HIGGS

Hydrogen in Gas Grids

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

D6.2

Report on main interoperability and cross border issues

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Executive Summary

Deliverable D6.2 "Report on main interoperability and cross-border issues" aims to describe the current discussions on the issue of blending at transport network level in the European Union and to analyse the influence of these discussions on the direction of the HIGGS project.

The Hydrogen and decarbonised gas market package “seeks to facilitate the penetration of renewable and low-carbon gases into the energy system enabling a shift from natural gas and to allow for these gases to play their needed role towards the EU climate neutrality in 2050”[1]. A harmonised approach at EU level is needed, otherwise Member States would set different standards, increasing the risk of cross-border flow restrictions and market segmentation. For the HIGGS project, which deals with hydrogen blending at transmission network level, the issue of blending limits is particularly relevant in this context. A distinction has to be made between a blending limit at border crossings and the flexibility at Member State level in national networks and, with appropriate agreements with neighbouring countries and higher blending limits at border crossings. At the time of writing, the level of the blending limit has not yet been determined, but the levels proposed in the documents of the European Commission (5 vol%; Article 20 of the Commission's proposal for a Directive of 15 December 2021), the European Parliament (3 vol%; Article 19 of the Parliament's final compromise amendments to the Regulation of February 2023) and the European Council (2 vol%, Article 19 of the General Approach of 28 March 2023) suggest a level in the range between 2 and 5 vol%.

A blending limit in this range has a massive impact on the objective and approach of the work in WP6 of HIGGS, as it prevents the strategic transport of hydrogen from regions with high production and import potential to regions with high demand through blending, and instead promotes the transport of hydrogen in pure hydrogen pipelines parallel to the natural gas infrastructure. A survey was conducted to get a picture of the mood of the European TSOs and thus a first assessment of the likelihood of higher blending limits in national networks and through bilateral/multilateral agreements also at border crossings. TSOs from a total of 30 countries (EU27+Norway, Switzerland and the UK) were contacted. Although the response rate is low, with replies from eight countries, it is still relevant and a trend can be identified: TSOs are generally in favour of blending at the level discussed for cross-border interconnection points. Only one response considered 5% by volume as a starting point that could be adjusted upwards. Based on these responses, it can be concluded that the European TSOs are also in favour of a separation between a pure hydrogen network and a natural gas network with limited blending.

An evaluation of the data from deliverable D6.1 once again illustrates the possible export potentials and import requirement in the different Member States of the European Union and thus the need for a rapid and targeted approach to the planning of a continental hydrogen network. Consequently, the plans of the TSOs with the European Hydrogen Backbone to create a European hydrogen network are progressing. In the latest publications on the European Hydrogen Backbone, five hydrogen corridors have been defined to connect the Member States of the European Union by 2030. Representatives of the two hydrogen corridors contacted by the HIGGS project reported that their respective pipelines are planned for pure hydrogen transport without blending. This is also in line with the discussions in the context of the Gas Package and the responses of the TSOs to the survey.

Questions about gas quality cannot be answered in isolation from the needs of customers. The future users of hydrogen, both in the transmission network and in the distribution network, can be divided into feedstock users (e.g. chemical industry, refineries) and energy users (e.g. electricity, steam and heat generation). The requirements for gas quality and variations in gas quality are therefore

[1] Proposal for a Directive of the European Parliament and of the Council on common rules for the internal markets in renewable and natural gases and in hydrogen, Brussels, 15.12.2021, 2021/0425 (COD)

extremely heterogeneous. The examples of gas turbines and the glass industry are discussed in this deliverable. When assessing the H_2 readiness of gas turbines, a distinction has to be made between existing plants and plants currently under development by manufacturers. Existing plants vary greatly in their suitability and need to be analysed on a case by case basis. As far as new plants are concerned, it should be noted that virtually all major manufacturers are planning to launch gas turbines in the next few years that can run efficiently on 100% hydrogen without exceeding emission limits. Blending and 100% hydrogen solutions are also possible for the glass industry; variations in gas quality are difficult for thermal processes, as the HyGlass project for glass production has shown. At the same time, the structures within the Member States are also very different in terms of energy supply, infrastructure and use, so the decision on blending at national level or through bilateral/multilateral agreements will be an individual decision based on regional circumstances.

It is important to interpret the results of this D6.2 correctly and to understand the limitations. These are the framework set by the Gas Package and the opinion of the European TSOs on blending. At the level of distribution system operators, the assessments are different.

1 Objective

It is widely acknowledged that renewable and low-carbon gases, such as hydrogen, will play a vital role in reaching the climate goals set by the European Commission [1]. Currently, large consumption of hydrogen is mainly seen as feedstock in specific sectors and industries, notably oil refining and production of methanol and ammonia. The role of hydrogen within the energy consumption is rather low at below 2 % by now [2]. Furthermore, the main production pathway today is steam methane reforming (SMR) of fossil feedstocks, such as natural gas and coal, which accounts for almost all hydrogen production [3]. As most of hydrogen is produced on-site for captive use in the EU, the current hydrogen pipeline network is very small compared to the natural gas grid (~ 1,600 km compared to 3,000,000 km) [4], [5].

However, the European hydrogen market will change drastically as the main production pathways will shift to sustainable production, and the use of hydrogen will be a dominant part in decarbonizing various sectors, as feedstock as well as energy carrier. This will lead to an increase in the European hydrogen production capacity, a higher importance of a hydrogen merchant market and consequently, an increased need of hydrogen transported via pipelines across the European Union to match production in suitable areas and demand in industrial, as well as rural areas. To facilitate an efficient and safe trade of hydrogen across the borders a legal and regulatory framework must be implemented that allows companies to operate gas infrastructure with hydrogen [1].

Objective of D6.2 is to analyse the current framework set by the European Commission regarding cross-border trading and the activities of gas transmission system operators.

2 Introduction

Sustainably produced hydrogen will play a decisive role in Europe's future energy and feedstock markets. It will contribute effectively to the decarbonisation of the various sectors. Along the hydrogen value chain, legislators, regulators, companies and research institutes are working intensively on:

- production of sufficient quantities of hydrogen locally in the EU.
- import of sufficient quantities of hydrogen through cooperation agreements with third countries.
- enabling infrastructure to import, transport, distribute and store the required quantities and qualities of hydrogen.
- conversion of production processes currently based on fossil fuels and/or feedstocks to hydrogen.
- development of sustainable hydrogen-based solutions for heterogeneous sectors such as heat and transport.
- establishment of political, regulatory and strategic frameworks for the integration of hydrogen into the economic system and the various sectors.

Against the background of the climate catastrophe, which is increasingly becoming the focus of public and political attention, and catalysed further by the Russian war of aggression against Ukraine and the resulting crises on the global energy markets, the transformation described above has gained further momentum. The EU has made it clear that hydrogen is seen as a key building block in addressing these challenges through a number of initiatives, strategies and plans. These include among others:

- 2020: Approval of European Green Deal with the primary goal of becoming the first climate-neutral continent by 2050 [6].
- 2020: EU Hydrogen Strategy (”A hydrogen strategy for a climate neutral Europe”) [1].
- 2020: Launch of IPCEI (”important projects of common European interest”) programme [7].
- 2021: Fit-for-55 package, including the “Hydrogen and decarbonised gas market package [8] and the Renewable Energy Directive. For the latter trilogue negotiations between the Parliament, the Council and the Commission concluded with a provisional agreement on 30th March 2023. The Council formally endorsed the final text on 16th June 2023 while the ITRE committee voted on the provisional agreement on 28 June; a plenary vote was carried out on 12th September 2023 [9].

- 2022: Publication of the REPowerEU plan, which envisages, among other things, the domestic production of 10 million tons of renewable hydrogen and 10 million tons of imports by 2030 [10].

- Ongoing: Launch and promotion of several industrial, funding and research and innovation initiatives on hydrogen such as Clean Hydrogen Partnership, European Clean Hydrogen Alliance and Hydrogen Public Funding Compass.

In addition, numerous Member States have published their own national hydrogen strategies and initiated and promoted projects to ensure the hydrogen ramp-up (s. Deliverables D2.3 and D6.3 published on the project website [11]).

This transformation must be achieved without shifting emissions from Europe's own balance area to third countries and without harming Europe as a business location.

In this dynamic context, it is not surprising that the framework for the HIGGS project has also changed over the course of the project. Originally, it was assumed that blending hydrogen into the existing high-pressure gas pipelines would be an effective way to transport large quantities of hydrogen in Europe, especially during the ramp-up of the hydrogen economy. The HIGGS project was designed accordingly. During the course of the project, it became clear that both the European Union and many transmission system operators consider the issue of hydrogen blending at transport network level to be a "last resort", apart from low percentage blends such as those currently being discussed in the context of the Gas Package. Rather, a strict separation between a so-called pure hydrogen network and a more or less pure natural gas network with minor hydrogen blends seems to be preferred for the large-scale and cross-border transport of hydrogen. However, this does not rule out the possibility of higher blends being used in national networks or in cross-border trade through bilateral agreements.

Chapter 3 of this deliverable describes the development of the hydrogen and decarbonised gas market package with a particular focus on interoperability, cross-border issues and blending rates.

Chapter 4 builds on the findings of D6.1 and illustrates the demand for hydrogen in Member States in 2030 and 2040. These findings are used in D6.3 to examine the extent to which these demands can be met by alternative plans for transport pipelines with 100% hydrogen.

Since even after the Gas Package enters into force, Member States will still be allowed to inject hydrogen into national transport networks at higher concentrations than specified in the Gas Package, and since Member States can also agree on higher concentrations in cross-border trade through bilateral agreements, it is interesting to compile the positions of the individual Member States regarding the injection of hydrogen into transport networks. For this purpose, the publicly available information on this issue is summarised in chapter 5. In order to obtain a more detailed and comprehensive picture, the HIGGS project has carried out a survey among the European TSOs to find out about their plans and preferences and to take them into account in the further project work (chapter 6).

The customers of the transmission network are mainly large industrial customers from the manufacturing sector, which use hydrogen either as an energy carrier or as a feedstock. Therefore, the issue of blending at the transmission network level is also of interest from a customer's point of view. Chapter 7 therefore describes the requirements of industrial customers as an example.

Finally, chapter 8 summarises some of the basics and published opinions on virtual blending as a possible option to enable the blending of hydrogen in regions that are not directly connected to a hydrogen network by means of certificate trading.

3 Relevance of the Hydrogen and decarbonised gas market package with regard to blending hydrogen in gas transmission grids

3.1 Background of the Hydrogen and gas markets decarbonization package in the context of the European Green Deal

On 12th December 2019, the European Council, together with the European Union, presented the European Green Deal (EGD), as a package of measures to combat climate change and achieve climate neutrality by 2050 [12].

Later, on 14th July 2021, the European Commission adopted a package of proposals to make the EU's policies fit for a reduction of net greenhouse gas emission by at least 55 % by 2030 ('fit for 55') [8]. By adopting the EU's climate, energy, land use, transport and taxation policies these proposals can be seen as 'legislative tools to deliver on the targets agreed in the European Climate Law'. In this context the Commission's proposals for the review and revision of the Gas Directive 2009/73/EC and Gas Regulation (EC) No 715/2009, referred to as **'Hydrogen and decarbonised gas market package' (= Gas Package)**, were published in December 2021 [13], [14]. Goal of these proposals is to "enable the market to decarbonise gas consumption, and puts forward policy measures required for supporting the creation of optimum and dedicated infrastructure, as well as efficient markets. It will remove barriers to decarbonisation and create the conditions for a more cost-effective transition". It is important to mention that these activities are complementary to the revised Renewable Energy Directive (REDII/III), Energy Efficiency Directive (EED) and Emissions Trading Scheme (EU ETS) [15], [16].

The European Parliament referred the file to the Committee on Industry, Research and Energy (ITRE). ITRE's report was adopted on 9th February 2023 and endorsed at the plenary session of 15th March 2023 [17].

On 28th March 2023 the European Council adopted its 'general approaches' at the energy ministers meeting [18].

At the time of writing, trilogue negotiations have come to an end. However, the final endorsement of the provisional agreement will have to wait for a final deal on the Reform of the Electricity Market Design. The texts will then be formally adopted by the European Council and the Parliament. Once this process is completed, the new legislation will be published in the Official Journal of the Union and enter into force.

Naturally, some aspects were diverging in the drafts of the European Commission, the Council and Parliament. The main differences that are relevant in the context of the HIGGS project are discussed below. Particular attention will be paid to interoperability, cross-border issues and blending.

For the sake of clarity, the content is explained based on the European Commission's proposals and then the divergent opinions in the publications of the Parliament and the Council are addressed as far as they are relevant for the HIGGS project.

The following sub-chapters do not claim to provide a complete summary of the contents of the Gas Package. Rather, the aim here is to prepare the ground to analyse to which extend the objectives of the HIGGS project are in line with the planned orientation of the Gas Package.

3.2 Interoperability within the Hydrogen and Gas Markets Decarbonisation package

The unhindered flow of gas between the countries of the European Union is a prerequisite for effective market integration. Therefore, and for “facilitating commercial and operational cooperation between adjacent transmission system operators” EC Regulation (Commission Regulation (EU) 2015/703 “establishing a network code on interoperability and data exchange rules”) provides rules and procedures to reach an “appropriate level of harmonisation towards efficient gas trading and transport across gas transmission systems in the Union”. EC Regulation 2015/703 is referenced in both proposals of the Gas Package, for the Regulation and the Directive [13], [14]. A particular focus is put on interconnection agreements, including rules for:

- flow control.
- measurement principles for gas quantity and quality for the matching process and for the allocation of gas quantities.
- communication procedures in case of exceptional events.
- common set of units.
- gas quality, including rules on managing cross-border trade restrictions due to gas quality differences and due to differences in odorization practises, short- and long-term gas quality monitoring and information provision.
- data exchange and reporting on gas quality.
- transparency, communication, information provision and cooperation among relevant market participants.

In Article 2 (66) of the **Commission’s Proposal for a Directive** on common rules for the internal markets in renewable and natural gases and in hydrogen the term “interoperability” is defined in the context of smart metering data as “[…] the ability of two or more energy or communication networks, systems, devices, applications or components to interwork to exchange and use information in order to perform required functions” [13].

The importance of smart metering systems in achieving interoperability is further defined in particular in Article 16 for natural gas and Article 17 for hydrogen systems. This is an important aspect for Member States to consider when introducing energy management systems. In Article 22 interoperability is further detailed for access to data [13].

Article 9 describes that the technical rules should ensure the interoperability of the system as a whole, while being objective and non-discriminatory [13].

Tasks of hydrogen network, storage and terminal operators are defined in Article 46. Among other things each operator of hydrogen networks, storage or terminal shall be responsible for "[…] (d) providing to the operator of other networks or systems with which its system is interconnected sufficient information to ensure the secure and efficient operation, coordinated development and interoperability of the interconnected system" [13].

Article 71 defines the general objectives of the regulatory authority. An important aspect related to interoperability is described under (c)

"eliminating restrictions on trade in natural gas and hydrogen between Member States, including eliminating restrictions due to differences in the quality of gases or differences in the volume of hydrogen blended into the natural gas system or to differences in the quality of hydrogen in the hydrogen system, developing appropriate cross-border transmission and/or transport capacities to meet demand and enhancing the integration of national markets ensuring the interoperability of the interconnected EU natural gas system or Union hydrogen system, which may facilitate natural gas flow across the Community Union;" [13]

Both, the Regulation and the Directive, emphasise the importance of harmonised gas quality and, in this context, of hydrogen blending rates for interoperability. In the spirit of this argument and in order to avoid cross-border problems, the blending limit at border crossings is also derived. This will be discussed in more detail in the following chapters [13], [14].

Article 23 of the **Commission's proposal for the Regulation** describes the tasks of ENTSOG. In brief, ENTSOG shall elaborate network codes among others in the field of interoperability rules. However, it is important to mention that the development of these network codes shall be "without prejudice to the Member States' right to establish national network codes which do not affect cross-border trade" [14].

Articles 53 and 54 further detail the establishment of network codes. Among other things, it is stated there that the Commission is empowered to adopt delegated acts […] with regard to the establishment of network codes in the area of "interoperability rules for the hydrogen network". Specific topics mentioned are addressing:

- interconnection agreements.
- units.
- data exchange.
- transparency.
- communication.
- information provisions and cooperation among relevant market participants.
- hydrogen quality:
    - common specifications and standardization.
    - odorization.

- cost benefit analyses for removing cross-border flow restrictions due to hydrogen quality differences.
- reporting on hydrogen quality [14].

3.3 Cross-border issues within the hydrogen and gas markets decarbonisation package

In its hydrogen strategy, the European Union has formulated the need to enable the unhindered transport of hydrogen between Member States.

'Current gas quality standards – national and CEN – would need to be updated. Moreover, reinforcement of instruments may be needed to secure cross-border coordination and system interoperability for an unhindered flow of gases across Member States. These options require careful consideration in terms of their contribution to the decarbonisation of the energy system as well as economic and technical implications.' [1]

This led to the Key Action 10 of the EU Hydrogen Strategy: "Design enabling market rules to the deployment of hydrogen, including removing barriers for efficient hydrogen infrastructure development, and ensure access to liquid markets for hydrogen producers and customers and the integrity of the internal gas market through the upcoming legislative reviews (e.g. review of the gas legislation for competitive decarbonised gas markets)", which is dealt with in particular in the new versions of the Directive and Regulation [1].

As stated in the introduction to the **Commission's proposal for the directive**, the currently valid regulatory framework:

- "does not address the deployment of hydrogen as an independent energy carrier via dedicated hydrogen networks".
- does not have "rules at EU level on tariff-based investments in networks, or on the ownership of dedicated hydrogen networks".
- does not include "[…] harmonised rules on (pure) hydrogen quality" [13].

This condition is considered as barriers for the development of "cost-effective, cross-border hydrogen infrastructure and competitive hydrogen market" which is "a prerequisite for the uptake of hydrogen production and consumption". Aim of the **"Hydrogen and gas markets decarbonisation package"** is to address these deficiencies while avoiding "fragmented regulatory landscape across the EU, which could hamper the integration of national hydrogen networks and markets, thereby preventing or deterring cross-border trade in hydrogen".

There is, of course, an interface between interoperability and cross-border issues. Different specifications on gas quality and blending limits in different Member States can significantly increase the complexity of trade and thus reduce cross-border flows. Therefore, some of the points already derived in the previous chapter on interoperability also apply to this chapter.

Article 3 “Competitive, consumer-centred, flexible and non-discriminatory markets for gas” of Chapter II “General rules for the organization of the market” explicitly states that “Member States shall ensure that their national law does not unduly hamper cross-border trade in gases […]” [13].

Access to upstream natural gas pipeline networks and settlement of cross-border disputes is dealt with in Article 28 [13].

Article 53 deals with financing cross-border hydrogen infrastructure which is also identified as potentially hindering market development [13].

Article 74 further defines the tasks of regulatory authorities and the needs to cooperate between regulatory authorities (and in particular within ACER) on cross-border issues. In this context, among others, the following is mentioned as being the tasks of the regulatory authorities: “foster the creation of operational arrangements in order to enable an optimal management of the network, promote joint gas and hydrogen exchanges and the allocation of cross-border capacity, and to enable an adequate level of interconnection capacity […] within the region and between regions to allow for development of effective competition and improvement of security of supply without discriminating between supply undertakings in different Member States.” and further to “ensure regulatory compliance of legal entities fulfilling transmission operators’ and network operators’ tasks at cross-border or regional level” [13].

The **Commission’s proposal for the Regulation** identifies the aims of the internal market in natural gas as “deliver real choice for all consumers in the Union, be they citizens or businesses, new business opportunities and more cross-border trade, so as to achieve efficiency gains, competitive prices and higher standards of service, and to contribute to security of supply and sustainability” [14].

In recital 57 it is pointed out that the “quality of hydrogen transported and consumed in Europe can vary depending on its production technology and transportation specificities.” It is concluded that “[…] a harmonised approach at Union level to hydrogen quality management at cross-border interconnectors should lead to the cross-border flow of hydrogen and to market integration.” [14]

The very first article of the first chapter of the Regulation, entitled "Subject matter and scope", sets out the **objective** of the Regulation, to facilitate “the emergence of a well-functioning and transparent wholesale market with a high level of security of supply in gases and provides mechanisms to harmonise the network access rules for cross-border exchanges in gases”. In addition, the general principles in Article 3 stress the importance for Member States, regulatory authorities, transmission system operators, distribution grid operators, storage operators, LNG operators, hydrogen system operators, and delegated operators […] to ensure that gases markets are operated in accordance with among others “barriers to cross-border gas flows, if existing, between entry-exit systems shall be removed”. In Article 9 TSOs are further required among others to “provide appropriate economic signals for the efficient and maximum use of technical capacity, facilitate investment in new infrastructure and facilitate cross-border exchanges in natural gas” [14].

A specific focus is placed on cross-border coordination on **gas quality** in Article 19. This article specifies that TSOs “shall cooperate to avoid restrictions to cross-border flows due to gas quality differences on interconnection points between Union Member States.” It is further explained that TSOs shall inform the concerned regulatory authorities without delay when a “restriction to cross-border flow due to gas quality differences cannot be avoided […]. If there is a case where the concerned TSO do not reach an agreement on a solution “each transmission system operator shall inform its regulatory authority without delay.” It is further explained that ACER shall decide on the restriction and shall decide on the solution to remove a recognized restriction. Further details required to implement elements of Article 19 “shall be set in a network code established on the basis of Article 53 of this Regulation.” Article 39 further extends the content of Article 19 to dedicated hydrogen networks [14].

The Union-wide ten-year network development plan that is dealt with in Article 43 shall among others "identify investment gaps, notably with respect to cross-border capacities" [14].

3.4 Blending within the Hydrogen and gas markets decarbonisation package

The issue of blending limits, in particular at border crossings, is central both to the previous sub-chapters on interoperability and cross-border issues and to the impact of the Gas Package on the objective of the HIGGS project.

Within the **Commission's Proposal for a Directive**, it is stated that in the stakeholder consultation respondents were "divided on hydrogen blending, but the majority agrees that it can provide a cost-efficient and fast first step, despite the high technical costs, to energy system decarbonisation." A cap of 5 % is mentioned in the proposal for a directive, however, it is mainly dealt with in the Proposal for a Regulation [13].

Recital 43 of the **Commission's Proposal for a Regulation** provides an insight into the rationale behind the Regulation's subsequent content regarding blending of hydrogen into the natural gas system.

- Blending of hydrogen is considered "less efficient compared to using hydrogen in its pure form and diminishes the value of hydrogen".
- Blending of hydrogen is considered to affect "the operation of gas infrastructure, end-user applications, and the interoperability of cross-border systems".
- It is considered that a "harmonised approach on blending hydrogen […] in the form of a Union-wide allowed cap at cross-border interconnection points […] would limit the risk of market segmentation.".
- Preservation of Member States' decision on whether to apply blending hydrogen in their national natural gas systems.
- Higher hydrogen blending levels for cross-border interconnection points are possible if adjacent transmission systems agree [14].

Recital 44 further defines the need for a "strong cross-border coordination and dispute settlement process between transmission system operators on gas quality […] to facilitate efficient transport of natural gas […] and to "move towards greater internal market integration." Gas quality parameters that are explicitly mentioned include among others "hydrogen blends and their development over time" [14].

Hydrogen blending limits are therefore considered to be an important parameter of gas quality and the objective of setting harmonised rules in the Gas Package is justified by the fact that non-harmonised rules would lead to cross-border flow restrictions and market segmentation [14].

Article 20 “Hydrogen blends at interconnection points between Union Member States in the natural gas system” sets the limit for hydrogen blends to be accepted by TSOs at border crossing points at **5 % by volume** [14].

The **Parliament’s Final Compromise Amendments on the Regulation** as of February 2023 is more stringent with regard to the blending of hydrogen. Recital 43 accordingly describes blending as a “last resort” and states that Member States shall “prioritise the production and use of renewable and low-carbon hydrogen in their pure form in the hard-to decarbonize sectors, such as industry and transport applications”. Great emphasis is placed on the efficient use of hydrogen, so that its use in certain sectors is actively discouraged. However, the view that Member States should be free to decide on the possibility of hydrogen blending is also supported by the European Parliament. In line with this more critical attitude towards blending of hydrogen, European Parliament sets the blending limits at cross-border interconnection points in Article 19 at **3 % by volume** and thus lower than in the proposal of the European Commission [19].

In its **General Approach of 28 March 2023, the European Council** supplements Recital 43 in such a way that “Member States should consult the other Member States if they are likely to be affected by the measure and take into account the situation in these countries” when considering agreements on higher hydrogen levels for cross-border interconnection points.

In Article 19, the European Council sets the **blending limit at 2% by volume**, and hence lower than the Commission and Parliament in their respective documents. In addition, it is added that Member States should ensure that the blends are within the technical specifications of the users [20].

In the final trilogue on 8 December 2023, the negotiators agreed on a maximum of 2% by volume as requested by the European Council. This was also recommended by the Commission de regulation de l’énergie (CRE).

Complementary to the hydrogen concentration limit at interconnection points in the Gas Package, the CEN standard EN 16726 determines the hydrogen concentration in H-gas for the overall gas chain, see Clause 5.10.

4 Derivation of future average and maximum hydrogen balances at national level

4.1 Introduction

Chapter 5 of Deliverable D6.1 “Considerations on H_2 injection potential to reach EU decarbonization goals” provides a detailed description of the current gas supply situation in the different Member States of the European Union and gives an outlook for the future based on publicly available sources. This information is transparently presented in Table 7 of D6.1. Subsequently, at the national level, the hydrogen balance was presented. Once in a "minimum demand case", where minimum production and consumption forecasts are related to each other, and once in a "maximum demand case", where maximum production and consumption forecasts are related to each other.

This approach will be extended here – in Deliverable D6.2 – by two further cases.

1. Average Case (AC): For each country, the arithmetic mean of production and demand is calculated from the maximum and minimum values. The difference between these two averages gives the average trade balance.

2. Maximum Gap Case (MaxGC): The difference between minimum production and maximum demand results in the largest trade deficit for each country.

The extension with these cases is intended to 1) illustrate the difference between the extremes and thus the uncertainty, and 2) prepare calculations to be carried out in D6.3.

4.2 Projection 2030

In the **Average Case (AC)**, there are high production surpluses in Scandinavia (Finland 45.5 TWh/a; Norway 19 TWh/a, Denmark 9.5 TWh/a) and on the Iberian Peninsula (Spain 44.5 TWh/a; Portugal 11 TWh/a). On this data basis, the largest demand surpluses are in Central and Central-Southern Europe (Germany -117 TWh/a, Switzerland -27 TWh/a; Italy -16 TWh/a). Eastern and South-Eastern Europe have smaller demand surpluses. Figure 1 illustrates a detailed overview.

Overall, the average case shows a production volume of about 452 TWh/a in the EU + UK and Norway. This corresponds to about 13.5 million tonnes, which is higher than the REPowerEU target of 10 million tonnes. The corresponding demand of around 490 TWh/a (=14.7 million tonnes) is only slightly higher than the production volume, so the figures used only indicate a low import requirement.

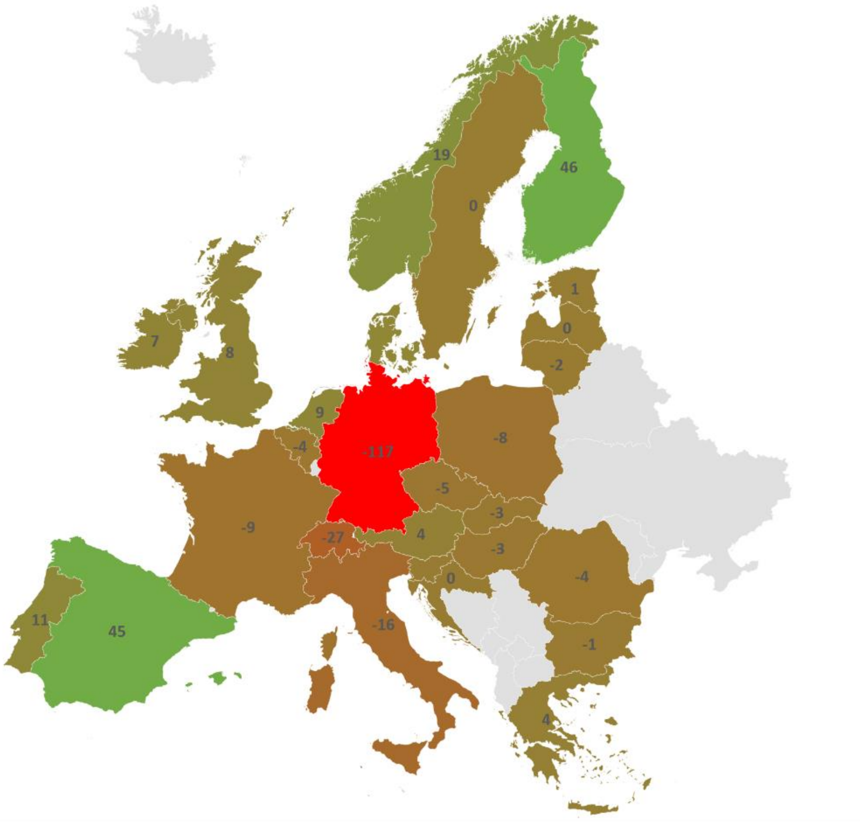


Figure 1: National hydrogen balances in Europe for the year 2030 in the Average Case (AC) in TWh/a (the colours of the countries represent their hydrogen balance. Green means production surplus, red means production deficit, gradations in the middle)

In the **Maximum Gap Case (MGC)**, the supply situation deteriorates dramatically and relevant production surpluses are only observed on the Iberian Peninsula (Spain 20 TWh/a; Portugal 10 TWh/a) and in Finland (36 TWh/a). The largest import demand in this scenario remains in central and central-southern Europe (Germany -217 TWh/a, Netherlands -44 TWh/a, Italy -29 TWh/a, Switzerland -27 TWh/a, Poland -19 TWh/a and France -16 TWh/a). Southeast Europe shows smaller demand surpluses in this scenario. A detailed view of the national balances can be found in Figure 2.

With 10.49 million tonnes of hydrogen production in the European Union (+UK & Norway), the production volume in this scenario is still above the REPowerEU target, but the production deficit increases to about 11.3 million tonnes of hydrogen. Accordingly, the REPowerEU import target of 10 million tonnes in 2030 seems reasonable.

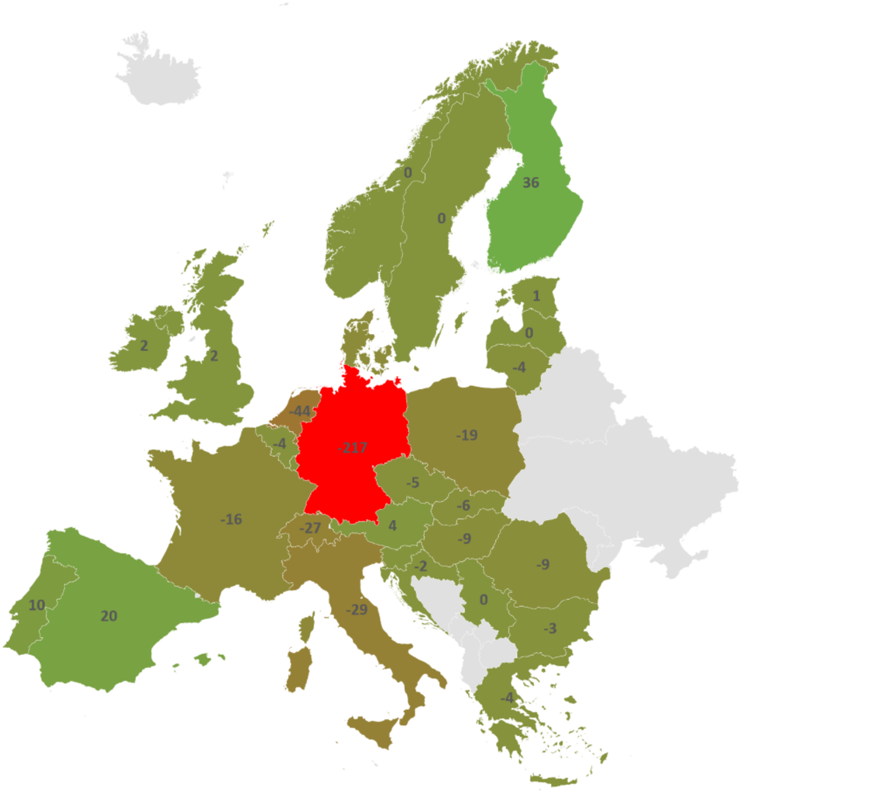


Figure 2: National hydrogen balances in Europe for the year 2030 in the Maximum Gap Case (MGC) in TWh/a (the colours of the countries represent their hydrogen balance. Green means production surplus, red means production deficit, gradations in the middle)

The range of balances in each scenario shows the current uncertainties in the development of the respective hydrogen markets. Ultimately, this also highlights the influence that the development of appropriate framework conditions has on domestic hydrogen production and demand.

4.3 Projection 2040

In the **Average Case (AC)**, there are high production surpluses in Scandinavia (Finland 58 TWh/a; Norway 75 TWh/a, Denmark 38 TWh/a, Sweden 63 TWh/a), on the Iberian Peninsula (Spain 30 TWh/a; Portugal 34 TWh/a), Great Britain (UK 27 TWh/a, Ireland 35 TWh/a) and to a lesser degree Romania (21 TWh/a), Greece (17 TWh/a) and France (11 TWh/a). On this data basis, the largest demand surpluses are in Central and Central-Southern Europe (Germany -252 TWh/a, Austria -29 TWh/a; Italy -35 TWh/a) as well as in Central-Eastern Europe (Poland -61 TWh/a, Czech Republic -16 TWh/a). For a detailed illustration, see Figure 3.

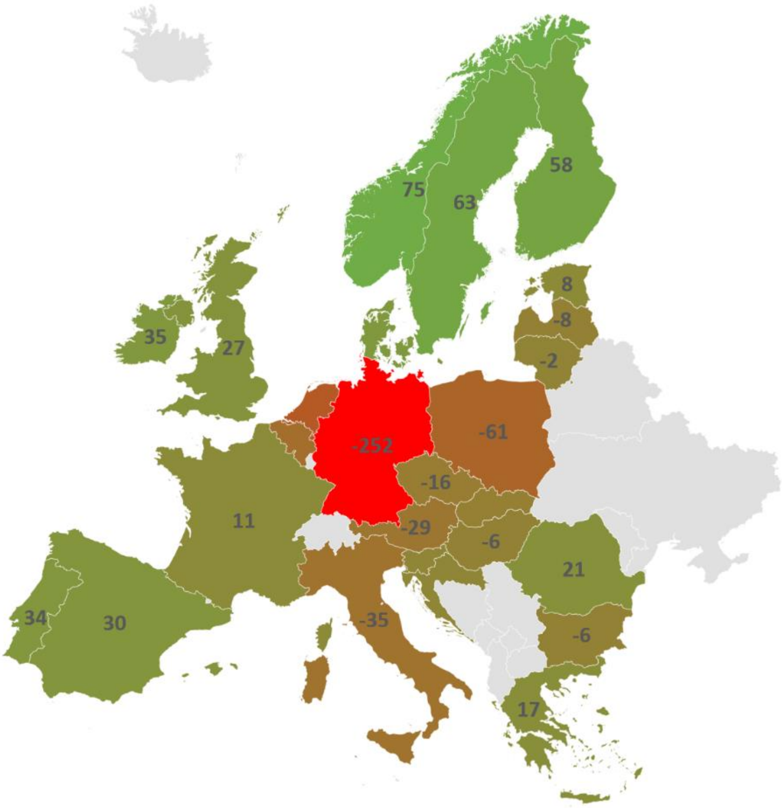


Figure 3: National hydrogen balances in Europe for the year 2040 in the Average Case (AC) in TWh/a (the colours of the countries represent their hydrogen balance. Green means production surplus, red means production deficit, gradations in the middle)

In the **Maximum Gap Case (MGC)**, the supply situation changes as follows. The only region with a large surplus is Scandinavia (Finland 40 TWh/a, Sweden 25 TWh/a, Norway 15 TWh/a). In addition, there are isolated countries with surpluses such as Portugal (33 TWh/a), Ireland (29 TWh/a) and Romania (16 TWh/a). The largest import demands remain in central and central-southern Europe (Germany -325 TWh/a, Italy -105 TWh/a, Austria -31 TWh/a) and central-Eastern Europe (Poland -77 TWh/a, Czech Republic -17 TWh/a) and Spain (-57 TWh/a). It is noteworthy that this scenario also shows high demand in Spain (-57 TWh/a) and the UK (-31 TWh/a). For detailed national balances, see Figure 4.

Figure 4: National hydrogen balances in Europe for the year 2040 in the Maximum Gap Case (MGC) in TWh/a (the colours of the countries represent their hydrogen balance. Green means production surplus, red means production deficit, gradations in the middle)

For the 2040 projection, the overall balance for the EU27+UK+Norway+Switzerland is as follows, based on the figures presented in D6.1:

- AC:
    - H_2-Production: 43.2 Millionen t/a.
    - H_2-Demand: 47.2 Millionen t/a.
    - Production deficit: 4.0 Millionen t/a.
- MaxGC:
    - H_2-Production: 37.8 Millionen t/a.
    - H_2-Demand: 58.3 Millionen t/a.
    - Production deficit: 20.5 Millionen t/a.

The range of balances in each scenario shows the current uncertainties in the development of the respective hydrogen markets. Ultimately, this also highlights the influence that the development of appropriate framework conditions has on domestic hydrogen production and demand.

5 National statements and statements from associations on the topic of blending in the transport network

5.1 Austria

In Austria's "2021 Coordinated Network Development Plan for the Gas Transmission System Infrastructure in Austria for the period from 2022 – 2031" in Chapter 5.3.5 "Network development at the Austrian – German interconnection point" following is stated.

"However, the extent of the demanded transport capacity cannot be represented through admixture (blending) of hydrogen into the gas flow, but requires a dedicated hydrogen infrastructure, i.e. new constructions or repurposing of existing pipelines. Because the demanded hydrogen transport is not possible through admixture into the gas flow of existing network infrastructure, the representation of this transport case makes it necessary to project a complementary transport (access) to the Austrian VTP" [26]

5.2 France

There is no legal requirement regarding admixture limits of hydrogen to natural gas. The grid and storage operators, GRTgaz, Terega and GRDF prescribe in their technical gas quality prescriptions a limit of 6% by volume hydrogen in natural gas and biomethane. This is also described in deliverable D.6.5 Roadmap H2NG for Europe of the EU-project THyGA (Testing Hydrogen admixture for Gas Applications) [25]. With view to the ability of most of the uses and also with view to the CEN standardisation process, i.e. the revision of EN 16726, a reduction is foreseen to 2% by volume. This also with respect to the plans to produce and use synthetic methane for which the 2% by volume limit is technically achievable.
However, according to the THyGA deliverable, the focus is on hydrogen-only networks and hydrogen producers do not plan to inject into natural gas pipelines [25].

5.3 Germany

In the hydrogen report on the status quo of the establishment of the hydrogen grid and on the development of the future network planning for hydrogen ("Wasserstoffbericht – Bericht zum aktuellen Ausbaustand des Wasserstoffnetzes und zur Entwicklung einer zukünftigen Netzplanung Wasserstoff gemäß § 28q EnWG") of FNB Gas (= the association of supra-regional gas transmission companies in Germany) it is clearly stated that the gas transmission grid operators of Germany have currently based their planning on a maximum blending concentration of 2 % by volume. Although it is not ruled out that higher blending rates will be possible in the future, an across-the-board or gradual increase is not considered expedient. This is justified by the fact that a constant hydrogen concentration which is relevant for some off-takers cannot be guaranteed due to changing flow directions. Blending at the distribution grid level, on the other hand, is considered useful [21]. The latter is confirmed by publications from H2vorOrt, an association of currently 48 partners that operate more than 50 % of the distribution grid kilometres and connections in Germany [22], which is cooperating with the European initiative of Ready4H2.

Consequently, the German Gas Network Development Plan 2020 - 2030 describes that hydrogen should be transported in a separate infrastructure at transport network level and admixture should only take place where a connection to a pure hydrogen infrastructure [...] is not possible from an economic point of view. Furthermore, it is pointed out that some customers with sensitive industrial processes would already have problems with a hydrogen concentration of 2% by volume. However, the potential for adding hydrogen at distribution grid level is also referred to in this network development plan [23].

5.4 Portugal

In Annex B ‘Country-specific development’ of the current EHB publication of April 2022 'A European hydrogen infrastructure vision covering 28 countries', information is provided for Portugal with regard to blending from the perspective of REN. According to this, hydrogen is expected to be transported within Portugal by blending in the existing infrastructure by 2030. A hydrogen content of up to 15% is expected by 2030. At the same time, the development of 100% networks in industrial clusters is expected. Subsequently, a gradual expansion of the 100% network is reported [27].

5.5 Spain

In Spain, at regulatory level, 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 the technical management of the gas system. It specifies that the current maximum concentration of hydrogen in natural gas in the gas grid is 5 Mol-%. Furthermore, the gas grid owner can reject gas, which is not according to the gas quality specifications, as the owner of the injection facility is responsible for the gas quality.

This currently applies, but recently, the Ministry has submitted for public consultation the Ministerial Order amending the norms of the technical management of the gas system and the protocols of detail currently in force (including PD-01), so a revision of the PD-01 is ongoing, but an increase in the 5 Mol-% maximum concentration of hydrogen admissible in the grid is not expected.

The expectation is that the backbone network (owned by ENAGAS) will be limited to the percentage established for international interconnections in the future European Gas Package (which is expected to be approved in the coming months, and in which the maximum admissible concentration of hydrogen in natural gas transmission grids might be reduced to a maximum of 2-3 Mol-%). Apart from that, for the rest of the network (primary transmission of local influence, secondary transmission and distribution) the percentage could be higher than 5% by volume, always subject to case-by-case analysis, etc.

Enagas GTS published in 2022 a report called “Rangos Admisibles H_2: Definición zonas óptimas de inyección en blending“ [24].The text discusses the challenge of integrating renewable H_2 production into the Spanish Gas System through blending with natural gas. The analysis provides an initial, non-binding overview of areas with high potential for blending and a qualitative assessment of hydrogen injection capacities. The analysis considers a 3 %vol blending target, aligning with the European Commission's communication from REpowerUE. It takes into account the current gas system configuration and operation, with potential impacts on results due to changes. The conditions and results may be updated based on new information and developments in the Spanish hydrogen market.

5.6 European Hydrogen Backbone Initiative

In the current draft of "A European Hydrogen Infrastructure Vision Covering 28 Countries" of April 2022, blending is described in Annex B as "[...] a suitable step, especially in the 2020s and early 2030s, in the transition to a dedicated hydrogen pipeline transport network" [27]. No details on volumes and blending limits are given.

As part of the HIGGS project, the European Hydrogen Backbone Initiative (EHBI) was also asked for its opinion on blending at transmission network level. However, due to the different opinions of the different members of the EHBI, there is no clear position.

In the EHBI publication mentioned above, five corridors were defined that could emerge by 2030 to connect regions with high H_2 production potential with those regions expected to have high H_2 consumption (especially in the centre of Europe) (Table 1). Figure 5 shows a derived map of Europe with corridors A, B, C, D and E [28].

Table 1: Hydrogen Corridors mentioned in the current drafts of the European Hydrogen Backbone Initiative

Corridor A	North Africa & Southern Europe
Corridor B	Southwest Europe & North Africa
Corridor C	North Sea
Corridor D	Nordic & Baltic regions
Corridor E	East & South-East Europe

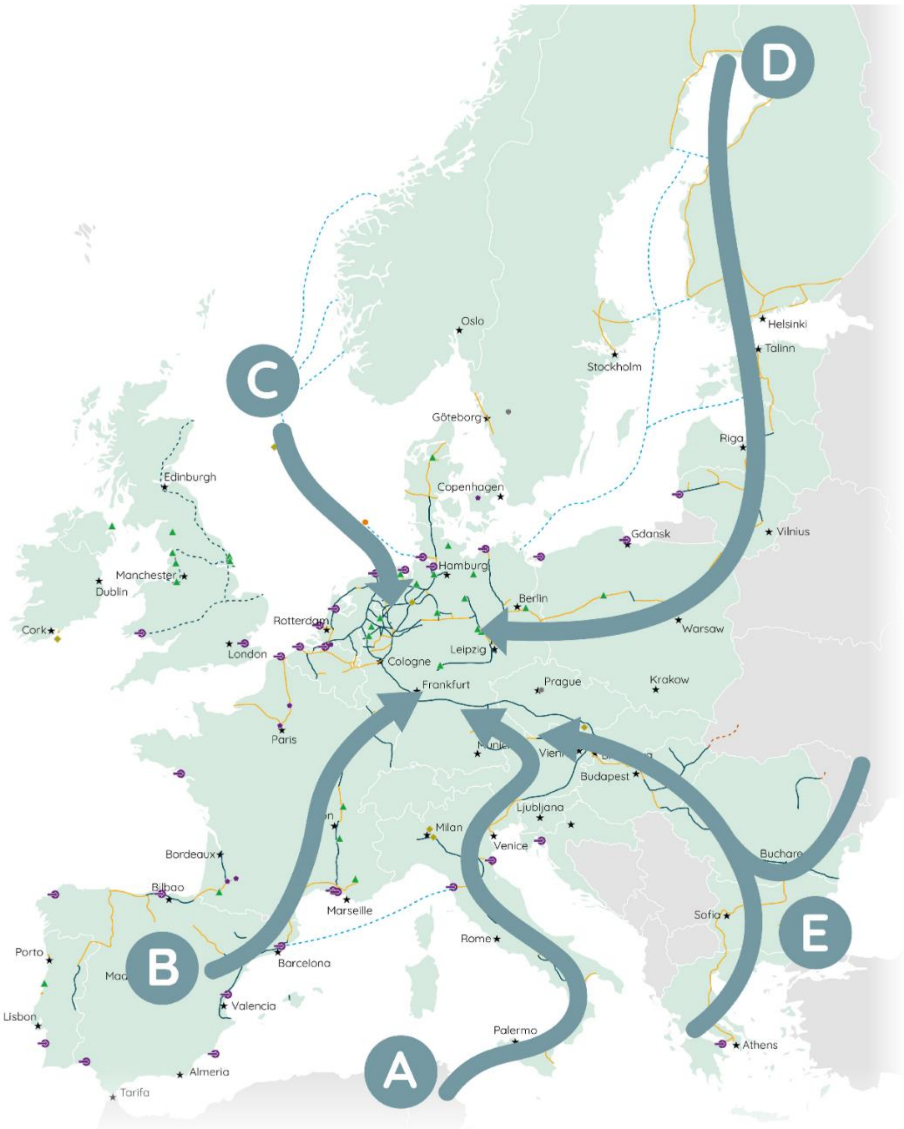


Figure 5: Five hydrogen supply corridors for Europe in 2030 [28]

Figure 6 also shows the current planning status of specific projects that have been initiated to implement the hydrogen corridors. In addition to the information presented, it should be noted that the majority of these projects aim to start by 2030 but are currently in the planning rather than the implementation phase. Final decisions on implementation will depend, among other things, on the financial and legal framework conditions, the strategic orientations of the companies involved and the respective Member States with their respective customer structures, and ultimately also on the availability of hydrogen and thus directly on the EU's import and production strategies. Project planning is therefore very important for the ramp-up of hydrogen in Europe and essential for the use of hydrogen in the Member States. It is also important to emphasise that, in addition to these hydrogen corridors, there will be other cross-border gas pipelines that are likely to be gradually converted to hydrogen in line with demand. It is therefore inadmissible to interpret this to mean that countries not connected to the hydrogen corridors will not have access to hydrogen. The same applies to countries that have a high production potential but are not officially part of a corridor. Of course, these countries will also be able to sell hydrogen in Europe by connecting to one of the corridors, either by converting existing pipelines or by building new ones. An example of this is Norway, which has developed a strategy to export hydrogen to Germany, in cooperation with Germany and others. [29].

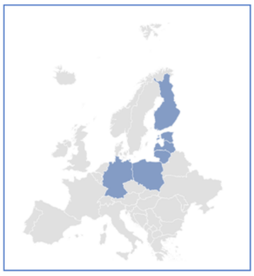
Corridor A	Corridor B	Corridor C	Corridor D	Corridor E
SoutH2 and sunsHyne	H2Med	Aquaductus / Aquventus (but others also discussed)	Nordic Baltic Hydrogen Corridor	Central European Hydrogen Corridor
				
4 Mtpa H_2 capacity	2 Mtpa H_2 capacity	1 Mtpa H2 capacity	not disclosed	not disclosed
Goal: 2030 operational	Goal: 2030 operational	Goal: 2030 operational	Goal: 2030 operational	not disclosed
SoutH2 Snam, Trans Austria Gasleitung, Gas Connect Austria, bayernets **sunsHyne** Snam, Trans Austria Gasleitung, eustream, NET4GAS OGE	enagas, GRTgaz, OGE, REN, Terega	Gascade, fluxys **Aquaductus is seen as a nucleus for further projects in the North Sea region.**	Gasgrid Finland Oy, Elering, Conexus, Amber Grid, Gaz-System S.A., Ontras	OGE, NET4GAS, eustream, Gas TSO of Ukraine

Figure 6: Current planning status of specific projects in the context of the hydrogen corridors [30], [31], [32], [33] [34], [35]

A large part of the hydrogen volumes transported within Europe will be transported along these corridors. It is therefore very relevant for the strategic importance of blending at the transmission network level whether these corridors are planned for blending or for the transport of pure hydrogen. As part of the HIGGS project, representatives of two initiatives (SoutH2 Corridor (A) and Nordic-Baltic Hydrogen Corridor (D) were contacted and asked about the consideration of blending in these corridors. At the current stage of planning, both pipelines are designed to transport 100% hydrogen.

5.7 ENTSOG

Within the ‚ENTSOG high-level position on hydrogen and decarbonized gas market package' from 24 February 2022 ENTSOG supports the EC proposal of 5% hydrogen content as a threshold at Interconnection Points (IPs) to implement the process of dispute settlement [36].

5.8 CEN standard on H-gas quality – EN 16726

The European standard EN 16726 [37] "specifies gas quality characteristics, parameters and their limits, for gases classified as group H that are to be transmitted, injected into and from storages, distributed and utilized".

In the currently ongoing revision of EN 16726, a hydrogen concentration limit is stipulated to facilitate the free flow of gases in Europe. As a starting point, the hydrogen concentration in H-NG is set for 2

% with the option to have locally/regionally higher H_2-concentrations in the grid, where technically and safely feasible. This approach reflects on one hand the abilities of the different parts of the gas value chain including sensitive equipment and applications. On the other hand, it replies to the intentions for higher concentrations and an efficient continuous take-up of hydrogen in gas systems, e.g. in distribution grid.

The draft of the revised EN 16726 is subject to CEN Public Enquiry from 21 December 2023 to 14 March 2024 (national deadlines are individually and shorter to allow the merger of comments and a timely national voting on the draft standard). Besides commenting via the National Standardisation Bodies also commenting via stakeholder organisations is possible. The stakeholder organisations have to address the comments directly to the CEN-CENELEC Management Center and/or to the responsible Secretariat of CEN/TC 234 Gas infrastructure. All comments will be evaluated in a comment's treatment. The draft for final approval is to be finished by October 2024, whilst the final voting (Formal Vote) is expected for the period December 2024 to March 2025 leading to public availability of the standard in April 2025.

With view to the status of the standards in the context of the draft European gas package, it is to highlight that a standard generally is voluntary. It can become binding if it is included in European or national legal provisions.

In case that the European Gas Package will include a limit value for hydrogen concentration at cross-border, the draft standard would need adaptation in terms of scoping and possibly hydrogen concentration values to focus on the areas of gas systems excluding cross-border transport and to align with the legal values if needed. Assuming that the European Gas Package will be completed before the finalization of EN 16726, in autumn 2024, this alignment would not delay the standardisation process.

In case that the European Gas Package will not include a limit value for hydrogen concentration at cross-border, the standard would give a European framework also for the cross-border transport, complementary to provisions in the interoperability network code and national gas quality legislation.

6 Survey

6.1 Purpose

For an efficient decarbonisation of the European energy system, hydrogen is an important option as it (1) fits well with intra-European renewable energy generation, (2) can act as a seasonal energy storage, (3) can use existing infrastructure, (4) can serve customers with molecular energy demand well, (5) offers the possibility to import renewable energy from regions with high generation potential. The latter includes imports from other continents as well as intra-European trade, e.g. from Spain to central Europe. According to the current planning status of the Gas Package, the envisaged hydrogen concentration at cross-border interconnection points is limited to 2/3/5% by volume. This means that strategic transport of hydrogen within Europe to decarbonise national energy systems through blending is limited and transport will be mainly via pure hydrogen pipelines. However, the Gas Package explicitly allows for different agreements between neighbouring countries and higher blending rates in national networks. To assess the likelihood of these measures, the HIGGS project has initiated a survey among European transmission system operators.

6.2 Distribution of the survey

In order to reach as many TSOs as possible, ENTSOG, Marcogaz and EHB were asked to distribute the link to the survey to their members in April and May 2023. The survey was conducted via the EUSurvey Tool and ran until 5 July 2023.

6.3 Structure of the survey

In the first section of the survey (0. About yourself), respondents were asked to provide information on their country of origin and whether they worked for a TSO. Further information on the company was optional. The background to this section was to be able to allocate the questions to specific Member States.

The second section explicitly asked about cross-border flows of hydrogen. Here the participants were asked to assess the level of the blending limit discussed in the Gas Package and to indicate whether they would accept bilateral agreements with higher blending limits. The answers to these questions are important in determining whether bilateral or multilateral agreements between neighbouring countries to strategically transport hydrogen via blending are a realistic option.

The third section dealt with the assessments and plans of the respective participants regarding their national transmission networks. First, they were asked about their preference for blending and a possible separation between hydrogen networks and natural gas networks. Additionally, regional differences were also explicitly asked for. Subsequently, statements were requested regarding currently applicable maximum values in the transmission network. The answers to these questions should show whether and to what extent blending is planned in the respective national transmission networks. From this it can be deduced whether blending of hydrogen, even if it is not relevant in cross-border flows, will play a relevant role in European transmission networks.

The fourth section asked about obstacles to blending hydrogen with natural gas. Once from a technical point of view and once from a regulatory point of view. Here, the participants could indicate blending limits that they personally see and give reasons for this.

The fifth section asked about the current hydrogen strategies within the respective countries.

Finally, in the last section, concluding comments could be made. Overall, it was important to work with free text fields in order to capture as comprehensive and differentiated an opinion as possible.

The exact questions of the survey are presented in Annex 10.1.

6.4 Results of the survey

Out of the 30 countries contacted through the European Hydrogen Backbone, ENTSOG and Marcogaz (EU27 + Norway, Switzerland and UK), TSO representatives from seven countries completed the questionnaire. Representatives from one other country provided information by telephone (s. Figure 7).

Figure 7: Countries from which representatives of at least one TSO have responded to the survey.

Contributors to the survey were assured that their responses would be anonymous and analysed in aggregated form so that no direct conclusions could be drawn from their answers. This was done to increase the likelihood of feedback from the TSOs and the likelihood of an honest response. Accordingly, the responses are not analysed individually in this deliverable, but only in the aggregate.

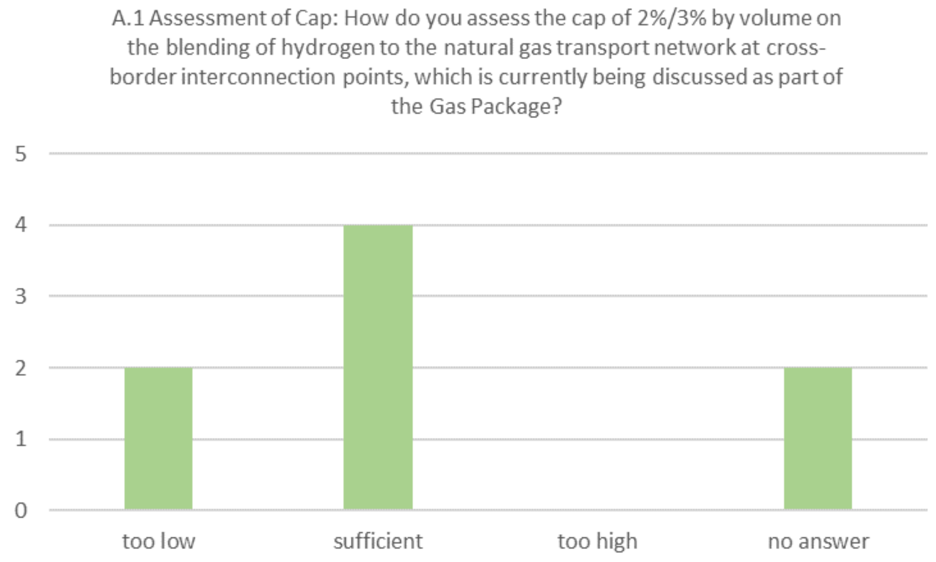


Figure 8: Aggregated responses to question A.1 on assessments of the cap currently discussed on institutional level

Figure 9: Aggregated responses to question A.2 on acceptance of bilateral agreements with higher blending rates than currently discussed on institutional level

The answers to questions A.1 and A.2 (Figure 8 and Figure 9) show that the majority of the responding TSOs prefer hydrogen blends within the limits discussed in the Gas Package (2 - 5 vol.%). Only one TSO was in favour of a minimum addition of 5 vol.%.

A closer look at the feedback shows that the setting of a maximum level is seen as positive in order to promote the introduction of hydrogen while avoiding market fragmentation. It is also seen as positive that higher values can be agreed between TSOs in neighbouring countries through bilateral agreements. However, it is also apparent that above 5 vol.% by volume (and in some cases above 10 vol.%) there are technical concerns, e.g. with different consumers, material compatibility and storage compatibility. In addition, logistical concerns were mentioned to ensure that bilateral agreements do not lead to spill-over at other border crossings.

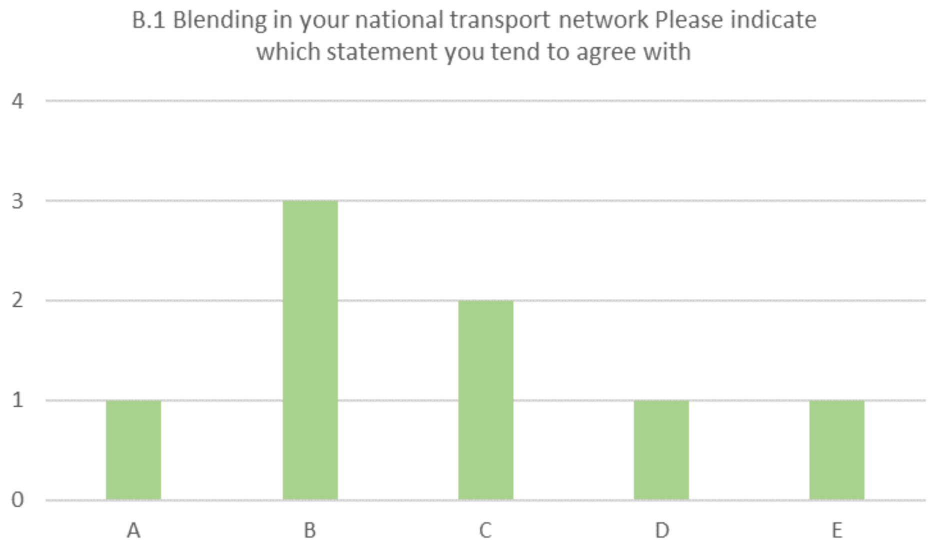


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Figure 10: Aggregated responses to question B.1 on preferences on blending
(A strict separation of hydrogen networks and natural gas networks is preferred (no blending), B limited blending in the amount set for cross-border interconnection points as currently drafted in the Hydrogen and Decarbonised Gas Market Package, C blending in a higher amount set for cross-border interconnection points as currently drafted in the Hydrogen and Decarbonised Gas Market Package, D no preference, E no answer)

Looking at blending at national level, the responses also show a trend that confirms the scale discussed in the context of the Gas Package (Figure 10). The strongest consensus was for limited blending at the levels set out in the Gas Package for border crossings. There were also two votes for higher blends. A closer analysis of the replies and comments to the survey shows that one voice favours a blending level of up to 5% and one TSO favours an initial blending level of 5% with a subsequent increase depending on the circumstances. Only one TSO agreed with the statement of a strict separation of the two networks without any admixture.

The responses to the questions on technical and legal/regulatory barriers show an unusually high degree of heterogeneity (Figure 11 and Figure 12). A closer look at the responses, including the comments section, shows that a clearer question would have helped here. Some TSOs mentioned minor changes as a reason for the current technical barriers of 0-5%, others said that after minor changes the way to 100% is clear. Another issue mentioned in the comments was different operating conditions, e.g. MOP, flow rates, etc. The same applies to legal and regulatory barriers. Again, different interpretations of the question are partly responsible for the wide range of responses. In some cases, reference was made to current regulations, in others to regulations that need to be adapted on an ongoing basis.

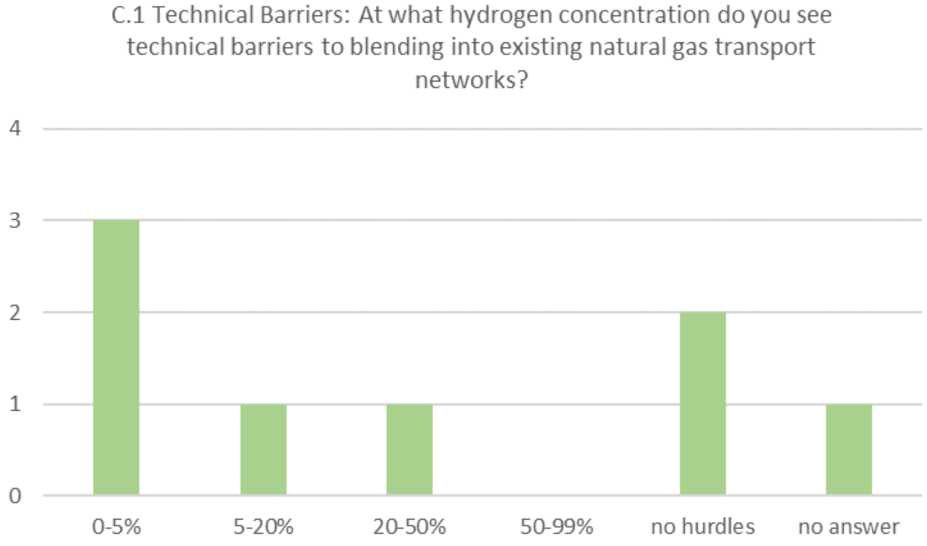

Figure 11: Aggregated responses to question C.1 on technical barriers

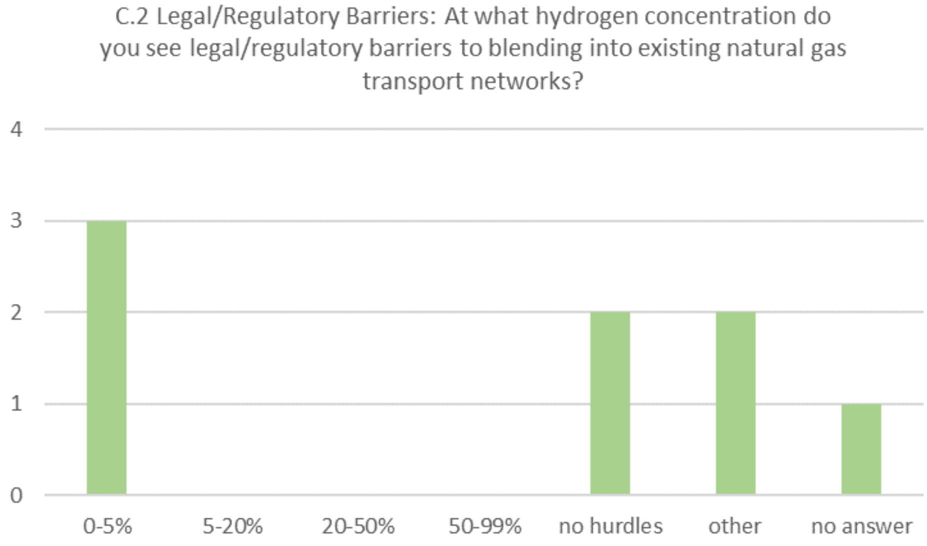

Figure 12: Aggregated responses to question C.2 on regulatory barriers

7 Industrial Demands

The total energy supply of the EU27 in 2021 was about 16,300,000,000 GWh, of which about 24% (3,950,000,000 GWh) was covered by natural gas [38]. The current use of natural gas in industry, commerce and households is very diverse. In addition, the breakdowns in the respective Member States of the European Union are also very different (see Figure 13). What the underlying processes have in common is that they have been developed for natural gas. The impact of a partial or complete substitution of natural gas by hydrogen must therefore be assessed on a process- and location-specific basis.

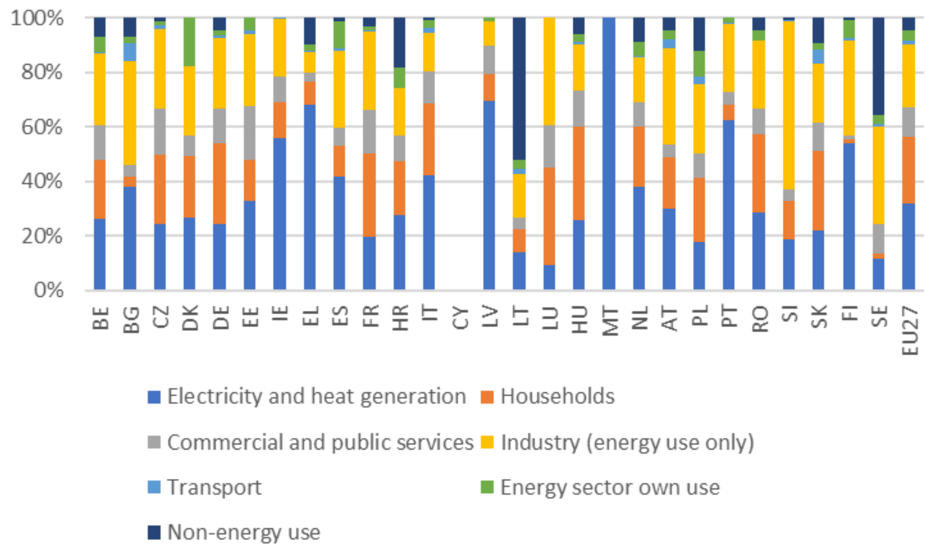

Figure 13: Gas consumption by sector in the Member States of the European Union in 2019 in %; own figure according to data from [39]

The EU project THyGA (Testing Hydrogen admixture for Gas Applications, Grant Agreement No. 874983) has already answered questions about the influence of natural gas-hydrogen mixtures on application processes, especially in the domestic and commercial sectors and thus typical customers in the distribution network [40]. The focus of HIGGS is on the transmission networks and typical industrial customers. The needs and challenges of these customers are therefore addressed below as examples.

In industry, hydrogen is currently used mainly as a raw material in the chemical industry and in refinery processes [41]. As industry transitions to sustainable processes, the focus will be on switching to carbon-neutral hydrogen. For existing processes that currently use hydrogen, this transition is straightforward. These include methanol and ammonia production processes. In some cases, new processes are being developed, often chemical catalytic processes, which open up new product areas by changing the raw material base. Examples include Fischer-Tropsch products or naphtha as platform chemicals. The use of climate-friendly hydrogen does not pose any additional challenges for the latter either.

Of particular interest in the future, however, is the expected significant increase in the use of hydrogen as an energy source, especially as a substitute for natural gas in thermal process engineering, steam generation, the process industry, mobility and power generation. These transitions must take into account the different properties (see below) of natural gas and hydrogen and the influence of mixtures of the two gases, for example by developing new burner technologies or production processes to avoid efficiency losses and safety issues.

- Energy content.
- Wobbe index.
- Flame velocity.
- Oxygen demand.
- Adiabatic flame temperature.

The differences in the physical and chemical properties of hydrogen and natural gas have been discussed in detail in various places (e.g. [42]). The properties of mixtures of natural gas and hydrogen, as a function of the mixing ratio, have also been described several times (e.g. [43]). The change of main gas quality as a function of hydrogen blending in methane is shown in Figure 14.

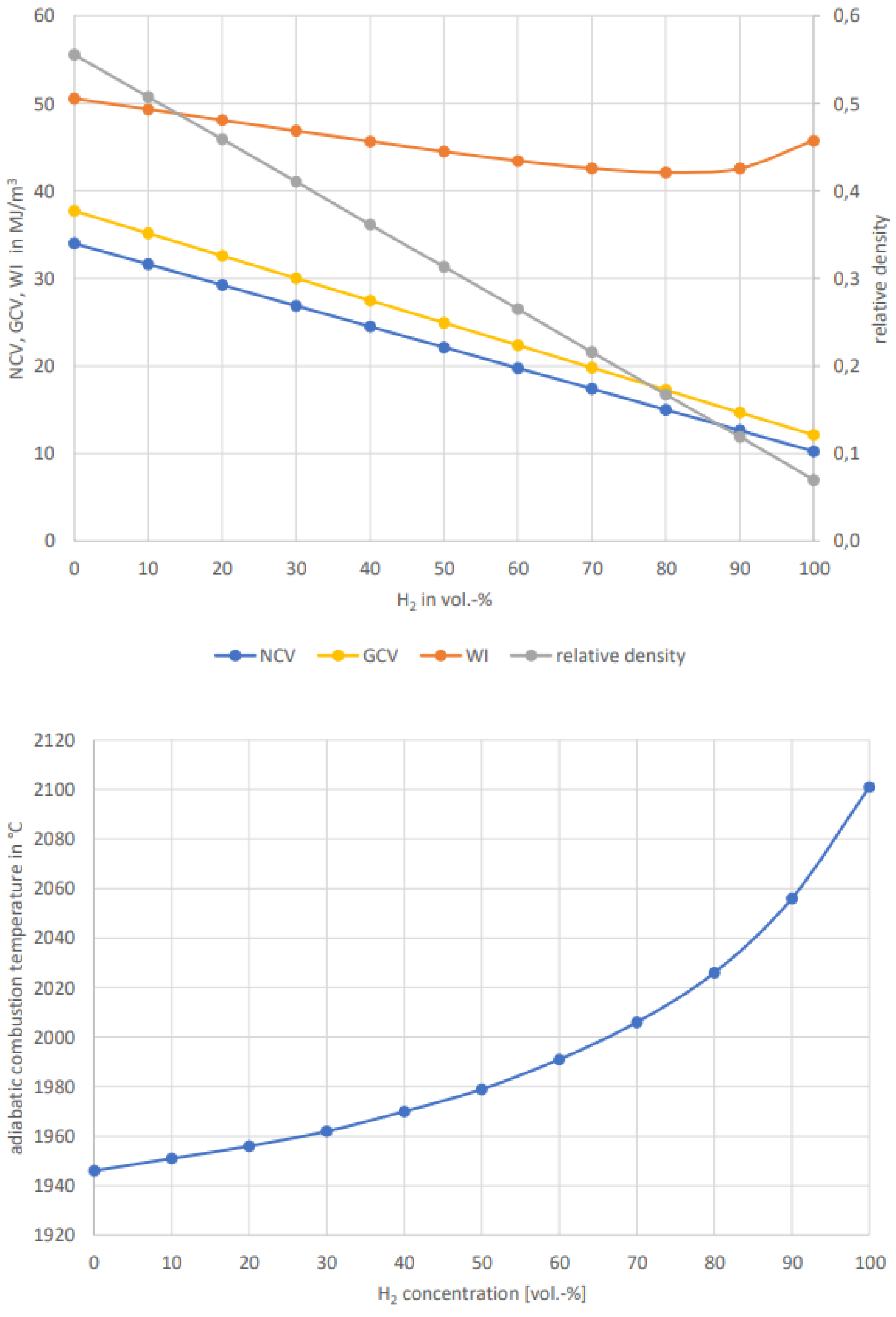

**Figure 14: Change of main gas quality criteria as a function of hydrogen blending to methane [43]. Above: NCV = net calorific value [MJ/m^3], GCV = gross calorific value [MJ/m^3], WI = Wobbe Index [MJ/m^3] and relative density [-]
Below: adiabatic combustion temperature [°C]**

There are specific challenges and solutions for the different processes, which are outlined below as examples for gas turbines and the glass industry.

Gas turbines

NREL has described the challenges for gas turbines using hydrogen in a report published in 2022. These challenges include the lower energy content, higher flame temperature and higher flame velocity of hydrogen compared to natural gas. The lower energy content of hydrogen means that either a higher pressure has to be used or a lower power has to be accepted. The higher flame temperature leads to (1) the need for cooling to protect the material, (2) higher NO_x emissions and (3) acoustic phenomena. Due to the significantly higher flame speed of hydrogen compared to natural gas, both flashback and blowout of the reaction can occur [44].

When assessing the H_2-readiness of gas turbines, a distinction must be made between new and existing plants. For new gas turbines, there is a definition of EU turbines that divides new plants into three different H_2-readiness levels and three different categories representing the effort required to convert to each H_2-readiness level (Figure 15).

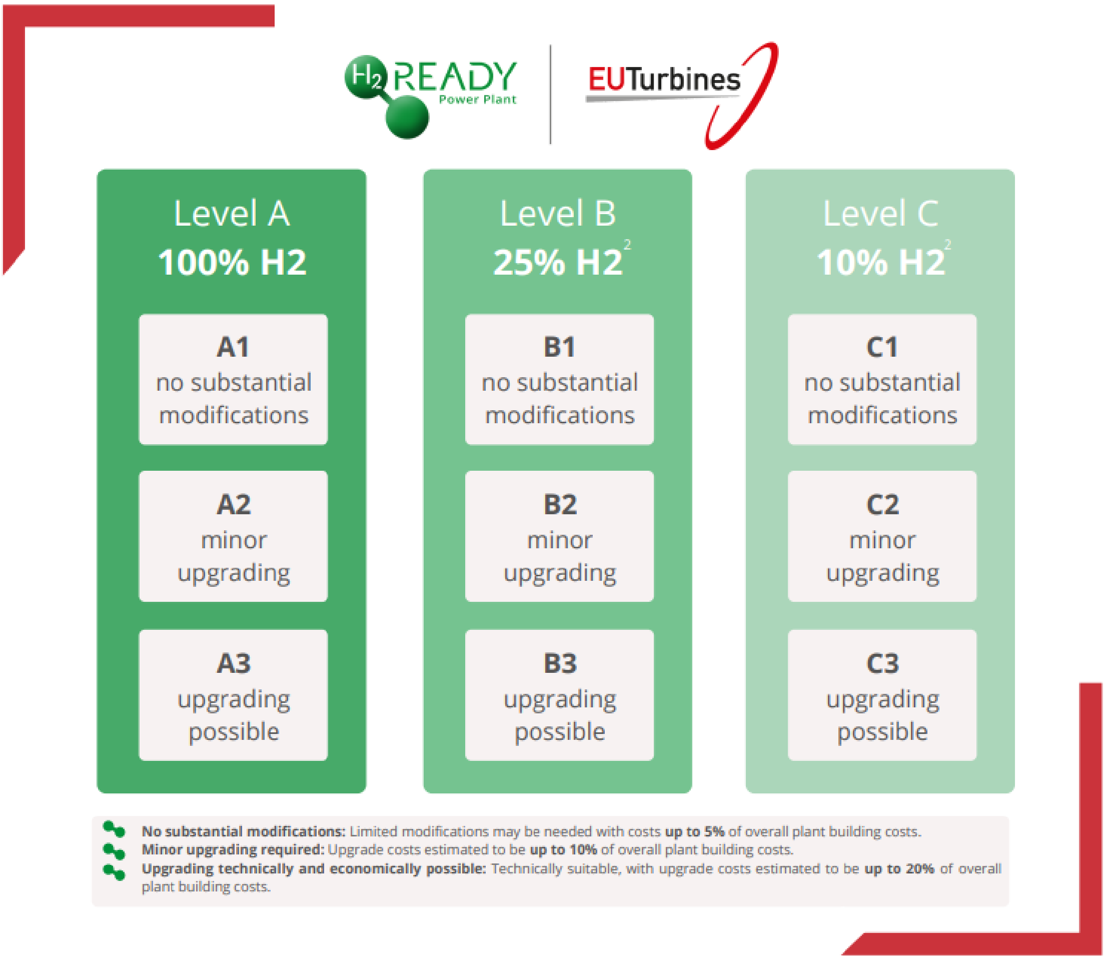

Figure 15: H2-readiness of new gas turbines according to EUTurbines [45]

Gas turbine manufacturers are working to convert parts or their entire product range to 100% hydrogen by the middle or end of the decade (e.g. [46], [47], [48], [49]). In October 2023, it was announced that a Siemens Energy gas turbine was operated for the first time on 100% renewable hydrogen as part of the HYFLEXPOWER project at a Smurfit Kappa site in France [50].

On the other hand, when considering existing gas turbines, a case-by-case analysis is required, taking into account not only the combustion system but also the fuel skid and controls. In this way, different maximum levels of blending are possible in existing plants, depending on the system and the level of retrofitting required. A detailed description of the parameters to be taken into account can be found in [49]. This source also provides an overview of recent developments in the hydrogen compatibility of gas turbines from various manufacturers. Gas turbines originally developed for syngas from the gasification of biomass or fossil fuels can already use 30-60 vol% hydrogen. The other component of syngas is usually carbon monoxide. Based on experience with syngas, conversion to a mixture of hydrogen and natural gas is possible. However, the handling of such reactive feed gas mixtures leads to higher NO_x emissions than in conventional gas turbines and, in some cases, to shorter lifetimes for certain components. Accordingly, ETN has assessed the acceptable proportion of hydrogen in existing gas turbines as shown in Figure 16.

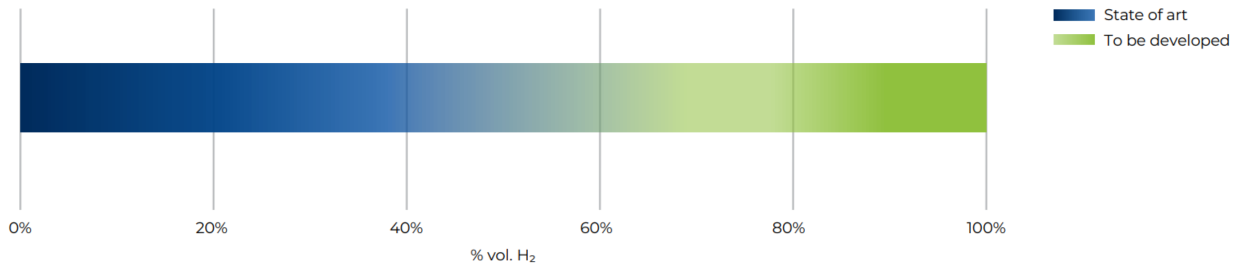

Figure 16: Currently acceptable share of H_2 in gas turbine products according to [49]

In addition, depending on the location and planned operation of the gas turbine, the influence of the fluctuating hydrogen concentration in the feed gas mixture must be explicitly considered. Particularly in the case of existing plants, it must be taken into account that gas turbines react sensitively to fluctuations in gas quality and that efficiency losses, increased emissions and lower product quality can be observed accordingly [51], [52].

Glass production:

The HyGlass research project investigated the effects of different levels of hydrogen addition, up to 100%, in the different firing processes along the glass production chain. The target parameters were efficiency, heat transfer, pollutants, temperatures, CO_2 emissions and economy as well as safety aspects. The impact on product quality, lifetime and plant operation was derived. The glass manufacturing process is an example of a very sensitive process within thermal processing technology that reacts strongly to changes. With regard to glass quality, the effects of increasing hydrogen concentrations were observed. For example, between 30 and 50 per cent hydrogen there was soot formation, which led to the formation of a deposit. These are known phenomena that can be mitigated or prevented by appropriate measures in the glass manufacturing process. However, the quality of the gas used must be known and variations must be avoided [53].

8 Virtual blending

In the European hydrogen strategy, the topic of 'virtual blending' is explicitly defined as

'[…] a share of hydrogen in the overall volume of gaseous energy carriers (i.e. methane) regardless as to whether these gases are blended physically in the same infrastructure or in separate, dedicated infrastructures' [1]

In principle, virtual blending allows the decoupling of physical flows and the legal purchase of hydrogen by trading appropriate certificates. The basics of the distinction between physical and virtual blending of hydrogen in natural gas have been developed in the EU funded HyDelta project and are described in [54].

Virtual blending can, in principle, be an option to give companies that are not initially connected to a hydrogen network a perspective to achieve (proportional) decarbonisation through trading with green certificates. This is particularly the case for many small and medium-sized enterprises located in regions that do not have access to hydrogen in the initial network planning. It is clear that decarbonisation via certificate trading can only be a temporary solution that does not stand in the way of the expansion of hydrogen networks and the achievement of climate targets.

As part of the HIGGS project, industry representatives from Germany were interviewed on the subject of virtual blending. In general, the risk is seen that companies that do not have direct access to a hydrogen network due to their geographical location will be disadvantaged. Trading of green hydrogen certificates was seen as an option to compensate for competitive disadvantages. However, in the feedback from industry representatives, the certificates were intended for users of hydrogen and not for users of natural gas in the form of virtual blending.

In the interviews, certificate trading was viewed quite positively in the case of replacing grey hydrogen with green certificates, whereas the replacement of natural gas with green hydrogen certificates was viewed more sceptically. The reasons for this restriction were, on the one hand, concerns about possible accusations of "green washing" and, on the other hand, fears that intensive trading in green certificates as a substitute for natural gas could delay or even prevent the rapid development of a comprehensive hydrogen infrastructure. To compensate for the poorer competitive conditions, the respondents call for an ambitious and rapid development of a hydrogen infrastructure in order to offer prospects to as many potential customers as possible.

It should be noted that these are isolated opinions from individual German associations and can in no way be taken as representative of all sectors and regions. The purpose of this section is simply to show that, in addition to the opportunities that trading in certificates undoubtedly offers, there are also issues that need to be considered in order to establish a meaningful and useful trading system. In addition, it can only be a limited solution and must be used in a targeted manner so as not to jeopardise its environmental usefulness or social and business acceptance.

9 Conclusions

The European Union has clearly identified hydrogen as an important building block in the new EU-wide energy and raw materials strategy and has set a decisive course for the production of hydrogen in Europe, its import into Europe and the development and use of a suitable hydrogen infrastructure. A major advantage of this strategy is that large parts of the existing gas infrastructure can continue to operate through retrofitting. Specific geographical conditions, especially with regard to hydrogen production and import, as well as structural differences in demand, show that cross-border transport of hydrogen will be necessary in the future to meet demand and fully exploit the economic and environmental potential within the European Union.

At the beginning of the project, it was assumed that hydrogen blending will play an important role in the ramp-up of the hydrogen economy, in order to transport hydrogen from regions with high hydrogen production and import potential to regions with high demand. However, an analysis of the blending provisions of the Gas Package, which is currently being finalised, shows that the institutions of the European Union - the European Commission, the Council of Europe and the European Parliament - want to significantly restrict the blending of hydrogen into the natural gas network at border crossings.

The transmission network operators of the Member States seem to share this approach and have early started and focused to plan a European hydrogen network, focusing on the transport of pure hydrogen.

The heterogeneity of the industrial and customer structure in the EU Member States and the requirements of the respective customers in terms of natural gas/hydrogen quality mean that there are no strategies that work equally efficiently in all regions. The Gas Package is likely to allow a degree of freedom, for example with regard to national blending and bi-/multilateral agreements with higher blending limits. However, it is clear that there needs to be a harmonised baseline system to avoid market fragmentation and inefficient curtailment of production and demand.

CEN is currently drafting a gas quality standards containing hydrogen concentration requirements respecting the technical feasibility in regional and local gas systems.

10 Appendices

10.1 Survey

HIGGS - Hydrogen Blending in Transmission Grids

Fields marked with * are mandatory.

To whom it may concern.

You have received the link to this survey because you are an expert in the field of high pressure gas networks.

As the consortium of the EU project HIGGS ("Hydrogen in Gas Grids – A systematic validation approach at various admixture levels into high-pressure grids"), we are very interested in your expertise and opinion regarding the admixture of hydrogen in high-pressure natural gas networks, as it is currently also being discussed intensively at the European level.

The aim of the HIGGS project is to show that the safe injection of hydrogen into the EU high pressure, transmission natural gas grid is a sustainable and long-term solution to decarbonize the energy system. The project consortium consists of Fundación Hidrógeno Aragón (FHA), German Technical and Scientific Association for Gas and Water (DVGW), Redexis, Tecnalia, European Research Institute for Gas and Energy Innovation (ERIG) and Eastern Switzerland University of Applied Sciences (OST). For more information about the project, please contact us or visit our project homepage (www.higgsproject.eu).

However, the discussions that took place during the drafting of the Hydrogen and Decarbonised Gas Markets Regulation, which will probably lead to a limit of 2%/3% by volume of hydrogen in the natural gas network at interconnection points, make us question our approach. This is further fuelled by the discussions that we are also witnessing at the national level, which are critical of the admixture of hydrogen into the transport network. Therefore, we are conducting a survey among European TSOs to get an overall picture and to draw conclusions for the continuation of the HIGGS project.
We kindly ask you as transmission system operators to participate in this survey. **We would like to use your replies in a qualitative way. We will publish any information in an anonymous and aggregated way.**

1

In case you have any questions or remarks please feel free to use section E. or to send us an e-mail at: stefan.gehrmann@dvgw.de

We look forward to receiving your contribution by 22 May 2023.
Thank you for your support!

Clean Hydrogen Partnership

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0. About yourself

* **0.1 Country:** Please indicate the country from the point of view of which you are answering the following questions.

- AT - Austria
- BE - Belgium
- BG - Bulgaria
- HR - Croatia
- CY - Cyprus
- CZ - Czechia
- DK - Denmark
- EE - Estonia
- FI - Finland
- FR - France
- DE - Germany
- EL - Greece
- HU - Hungary
- IE - Ireland
- IT - Italy
- LV - Latvia
- LT - Lithuania
- LU - Luxembourg
- MT - Malta
- NL - Netherlands
- NO - Norway
- PL - Poland
- PT - Portugal
- RO - Romania
- SK - Slovak Republic
- SI - Slovenia
- ES - Spain
- SE - Sweden
- CH - Switzerland

2

- Other - Please specify

* Please state

* **0.2 Company:** Do you work for a European gas infrastructure operator?
- Yes
- No
- Other

Please specify

Company: Here you can voluntarily enter the company you work for. This voluntary information helps us to evaluate the results. We assure you that we will not publish any company related statements.

A. The following questions refer to hydrogen blending at cross-border interconnection points

* **A.1 Assessment of Cap:**
How do you assess the cap of 2%/3% by volume on the blending of hydrogen to the natural gas transport network at cross-border interconnection points, which is currently being discussed as part of the Hydrogen and Decarbonised Gas Package?
- too low
- sufficient
- too high
- other

* Please explain

* **A.2 Bilateral Agreements**
Would you accept higher blending rates than 2%/3% by volume at at cross-border interconnection points if bilaterally agreed on?
- yes
- preferably not

3

- no
- other

* up to

* Please specify the unit

- % by volume
- % by mol

* Please explain

B. The following questions refer to hydrogen blending at your national transport network

* **B.1 Blending in your national transport network**

Please indicate which statement you tend to agree with

- strict separation of hydrogen networks and natural gas networks is preferred (no blending)
- limited blending in the amount set for cross-border interconnection points as currently drafted in the Decarbonised Gas Package is preferred.
- blending in a higher amount set for cross-border interconnection points as currently drafted in the Decarbonised Gas Package is preferred.
- no preference.

* up to

* Please specify the unit

- % by volume
- % by mol

Please describe regional particularities in the approach, if any:

4

* **B.2 Maximum blending by law**

Does your country currently have a legal maximum blending rate of hydrogen in natural gas transport systems?

- yes
- not yet, but there are intentions
- no
- other

* What is the current legal maximum blending rate?

* Please specify the unit

- % by volume
- % by mol

* What is the expected maximum legal blending rate?

* Please specify the unit

- % by volume
- % by mol

* Please explain

C. The following question refers to your opinion on maximum hydrogen blending rates in natural gas transport systems

5

* **C.1 Technical Barriers:**
At what hydrogen concentration do you see technical barriers to blending into existing natural gas transport networks?
  - 0-5%
  - >5-20%
  - >20-50%
  - >50-99%
  - no hurdles up to 100%
  - other

Please specify the concentration

* Please specify the unit
  - % by volume
  - % by mol

* Please give details

* **C.2 Legal/Regulatory Barriers:**
At what hydrogen concentration do you see legal/regulatory barriers to blending into existing natural gas transport networks?
  - 0-5%
  - >5-20%
  - >20-50%
  - >50-99%
  - no hurdles up to 100%
  - other

Please specify the concentration

* Please specify the unit
  - % by volume

6

○ % by mol

* Please give details

D. National hydrogen strategy

* **D.1 Does your country currently have a national hydrogen strategy?**

○ yes
○ no
○ I do not know

* From which year does the current version of the national hydrogen strategy date?

Can you please **share a link** to this national hydrogen strategy or alternatively upload the current version (both preferably in **English language**)?

Please upload your file(s)

E. Concluding remarks

Do you have any concluding remarks on this survey or on the blending of hydrogen in the natural gas transport systems?

7

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