NL) I (OGE)	162.2	Open Grid Europe	DE	GTS	NL
	71.5	GTS	NL	Open Grid Europe	DE
Bunde (DE) / Oude Statenzijl (L) (NL) (GTG Nord)	70.2	GTS	NL	Gastransport Nord	DE
Bunde (DE) / Oude Statenzijl (L) (NL) (GUD)	181.8	GTS	NL	Gasunie Deutsch-land	DE
Etzel (DE) (Crystal) / Oude Statenzijl (NL)	64.4	GTS	NL		
	103.2			GTS	NL
Etzel (DE) (EKB) / Oude Statenzijl Et-zel (NL)	68.8	GTS	NL		
	114.2			GTS	NL

Point name	Technical physical capacity (GWh/d)	From Operator	From CC	To Operator	To CC
Etzel (DE) (OMV) Freya / Oude Statenzijl Etzel	71.8	GTS	NL		
	91.2			GTS	NL
Nüttermoor (DE) (EWE) H / Oude Statenzijl (H) (NL)	51.6	GTS	NL		
	53.4			GTS	NL
Nüttermoor H-1 (DE) (EWE) Renato / Oude Statenzijl (NL)	67.7	EWE Gasspeicher	DE	GTS	NL
	48.7	GTS	NL	EWE Gasspeicher	DE
Bacton (IUK)	651.7	National Grid Gas	UK	Interconnector	UK
Moffat	476.2	National Grid Gas	UK	GNI	IE
				Premier Transmission	UK
Oberkappel	159.9	Gas Connect Austria	AT	Open Grid Europe	DE
				GRTgaz Deutschland	DE
	199.4	Open Grid Europe	DE	Gas Connect Austria	AT
		GRTgaz Deutschland	DE	Gas Connect Austria	AT
Obergailbach (FR) / Medelsheim (DE)	605.7	Open Grid Europe	DE	GRTgaz	FR
		GRTgaz Deutschland	DE	GRTgaz	FR
Überackern ABG (AT) / Überackern (DE)	0.0	Gas Connect Austria	AT	bayernets	DE

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
	0,0	21Z000000000002E		Gas Connect Austria	AT
Überackern SUDAL (AT) / Überackern 2 (DE)	174.6	Gas Connect Austria	AT	bayernets	DE
	114.0	bayernets	DE	Gas Connect Austria	AT
Murfeld (AT) / Ceršak (SI)	112.5	Gas Connect Austria	AT	Plinovodi	SI
Tarvisio (IT) / Arnoldstein (AT)	1.148.8	TAG	AT	Snam Rete Gas	IT
	193.3	Snam Rete Gas	IT	TAG	AT
Griespass (CH) / Passo Gries (IT)	635.4	FluxSwiss	CH	Snam Rete Gas	IT
		Swissgas	CH	Snam Rete Gas	IT
	428.5	Snam Rete Gas	IT	FluxSwiss	CH
				Swissgas	CH
Wallbach	172.8	FluxSwiss	CH	Fluxys TENP	DE
				Open Grid Europe	DE
	317.9	Fluxys TENP	DE	FluxSwiss	CH
				Swissgas	CH
		Open Grid Europe	DE	FluxSwiss	CH
				Swissgas	CH
Gorizia (IT) /Šempeter (SI)	28.3	Snam Rete Gas	IT	Plinovodi	SI
	21.4	Plinovodi	SI	Snam Rete Gas	IT
Rogatec	7.7	Plinacro Ltd	HR	Plinovodi	SI
	53.7	Plinovodi	SI	Plinacro Ltd	HR
Oltingue (FR) / Rodersdorf (CH)	100.0	FluxSwiss	CH	GRTgaz	FR
		Swissgas	CH	GRTgaz	FR
	223.0	GRTgaz	FR	FluxSwiss	CH

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
				Swissgas	CH
Ellund	166.5	Open Grid Europe	DE	Energinet	DK
		Gasunie Deutsch-land	DE	Energinet	DK
	91.0	Energinet	DK	Open Grid Europe	DE
				Gasunie Deutsch-land	DE
Mallnow	184.8	GASCADE Gas-transport	DE	GAZ-SYSTEM (ISO)	PL
	931.5	GAZ-SYSTEM (ISO)	PL	GASCADE Gas-transport	DE
Brandov STEGAL (CZ) / Stegal (DE)	0.0	NET4GAS	CZ	GASCADE Gas-transport	DE
Olbernhau (DE) / Hora Svaté Kateřiny (CZ)	287.7	GASCADE Gas-transport	DE	NET4GAS	CZ
Hora Svaté Kateřiny (CZ) / Deutsch-neudorf (Sayda) (DE)	14.9	NET4GAS	CZ	ONTRAS	DE
	95.0	ONTRAS	DE	NET4GAS	CZ
Brandov-OPAL (DE)	951.9	OPAL Gastransport	DE	NET4GAS	CZ
		LBTG	DE	NET4GAS	CZ
		OPAL Gastransport	DE	NET4GAS	CZ
Waidhaus	906.9	NET4GAS	CZ	Open Grid Europe	DE

Point name	Technical physical capacity (GWh/d)	From Operator	From CC	To Operator	To CC
				GRTgaz Deutschland	DE
Cieszyn (PL) / Český Těšín (CZ)	28.0	NET4GAS	CZ	GAZ-SYSTEM	PL
Lanžhot	913.7	NET4GAS	CZ	eustream	SK
Baumgarten	246.5	Gas Connect Austria	AT	eustream	SK
		Gas Connect Austria	AT	eustream	SK
		TAG	AT	eustream	SK
		Gas Connect Austria	AT	eustream	SK
	1.570.4	eustream	SK	Gas Connect Austria	AT
				Gas Connect Austria	AT
				TAG	AT
Mosonmagyarovar	153.1	Gas Connect Austria	AT	FGSZ	HU
Kiskundorozsma (HU>RS)	142.0	FGSZ	HU	Srbijagas	RS
Zvornik	18.0	Srbijagas	RS	BH Gas	BA
Kyustendil (BG) / Zidilovo (MK)	20.4	Bulgartransgaz	BG	GA-MA - Skopje	MK
Kulata (BG) / Sidirokastron (GR)	117.1	Bulgartransgaz	BG	DESFA	GR
	46.5	DESFA	GR	Bulgartransgaz	BG
Strandzha (BG) / Malkoclar (TR)	477.0	Bulgartransgaz	BG	Botas	TR
Negru Voda I (RO) / Kardam (BG)	187.8	Transgaz	RO	Bulgartransgaz	BG

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
Negru Voda II, III (RO) / Kardam (BG)	541.1	Transgaz	RO	Bulgartransgaz	BG
		Transgaz	RO	Bulgartransgaz	BG
Karksi	63.0	Conexus	LV	Elering	EE
Kiemenai	67.6	Amber Grid	LT	Conexus	LV
	65.1	Conexus	LV	Amber Grid	LT
Sakiai	114.2	Amber Grid	LT	Gazprom	RU
Csanadpalota	52.1	FGSZ	HU	Transgaz	RO
	2.5	Transgaz	RO	FGSZ	HU
Dravaszerdahely	78.3	FGSZ	HU	Plinacro Ltd	HR
Dolni Bojanovice	74.3	eustream	SK	SPP Storage	CZ
	95.6	SPP Storage	CZ	eustream	SK
Láb (SK) / Láb IV (AT)	138.3	Gas Connect Austria	AT	NAFTA	SK
				POZAGAS	SK
	138.3	NAFTA	SK	Gas Connect Austria	AT
		POZAGAS	SK	Gas Connect Austria	AT
Haiming 2 7F	37.9	bayernets	DE		
		Open Grid Europe	DE		
	5.3			bayernets	DE
				Open Grid Europe	DE
Haiming 2-RAGES/bn	5.4	bayernets	DE	RAG	AT

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
	1.0	RAG	AT	bayernets	DE
Haidach (AT) / Haidach USP (DE)	267.8	bayernets	DE	astora	AT
				GSA LLC	AT
	299.9	astora	AT	bayernets	DE
		GSA LLC	AT	bayernets	DE
Haanrade	1.9	GTS	NL	Thyssengas	DE
Bizzarone	12.9	Snam Rete Gas	IT		
VIP IBERICO	144.0	Enagas	ES	REN - Gasodutos	PT
	80.0	REN - Gasodutos	PT	Enagas	ES
Jura	37.4	GRTgaz	FR	Gaznat	CH
VIP Kiefersfelden-Pfronten	23.0	bayernets	DE		
Tegelen	4.7	GTS	NL	Open Grid Europe	DE
Budince	416.0	eustream	SK	PJSC Ukrtransgaz	UA
	249.6	PJSC Ukrtransgaz	UA	eustream	SK
Ungheni	1.3	Transgaz	RO	Vestmoldtransgaz	MD
Jemgum (DE) (astora) / Oude Statenzijl (NL)	138.8	GTS	NL		
	193.1			GTS	NL
Jemgum (DE) (EWE) / Oude Statenzijl (NL)	138.8	GTS	NL		
	193.1			GTS	NL
Balassagyarmat (HU) / Velké Zlievce (SK)	127.0	eustream	SK	MGT	HU
VIP PIRINEOS	224.4	Enagas	ES	TERÉGA	FR
	165.0	TERÉGA	FR	Enagas	ES
RC Basel	8.8	terranets bw	DE	GVM	CH

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
RC Lindau	25.4	terranets bw	DE	Vorarlberger Erdgas	AT
Misso Izborsk	105.0	Elering	EE	Gazprom	RU
	178.5	Gazprom	RU	Elering	EE
GCP GAZ-SYSTEM/ONTRAS	48.7	ONTRAS	DE	GAZ-SYSTEM	PL
	0.1	GAZ-SYSTEM	PL	ONTRAS	DE
Ruse (BG) / Giurgiu (RO)	7.9	Bulgartransgaz	BG	Transgaz	RO
	1.6	Transgaz	RO	Bulgartransgaz	BG
VIP Brandov-GASPOOL	183.4	NET4GAS	CZ	GASCADE Gas-transport	DE
	72.2	GASCADE Gas-transport	DE	NET4GAS	CZ
VIRTUALYS	620.0	Fluxys Belgium	BE	GRTgaz	FR
	270.0	GRTgaz	FR	Fluxys Belgium	BE
Rep. San Marino	4.2	Snam Rete Gas	IT		

Table 29. Intra-Balancing Zone Points [10]

Point name	***Technical physical capacity (GWh/d)***	***From Operator***	***From CC***	***To Operator***	***To CC***
Nybro	396.0	DONG	DK	Energinet	DK
Kienbaum	66.6	GASCADE Gastransport	DE	Open Grid Europe	DE
Broichweiden Süd	4.8	GASCADE Gastransport	DE	Thyssengas	DE
Lampertheim IV	27.4	GASCADE Gastransport	DE	terranets bw	DE
Emsbüren-Berge	6.6	Gasunie Deutschland	DE	Thyssengas	DE
Steinitz	66.6	ONTRAS	DE	Open Grid Europe	DE
	34.4	Open Grid Europe	DE	ONTRAS	DE
Gernsheim	106.6	GASCADE Gastransport	DE	GRTgaz Deutschland	DE
Point of Interconnection (PWP) (PL)	275.5	GAZ-SYSTEM (ISO)	PL	GAZ-SYSTEM	PL
Zone L-Gas GUD/OGE	36.2	Gasunie Deutschland	DE	Open Grid Europe	DE
Carrickfergus	42.0	Premier Transmission	UK	GNI (UK)	UK
Vecsés MGT / FGSZ	51.5	FGSZ	HU	MGT	HU
	129.4	MGT	HU	FGSZ	HU
Zone GASCADE / OGE	14.9	GASCADE Gastransport	DE	Open Grid Europe	DE
Transfer Point NGTN <-> GTNTT	42.3			Bulgartransgaz	BG
	21.1	Bulgartransgaz	BG		
VIP L GASPOOL-NCG	70.4	Nowega	DE		
GDLux (BE) / Bras Petange (LU)	48.8	Fluxys Belgium	BE	Creos Luxembourg	LU

Table 30. Cross-border IP with non-EU (import) [10]

Point name	*Technical physical capacity (GWh/d)*	*From Operator*	*From CC*	*To Operator*	*To CC*
St. Fergus	705.8	Gassco	NO	National Grid Gas	UK
Dornum (EPT1 & EPT2)	422.7	Gassco	NO	Gasunie Deutschland	DE
				jordgas Transport	DE
				Open Grid Europe	DE
Emden (EPT1)	1.481.6	Gassco	NO	Open Grid Europe	DE
				Gasunie Deutschland	DE
				GTS	NL
				Thyssengas	DE
Zeebrugge ZPT	488.0	Gassco	NO	Fluxys Belgium	BE
Dunkerque	570.0	Gassco	NO	GRTgaz	FR
Easington	793.3	Gassco	NO	National Grid Gas	UK
Tarifa	442.7	EMPL	DZ	Enagas	ES
Almería	289.0	Medgaz	DZ	Enagas	ES
Mazara del Vallo	1.150.3	TMPC	DZ	Snam Rete Gas	IT
Gela	499.0	Green Stream	LY	Snam Rete Gas	IT
Imatra	220.0	Gazprom	RU	Gasum Oy	FI
Korneti	178.5	Elering	EE	Conexus	LV
	105.0	Conexus	LV	Elering	EE
Kotlovka	325.4	Gazprom Belarus	BY	Amber Grid	LT
Tieterowka	7.3	Gazprom Belarus	BY	GAZ-SYSTEM	PL

Kondratki	1.024.3	Gazprom Belarus	BY	GAZ-SYSTEM (ISO)	PL
Wysokoje	169.1	Gazprom Belarus	BY	GAZ-SYSTEM	PL
Drozdovichi (UA) -Drozdowicze (PL)	135.6	PJSC Ukrtransgaz	UA	GAZ-SYSTEM	PL
Uzhgorod (UA) - Velké Kapušany (SK)	2.028.0	PJSC Ukrtransgaz	UA	eustream	SK
		PJSC Ukrtransgaz	UA	eustream	SK
		PJSC Ukrtransgaz	UA	eustream	SK
		PJSC Ukrtransgaz	UA	eustream	SK
Beregdaróc 1400 (HU) - Beregovo (UA) (UA>HU)	516.6	PJSC Ukrtransgaz	UA	FGSZ	HU
Isaccea (RO) - Orlovka (UA) I	202.1	PJSC Ukrtransgaz	UA	Transgaz	RO
Isaccea (RO) - Orlovka (UA) II	289.7	PJSC Ukrtransgaz	UA	Transgaz	RO
Isaccea (RO) - Orlovka (UA) III	251.4	PJSC Ukrtransgaz	UA	Transgaz	RO
Kipi (TR) / Kipi (GR)	48.6	Botas	TR	IGI Poseidon	GR
				DESFA	GR
Värska	35.7	Gazprom	RU	Elering	EE
Greifswald	1.742.0	Nord Stream	RU	LBTG	DE
VIP Mediesu Aurit - Isaccea (RO-UA)	370.9	PJSC Ukrtransgaz	UA	Transgaz	RO
Misso / Estonia	0.3			Elering	EE
Dornum GASPOOL	306.4			Open Grid Europe	DE
Beregdaróc 800 (HU) – Beregovo (UA) (HU>UA)	0.0	FGSZ	HU	PJSC Ukrtransgaz	UA

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