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Guide to planning gas distribution networks for hydrogen

Overall process of planning gas distribution networks for hydrogen: conversion and new-build, 100% hydrogen and blends with natural gas

Final Report

ready4H_2

Energy with Future. Environment and Responsibility.

Final Report

Ready4H2 – Guide to planning gas distribution networks for hydrogen

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Management Summary

The “Guide to planning distribution grids for hydrogen” was created for the Ready4H2 project to demonstrate the technical feasibility of “getting ready for hydrogen” and the status of the regulatory and technical readiness in Ready4H2 member countries. Ready4H2 consists of more than 60 European Gas Distribution System Operators (DSOs) and national associations in 10 countries throughout Europe, working together to support a hydrogen market for future energy delivery through the transformation of gas distribution networks to deliver hydrogen and contribute to a common European understanding of the role of gas distribution grids in delivering hydrogen.

Project activities have included researching the role of DSOs in the energy transition through the continued use of distribution grids for hydrogen, both by building new hydrogen-dedicated networks as well as converting existing natural gas networks, the cost benefits of hydrogen delivery, the readiness of DSOs to get transform their operations to hydrogen, and the flexibility that gas grids offer an integrated gas/electricity energy system throughout Europe.[1] Previous research identified the essential role that DSOs will play in delivering at least half the hydrogen to hard-to-decarbonise sectors of buildings, heavy transportation, certain industrial and chemical processes and power generation, as well as the affordability and flexibility that hydrogen delivery through distribution networks offers.

The project seeks to demonstrate the ability of distribution grid operators to adapt their business to hydrogen from a technical and operational perspective. This Planning Guide shows the feasibility of adapting existing gas grid sections to hydrogen as well as expanding existing grids with new hydrogen-dedicated sections. Repurposing or developing to 100% hydrogen and hydrogen-methane blends have both been considered.

Using the already-established German framework developed by DVGW as the basis,[2] three technical pathways for hydrogen have been considered: conversion of existing natural gas networks, construction of new hydrogen networks, and blending of hydrogen into the existing natural gas grid. The most appropriate option depends on the specific circumstances of each European country and region, including the condition and structure of the existing network, regulatory frameworks, demand development, hydrogen availability, and long-term energy policy objectives. In practice, these pathways may complement one another; some regions may prioritise the conversion of existing assets, others may require targeted new construction, and in certain contexts blending will serve as an intermediate or long-term solution. The Planning Guide therefore recognises all three options as valid elements of a broader transformation strategy.

The findings in this report demonstrate that hydrogen transportation through the distribution networks is feasible and within reach, the techniques and tools are well understood and available, and, by harmonising working practices across Europe, hydrogen distribution networks can provide a foundation to supply hydrogen demand and reduce energy delivery costs at scale.

[1] The Ready4H2 Report on Research conducted in Phase 3 shares the results of the 4 studies: DBI *Costs Of Transformation*, Frontier Economics *The Role of Distribution Grids in Delivering Hydrogen* and internal project database and DSO Readiness under the Ready4H2 Transformation Roadmap.

[2] DVGW “Switching Manual”: H2-Umstellmanagement für Gasverteilnetze (H2-Umstell; DVGW-Innovationsprogramm Wasserstoff - G 202312).

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List of abbreviations

CHP	*Combined heat and power*
DSO	*Distribution System Operator*
EHB	*European Hydrogen Backbone*
EIA	*Environmental impact assessment*
EN	*European standard*
ENTSO-E	*European Network of Transmission System Operators for Electricity*
GDP	*Grid Development Plan*
GH_2	*Green hydrogen*
GIS	*Geographic Information System*
GN-H_2 -Mix	*Natural gas-hydrogen mix*
GPRMS	*Gas Pressure Regulating and/or Metering Station*
GRIP	*Gas Regional Investment Plan*
GTP	*Gas Distribution Transformation Plan*
H_2	*Hydrogen*
HP	*High pressure*
i.N.	*under standard conditions*
ISO	*International Standards Organisation*
LEL	*Lower explosion limit*
MOP	*Maximum operating pressure*
NCA	*National competent authority*
NCP	*Network connection point*
NDT	*Non-destructive testing*
ÖNIP	*Integrated Austrian Grid Infrastructure Plan*
PCI/PMI	*Project of Common Interest/Project of Mutual Interest*
R&D	*Research and development*
SCADA	*Supervisory Control and Data Acquisition*
SGEI	*Service of general economic interest*
SLP	*Standard load profile*
SME	*Small and medium-sized enterprises*
SSO	*System Security Operator*
TNE-E	*Trans-European Energy Infrastructure*
TSO	*Transmission System Operator*
TYNDP	*Ten-Year Network Development Plan*
UEL	*Upper explosion limit*

1 Introduction

The Ready4H2 project consists of more than 60 European Gas Distribution System Operators (DSOs) and national associations in 10 countries throughout Europe, working together to support a hydrogen market for future energy delivery through the transformation of local gas distribution networks to deliver hydrogen and contribute to a common European understanding of the role of gas distribution grids in delivering hydrogen.

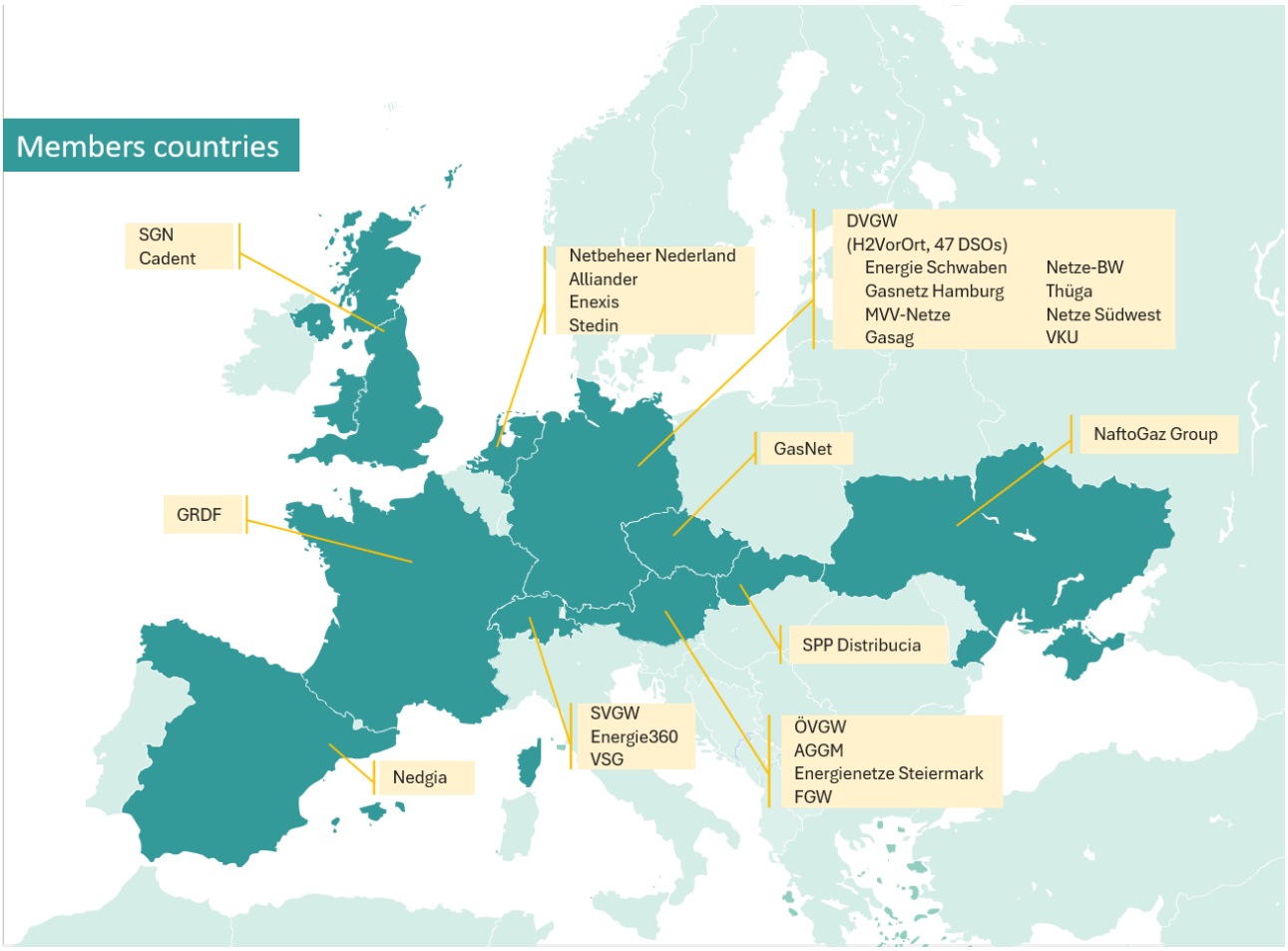


Figure 1: Ready4H2 project member countries

Project activities include researching the role of DSOs in the energy transition through the continued use of distribution grids for hydrogen, the cost benefits of hydrogen delivery and the flexibility that gas grids bring to the integrated gas/electricity energy system throughout Europe. Previous research identified the essential role that DSOs will play in delivering at least half the hydrogen to hard-to-decarbonise sectors (buildings, heavy transportation, certain industrial and chemical processes and power generation), as well as the affordability and flexibility that hydrogen delivery through distribution networks offers.[3] [1, 2] The significance of the DSOs in delivering hydrogen to all sectors of buildings, industry, power and transportation is shown in Figure 2 below, which also shows the wide geographical spread of gas DSOs that need to become H2-ready to meet demand.

[3] The Ready4H2 Report on Research conducted in Phase 3 shares the results of the 4 studies: DBI study *Costs Of Transformation*, Frontier Economics study *The Role of Distribution Grids in Delivering Hydrogen* and internal project database and DSO Readiness assessment against the Ready4H2 Transformation Roadmap.

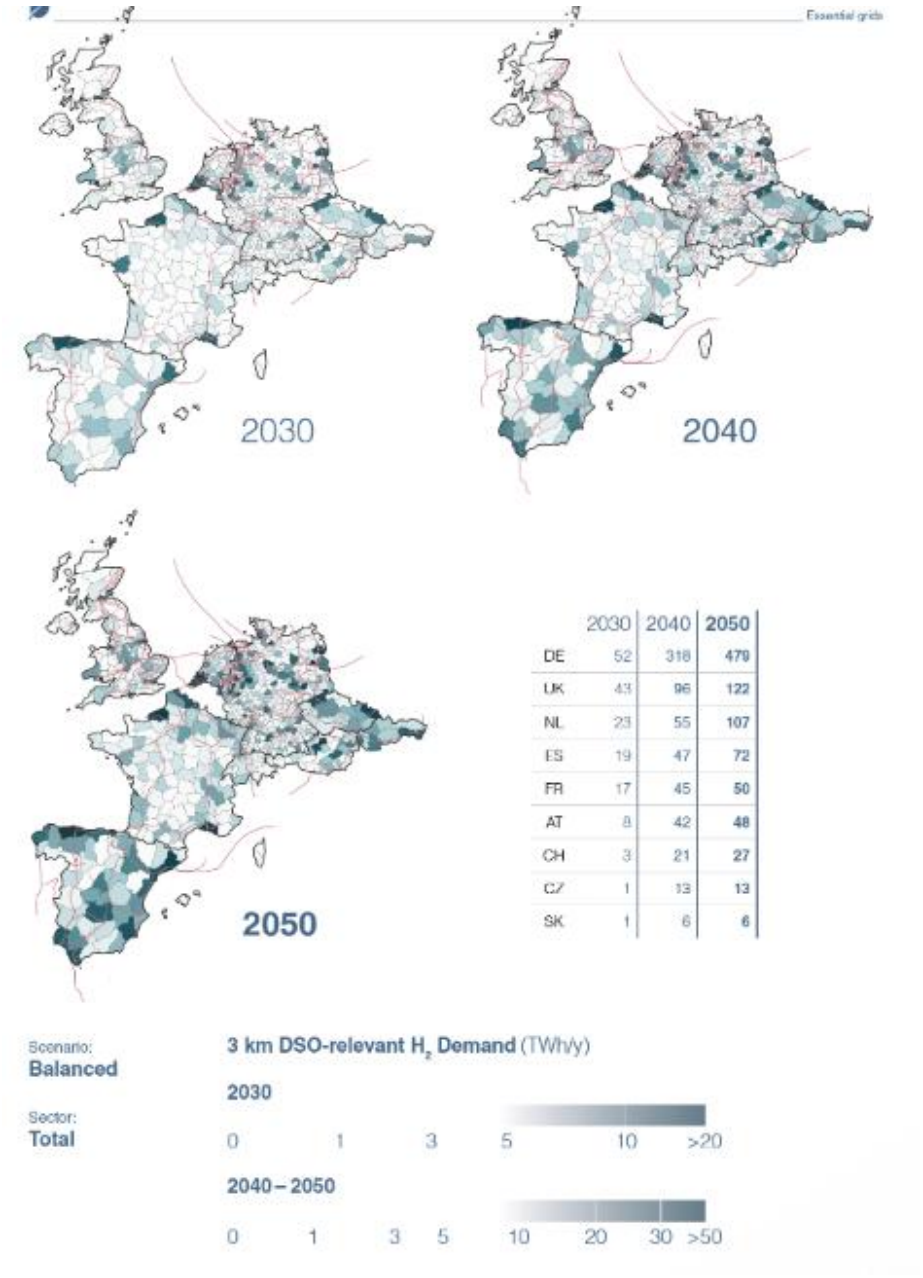


Figure 2: Results of Ready4H2 2024 Geospatial study showing the role of DSOs in delivering hydrogen, showing the EHB (red lines) and density of hydrogen demand located more than 3km from the EHB

The next step in the project is to demonstrate the technical feasibility of expanding a network for hydrogen or converting existing gas networks. Hence, Ready4H2 contracted DBI to create this “Guide to Planning Gas Distribution Networks for Hydrogen” (Planning Guide) to demonstrate the ability of distribution grid operators to adapt their business to hydrogen from a technical and operational perspective.

The Planning Guide shows the feasibility of adapting existing gas grid sections to hydrogen as well as expanding existing grids with new hydrogen-dedicated sections. Repurposing existing gas networks and developing new hydrogen-ready networks, for both 100% hydrogen and hydrogen-methane blends have been considered.

The recently issued EU "Hydrogen and Decarbonised Gas Market Package" provides the framework for the conversion of a gas DSO business for hydrogen, in particular Directive (EU) 2024/1788 and Regulation (EU) 2024/1789 that establish common rules and market mechanisms for renewable gases, natural gas and hydrogen, as well as the development of a future hydrogen market (including an infrastructure framework).

In terms of content, the Planning Guide focuses primarily on gas distribution networks operating at pressures

up to 16 bar, despite higher pressures being permissible for hydrogen. In addition, The Planning Guide is focused on the technical conversion of the distribution network. However, other external factors will need to be assessed by DSOs to determine the feasibility of conversion to hydrogen, such as the availability and price of hydrogen production and end-use appliances.

The following three key development pathways have been considered in the Planning Guide:

- conversion of existing networks to be able to transport hydrogen as well as methane
- construction of new networks for hydrogen service (and by default methane)
- hydrogen blended with methane as a transitional or long-term option

The Planning Guide maps these pathways at the process level, describing the overall processes and focussing on the preparatory work and analyses, including relevant boundary conditions and typical "stumbling blocks" (data availability, material and operational suitability, customer compatibility, safety and operational issues, approval and stakeholder requirements). The starting point is the already-proven German pathway, which has been expanded to include European perspectives in order to ensure transferability.

The aim of the Planning Guide is thus to create a technical process framework to enable planning of the conversion/building of new networks for hydrogen that is robust and compatible between Ready4H2 countries, but at the same time remains flexible enough to accommodate different national specifics. Based on contributions from Ready4H2 members, generic core components (which are required in almost all contexts) have been distinguished from context-dependent options (regulatory variants, technical constraints, market and customer structure) as a basis for a plannable approach and accelerated know-how development throughout Europe.

2 Overall process of planning gas distribution grids for hydrogen

This chapter outlines the overall approach to transforming gas distribution networks for hydrogen. The following three technical pathways have been considered: conversion of existing natural gas networks, construction of new hydrogen networks, and blending hydrogen in the existing natural gas grid. The most appropriate option depends on the specific circumstances of each European country and region, including the condition and structure of the existing network, regulatory frameworks, demand development, hydrogen availability, and long-term energy policy objectives. In practice, these pathways may complement one another. Some regions may prioritise the conversion of existing assets, others may require targeted new construction, and in certain contexts blending will serve as an intermediate or long-term solution, in particular when the supply of hydrogen is in its own ramp up phase. The Planning Guide therefore recognises all three options as valid elements of a broader transformation strategy.

Safety aspects (Chapter 2.1) form a fundamental basis for all planning and implementation steps. Due to the specific physical and chemical properties of hydrogen, such as its low ignition energy, high diffusivity and wide flammability range, established safety concepts for natural gas systems must be reviewed and, where necessary, adapted.

Hydrogen quality (Chapter 2.2) is another key factor influencing the design and operation of hydrogen networks. Depending on the intended application, different purity levels and limits for accompanying substances must be ensured.

Chapter 2.3 describes the process of **converting** gas distribution networks to hydrogen – from strategic classification to preparatory analyses, and adaptation measures to the actual conversion. This creates a uniform process framework that makes the essential steps and decision-making logic of a typical conversion project comprehensible while keeping the interfaces to decisions on new construction, expansion and decommissioning visible. In addition to the conversion of gas distribution networks, the areas of gas installation and gas application have also been taken into account and transferred to an overall process. The chapter also covers permits and approvals in Ready4H2 countries, available programmes and system tools for installation, and field logistics for the conversion of natural gas networks to hydrogen.

Chapter 2.4 describes the **construction** of new network sections for hydrogen and explains the technical and safety-related differences compared to natural gas networks. In particular, it discusses the specific properties of hydrogen, such as its lower volumetric energy density, higher diffusivity, reactivity, and altered thermodynamic behaviour. These properties have an impact on material selection, dimensioning, safety concepts, and operation. It also shows that in addition to technical design, approval issues, route planning, local acceptance and ownership structures play a central role in new construction. Another focus is on the need for adapted safety and explosion protection concepts and on testing the hydrogen suitability of components. In addition, the chapter provides an overview of the very different strategies and implementation statuses in the Ready4H2 countries.

Chapter 2.5 deals with **blending** hydrogen into natural gas networks and describes the boundary conditions and limitations. To this end, the relevant gas quality parameters (calorific value, Wobbe index, relative density) and the resulting maximum hydrogen content are presented. Another focus is on billing and measurement: the determination of the billable calorific value (hourly, daily, monthly) and the permissible averaging methods are crucial. From a technical perspective, the chapter outlines the current status of hydrogen compatibility of infrastructure and end devices at various blending ratios. Finally, the chapter provides an overview of the activities of the Ready4H2 countries in the area of blending. This option is used to varying degrees in all countries; as a market ramp-up instrument, a transitional solution, or only in limited niches.

Finally, **operational considerations** (Chapter 2.6) address the adjustments required for the safe and efficient operation of hydrogen networks compared to conventional natural gas systems.

2.1 Safety aspects

Safety findings on hydrogen releases in gas infrastructures

While transforming existing gas infrastructures to hydrogen, the safe control of controlled gas releases is of central importance. Current regulations and design concepts in Europe are predominantly based on natural gas and have so far only taken limited account of the specific physical properties of hydrogen. However, due to its low density, high flame temperature, very low ignition energy and the limited visibility of hydrogen flames, different safety requirements apply in comparison to those of natural gas.

Based on a completed safety research project on hazardous areas in gas system pipelines open to the atmosphere (completed in July 2025, conducted by DBI and OGE [3]), it is clear that hydrogen releases require specific safety assessments. This applies in particular to the dimensioning of potential explosive areas and the assessment of sound, overpressure and heat radiation effects. In particular, the geometry of blow-off devices and the respective mass flow have a significant influence on the hazard potential. Certain designs, in which air intake causes early dilution of the hydrogen, can reduce the formation of flammable mixtures, but at the same time promote other effects, such as increased heat radiation.

Explosion noise, the intensity of which depends heavily on the design of the release device, has proven to be a safety-relevant effect. While certain design principles can lead to a reduction in overpressure and noise exposure, a holistic approach is always necessary, as conflicts of interest between noise, pressure and heat radiation can arise. Numerical flow simulations have proven to be a suitable tool for safety assessments, particularly for estimating the spread of hydrogen clouds and for dimensioning safety distances. Validation of such models using experimental data is essential.

In addition to open blow-off devices, flare systems play an important role in the safe operation of hydrogen networks. This results in increased requirements for ignition safety, thermal shielding and mechanical stability. Concealed or encapsulated flare concepts can help to reduce heat radiation in the surrounding area and therefore represent a promising approach for European applications.

Based on available findings, it can be concluded that existing national and European regulations should be further developed in the future. Key aspects of this are the explicit consideration of explosion noise and heat radiation as design parameters, the definition of suitable boundary conditions for release devices, and the development of hydrogen-specific calculation and evaluation approaches. In addition, training for operating personnel, regular functional tests of safety-relevant equipment and a conservative design of safety distances are essential components for a safe European hydrogen ramp up.

Experience from practical projects: [4]

- the safety concept should be based on existing natural gas standards and only be expanded where necessary for hydrogen-specific requirements
- risk analyses (e.g. HAZOP) help to identify additional measures with a focus on tightness, explosion protection and odorisation
- regular inspections and visual checks are necessary, at least initially, especially for small networks with sensitive technology and in winter conditions
- network checks are recommended at shorter intervals than for natural gas, at least initially
- the technical and organisational integration of hydrogen into operating instructions and training concepts should take place at an early stage
- training for internal and external parties involved (installers, fire brigade, chimney sweeps) is essential, ideally with practical exercises
- ATEX-related aspects must be considered, including the classification of hazardous areas (zoning), the assignment to the appropriate gas group, and the selection of suitable equipment and protection concepts

Energy source comparison

An important aspect that must be considered when converting the gas network infrastructure from natural gas to hydrogen is the different properties of hydrogen compared to natural gas. These properties mean that, in addition to verifying the hydrogen readiness of components and materials, the existing safety concept must be adapted to the specific characteristics of hydrogen as a medium.

Table 1 shows some of the differences between the parameters of hydrogen and those of methane. It should be noted that these (unless explicitly stated) were measured at a temperature of 25°C and an ambient pressure of 1013.25 hPa.

Hydrogen is the lightest element in the universe. Methane is about eight times heavier and has a density about eight times higher. The striking differences in mass and density have far-reaching implications for the infrastructure used and energy density.

Hydrogen contains more than twice as much energy per weight. Methane, on the other hand, contains around three times as much energy per volume. This means that significantly larger volumes of hydrogen are required to produce the same amount of energy.

The explosion limit in air indicates the concentration range of a combustible gas (in volume percent) within which a mixture with air can explode when exposed to an ignition source. Hydrogen can ignite in a much wider range. In addition, the gas is significantly more reactive and therefore more technically challenging than methane.

Note on the Netherlands: *Experimental studies carried out in the Netherlands by Alliander and Kiwa Technology demonstrate that hydrogen–air mixtures below approximately 6 % could not be ignited in practical tests, indicating that the commonly cited lower explosion limit of 4 % hydrogen in air does not automatically imply ignition or explosion under typical conditions. [5]*

Table 1: Material characteristics of hydrogen and methane [4]

Parameter	Unit	Hydrogen (H_2)	Methane (CH_4)
Density	kg/m³	0,09	0,72
Calorific value (mass-related)	kWh/kg	33,3	13,9
Calorific value (volumetric)	kWh/m³	3,0	10,0
Lower Wobbe index	MJ/m³	40,90	48,17
Upper Wobbe index	MJ/m³	48,34	53,45
Joule-Thomson coefficient	-	-0,024	0,41
Lower explosion limit in air (20°C)	Vol.-%	4,0	4,2
Upper explosion limit in air (20°C)	Vol.-%	77,0	16,6
Minimum ignition energy (λ=1)	mJ	0,017	0,23
Combustion speed in air (λ=1)	cm/s	275	43
Diffusion coefficient in air	cm²/s	0,61	0,16
Specific CO_2 emissions	g/MJ	0	55
Dynamic viscosity	$Pa*10^{-6}$	8,42	10,2
Kinematic viscosity	mm²/s	93,7	14,2
Minimum gap width	mm	0,29	1,14

Note: In the table, the ignition energy of hydrogen seems very low compared to natural gas. However, in reality the ignition energy is not a point as shown in the table, but a range depending on the percentage of hydrogen in air. This background knowledge is crucial in understanding the context of the values in the table and interpreting the safety risk of hydrogen. For hydrogen, the lowest ignition energy is reached at 29.5 % hydrogen in air whilst for natural gas the lowest point is at 9.5% natural gas in air. In essence, it is easier to ignite natural gas than hydrogen. This is crucial in understanding risk: indoor leakages typically lead to concentrations of hydrogen around 0.3% (DNV research for Alliander) and large leakages (which are seldom) are typically less than 5-7% (Hyhouse report KIWA UK).

2.2 Hydrogen Quality

This chapter summarises the different hydrogen quality levels currently under discussion in Europe and outlines potential sources of contamination along the hydrogen value chain. [4]

Across Europe, hydrogen quality requirements are typically defined according to the intended end use. In general, two broad quality levels can be distinguished:

- **hydrogen with a purity of ≥ 98 mol-%**, typically considered sufficient for energy transport and combustion applications in infrastructure systems
- **high-purity hydrogen with ≥ 99.97 mol-%**, required in particular for sensitive applications such as fuel cells or certain industrial processes

It should be noted that hydrogen supplied via infrastructure does not necessarily need to meet the highest purity level at the point of delivery. If required, appropriate on-site purification and conditioning technologies can be applied to upgrade grid-supplied hydrogen to the quality needed for sensitive applications such as fuel cells or specific industrial processes.

However, hydrogen purity cannot be assessed solely on the basis of the hydrogen concentration itself. Equal attention must be paid to accompanying components and trace substances, including water, oxygen, nitrogen, carbon monoxide, sulphur compounds, ammonia and halogenated substances. The permissible limits for these substances vary depending on the application and are defined in relevant European and international standards (such as *EN 17124* for fuel cell hydrogen). In addition, hydrogen transported in pipeline systems must be technically free from liquids, aerosols and solid particles to ensure operational safety and system integrity.

Sources of contamination

Hydrogen can become contaminated at various stages of the value chain. Potential sources include:

- production processes (depending on the technology used, namely electrolysis, steam reforming, ammonia cracking)
- pipeline transport (especially in repurposed natural gas pipelines)
- storage (namely salt caverns or porous storage systems)
- odorisation processes
- backfeeding or mixing with other gases

The consequences of contamination may include corrosion, material degradation, impairment of combustion properties, or adverse effects on downstream industrial processes. Catalytic applications and fuel cell technologies are highly sensitive to certain trace components such as sulphur compounds or carbon monoxide.

Findings from recent research projects

Several national and European research projects are currently addressing hydrogen quality and contamination

issues. In Germany, for example, large-scale research initiatives have investigated hydrogen quality requirements for an integrated hydrogen network, including the identification of contamination sources and necessary purification processes across production, transport, distribution and storage (*DVGW research project G 202140 Hydrogen quality in a nationwide network and DVGW research project G 202318 Follow-up study on hydrogen quality in a pan-German hydrogen network [6]*).

The results indicate that all major hydrogen production technologies, when combined with appropriate purification systems, are capable of delivering hydrogen that meets even the highest quality requirements. The studies also highlight that:

- in electrolysis-based production, the main potential impurities are moisture and oxygen
- in ammonia cracking, particular attention must be paid to possible ammonia and nitrogen residues
- new pipelines do not typically introduce significant additional contamination
- repurposed natural gas pipelines may contribute impurities such as sulphur residues, moisture or nitrogen
- in underground storage systems, geological conditions, microbiological activity and previous usage can influence hydrogen quality

The ongoing *DVGW research project G 202439 Hydrogen Quality, Processing, Measurement Technology and Economic Optimisation [7]* aims to present the demand and corresponding costs of gas processing for different hydrogen qualities, as well as their optimal location in terms of economics. This may serve to support the ramp-up of hydrogen. The quality requirements of different customers and applications are evaluated in relation to the investment and operating costs of producers, transporters and infrastructure operators. It is good to realise that DSO have little or no means of ensuring the quality at the exit point at this moment.

Open questions at the European level

Despite significant progress, hydrogen quality remains a relevant European research field. In particular, harmonised requirements for hydrogen purity in cross-border pipeline systems, as well as clear rules for handling contamination risks in repurposed infrastructure, are essential for ensuring interoperability and market integration. In addition, ongoing European projects such as *HyQualNet* are further investigating grid contamination effects, including odorant residues and legacy pipeline deposits. Earlier preparatory studies for the European Commission have already highlighted the importance of defining consistent quality parameters and monitoring concepts. The final results of these projects are expected to contribute to a more harmonised European framework for hydrogen quality management.

Overall, hydrogen quality must be considered not only as a technical parameter but also as a key enabler for market development, cross-border trade and the secure integration of hydrogen into existing and future energy systems.

2.3 Conversion

The conversion of an existing gas infrastructure to hydrogen involves preparatory analyses, adaptation measures derived from these analyses, and implementation of the actual conversion (for example section-by-section flushing/gassing). The network, customer installations and gas applications must all be considered together, as there are typically dependencies between these areas in terms of content and timing.

This chapter deals with the conversion process: the sequence (order and procedure), the most important restrictions (including technical, operational and regulatory conditions), and the derivation of the schedule and conversion plan including typical dependencies. In addition, the most important cost blocks are discussed in order to create a reliable basis for project management and early profitability assessments. Other focus topics include permitting and approvals.

2.3.1 Gas distribution network conversion to hydrogen

2.3.1.1 Preliminary analyses and conversion concept

Four analysis areas were used as the technical basis for a safe, zone- or sub-network-related conversion: **feed-in analysis, customer analysis, capacity analysis and network analysis**. The results were incorporated into a conversion concept; the overall process must be iterative because analyses and concepts influence each other (see Figure 3). At the same time, preparatory, early and continuous **communication** with affected customers and authorities, as well as the consideration and integration of **network development plans and regional strategies**, are crucial.

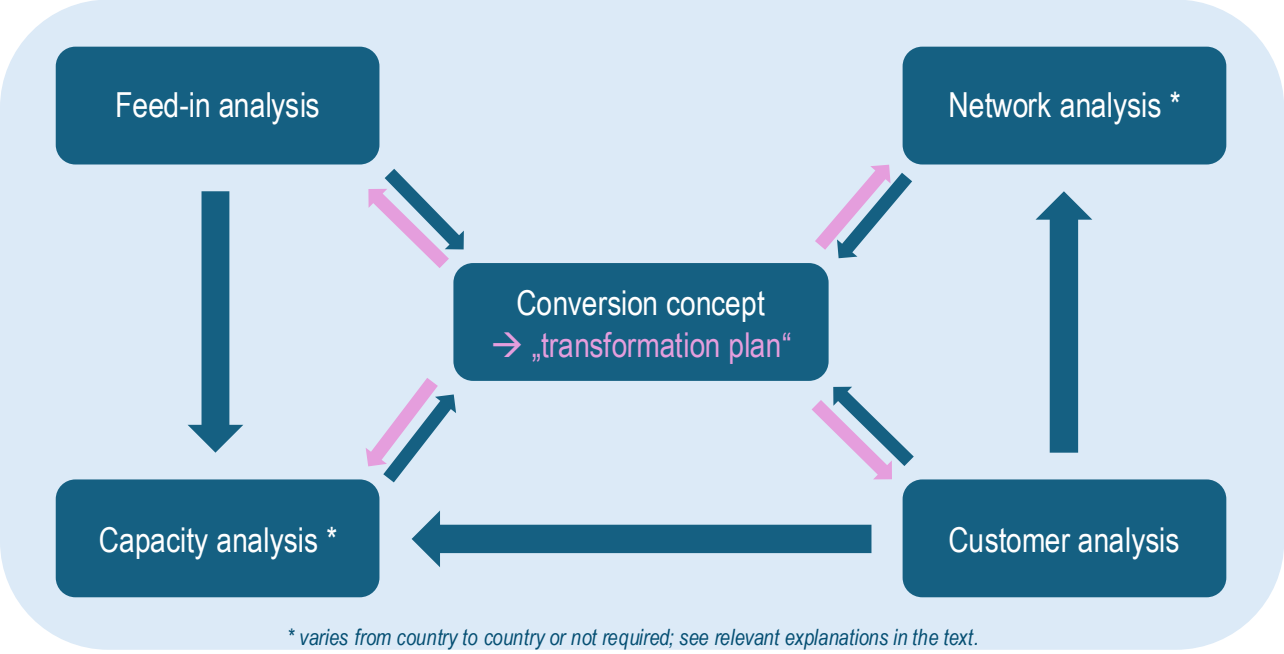


Figure 3: Transformation plan for converting a network area to hydrogen [Source: DBI GUT]

Communication with affected customers and authorities

Structured communication with affected customers and authorities is a key success factor in preliminary analyses. It must be clearly defined **early in the project** who will receive what information, when, how and through which channels – for example via regular status reports, meetings or written communications. This not only helps to synchronise expectations, but also builds trust and reduces uncertainty on the part of all those involved. [8]

The Council of Europe integrates **communication guidelines** into its project management methodology, which accompany the project from initiation to completion and are designed to ensure that information is communicated continuously, transparently and in a manner appropriate to the target group. This also includes communication with authorities, partner organisations and the public, with the declared aim of creating acceptance and ensuring the long-term success of the project. [9]

It is advisable to integrate **feedback and participation processes**; not just provide information unilaterally but actively open up spaces for dialogue. This can be done through workshops; consultation rounds or digital platforms where affected stakeholders can contribute comments and ask questions – a principle that is firmly anchored in a wide range of EU-funded programmes for citizen and public authority participation. Such approaches not only promote mutual understanding but also reduce potential resistance and support a robust basis for decision-making for further planning steps. [10]

At EU level, **public participation** requirements are primarily enshrined in environmental and licensing law that are derived from the principles of the Aarhus Convention. Central to this is *Directive 2003/35/EC [11]* which sets out requirements for "early and effective" public participation in certain environment-related plans/programmes, at the same time strengthening participation rights in authorisation procedures. In practice, these requirements apply in particular via the *EIA Directive 2011/92/EU [12]* (usually for larger infrastructure and industrial projects) and via the *SEA Directive 2001/42/EC [13]* (for plans and programmes): both frameworks require that environmental information and documentation be made publicly available, that the public be given the opportunity to comment, and that the results be taken into account in the decision-making process.

Proven approaches can be derived from **previous project experience**. Early, transparent and structured communication with all stakeholders (local authorities, local and national safety and regulatory authorities, end consumers, residents, etc.) is of central importance. In particular, all parties involved should be informed and responsibilities and interfaces should be clarified at an early stage.

In addition to involving public authorities and the affected population, targeted communication with **large industrial customers** also plays an important role. Network operators should be in close contact with all relevant large consumers in order to analyse specific conditions. These include in particular the technical equipment used on site that could potentially be affected by the use of hydrogen, the respective decarbonisation targets and the expected future demand for natural gas and/or hydrogen. Based on this dialogue, suitable future supply areas for hydrogen distribution can be planned and designed accordingly.

The Lochem trial (Netherlands), which was completed in 2025 after three years of operations, shows that close **involvement of local residents** from the outset contributed significantly to the project success. The project was implemented as a joint initiative between local residents and the gas DSO Alliander. Comprehensive transparency regarding safety aspects and other project-related issues proved particularly helpful. All available research results on safety were communicated openly. Cooperation with the local residents' association also played an important role. [14] Early contact with the national research institute for firefighters further helped to build trust. Overall, all relevant stakeholders and the institutions behind them were systematically identified and approached. A similar communication approach was also pursued in other projects in the Netherlands - *Wagenborgen* (ongoing), *Hoogeveen* (currently in the scaling up phase), and *Stad aan 't Haringvliet* (coming online in 2028).

Specific experience with direct customer communication is also available from a pilot project on hydrogen blending in *Hranice u Aše* (the Czech Republic). In addition, newly connected customers are informed at an early stage about the prospective blending of hydrogen or the later use of 100% hydrogen. This applies in particular to CHP plants being converted from coal to gas.

It is also important that regional and local authorities are actively involved in the conversion process. In this context, the cantons in Switzerland play a central role as regional structures, as the future use of renewable gases is defined through the existing cantonal energy strategies. The creation of a structured "safety and contingency plan" has proven to be a tried and tested instrument.

As part of the transition from natural gas to climate-neutral gas networks in Europe, there are now a number of **useful documents and guidelines** available to help network operators structure and clarify their **communication with various stakeholders** from households and industry to political actors: a key German tool is the *Guideline on the Gas Network Area Transformation Plan [15]*, which was developed by the *"H2vorOrt"* initiative in collaboration with the DVGW and other associations. In addition to technical and regulatory aspects, this guideline also describes processes for customer analysis and for involving relevant stakeholder groups in the context of the upcoming transition – and is explicitly based on the new European requirements of the EU Internal *Gas Market Directive (EU) 2024/1788*. In addition, policy framework and green papers such as the German Green Paper *"Transformation of Gas/Hydrogen Distribution Networks" [16]* provide important background information on how security of supply, supply transitions and end customer interests should be taken into account in long-term planning – content that can be used as a good basis for stakeholder communication. At the European level, there are also various technology and practice guides on topics such as hydrogen blending into existing gas infrastructures [17], which highlight technical possibilities and limitations

and thus help explain technical and commercial issues to industrial and regulatory stakeholders in an appropriate manner. Such overviews can be provided, for example, by gas and infrastructure associations and scientific project reports, and can be used to create understandable information materials for consumers, industry partners and political decision-makers. This collection of different sources (national planning guidelines, policy framework documents and topic-specific European reports) makes it possible to support the transformation of gas networks not only technically and regulatory, but also communicatively in a manner appropriate to stakeholders.

Consideration/integration of network development plans and regional strategies

At the European level, transformation and system development planning is increasingly multi-level: across the EU, the guidelines (*TEN-E Regulation (EU) 2022/869 [18]*) provide the framework for "interoperable" trans-European energy infrastructure and link infrastructure development with EU climate and energy strategies as well as corridors/priorities (including offshore grid planning).

The *Ten-Year Network Development Plan (TYNDP)* provides an overview of the European gas infrastructure and its future developments, and it maps the integrated gas network according to a range of development scenarios. The TYNDP also includes a European supply adequacy outlook and an assessment of the network resilience. Gas Regional Investment Plans (GRIPs) led by TSOs with ENTSOG assistance complement the TYNDP by focusing on issues of particular regional importance. *EU Gas Regulation (EU) 2024/1789* requires ENTSOG to develop the TYNDP on a biennial basis. [19]

ENTSO-E explicitly emphasises that the TYNDP results serve as input for national development plans (and supplement them), and ENTSOG addresses the role of hydrogen infrastructure (including "infrastructure gaps") very clearly for the first time in TYNDP 2024. [20]

In practical terms, this means that for **transformation planning**, **regional strategies** (including offshore clusters, import corridors and hydrogen backbones/valleys) should be reviewed at an early stage to ensure that assumptions for demand, time horizons and corridors are consistent with the European scenario framework and identified system requirements. Otherwise, there is a risk of duplicate planning, bottlenecks "at the border" or subsequent approval/financing risks.

Based on this, the projects/conversions should take the following aspects into account or be reflected in the preliminary analyses:

- the current European TYNDP context
- national grid development plan (GTP) assumptions
- regional strategies (countries/regions/clusters)

This is particularly important where interfaces such as import corridors, storage facilities, industrial anchor customers or border crossings are needed to be created.

Feed-in analysis

The feed-in analysis considers the type and location (assignment to a conversion zone) of secured decentralised feed-ins of climate-neutral hydrogen into the existing gas network. In the case of isolated solutions, the need for intermediate storage must be taken into account in order to ensure security of supply throughout the year.

In addition, future feed-in potential of climate-neutral gases in the network area should be taken into account, such as from feed-in requests or potential analyses. The feed-in capacities derived from this (including the planned start of feed-in) are assigned to individual conversion phases of a conversion zone and are incorporated into downstream capacity and (flow-related) network considerations.

Customer analysis

The purpose of the customer analysis is to investigate whether and when a switch to hydrogen is possible on the customer side. To this end, the type and structure of the connected gas customers are first determined and current gas requirements and future hydrogen requirements are recorded.

Specifically, this includes (as work steps/results):

- determination of the gas and hydrogen demand of "anchor customers" (including industry, commerce, power plants; customers with registered power measurement)
- determination of the gas and hydrogen requirements of households and small businesses (standard load profile customers)
- determination of the connected load and, if applicable, the annual gas demand per customer
- consideration of the decommissioning of house connections as a possible option in the course of determining demand

The expected future load values are incorporated into the target network/network planning (including flow-related considerations for the network sections to be converted) and, in aggregated form, into the capacity analysis. To ensure a safe conversion, it is also necessary to record the existing gas applications at the customer premises (especially with regard to hydrogen compatibility). A distinction must be made between industrial and domestic customers. Based on a device/application survey, necessary adjustments and conversions and replacement requirements can be identified. In addition, the time required for the conversion per customer (depending on the gas appliance and house connection) should be estimated.

The results of the customer analysis will show the extent to which a conversion is necessary or possible on the customer side and which customers will withdraw (completely) from the gas network.

Capacity analysis

As part of the capacity analysis, an initial determination or definition of conversion zones is carried out. For all conversion zones, the required capacity (necessary work in kWh/a and maximum power in kW) at the network connection points (NCP) to upstream network operators is determined (bottom-up assessment). Capacity values for both natural gas and hydrogen must be considered.

As the capacity values at the NCPs change continuously due to the gradual conversion of grid sections, the values for each conversion phase of a zone, including the associated time period, must be specified. This requires cross-network cooperation with the upstream network operator in order to coordinate hydrogen availability at the NCPs (timing, capacity and quantity) (top-down validation).

Capacity values are composed of the aggregated outputs of the network customers (in the feed-in analysis) and the capacity values of downstream network operators at the corresponding NCPs. Feed-in projects may reduce the capacity required at NCPs for upstream network operators. In addition, results from the network analysis and new construction measures may influence the capacity values.

Country-specific note: *In the Netherlands and other regions supplied with L-gas, a dedicated capacity analysis is generally not required, as the calorific value of L-gas is relatively close to that of hydrogen. However, several factors still indicate that capacity constraints may arise during the transition to hydrogen. These include the expected reduction in overall gas demand, both in terms of transported volumes and the number of connected customers, both of which can affect network utilisation and load patterns. Capacity forecasts for natural gas are developed jointly with the national transmission system operator and form the basis of assessing the implications of a future hydrogen supply.*

<u>Flow velocities in pipelines</u>

A key question in the conversion of the gas infrastructure to high hydrogen content and even to operation with pure hydrogen is whether higher flow velocities are permissible in existing pipelines at higher volume flows.

Regulatory approaches to this issue are not harmonised across Europe. In some countries, specific velocity limits are defined for certain installations. In other regulatory frameworks, such as in Germany, current technical standards and regulations do not define binding maximum flow velocities that must be strictly adhered to. Instead, they generally state that flow velocities should be kept sufficiently low to prevent excessive entrainment or migration of impurities and to avoid unacceptable noise emissions.

In addition, it is recognised that higher flow velocities result in increased pressure losses within the pipeline (see *Appendix 2*). The values mentioned in these contexts are typically recommendations intended as technical guidance rather than mandatory limits. Against this background, any assessment of permissible flow velocities in the context of hydrogen conversion must consider the specific national regulatory framework in addition to technical and operational constraints.

Due to these ambiguous specifications in the German regulations, sample calculations of pressure losses were performed. For this purpose, the formula set from *“Appendix 1: Calculation formulae for pressure loss”* [21] was taken and used. The calculations were performed for different operating pressures and various exemplary pipe inner diameters. Natural gas and hydrogen were always considered as real gases, and the material values for the different operating conditions were calculated using GasCalc. [22] For better comparability, a uniform pipe length of 1 m was used.

The calculations assumed that the amount of chemical energy transported by the gas flow in the pipelines is the same for both natural gas and hydrogen. Exemplary limit values for flow velocities were applied for natural gas.

Due to the ratio of the calorific values of an exemplary natural gas (11.18 kWh HHV/Nm³) and hydrogen (3.55 kWh HHV/Nm³) of 3.16, the volume flows and flow velocities are approximately three times higher when switching to hydrogen. Since the density and viscosity of hydrogen (0.0898 kg/Nm³ | 8.3997 µPa*s) are lower than those of natural gas (0.7423 kg/Nm³ | 10.2747 µPa*s), the pressure losses do not increase threefold.

It should also be noted that very high flow velocities on short pipe sections of a few metres can be considered "acceptable" because the pressure losses over short distances may not have a negative impact on compliance with specified minimum pressures. However, the same flow velocities on longer pipe sections of several hundred metres or kilometres may mean that customers are no longer supplied with the required minimum pressure.

"Appendix 2" lists the flow velocities for natural gas and hydrogen and the resulting increase in pressure losses. It shows that pressure losses increase by only 33% on average when the same amount of energy is transported with hydrogen at approximately three times the flow velocity.

Since no limit values for flow velocities are specified for pipelines in the regulations, the primary focus when designing networks or investigating the conversion to hydrogen should be on compliance with specified minimum pressures. Compliance with the (self-imposed) limit values for flow velocities is secondary/negligible.

If the minimum pressures are not reached, it can be investigated whether excessive flow velocities in certain pipe sections are the cause and, if necessary, the nominal diameters of the affected pipes must be increased.

Capacity calculation of control systems

One question that arises when converting the gas infrastructure to high hydrogen content or even pure hydrogen operation is whether the existing GPRMS have sufficient capacity for the higher volume flows. The natural gas capacities of GPRMS can be checked using the Excel calculation tool developed by DVGW expert *Dipl.-Ing. V. Ollesch.* [23] The formulae required to calculate the capacities of individual components of a GPRMS can be found in the book written by *Dr.-Ing. B. Naendorf*. [24] They have been converted for the calculation of the standard volume flow and are listed in *“Appendix 3: Calculation formulae for GPRMS capacity calculation”.*

These formulae were examined in the DVGW research project "*Operating limits analysis and capacity calculation of the overall system of gas pressure regulating and metering systems"* for their applicability in the operation of systems with hydrogen. [25]

It should be noted that the formula listed for preheating is used without conversion to calculate the heat requirement necessary to raise the gas to the required temperature so that it does not cool down too much after expansion in the gas pressure regulator.

Due to the negative Joule-Thompson coefficient of hydrogen, preheating is no longer necessary at hydrogen concentrations of approx. 60%. [26, p. 46] For gas pressure regulators, the research report and other technical literature provide adjustments for calculating their capacity when operating with other gases. The capacity of gas pressure regulators is calculated using the $K_G$value.

"The $K_G$value is equal to the standard flow rate when the actuator is fully open at an absolute inlet pressure of p_u= 2 bar and an absolute outlet pressure of p_d= 1 bar. It refers to natural gas with a standard density of *ρ_n= 0.83 kg/m³ at* a temperature of *t = 15 °C and has the unit m³/(h*bar)".* [27, p. 16]

The specified standard density corresponds to average values for natural gas L [28], which thus serves as the basis for calculating the capacity of gas pressure regulators.

For the capacity of gas pressure regulators when operating with other gases such as natural gas H or hydrogen, a conversion factor f is used at [24], [25], [26] and [28] to calculate an equivalent flow rate. To do this, the densities of natural gas L and the replacement gas are compared.

$$f = \sqrt{\frac{0{,}83\,\frac{kg}{m^3}}{\rho_{n_{Gas}}}}$$

Formula 1

The following conversion factors apply for natural gas H and hydrogen.

Table 2: Conversion factors for gas pressure regulators (under standard conditions. 0 °C, 1013 mbar)

	Density	Conversion factor f
Natural gas L	0.83 kg/m³	1
Natural gas H	0.78 kg/m³	1.03
Hydrogen	0.08989 kg/m³	3.04

Accordingly, a gas pressure regulator would have to be able to pass through approximately three times the amount of hydrogen instead of natural gas at the same inlet and outlet pressures without further adjustments.

Material properties are not taken into account when calculating all other system components. For the nominal inlet and outlet diameters and the SAV, the maximum flow velocities specified in [29] limit the capacity. For filters, the maximum filter load limits the capacity, and for meters, the meter size limits the capacity. If these parameters are not adjusted, the maximum capacity in terms of maximum volume flow remains unchanged. As the hydrogen content increases, the calorific value decreases and with it the maximum capacity of the system in terms of the amount of chemical energy flowing through the system with the gas flow. [25, p. 41]

In April 2021, *Kiwa Technology B.V.* published a project report on behalf of *Netbeheer Nederland*, which examined the suitability of gas pressure regulating systems for operation with hydrogen. [30] In particular, the technical function of various components of a gas pressure regulating system was examined. These included dust filters, regulators, safety shut-off valves, safety shut-off flaps, shut-off valves and the associated piping. They were tested both with the volume flow of natural gas for which the system was designed and with three times the amount of hydrogen.

The conclusion of the project was: *"The tested gas pressure regulating system, which is designed for natural gas, can be used for hydrogen without any* (technical) *modifications. This conclusion only applies to the technical function. No statement can be made about long-term behaviour."* [30]

This applies to the small design size of 750 m³/h (i.N.) natural gas. No reliable statement can yet be made about systems with higher output or other designs. However, the results suggest that similar statements could

also be made for larger systems.

Even though the results of the practical project carried out by *Kiwa Technology B.V.* for small control systems are promising, further theoretical and practical research is needed for all components of a GPRMS, such as to further adapt the capacity calculation for hydrogen and gain practical experience. This is currently being investigated in the DVGW research project *"HySpeed".* [31] Nevertheless, it is likely that individual testing of non-standard systems, in particular, will be mandatory before a network can be converted to hydrogen operation (may depend on national regulation).Nevertheless, it is likely that individual testing of non-standard systems, in particular, will be mandatory before a network can be converted to hydrogen operation (may depend on national regulation).

Network analysis (hydrogen readiness and network modelling)

The technical network analysis comprises (i) the testing and evaluation of the hydrogen readiness of existing pipeline materials, network components and gas engineering systems, and (ii) a network hydraulic analysis as part of target network planning.

From a technical point of view, two states must be clearly defined and compared:

- current status (natural gas operation): current design/performance data, operational experience and conditions
- target status (future hydrogen operation): design pressures, maximum/minimum permissible operating pressures, permissible flow/performance ranges, gas composition, and gas and external temperature; also specifications for pressure protection, including settings of safety shut-off devices for hydrogen

As part of the target/actual comparison, the hydrogen compatibility of the gas network sections and systems to be converted for hydrogen distribution must first be tested, evaluated and verified. The related decisive factors are (a) the resistance and function of the materials used (components/assemblies/devices) in relation to hydrogen and (b) the guaranteed tightness of pipes, fittings and connecting elements. This test is a prerequisite for identifying potential weak points and, if necessary, deriving the necessary upgrading measures to achieve hydrogen readiness.

In addition, network hydraulic analysis as part of target network planning enables the assessment of the flow-related effects of the conversion (entire network and network sections to be converted in stages). From this, concrete measures can be derived to ensure the required capacities and to guarantee the gas/hydrogen supply before, during and after the conversion process.

Country-specific note: *With regard to the materials and connection types used, such an analysis is currently not required in the Netherlands. This is based on a KIWA report confirming that all materials used in Dutch gas networks are suitable for the intended use from a chemical point of view and in terms of probability of failure.*

Known material restrictions (such as the incompatibility of certain rare earth materials, as used in magnets in pulse measurement systems, for example) have been taken into account. These materials must not come into direct contact with hydrogen, as this can lead to material degradation. However, the relevant components are designed in such a way that direct contact with hydrogen is impossible.

Analysis of the hydrogen compatibility of gas networks and facilities

The process of testing and verifying the hydrogen compatibility of networks and facilities can be divided into two phases. The first phase deals with data collection and the second phase with the assessment of hydrogen compatibility.

Phase 1: Data collection

The assessment of hydrogen compatibility is based on a systematic survey of the existing documentation for

the section of the gas network to be converted; the aim is (i) to inventory the installed network components and (ii) to compile the associated documentation.

- Inventory (database):

The inventory table contains all gas network components of the network sections to be converted and is fed from digital equipment information systems (asset/GIS/meter management) and construction files/pipe books; if necessary, analogue data sources could first be digitised. At a minimum, the following information should be recorded for each component: number, year of manufacture, material, design/dimensioning parameters (such as nominal diameter/pressure, and for steel pipes the wall thickness), operating pressure, manufacturer and product name.

- Additional information (useful for later planning of measures):

Additional identification and location parameters are particularly helpful for the subsequent localisation of necessary retrofitting measures (object ID in GIS and assignment to conversion zones/districts via location/address and asset numbers).

- Compiling documentation (safety focus):

The documents to be submitted for the conversion include declarations of conformity and manufacturer's declarations regarding the future use of hydrogen (as assistance for providing evidence), construction documents (construction documentation, acceptance test certificates including drawings/material lists, material tests/material test certificates, information on pressure tests), reports on leak testing/pipe network monitoring/material testing, as well as safety-related documents such as safety data sheets, NDT documentation, explosion protection documents, risk assessments, ATEX zoning documents and expert reports.

This also includes documents on previous operating modes and maintenance (gas composition, external influences such as corrosive soils/buildings, operating instructions and modifications, operating and maintenance experience with natural gas, including continuous pipe network inspections, test certificates for maintenance/recurring inspections, evaluation of fault/damage statistics, risk assessments, measurement reports).

- Quality assurance of data collection:

It is recommended that an expert/specialist authority be involved at an early stage during data collection in order to coordinate requirements for documentation and data for providing evidence. Subsequently, a joint quality check should be carried out to ensure that the data and documentation are complete.

- Dealing with data gaps (if hydrogen readiness cannot be reliably determined):

If no statements on hydrogen readiness can be made due to incomplete documentation/data, measures must be taken to close data gaps as far as reasonably practicable and enable evaluation/verification. These include, for example:

- using construction sites on gas pipelines to complete documentation
- taking and testing representative samples (critical pipes and components)
- drawing analogies (such as based on year of construction, purchase/product-specific data for each time period, queries to knowledge carriers)
- inspections and above-ground checks of underground pipelines
- use of monitoring systems for early detection of leaks (shock odorisation, means a short-term, targeted increase in the concentration of odorant in a gas network)
- operational trials/tests (including pressure tests; tests for internal/external tightness, gas permeability; functional and response behaviour)
- engineering assessments taking into account operational experience/conclusions regarding the use

of hydrogen in gas distribution

- preparation or revision of risk assessments (including condition of components, materials/seals, dimensioning, completeness of documentation

Phase 2: Assessment of hydrogen suitability

Hydrogen suitability is assessed on the basis of the data collected and documentation; the documentation is first checked for completeness and currency. If a complete statement is not possible, the operator must implement appropriate measures to complete the data and documentation. In this context, *suitability* refers to the fundamental ability of a component, material or system to operate safely and reliably with hydrogen under the intended conditions. This must be clearly distinguished from *compatibility*, which describes the material-specific resistance to hydrogen, such as embrittlement, permeation or chemical interaction.

The assessment includes individual assessments of the hydrogen suitability of the installed components as well as an overall assessment of all components of the network section to be converted, taking into account operational and safety aspects.

If hydrogen compatibility is not fully ensured, parts of the network will need to be upgraded and adapted. Once this has been completed, the documentation must be supplemented/updated accordingly. If hydrogen compatibility is fully ensured, proof of technically safe operation with hydrogen has been provided and typically serves as the central basis for the further implementation of the conversion project.

A fracture mechanics assessment may be necessary when converting steel pipelines. The research project *BAG 464* (Germany) investigated the need to carry out a fracture mechanics assessment in the distribution network up to 16 bar. It concluded that no fracture mechanics calculation is necessary for a MOP of up to 12 bar, regardless of the steel grade used. This also applies to a MOP between 12 and 16 bar and a nominal diameter ≤ DN 200. [32]

Note on the scope of the assessment of the hydrogen suitability of gas networks

The required scope of the assessment of the hydrogen suitability of existing gas networks depends on the respective national conditions, in particular the technical framework conditions, the applicable laws and the regulatory and normative requirements.

In the Netherlands, for example, a segment-by-segment assessment of the network infrastructure is not considered necessary. This assessment is based on the finding that hydrogen is less aggressive than natural gas from a chemical point of view. In addition, no additional or more severe failure mechanisms could be identified that would suggest an impairment of the components used in the network. Only at very high operating pressures (above approx. 60 bar(g)) can hydrogen embrittlement occur, depending on the type of steel used. In the Netherlands, this issue is assessed at network level, but not on a section-by-section or segment-by-segment basis.

Other countries are pursuing different approaches in some cases, resulting from national regulatory requirements. Germany, for example, has a much more detailed testing and verification process in place with its verifHy procedure. Although this approach ensures a high level of testing depth, it cannot be easily transferred to all national systems.

Against this background, no blanket recommendation for a segment-by-segment assessment in all countries should be derived from this report. Rather, the appropriate level of detail for assessing H_2 suitability must be consistently adapted to the respective national framework conditions.

Hydrogen target network planning and flow analysis of network sections

As part of target network planning, the hydraulic and network topology feasibility of a conversion to hydrogen and subsequent safe network operation must be assessed. For each (sub)network, it must be ensured that supply is guaranteed at all times during the respective conversion steps (natural gas and/or hydrogen). The results are used to derive necessary adaptation measures in the target network, such as expansion/new

construction of pressure regulating and feed-in facilities, pipeline reinforcement or new construction, and the determination of suitable separation points (existing or new). The target network should be designed in such a way that defined minimum pressures (and, where relevant, limits for flow velocities) are maintained for the critical conversion steps.

Figure 4 describes the process of network hydraulic analysis using network calculation. The performance data is required, among other things, for calculating the heavy load case.

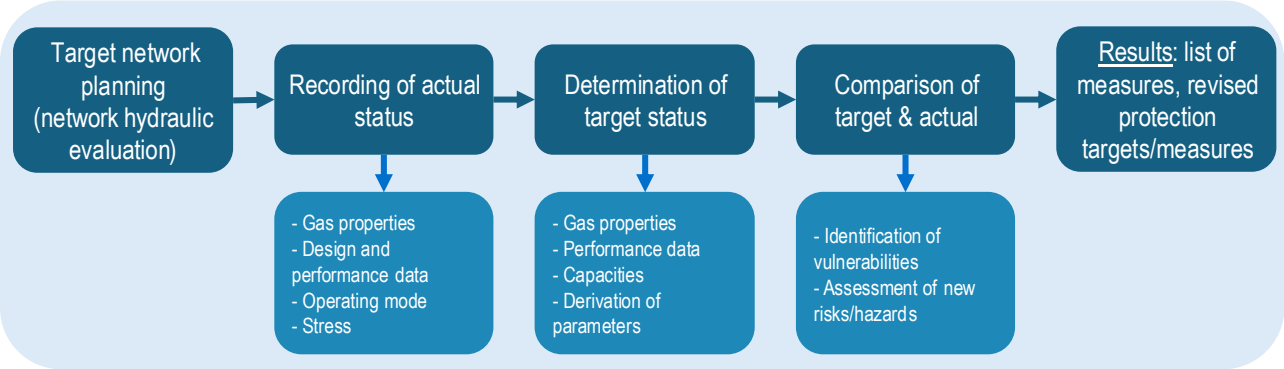


Figure 4: Process diagram for network hydraulic analysis (target network planning) [Source: DBI GUT]

Data basis and model structure

A prerequisite is a calibrated network model that reflects the actual situation as realistically as possible. Minimum requirements are:

- **pipes**: location/topology, length, internal diameter, material and roughness
- **shut-off devices**: location, switching states
- **control stations**: location, outlet pressure, technical capacity
- **loads/consumers**
- **standardised customer load profiles** (annual consumption, allocation/position)
- **measured load profiles** (ideally at least hourly for SLP customers, position)
- **gas properties**: Composition and derived material values (density, viscosity)
- **weather/temperature data**: Measured temperature series and design temperature (if load/pressure levels depend on this)
- **grid odorisation** strategy and details

Comparative measurements are necessary for plausibility checking/validation, such as flow measurements at stations and long-term pressure measurements at suitable measuring points. The number and location of the pressure measuring points depend on the task at hand, the size of the network and the degree of meshing.

Target state and boundary conditions

The target state is defined on the basis of the validated model: which parts of the network will be converted to hydrogen, which will be decommissioned (if necessary) and which (if planned) will continue to be operated with natural gas. Feed-in points/gas compositions in the model must be adjusted accordingly. New hydrogen feed-ins (such as from upstream networks) are added, and feed-ins that are becoming obsolete are removed. In addition, expected changes in consumers (such as structure and demand) must be taken into account in the model.

Identification of weak points and measures

Simulations under the target boundary conditions reveal potential pressure drops and bottlenecks. The causes must be analysed; high flow velocities can be an indication of hydraulic limitations. Typical measures include

nominal diameter adjustments, new pipeline construction, new/conversion of stations or adjustments to operating pressures. At the same time, it is possible to determine which assets will become dispensable in the target scenario and can be decommissioned/dismantled (for example to reduce operating costs).

This target network review provides the basis for subsequently developing an independent conversion concept (sequence/districts/steps).

Conversion plan

For operational implementation, the network is divided into **conversion zones** (strategic, hydraulically separated) and **conversion districts** (operational). Conversion zones should be dimensioned so that they can be converted within one year. Conversion districts are typically selected so that they can be converted within a short, defined time window (for example a "working week") in order to minimise supply interruptions.

Criteria for district formation:

- **customer structure & appliances**: proportion of H_2-ready vs. replacement/retrofitting; for industrial customers the duration can vary greatly (depending on the process/system)
- **service providers/fitters**: available capacity for customer conversions (appliances, domestic installations)
- **network topology & separability** are the existing section valves sufficient or are additional valves/bleed valves necessary (network simulation/test runs if necessary)
- **network hydraulics after separation**: security of supply/stability of the remaining network must be guaranteed at all times; new pipes or new pressure control/measuring systems may be required
- **coordination with upstream/downstream network operators**: coordinate schedule and fix it in the conversion schedule
- **season/acceptance**: residential districts preferably outside the heating period; districts with a high proportion of commercial/industrial users also possible during the heating period
- **grid odorisation** strategy and details

An indicative conversion sequence is then drawn up with conversion dates for the strategically selected zones and the districts and customers contained therein at the operational level. This also includes the identification of dependencies and flexibilities in the context of the conversion.

The result is a temporal and spatial conversion plan (transformation roadmap), including an investment-ready plan for achieving hydrogen readiness and network convertibility.

In practice, network areas with a meshed network structure are usually built or converted, tested and commissioned. The common practice of network operators is to commission the new network areas in sections.

In the following, a "pipeline section" is therefore understood to be an unbranched supply pipeline that is put into operation from T-piece to T-piece, for example. This also ensures that there are no points during the conversion where natural gas is not completely replaced by hydrogen (dead spaces). Otherwise, this could later mix with the hydrogen and jeopardise the safe operation of gas applications.

European standard *EN 12327* defines:

- commissioning = measures required to pressurise a pipeline system, including stations, facilities and equipment with operating gas for subsequent commissioning
- decommissioning = necessary measures for taking gas-filled pipeline systems, stations, facilities or equipment out of service for separation from the system

According to *EN 12327*, pipeline sections must be made free of combustible gases or flushed. According to *EN 12327*, flushing is the process of safely displacing inert gas in pipeline systems and equipment with gas or vice versa.

Significant cost blocks

The main cost categories are addressed in a structured manner below in order to create a basis for project management, variant comparisons and early economic assessments. However, at the current stage of the transformation developments, there is still **no reliable cost data** that would allow for a robust monetisation of individual measures. Cost levels vary greatly between regions, grid types and conversion approaches. In addition, much of the empirical data is either not yet available or is based on pilot projects with limited transferability. Therefore, only an identification and qualitative description of key cost categories can be provided at this stage.

The largest structural cost factor is **civil engineering**. Particularly in the case of section-by-section conversions, the process requires interventions at numerous junctions and network nodes, which significantly determines the costs based on the number, location and accessibility of the intervention points. Not only is the number of excavation pits required relevant, but also the technical solution chosen in each case: permanent installations (such as additional fittings) incur higher investment costs, while temporary shut-off methods (such as shut-off bladders) can generally be more cost-effective, but have not yet been conclusively evaluated or approved in regulatory, technical and operational terms. Methods such as the Stopple method represent a possible middle ground but are also associated with project-specific testing and approval requirements. Regional differences, including urban areas vs. rural areas, soil conditions and local construction prices, have a significant impact on costs and must therefore always be considered on a site-specific basis. *Note that these costs can be reduced with 80 - 90 % if a multifuel boiler and meter is being used.*

Another key cost factor is the **personnel required for the conversion itself**. There is still considerable uncertainty regarding the optimal team sizes, the parallelisation of work steps and the time slots required per network section. There is a lack of reliable empirical data as large-scale, serial conversions are still in the preparatory stage.

In addition, the **conversion of end devices** (most commonly gas boilers) can be considered as a further cost factor. While rough guidelines already exist for devices and conversions, labour costs are also subject to significant regional variations (urban/rural, qualifications, labour market).

Cost comparisons should therefore be made on a relative basis for the time being, such as direct vs. indirect flushing methods, early installation of H_2-ready appliances vs. later full conversion. The monetary assessments will then be specified in later project phases on the basis of network operator-specific assumptions.

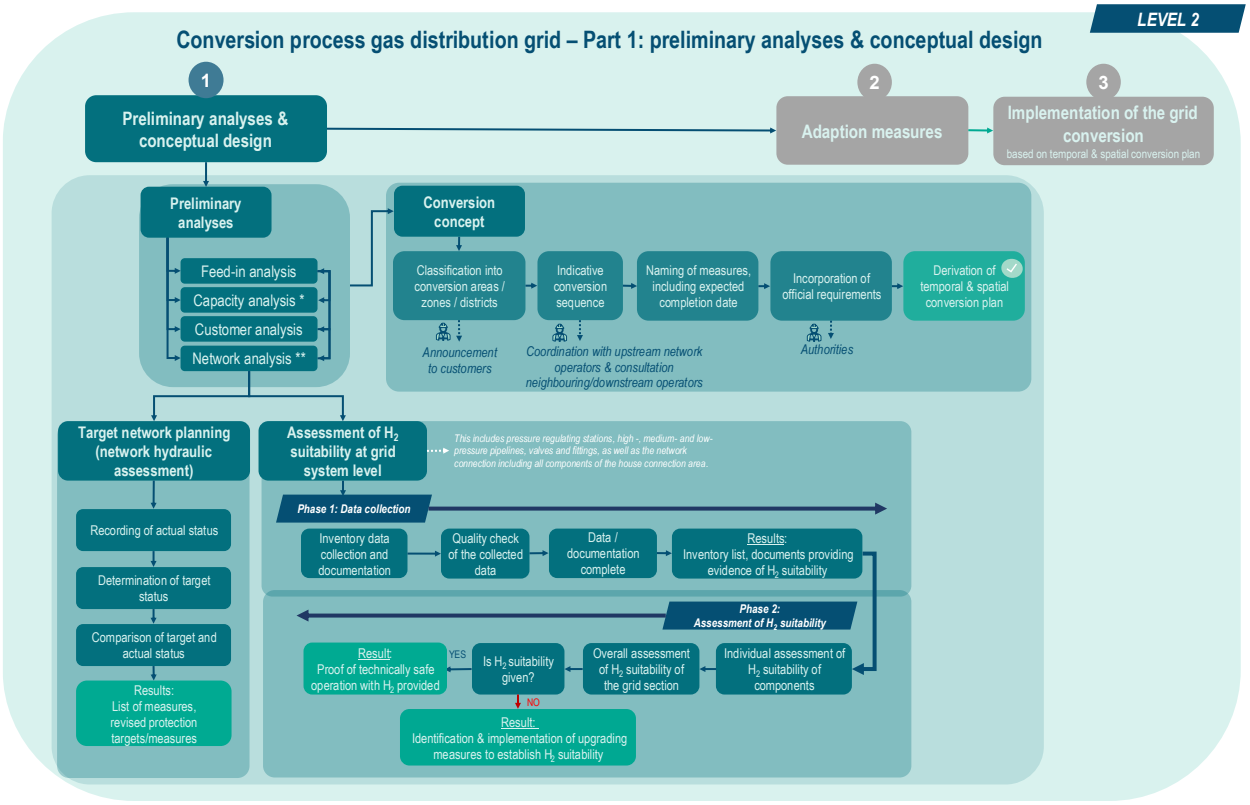


Figure 5: Gas distribution network conversion process – Part 1: Preparatory analyses & conversion concept [Source: DBI GUT]

2.3.1.2 Adaptation measures

The necessary adaptation measures are based on the preparatory analyses. These relate to both the network and customer installations. Figure 6 shows the "Conversion process for gas distribution networks – Part 2: Adaptation measures" and organises the activities in terms of process and time.

The following **specific upgrading and conversion measures** are to be carried out in the gas distribution network:

- replacement of non-hydrogen-compatible components
- construction of new pipelines (such as for hydrogen natural gas supply)
- preparation of sites for replacement gas supply
- construction or adaptation of facilities (such as GDRM facilities)
- installation of gas shut-off elements
- operational measures for converting distribution networks
- decommissioning of non-hydrogen-compatible appliances (in some cases before the actual conversion date)

These measures are accompanied by **formal and organisational steps**, such as involving and informing residents, customers and local authorities, organising contract installation companies, drawing up and implementing a safety concept, training staff and the fire brigade (including drawing up emergency plans), advising customers and, if necessary, developing conversion strategies for end consumers.

Preparing **sites for the replacement gas supply** is a crucial step in the conversion from natural gas to hydrogen. These sites ensure a continuous energy supply during the network adaptation phases.

Important aspects of **site preparation**:

- Network analysis and site selection: A comprehensive analysis of the existing network structure is necessary to identify strategically favourable locations for the replacement gas supply. Factors such as proximity to consumption centres, logistical accessibility and safety requirements should be taken into account.
- Technical adjustments: The selected sites must be equipped with suitable technologies that enable operation with both natural gas and hydrogen. This includes the installation of compatible components and consideration of hydrogen-specific properties.
- Safety and approval procedures: It is essential to comply with all relevant safety standards and obtain the necessary approvals for the operation of the replacement gas supply facilities.

Careful planning and implementation of these steps will ensure a reliable replacement gas supply during the transformation of the gas network. [33]

Note on the replacement of components not suitable for hydrogen

The process described in Figure 6 has already been applied in practice in several projects. However, no network components were replaced in into account the Dutch projects listed, as this was not considered necessary from a technical point of view. **Therefore, Figure 6 notes that, depending on the country, this may affect less than 2% of components.**

In the Netherlands and Spain, it has also been clearly stated that grey cast iron and asbestos pipes are not intended for into account be used for hydrogen. This decision is not based on any specific adverse effect of hydrogen, but on the material properties of these pipes. Regardless of the medium transported, these materials can fail and break over time due brittleness. In addition, communication and social aspects also play a role: damage to such pipes would probably be attributed to hydrogen as an energy source in the public perception, even if the cause is material-related. Negative media coverage could thus affect the acceptance of hydrogen projects. Regardless of this, it is planned that all grey cast iron pipes in the Netherlands will be replaced by 2031 at the latest, so that this issue will no longer be relevant in the future.

In Germany, only around 3% of pipes have been constructed from materials such as ductile cast iron, grey cast iron or materials with unclear data. These must be checked separately during conversion and, if necessary, upgraded or replaced, as their suitability cannot be assumed across the board. According to the DVGW-supported *Gas Distribution Transformation Plan* (H2vorOrt initiative), more than 97% of the pipelines in German gas distribution networks are made of steel or plastic and are therefore technically suitable for hydrogen distribution, indicating that the vast majority of existing networks are already largely hydrogen-ready. Asbestos cement pipes do not play a role in the German gas network; the use of this material has been banned since the 1990s.

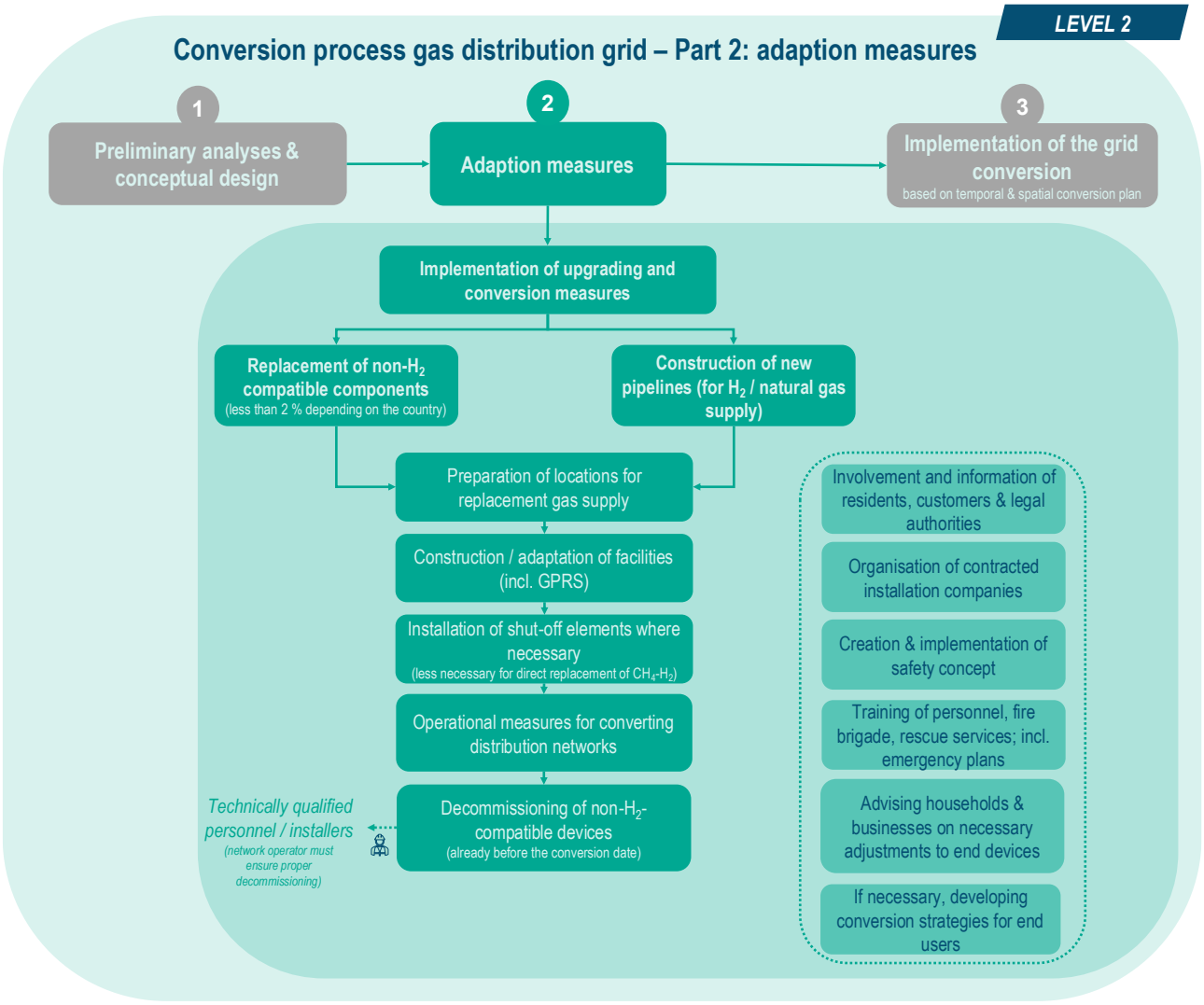


Figure 6: Gas distribution network conversion process to hydrogen – Part 2: Adaptation measures [Source: DBI GUT]

2.3.1.3 Permits and approvals

European roots

The *European Green Deal* sets the EU's overarching strategy to transform the economy toward climate neutrality by 2050. The *Fit for 55 package* translates this strategy into a coordinated set of legislative measures aimed at achieving at least a 55% net reduction in greenhouse-gas emissions by 2030 (compared with 1990). This includes measures targeting permits and approvals for the conversion of gas pipelines for hydrogen transport. Permits for physically converting an existing natural gas pipeline to hydrogen are granted under national planning/construction and safety laws. However, EU regulations and directives guide the permitting and approval process.

Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure (TEN-E) aims to facilitate the approval process for strategically important cross-border energy infrastructure, namely Projects of Common Interest / Mutual Interest (PCI/PMI). The TEN-E Regulation requires each Member State to organise the permit-granting process for PCIs/PMIs through a designated national competent authority (NCA) and a dedicated permitting scheme. This scheme serves to integrate and coordinate permits to be issued by concerned authorities (such as environmental authorities) to reach a so-called "comprehensive decision". This decision constitutes the final authorisation enabling the project promoter to proceed with the implementation, and construction of the project. To accelerate this process, TEN-E also introduces time limits for the authorities

concerned and may overrule outstanding permits if delayed.

Independent of PCI/PMI projects, the EU hydrogen and gas decarbonisation package, consisting of the *Gas & Hydrogen Market Directive (EU) 2024/1788* and *Regulation (EU) 2024/1789*, influences the permitting and approval. The package updates the rules on the EU natural gas market set out in the *Gas Directive 2009/73/EC* and *Gas Regulation 715/2009*. The revised gas market rules entered into force in August 2024. These rules aim to facilitate the uptake of renewable and low-carbon gases, including hydrogen, while ensuring EU-wide security of supply and energy affordability. The package also constitutes a new regulatory framework for dedicated hydrogen infrastructure and EU member states are required to transpose the new rules into national law by mid-2026.

Brief overview Austria

In Austria, hydrogen is already legally linked to existing gas legislation. The feed-in of hydrogen as a "renewable gas" into the existing gas infrastructure is covered by the *Gas Industry Act 2011 (GWG 2011)*. The GWG 2011 also defines "renewable gas" in such a way that renewable hydrogen is explicitly included. E-Control is the independent electricity and gas regulatory authority in Austria. [34] It has also recently been given responsibility for hydrogen.

Preparations for the implementation of the *EU Gas and Hydrogen Market Package* into national law have begun. [34]

In Austria, recourse to technical rules is central to practical implementation. The feed-in of hydrogen is possible in accordance with the ÖVGW technical rules. The rules specify the permissible admixture. At the same time, the ÖVGW is specifically expanding the technical regulations for hydrogen and states that existing natural gas regulations will be adapted for hydrogen and continuously expanded. An initial hydrogen guideline was published in 2023, and by the end of 2025, ten more dedicated hydrogen guidelines had been established in working groups. Further topics, such as hydrogen explosion protection, are currently being developed. [35]

Approval of certain planning activities for a pure hydrogen network within the framework of the planning instruments has been granted in the grid development plans, but no approval has been granted for implementation projects, including cost recognition on the merits. [34]

Brief overview Czech Republic

Discussions are currently underway in the Czech Republic on the implementation of the general framework of the *European gas package*. Specific details have not yet been discussed in depth. Exceptions to date include questions of overarching planning responsibility and possible financial flows or demarcations between the existing natural gas sector and hydrogen.

A special permit has been granted for a pilot blending project. However, no specific approval and licensing procedures are currently planned for future standard conversion projects to 100% hydrogen or for the injection of hydrogen into natural gas.

Brief overview France

The *European Gas Package* has not yet been fully transposed into national law. The *DGEC* (Energy Administration) conducted a stakeholder consultation on this in May 2025. Implementation is to take place via the *DDADUE* law currently under discussion. However, the current version does not provide for the "distribution of hydrogen".

Technically, hydrogen pipelines must currently comply with transmission regulation rules. At the same time, work is underway with the *DGPR* (safety/risk prevention) to adapt the requirements for polyethylene pipes up to 10 bar.

Brief overview Germany

In Germany, the *Energy Industry Act (EnWG)* significantly simplifies the permitting for conversion projects: existing official approvals for natural gas supply pipelines have generally also been considered to be approvals for the transport of hydrogen (in German "Zulassungsfiktion"). This means that a new planning approval/plan

approval procedure is not typically required for a pure media change solely because of the medium. In addition, this “Zulassungsfiktion” is also extended to certain approvals/notification reservations under other laws; at the same time, § 43l EnWG clarifies that the technical safety requirements and the conversion notification procedure remain unaffected. [36]

Irrespective of this, the conversion must be notified to the competent authority at least 8 weeks before it begins (§ 113c (3) EnWG). The notification must be accompanied by all safety-relevant documents and an expert opinion from a specialist confirming that the line meets the technical safety requirements (in particular § 49 (1) EnWG). The authority may object to the conversion within 8 weeks (the deadline is linked to the completeness of the documents). [36]

If structural/technical changes or extensions to the line/facilities are necessary for the conversion, the notification procedure for minor changes pursuant to § 43f EnWG also applies: insignificant changes can be approved via a notification procedure instead of a planning approval procedure; whether a change is "insignificant" depends, among other things, on whether there is no EIA requirement, no conflicting public interests are affected, the necessary individual decisions have been made and no third-party rights are impaired (or corresponding agreements exist). The competent authority under state law ultimately decides whether a formal procedure is necessary. [36]

In Germany, responsibility for notification and (where applicable) approval procedures for hydrogen conversions and pipeline projects lies in principle with the authorities responsible under state law. In addition, the Federal Network Agency (BNetzA) acts as the regulatory authority in the hydrogen sector, particularly when it comes to the inclusion of hydrogen networks in regulation and network access/tariff rules. The Energy Industry Act in Germany stipulates that operators can submit to regulation. The BNetzA publishes a list of regulated operators for this purpose. The BNetzA is the competent decision-making authority for assessing the need for hydrogen infrastructure in accordance with § 28p EnWG. With regard to the tariff regime, it is crucial that § 28o EnWG bases the rules on conditions and tariffs for access to hydrogen networks on § 21 EnWG, but at the same time expressly states that incentive regulation (§ 21a EnWG) and tariff approval (§ 23a EnWG) do not apply to operators of hydrogen networks. [37]

In Germany, the EnWG explicitly links the technical safety of gas and hydrogen installations to the generally accepted rules of technology. Compliance with these rules is assumed if the technical rules of the DVGW are applied to gas and hydrogen. This means, in practice, that the DVGW rules are the authoritative reference framework for demonstrating technical safety. The regulations for the use of up to 100% hydrogen are currently complete or nearly complete in many areas and are being continuously developed.

Brief overview United Kingdom

There is a strongly safety-oriented approach to hydrogen admixture in gas networks: higher H_2 proportions in the gas network have been/are being made possible by exemptions from the gas quality limits of the Gas Safety (Management) Regulations granted by the HSE (in the case of *HyDeploy*). At the same time, an economic regulatory framework for 100% H_2 pipelines is being developed. The Iron Mains Risk Reduction Programme means that much of the network has been replaced with new H_2-ready plastic pipes. [38]

Brief overview Netherlands

In the Netherlands, there is ongoing dialogue with the ministries that set the rules for regulatory authorities. The Dutch Authority for Consumers and Markets (Autoriteit & Markt, ACM) allows hydrogen pilot projects in the built environment, provided that the safety of the projects is guaranteed and the consumer protection regulations of the temporary framework for hydrogen pilot projects are complied with. On this basis, the ACM has already approved four selected projects. In doing so, it reviewed the quality of the projects and customer protection, while also calling for the development of a safety framework. The ACM has created a *"Tijdelijk kader voor waterstofpilots"* (temporary framework for hydrogen pilots) that allows pilot projects to be carried out subject to safety and consumer protection requirements. [39]

This safety framework was developed by the responsible ministry, which commissioned the State Mining Regulatory Authority (SodM) to conduct safety assessments of the projects. The SodM, which is also

responsible for safety supervision in the natural gas sector, required the conclusion of a contract with the distribution network operators, as there is currently no legal basis obliging them to follow the SodM instructions, as is the case in the natural gas sector. The existing framework for hydrogen pilot projects is to be partially incorporated into energy law.

In addition to the four pilot projects approved by ACM, other smaller projects have also been approved in the Netherlands, such as temporary conversions or demonstration projects. These include the temporary conversion in *Uithoorn*, the *Green Village* and a *demonstration house by KIWA*. The project in *Uithoorn* (Stedin) involved 14 unoccupied houses and was implemented as a joint initiative with the safety authorities (SodM, responsible safety region and local fire brigade) and the local government. The buildings were heated with hydrogen for a period of two weeks before being demolished. The *KIWA/Alliander demonstration house* is located on the KIWA premises, so only a regular building permit and a safety permit were required. As a hydrogen permit was already in place for large parts of the site, this project was approved within six weeks.

Experience from these projects shows that the 29 autonomous safety regions in the Netherlands have very different levels of knowledge about hydrogen, which has a direct impact on the duration and process of the approval procedures. The form of cooperation also plays a key role: if the safety regions are involved as partners in project development at an early stage, this has a positive effect on response speed and willingness to cooperate. While safety regions are not usually involved in approvals for natural gas projects, participation is more frequently required for hydrogen projects. This is comparable to the approval process for hydrogen filling stations, where approval is granted by the competent local authority on the basis of a statement from the fire brigade, which is part of the respective safety region. The safety regions have a national knowledge centre for safety issues. The industry, worked closely with these structures, particularly between 2018 and 2021, including through joint knowledge-building and training formats. In this context, the central knowledge centre was also specifically invited to training courses conducted jointly with KIWA UK.

So far, only a small part of the *European gas package* has been transposed into national law. However, the new *Dutch Energy Act*, which replaces the previous gas and electricity laws as of 1 January 2026, already contains provisions that allow for the later integration of hydrogen. These provisions will only take effect once the subordinate legislation has been adopted. The Ministry of Climate and Sustainable Growth plans to hold a second round of consultations on the implementing legislation with the relevant stakeholders in April 2026. The implementation of the European requirements is to be carried out in or with reference to the Energy Act and is scheduled to take effect on 1 July 2027. From this date onwards, it will be possible to designate regulated network operators for hydrogen.

At national level, the Dutch transmission system operator (TSO) has been awarded a service of general economic interest (SGEI) for the development of the national hydrogen backbone. However, there is currently no regulated task in the hydrogen sector for distribution system operators. The regulated part of a DSO is not allowed to distribute hydrogen. However, non-regulated sister companies of DSOs are allowed to build hydrogen networks on an economic basis. In principle, the expansion of hydrogen networks is currently a commercial activity open to all companies, with the exception of regulated DSOs.

Existing electricity and gas DSOs are therefore not automatically hydrogen network operators. Any company can apply to become a network operator for a specifically defined hydrogen network without regional exclusivity. This allows new market participants to operate even in areas where a hydrogen DSO is already active, which entails the risk of cherry picking and represents an additional economic risk for the network operator who invests first.

In addition, there are national guidelines for the safe handling of hydrogen, which provide guidance for project implementation in areas where no binding legal regulations yet exist. At the same time, several Dutch NEN standards are gradually being converted to hydrogen. This adaptation process is not yet complete. [40]

Brief overview Spain

In recent years, Spain has gradually fleshed out its regulatory framework for hydrogen. Of particular relevance is the fact that, with *Real Decreto-ley 8/2023*, the state has created a provisional governance structure for the development of a national hydrogen backbone infrastructure. At the same time, the legal framework for

production, feed-in/blending and direct supply models is being further developed; the complete design in line with the EU approach is still under construction. The methodology to inject hydrogen in the natural gas network has been recently issued by means of a particular regulation *"Circular de acceso y conexion 2/2025 de 9 de abril de la Comision Nacional de los Mercados y la Competencia"*. Based on that, the national natural gas network has been mapped in areas with hydrogen injection capacity predefined for each area accordance to the current blending hydrogen threshold set out by law (2%-5%).

At the same time, a new technical gas framework where hydrogen is directly covered, is currently undergoing the administrative approval process. For transport and distribution networks for hydrogen, this framework is to be based primarily on European standards (including *EN 1594, EN 12186, EN 12583 and EN 17928*) and also take into account international references such as *ASME B31.12*.

Brief overview Slovakia

The legal framework is under development and closely linked to EU requirements. The Slovak Ministry of Economy reports that a draft amendment to the Energy Act has been approved by the government and will incorporate *"new legislation on the hydrogen economy"* in line with EU directives. [41]

The Regulatory Authority for Network Industries (ÚRSO) is the central player in the legal framework for the energy sector. In Slovakia, legislative steps are being taken to integrate hydrogen economy/ hydrogen market rules into the national legal framework (in line with EU requirements), while the specific, fully differentiated framework for networks/regulation is currently still being developed. Discussions with the regulatory authorities in the field of the hydrogen value chain are very limited.

DSOs are required to obtain approval from the regulatory authority for the distribution of hydrogen or hydrogen mixtures within the national legal framework. This approval is closely linked to the regulatory policy for the hydrogen ecosystem in the respective country or Member State. In addition, both the conversion of existing infrastructure and the construction of new facilities require approval by the competent national authority for certification and safe operation.

The major TSO, DSO and SSO cooperate closely in the development of pilot projects. The SSO and TSO actively participate in IPCEI, PCI and CEF projects related to the development of the Slovak Hydrogen Backbone, which forms part of the future European Hydrogen Backbone, including the storage of hydrogen-natural gas blends in underground porous gas storage facilities. The DSO has already technically certified its entire network for the distribution of 10% hydrogen blends in networks below 4 bar and 5% for PRMSs and high-pressure networks (25/40/63 bar). In 2022, the DSO successfully demonstrated the distribution of a 10% hydrogen blend in an area with 300 customers over a period of four months.

Brief overview Switzerland

The CH42-initiativ is an association of Swiss gas network operators (TSO and DSO). The initiative seeks to jointly advance the transformation of the existing gas infrastructure towards a future-proof target network for renewable gases. In this context, CH42 is developing a shared vision for the future structure and availability of gas networks for biomethane, synthetic gases and hydrogen. Its activities focus on creating the technical, regulatory and organisational framework necessary for this transition, while at the same time supporting security of supply, economic resilience and affordable energy. Furthermore, the participants in CH42 serve as a platform for coordination and exchange with authorities, regulatory bodies and other stakeholders.

The planning, construction, and operation of pipelines for hydrogen and other renewable gases are governed by Swiss legislation (RLG, RLV, RLVS) as well as the relevant cantonal legislations. However, there is currently no specific statutory regulatory framework for the use of the existing gas infrastructure. At the same time, a specific regulatory framework for hydrogen and gas is currently being prepared, which, as things stand at present, is expected to largely correspond to the approach taken by the European Union.

When hydrogen is blended into natural gas, a safety assessment by the network operator is required for blending rates above 2 mol%. This assessment covers, among other things, requirements for monitoring and measurement, odorization, commissioning tests, emergency procedures, and a documented risk and integrity assessment of the gas infrastructure and its end uses. The assessment is then submitted to the relevant

authorities for approval.

In practice, the competent authorities and inspectors expect comprehensively documented proof of safety and integrity, as well as compliance with recognised Swiss technical rules. The regulations of the Swiss Gas and Water Industry Association (SVGW) are particularly important in this context. The *SVGW guideline on hydrogen pipelines* (2025 edition) [42] serves as the central technical basis and is expressly used by the *CH42* group as a reference for the planning, approval and implementation of hydrogen projects.

Conclusion

Individual European countries are at very different stages of development; while some countries already have specific legal and regulatory structures for hydrogen networks, others are still working with transitional or pilot regulations. However, it is clear that almost all countries are gradually integrating hydrogen into existing gas and energy legal frameworks, relying heavily on pilot projects, safety certifications and technical regulations as a bridge. Finally, the examples provided above underscore that early coordination with the authorities, clear responsibilities and technically flexible solutions are crucial to implement changeovers in a practical, safe and economical manner.

2.3.1.4 Implementation of the changeover in the network ("changeover day")

Once the adaptation measures have been fully completed, the final phase of the changeover begins: the actual implementation of the changeover or "changeover day". The necessary steps are listed in Figure 7 "Changeover process for gas distribution networks – Part 3: Implementation".

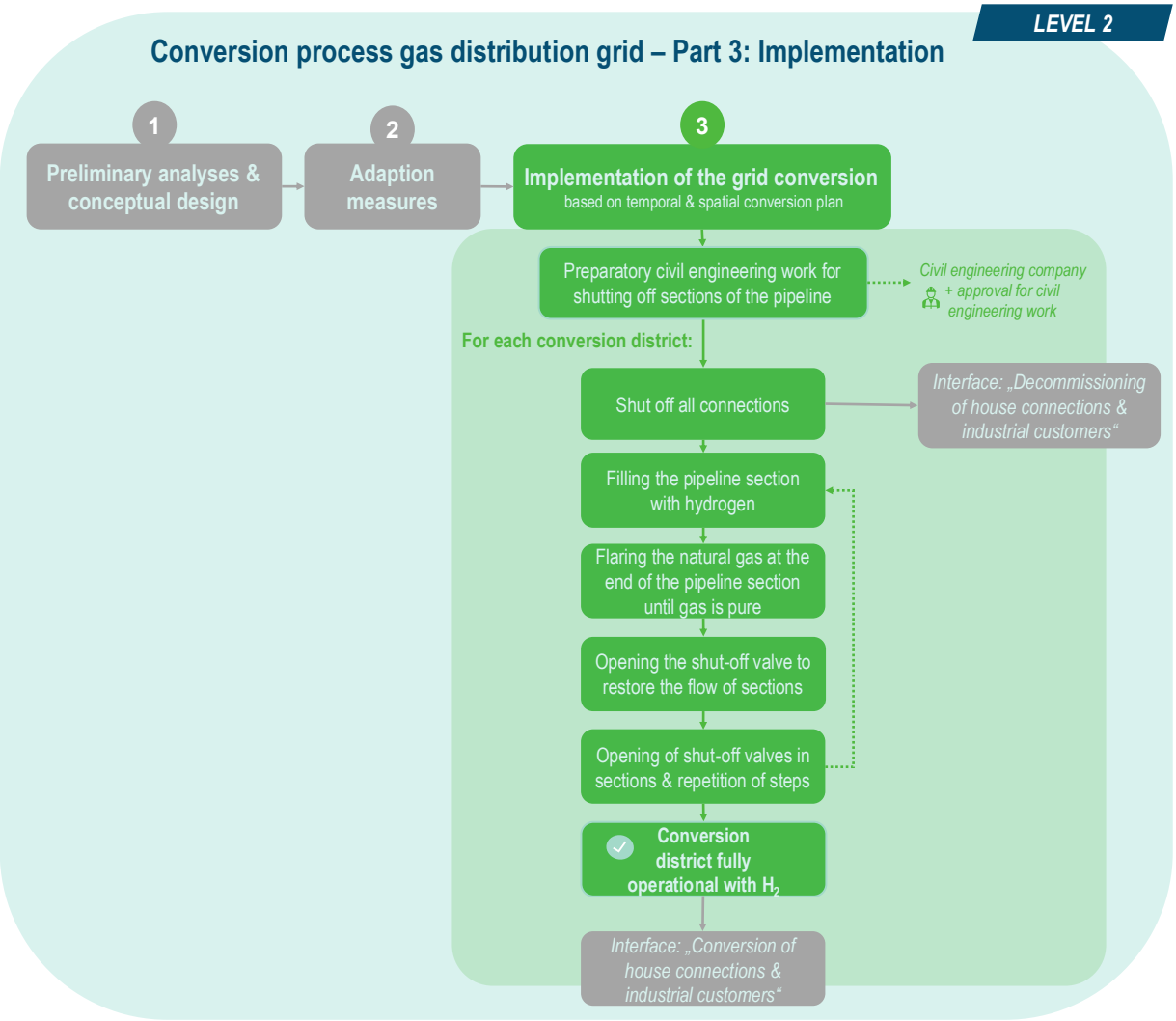


Figure 7: Conversion process for gas distribution networks to hydrogen– Part 3: Implementation [Source: DBI GUT]

Implementation of the network conversion is based on the temporal and spatial conversion plan created in phase 1. At the beginning, preparatory civil engineering measures are necessary to erect new or temporary barriers. This requires appropriate construction companies and permits. Subsequently, the following further steps are carried out individually for each conversion district:

- barricade all branches
- fill the pipeline section with hydrogen
- flare the natural gas at the end of the section until the flame changes and/or the gas purity of the hydrogen is measured
- open the barrier to restore the network

Flaring is necessary because it is not a controlled process and there is a risk of operating the gas boilers etc. with off-spec gas (this was tested in the *German DVGW project "H2Umstell"*). [43]

After these steps, the conversion district is fully converted. The house connections to already converted pipeline sections could also be converted while subsequent pipeline sections are still being converted.

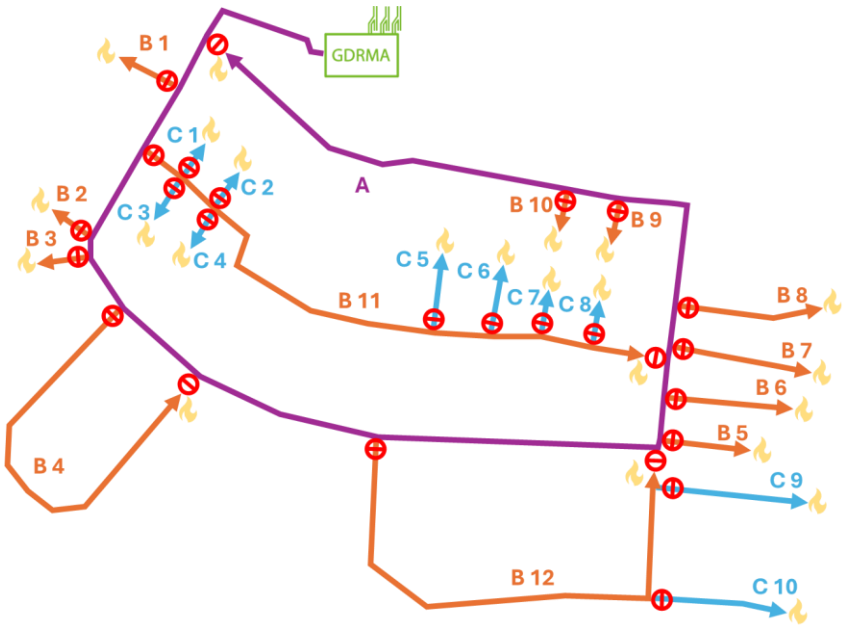


Figure 8: Formation of pipeline sections in conversion districts [Source: DBI GUT]

Closed shut-off valve

Gas flare

Figure 8 shows in detail how the conversion of meshed natural gas network sections (conversion districts) to hydrogen takes place. The common practice of network operators is to commission the new network areas section by section. The following steps are to be carried out, based on Figure 8:

1. Determination of unbranched pipeline sections
   A
   B 1 – B 12
   C 1 – C 10
2. Shut off all branches from pipeline section **A** to **B 1 – B 10**
3. Flush line section **A** with hydrogen (in the case of indirect flushing with nitrogen) and flare the natural gas at the end of line section **A** until the flame changes and/or methane-free is measured
4. Shut off all branches from pipe sections **B 1 – B 10** to **C 1 – C 10**
5. (Sequentially) Open the shut-offs from pipeline section **A** to **B 1 – B 10** to flush pipeline sections **B 1 – B 10** with hydrogen (in the case of indirect flushing with nitrogen) and flare the natural gas at the end of pipeline sections **B 1 – B 10** until a change in the flame occurs and/or methane-free status is measured
6. (Sequentially) Open the shut-off valves from pipeline sections **B 1 – B 10** to **C 1 – C 10** to flush pipeline sections **C 1 – C 10** with hydrogen (in the case of indirect flushing with nitrogen) and flaring of the natural gas at the end of pipeline sections **C 1 – C 10** until a change in the flame occurs and/or the absence of methane is measured
7. District completely converted
   In the case of indirect flushing, start again at 1. to flush the pipes filled with nitrogen with hydrogen

As a rule, there are not enough shut-off valves to shut off each pipe section individually. Retrofitting with appropriate civil engineering work would be necessary.

There are (theoretically) two different procedures for exchanging different fuel gases. In Germany, only the

indirect flushing procedure is currently permitted, as the German Technical and Scientific Association for Hydrogen and New Energies regulations only describe the processes of commissioning and decommissioning. In order to commission a pipe with hydrogen, it must therefore first be decommissioned with natural gas. Decommissioning is described as flushing the pipeline with an inert gas such as nitrogen. Due to the lower explosion limit, it is essential to flush with nitrogen when converting to hydrogen. The disadvantages of indirect flushing are the double effort, as the pipelines always have to be flushed twice, and the additional costs for the provision of nitrogen.

Safety-related technical constraints:

Flow/flushing speeds: Annex A of *EN 12327* lists minimum flushing speeds for the replacement of air/inert gas with natural gas or vice versa (note that this standard is under revision, by the *CEN/TC/WG16*, to include hydrogen.). These are between 0.6 and 1.7 m/s for pipe diameters of 150 to 1,200 mm, and a maximum of 20 m/s should not be exceeded. Practical values in the range of approx. 3–7 m/s are common. In addition, attention is drawn to the need to take into account the risks of mixing/stratification and to verify this by measurements at the end of the pipeline if necessary.

Blowing out/flaring: It should be noted that *EU Regulation 2024/1787 on the reduction of methane emissions in the energy sector* contains restrictions on blowing out and flaring. For the removal of displaced gas, it must be determined at an early stage whether and under what conditions flaring is possible or whether safe venting is preferable; it should also be noted that restrictions and exceptions (commissioning, maintenance, decommissioning, incidents) must be taken into account. According to the wording of Article 15 of the EU Regulation, flaring would only be permitted for the conversion process involving the decommissioning and commissioning of pipeline sections, as the direct replacement of natural gas with hydrogen – i.e. the concept of "conversion" – does not constitute any of the aforementioned exceptions of operational disruption, repair, maintenance, decommissioning or commissioning, for which flaring is permitted. If necessary, the EU Regulation should be amended to include the exception of "conversion". There are currently no comparable regulations or restrictions for hydrogen emissions.

Conversion of gas pressure regulating systems: The number and location of gas pressure regulating systems has a significant influence on the design of the conversion districts and on the sequence of conversion of the districts and high-pressure pipeline sections. The conversion of gas pressure regulating stations to hydrogen should be prepared during the conversion of the inlet (high-pressure) pipeline and must be completed before the conversion of the outlet conversion area begins.

2.3.1.5 Available programmes and system tools for installing

Database & inventory

A consistent and reliable database is of central importance for the conversion of gas networks to hydrogen. The basis for this is a structured inventory table for each conversion section, which is fed from digital equipment information systems (namely BIS, GIS and meter management) as well as from construction files and pipe books. In many cases, this requires the prior digitisation of analogue inventory documents.

The inventory should contain at least information on the number, year of construction, material, dimensioning parameters (such as DN/PN), operating pressure and (if available) manufacturer and product information. In addition, GIS object IDs and location parameters are helpful in ensuring clear assignment to network districts and conversion zones.

Network modelling and hydraulic simulation

Based on this data, a computable network model can be constructed, for example in network calculation programmes such as *STANET*® (Germany) or *ROKA 3* (Switzerland). Such models make it possible to carry out network hydraulic simulations as part of the conversion planning and to ensure that the conversion can take place without serious supply failures. Individual conversion districts can be considered separately from the rest of the network in order to check whether the remaining lines and control systems are capable of coping

with the changed load flows and capacity requirements (see "Capacity Analysis" in Chapter 2.3.1.1).

Measurement evaluation and the development of a software tool (*SIMONE*) for calorific value calculations

This measurement systems for determining the energy value of energy gases and mixtures provide calorific value calculations based on a combination of measured and operational data across distribution and transmission networks. The system enables the determination of energy content even at locations without direct chromatographic or other designated measurements, which is essential when introducing alternative gases such as hydrogen or hydrogen-natural gas blends. The reconstruction of the calorific value relies on the physical behaviour of gas flows, gas quality parameters, and relevant operational data, ensuring accurate evaluation under changing gas compositions. The resulting energy conversion supports billing, analytics, and operational decision-making while meeting established metrological uncertainty requirements. Overall, these systems form a key component for achieving precise and transparent energy characterisation in modern networks undergoing transformation toward low-carbon and H_2-ready infrastructures.

In addition, Synergi Gas (DNV) tools can be applied for network modelling and detailed hydraulic simulation of gas infrastructure systems.

Application of *Irene Pro* as software tool for network analysis and gas quality measurement

Irene Pro is a comprehensive and user-friendly analysis and calculation package for gas networks. Developed by Kiwa, this tool is an important resource for many network operators in the construction, management, and maintenance of gas networks. The system supports the simulation and assessment of gas flows, gas composition, and calorific value development within distribution networks under varying operational conditions. It enables the evaluation of blending scenarios, including the integration of hydrogen and other alternative gases, by modelling their impact on network performance, gas quality parameters, and customer supply. By combining network topology data, operational inputs, and gas property calculations, *Irene Pro* facilitates transparent and traceable analyses that support planning, operational decision-making, and regulatory compliance. [44][46]

Digital evaluation and decision-making tools

In addition to these analytical tools, the German *verifHy* database is an example for a central digital instrument for assessing the hydrogen compatibility of existing gas infrastructures. *verifHy* has also been available in English since its launch. The only exceptions are the product profiles, as the respective manufacturers are responsible for content. The component and material profiles have been translated into English accordingly.

verifHy serves as a central platform for collecting, processing and providing validated information on the hydrogen compatibility of materials, components, products and system aspects. The database is based on the H_2-Compendium and integrates content from research, manufacturer specifications and standardisation activities, supplemented by continuous quality testing, versioning and knowledge expansion.

Standardised interfaces allow network inventory data to be integrated and systematically compared with the stored compatibility information. The underlying quality gate and clearing house concept ensures the plausibility of new information and enables the structured integration of manufacturers and research institutions. The *verifHy* tool thus functions not only as a technical assessment tool, but also as a documentation and communication tool that contributes to the harmonisation of assessment approaches and the safeguarding of strategic conversion decisions.

2.3.2 Industrial pipelines and plant networks

Hydrogen and natural gas have comparable lower explosion limits (LEL). However, there is a significant difference in the upper explosion limit (UEL): the upper ignition limit of hydrogen is about five times higher than that of natural gas. This effect is particularly relevant in the case of smaller leaks, such as localised leaks due to corrosion or material fatigue, as high concentrations of combustible gas can be reached locally.

Safety measures such as leak detection or gas warning devices can generally be retained, provided they are suitable for the respective gas type. Since the trigger and setting values of such devices are based on the LEL, there is usually no need for adjustment. Irrespective of this, the accumulation of hydrogen in enclosed spaces must be consistently prevented by means of suitable technical and structural measures. These include, in particular, measures such as ventilation concepts and odorisation. Since the lower flammability limit is primarily decisive for the formation of a flammable mixture, there are no fundamental differences in this respect compared to natural gas.

In reference projects carried out by DBI GUT in industrial plants to date, the focus of the investigations has been on the complete evaluation of the installed components, in particular the tightness and condition assessment of the piping systems. Before converting to hydrogen, at least the following checks should be carried out to ensure the proper operation of the plant network:

- review and comparison of test plan and test requirements
- visual inspection of the pipeline system
- leak test of all pipeline sections
- assessment of the structural condition
- analysis of the history of defects and malfunctions
- evaluation of installed components
- obtaining manufacturer declarations on hydrogen compatibility or evaluation by experts
- repair and/or replacement of unsuitable or defective components/pipes
- adjustment of test plans, test times, and evaluation and classification schemes
- complete documentation of results

2.3.3 Domestic gas installations

Hydrogen-based heating systems are considered a promising option for decarbonising heat supply in the private and commercial sectors. They can be used in gas appliances specially designed for hydrogen, known as H_2-ready gas condensing boilers or fuel cell heating systems.

Preparatory analyses & organisational measures

At the start of the conversion, connected end consumers are classified and structured contact is established with the customers affected. This includes:

- information letters about the planned conversion
- information events to explain the technical and organisational implications
- setting up hotlines and information telephone lines

At the same time, random checks of house connections and cable systems in buildings will be carried out. This involves:

- survey and documentation of all installed components
- assessment of the installation for hydrogen compatibility
- identification of unsuitable components, namely:
    - regulators without a manufacturer declaration
    - bellows gas meters *(note that with a multi fuel boiler and fluctuating gas mix an “energy” meter*

will be needed.)

- gas flow monitors
- gas appliances

- carrying out serviceability or leak tests, alternatively shock odorisation
- issuing of a defect card if the test is not passed

In addition, training courses are held for network operators, installation companies and rescue services, and a general safety and billing concept is developed.

Table 3: Suitability of components in gas installations [43]

Component	Suitability & function	Note	Source
Bellows gas meter	Confirmed	Verification of dimensions and replacement if necessary	DVGW R&D project G 202010
Components of existing gas installation piping systems	Confirmed	Testing of serviceability/tightness	DVGW research projects G 201824-D3.5, G 202006 (SyWeSt), G 202333 (BAG464), G 202010 (H_2 -Mess), G 202021 (R&D for H_2), G 202138 (EclHypse)
Pressure regulators	Confirmed	Manufacturer declaration or type examination certificate required for mixtures	R&D project G 202010 (H_2 measurement)
Gas flow monitor	confirmed	Retrofitting sometimes necessary and check of dimensions recommended	
Heating appliances	Technically feasible for 100% H_2	First products with market approval Retrofit kits for modern existing appliances (depending on manufacturer) available from 2026	

Adaptation measures and preparation for feed-in

Once the preliminary tests have been completed, technical adaptation measures will follow, in particular the replacement of gas meters and gas appliances. The availability of conversion kits that can be used on the day of hydrogen supply will be checked. In addition, the following activities will be carried out:

- replacement of unsuitable components
- training technical personnel
- carrying out necessary civil engineering work
- coordination with all parties involved (including installers, chimney sweeps, customers)
- checking the usability or tightness of the pipe system

Conversion process

The actual conversion is carried out in the same way as for industrial gas applications. Firstly, the systems are shut off and the pipes depressurised. To do this, the gas pressure in the system is maintained by continuing to operate the connected devices until the main shut-off device closes automatically. This brings the combustion process to a controlled end and completely depressurises the pipe system.

On the day of hydrogen conversion, all designated components are converted or replaced. The pipeline system is then flushed/gas-filled to the gas appliance or industrial gas application. Displaced gas is flared in a controlled manner until a hydrogen content of at least 80% is reached. Once flushing is complete, gas appliances are connected, put into operation and trouble-free operation is documented. Once recommissioning has been successfully completed, the conversion is considered complete.

The process described is applicable to private households and commercial enterprises and, with restrictions, also applies to larger industrial plants such as steam boilers and industrial furnaces. Gas turbines are not covered by this process.

Figure 9 provides a detailed overview of the process for converting domestic and commercial gas installations to hydrogen. The process is structured horizontally from left to right and includes all the steps described above. Finally, the diagram shows the interface for the conversion, replacement or commissioning of gas appliances in accordance with manufacturer specifications, as well as quality assurance, which includes a complete check of the tightness of all gas connections.

Current discussions and normative developments

In Germany, both the ignition test in stationary operation and nitrogen purging are currently the subject of intense debate. Several research and demonstration projects have shown that nitrogen purging is not absolutely necessary. [45] Against this background, work is underway on a normative regulation that will make the previous nitrogen purging unnecessary in the future. Direct flushing with hydrogen offers potential for reducing costs, labour and conversion time.

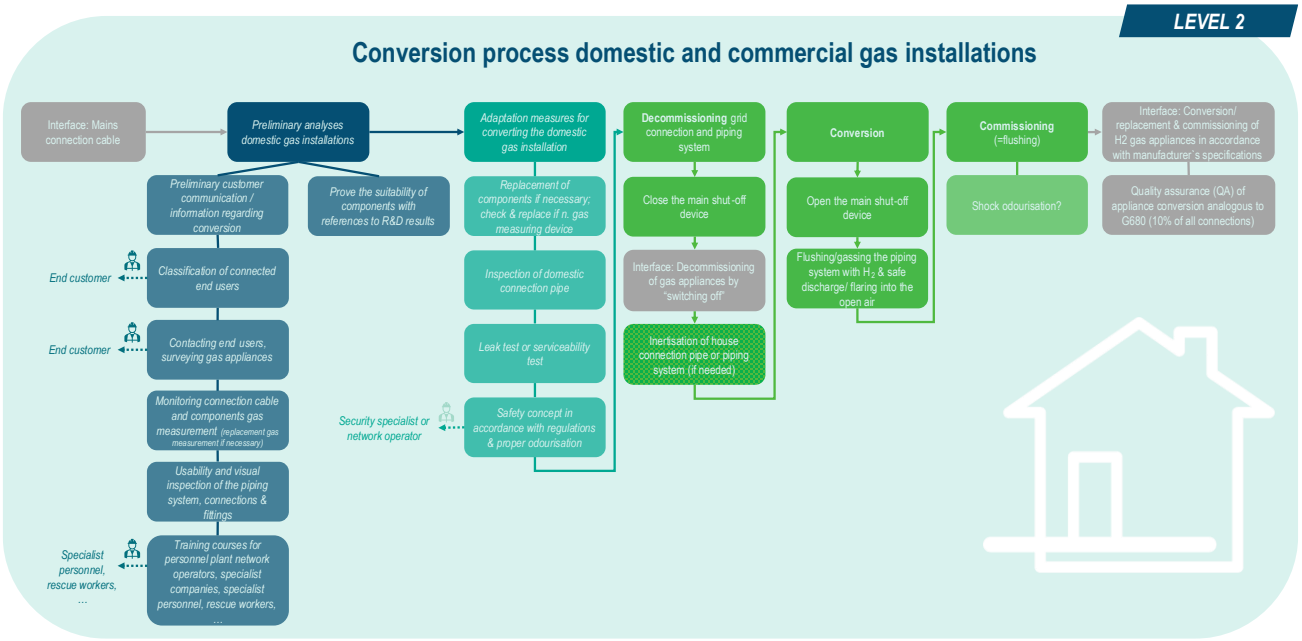


Figure 9: Conversion process for domestic gas installations and industrial pipelines [Source: DBI GUT]

2.3.4 Gas applications

Conversion of industrial gas applications

Conversion of industrial gas applications is fundamentally the responsibility of the operator and requires close coordination with manufacturers, particularly in the field of burner technology.

Recording and suitability testing

Industrial gas applications must be recorded separately as part of the preliminary analysis and evaluated for their suitability for hydrogen. *EN 16726* is currently being updated and increasingly takes into account hydrogen contents of up to 20 vol.%. This standard harmonises the gas quality requirements for Group H natural gas throughout Europe.

Conversion and renewal

The assessment and conversion are carried out by qualified personnel in accordance with *EN ISO 13577-2*. Essential requirements relate in particular to the safe removal of fuel residues and reduced safety times during hydrogen operation. The basis for assessment is always that the LEL is not exceeded.

Figure 10 shows a schematic process overview for converting industrial gas applications to hydrogen. The process is shown from left to right and begins with an inventory of all industrial gas applications and, if relevant, domestic gas applications. This is followed by a preliminary analysis and the development of a conversion concept for plant networks and pipelines (similar to gas distribution networks), including tests to determine the hydrogen suitability of existing systems.

Based on the successful commissioning of the gas distribution network (interface; see chapter 2.3.1), gas applications are adapted or replaced as necessary. Manufacturer declarations must be taken into account for this purpose.

Another interface is the conversion and filling of existing installations and piping systems for operation with 100% hydrogen (see chapter 2.3.2). The right-hand side of Figure 10 shows the actual commissioning of hydrogen gas applications, noting that manufacturer specifications and regulatory approvals may be required. This is followed by the process steps of flushing the systems, ignition testing and stationary operation, which is documented and verified by exhaust gas measurements.

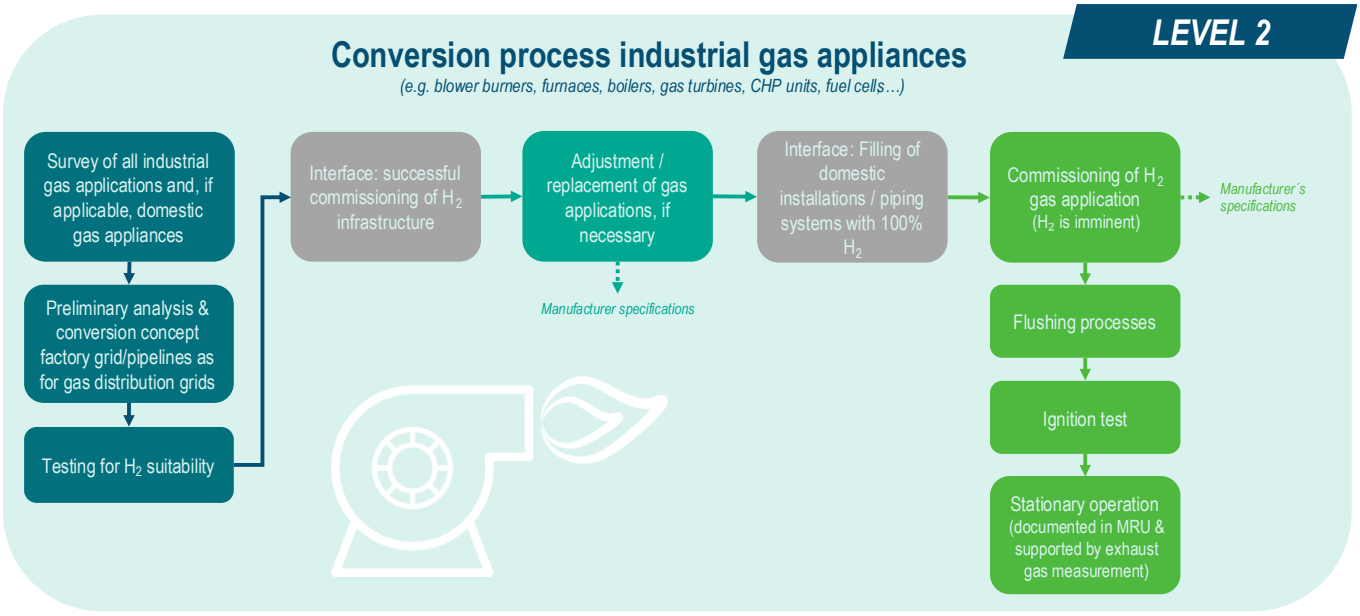


Figure 10: Conversion process for industrial gas applications to hydrogen [Source: DBI GUT]

Domestic gas consumption systems

Overview of available appliances

The term *H_2-ready* is used inconsistently in the market and therefore requires clarification. In some contexts, H_2-ready refers to appliances that can operate with natural gas containing up to 20 vol.% hydrogen without modification. In other cases, it describes appliances that are designed to operate with 100% hydrogen after relatively minor technical adjustments (namely burner or control system modifications). For the purposes of this report, the term will be used with explicit reference to the respective hydrogen concentration. *The Ready4H2 project defines a H_2-ready network as one that is able to transport hydrogen without operational constraints, including technical, commercial and safety considerations.*

DVGW-certified H_2-ready gas appliances can currently use natural gas-hydrogen mixtures with a hydrogen content of up to 20 vol.%. Such systems are particularly attractive because they use the existing gas network and can be operated without major infrastructure changes. Various manufacturers already offer appliances that meet these requirements and support hydrogen blending, which offers the long-term possibility of reducing CO_2 emissions.

For the largest group of household users, further blending of up to 20 vol.% hydrogen with natural gas is possible, provided that appliance types have been explicitly declared suitable for this hydrogen content by the manufacturer. The German Federal Association of the Heating Industry (BDH) has stated that all appliances manufactured after 1996 are suitable for use with natural gas containing up to 10 vol.% hydrogen. Older appliances are deemed unsuitable[4].

Currently available heating appliances can operate with natural gas–hydrogen mixtures containing up to 20 vol.% hydrogen. Many of these appliances have been designed to be convertible to 100% hydrogen in the future. However, as the hydrogen infrastructure is still under development, full operation with pure hydrogen is expected only in the medium term. Nevertheless, these systems already offer a viable and increasingly sustainable solution for low-emission heat supply, particularly as hydrogen becomes more widely available.

The highest cost factor in the transition is the replacement of existing gas appliances that are not suitable for hydrogen blending. At a hydrogen content of 20 vol.%, adjustments to the current Wobbe index limits for G-gas are required. Some studies indicate that many appliances are technically capable of handling hydrogen concentrations higher than 3 vol.%. A comprehensive assessment of the technical and legal implications, as well as associated risks of hydrogen blending for existing appliances, is essential to inform appropriate policy and regulatory decisions. [46]

Replacement vs. conversion

Appliances that are suitable for use with natural gas and natural gas-hydrogen mixtures (up to 20 vol.%) and can also be used for hydrogen after conversion offer the advantage that conversion can be implemented much quicker (for example through the use of new burners and replacement of the burner control system if necessary). Based on state-of-the-art practice, this appliance conversion can be carried out in around 30 minutes. Replacing a gas appliance takes between one and three days, depending on the installed and new appliances.

Development of multi-fuel boilers

Multi-fuel systems are currently being developed that have been designed to operate with 100% natural gas, 100% hydrogen and all mixture ratios in between. This applies equally to network infrastructure, measurement and metering technology and end-use appliances. This facilitates both the gradual transition from natural gas to hydrogen and the security of supply, for example by using methane (natural gas or biomethane) as a reserve in the event of insufficient hydrogen availability. The aim is to ensure technical and operational flexibility throughout the entire conversion process. At the same time, the development of multi-fuel and energy meters is necessary; corresponding solutions are being developed in laboratory setups.

[4] Politikbrief „CO2-Senkung im Wärmemarkt mit Wasserstoff “, Bundesverband der deutschen Heizungsindustrie, 12/2019

Advantage 1: Efficient conversion of existing networks

In a conventional conversion of an existing natural gas network to hydrogen, conventional natural gas boilers cannot continue to be used; they must be replaced by pure hydrogen appliances. Since both natural gas and hydrogen boilers can only be operated with one type of gas, conversion is inevitably linked to the speed at which the network itself is converted. Gradual conversion of each individual house is costly and time-consuming. In addition, complex transitional network solutions are required, as individual streets must be operated with different gases at times. During the transition phase, both gases must be supplied and coordinated in parallel, which further slows down the conversion process.

Multi-fuel appliances avoid these limitations. Boilers and meters can initially continue to be operated in a natural gas network. Once all households and small commercial customers in a defined network section are equipped with multi-fuel appliances, the entire network – or part of it – can be converted to hydrogen in a single step. It is not necessary to completely remove natural gas from the network in advance: gas mixtures that arise during the transition can be processed by multi-fuel appliances. This enables a significantly faster, simpler and more cost-efficient conversion.

Advantage 2: Balancing and security of supply in new and existing networks

If all connections in an area are equipped with multi-fuel devices, both physical balancing and security of supply are greatly simplified. Grid operators must ensure supply even under extreme weather conditions (for example, down to −17 °C at the transmission grid level and down to −12 °C and 5 m/s wind speed at the distribution grid level). In a purely hydrogen-based network with only hydrogen-compatible equipment, this would require the use of heavily oversized electrolysers or very large storage facilities – even though such extreme conditions only occur statistically every 10 to 15 years. This leads to high investments for rare peaks in demand.

Multi-fuel systems offer an alternative solution here. In principle, networks can be operated with hydrogen during normal operation. In periods of exceptionally low temperatures or unexpectedly high demand, natural gas networks can be temporarily switched on so that the network is supplied with a mixture of natural gas and hydrogen on a few cold days, for example. In this way, security of supply and heat provision can be guaranteed with comparatively little additional effort. At the same time, the natural gas network serves as a buffer, for example in the event of electrolyser failures or short-term load peaks, thereby significantly increasing the robustness of the overall system.

2.3.5 Field logistics for section-by-section conversion of natural gas networks to hydrogen

In the context of this conversion, the term “field logistics” encompasses operational planning, coordination and implementation of all logistical and organisational measures on site. This ensures that personnel, materials, equipment, information and timelines are precisely coordinated, guaranteeing a safe and efficient conversion.

The approach to section-by-section conversion should be embedded in an overarching **conversion concept and structured work programme**, as described, for example, in the *HyDelta Model Conversion Plan* (D7.2). This concept provides a systematic framework for the phased transformation of natural gas distribution networks to hydrogen, including governance structures, technical preconditions, safety procedures, communication strategies and regulatory interfaces. [47]

In addition, the *HyDelta Inventory of Relevant Aspects for Conversion* (D7.1) highlights cross-cutting technical, legal, safety-related and organisational factors that must be considered during planning and execution. These include material compatibility, grid topology, pressure levels, customer installations, metering concepts, emergency response structures and permitting requirements. Field logistics therefore represent the practical implementation layer of this broader strategic and regulatory framework. [48]

The following aspects must be taken into account when planning field logistics for the conversion of gas

networks to hydrogen. It is advisable to record these in a work programme drawn up by the network operator.

Measures and steps involved in the conversion are as follows:

Identification of natural gas pipelines or network sections to be converted (conversion districts).

- prepare measures to enable conversion, for example installation of additional shut-off valves to section the network[5]
- carry out the conversion from natural gas to hydrogen

The following preparatory steps must be carried out:

- draw up a schedule and sequence plan for the conversion
- check shut-off valves required for the switchover
- define necessary safety measures for adjacent facilities (including hazardous areas)
- examine of the effects on supply security, including in adjacent network sections (replacement gas supply may be necessary)
- notify emergency services
- obtain approvals (if necessary)

Personnel planning:

- plan the required personnel and defining responsibilities
- create communication lists
- provide communication tools for personnel (mainly radios and telephones)
- occupational safety concept and provision of necessary equipment (personal protective equipment, hearing protection, fire extinguishers, gas concentration measuring devices, barrier material and weather protection, if necessary)

Equipment logistics (required operating resources):

- machines/equipment (including deployment planning, location, deployment time, safety zones, maintenance, redundancy and transport, as well as personnel requirements)
- use of mobile flares for safe flaring of natural gas or hydrogen during purging
- assessment of environmental influences (such as wind direction) and the surrounding situation (such as buildings, traffic routes and flight paths), as well as derivation of any necessary safety measures
- if necessary, make inert with nitrogen using mobile nitrogen tanks, including evaporators
- if necessary, use of a replacement gas supply

Construction logistics aspects:

- excavation pits: plan, secure, drain and provide access for personnel and equipment
- storage areas: set up temporary storage areas for pipes and materials, assess load-bearing capacity, install barriers
- sanitary facilities: mobile toilets, washing facilities and recreation containers

[5] Any construction work required for the conversion should be completed well in advance of the switch from natural gas to hydrogen.

- energy and water supply: mobile generators, lighting, water points
- waste and disposal logistics: collection points, disposal intervals and hazardous material handling
- arrival and departure logistics: access control, traffic safety and parking zones for emergency vehicles

Concepts for safety, environmental, quality and progress control and documentation requirements:

- compliance with emission and safety requirements
- documentation and monitoring of measurement and flaring processes
- quality controls, including performance of leak and pressure tests and material checks if necessary

Furthermore, the extent to which the surrounding area must be involved needs to be examined. All external parties affected or impacted by the processes must be informed in a timely manner, as required. For example:

- neighbours, if they will be affected by construction work or flaring (in particular noise)
- police, fire department and local authorities
- authorities, if required by the approval notice
- operators of upstream and downstream facilities
- road operators, if traffic flow has to be interrupted
- operators of affected third-party facilities located in hazardous areas (commonly railway facilities, power grids, transmission masts and wind turbines)

2.4 Building new

This section deals with the construction of new grid sections for hydrogen and highlights design and safety considerations for new hydrogen pipelines. New hydrogen grids may need to be built to augment the existing grid to supply new customers or to supply existing customers during periods when those existing customers cannot or do not wish to stop natural gas supply.

In several European countries, the development of dedicated new hydrogen infrastructure is currently prioritised over large-scale conversion of existing natural gas networks. In particular, countries such as Spain, the Netherlands and France foresee parallel hydrogen systems to complement existing gas grids, for example to supply industrial clusters or transport applications, while maintaining natural gas or biomethane infrastructure for residential use.

However, the increasing focus on new hydrogen infrastructure is not only driven by technical considerations. In many cases, it reflects market and customer preferences. End users, particularly in the residential and commercial sectors, are often reluctant to give up their existing natural gas connection. At the same time, industrial and mobility customers show a growing demand for hydrogen as an additional energy carrier rather than a full replacement of natural gas.

As a result, the development of parallel hydrogen networks is frequently preferred, enabling the supply of hydrogen to dedicated consumers while maintaining the existing natural gas or biomethane infrastructure. In contrast, the reuse of existing natural gas pipelines for hydrogen typically requires a (partial or collective) transition of connected customers, which is not always feasible or accepted in practice.

Numerous dedicated hydrogen new build projects are currently under development or implementation across Europe, particularly in industrial clusters and hydrogen valleys. A non-exhaustive overview of relevant projects is provided in *Appendix 4: Ready4H2 project database*.

New build infrastructure offers several technical and operational advantages compared to conversion of existing natural gas networks. Dedicated hydrogen pipelines can be designed for higher operating pressures where required, enabling the transport of larger hydrogen volumes to industrial consumers. In addition, new steel pipelines allow improved control of hydrogen quality, as they are free from historical odorant residues and legacy contamination.

Furthermore, new infrastructure can be designed to be inspected internally using pigs from the outset, facilitating inspection, cleaning and maintenance procedures that are often difficult or impossible in legacy distribution grids. These aspects may significantly improve long-term operational flexibility and gas quality management.

2.4.1 Design and safety considerations for new hydrogen pipelines

The design and construction of new hydrogen pipelines require specific technical and safety considerations that reflect the physical and chemical properties of hydrogen. When infrastructure is purpose-built for hydrogen, materials, dimensions and operational concepts can be optimised from the outset for the intended application, whether for industrial supply, mobility use or dedicated hydrogen clusters. [4]

Key technical and safety aspects for new hydrogen infrastructure include the following:

Behaviour in enclosed spaces

In the event of a leak in enclosed or partially enclosed spaces, hydrogen rises rapidly due to its low density and high diffusivity. Ventilation concepts, gas detection systems and the positioning of potential ignition sources must therefore be designed to account for upward gas migration and rapid dispersion. Detection systems should preferably be installed in elevated positions where accumulation is most likely.

Energy transport and dimensioning of pipelines

Hydrogen has a lower volumetric calorific value than methane. Where hydrogen is intended to deliver equivalent energy quantities, higher volumetric flow rates may be required. For newly built hydrogen pipelines, this is not a constraint inherited from legacy systems, but a design parameter that must be considered during planning. Pipe diameters, compressor capacity, pressure levels and metering systems should therefore be dimensioned specifically for the targeted hydrogen demand profile (e.g. industrial clusters, refuelling stations, or mixed-use applications).

Thermodynamic behaviour during pressure reduction

Hydrogen has a negative Joule-Thomson coefficient under typical distribution conditions. As a result, gas temperature increases during pressure reduction rather than decreases. In practice, this may eliminate the need for measures commonly applied in other gas systems, such as electrical preheating or heat tracing at pressure reduction stations. However, material selection and component design must consider potential temperature increases and their impact on seals, valves and measurement devices.

Ignition and flammability characteristics

Hydrogen has a wide flammability range in air and specific ignition characteristics that must be considered in safety concepts. However, ignition behaviour depends strongly on concentration. The minimum ignition energy is not a fixed value but varies as a function of hydrogen concentration in air. Experimental investigations have shown that ignition energy is lowest at concentrations around 29–30 vol.% hydrogen in air. At low concentrations (e.g. 1–10 vol.%), typical for many indoor leakage scenarios, ignition energy can be higher than that of natural gas. Furthermore, laminar flame propagation has been observed at certain concentrations without explosive behaviour.

Safety concepts for hydrogen systems should therefore be based on concentration-dependent risk assessment rather than generalised assumptions. Adequate ventilation, avoidance of confined accumulation zones, ignition source control and reliable detection systems remain essential. Hydrogen requires careful

handling, but its risks should be evaluated on the basis of validated experimental data and realistic leak scenarios.

Pigging and maintenance operations

If pipelines have been designed to be internally inspected using pigs, pigging procedures must take hydrogen-specific ignition and flammability characteristics into account. Inertisation procedures, gas monitoring and exclusion of ignition sources during pig launching and receiving operations are essential elements of operational safety concepts.

Leakage and dispersion behaviour

Due to its high diffusion coefficient, hydrogen disperses rapidly in open environments. This rapid dilution may reduce the duration of hazardous concentrations in outdoor leak scenarios. Nevertheless, the fast dispersion rate requires rapid detection and monitoring systems to identify and isolate leaks at an early stage. Overall safety assessments should therefore distinguish between confined and open environments.

Prevention of hydrogen-air mixtures within systems

During commissioning, maintenance or shutdown procedures, the formation of hydrogen-air mixtures inside pipelines and installations must be avoided. Purging procedures using inert gases or controlled hydrogen displacement methods must be clearly defined and documented. Particular attention should be paid to dead ends, low points and system geometries where stratification effects could occur.

2.4.2 Planning, approval and route development

The construction of new hydrogen pipelines must comply with applicable national legal frameworks and permitting procedures. Rather than inherent conflicts between technical feasibility and legal requirements, the key challenge lies in aligning technical design, spatial planning, environmental protection and stakeholder expectations within the approval process.

Early route planning supported by spatial resistance mapping, environmental impact assessments and structured stakeholder engagement is therefore recommended. Transparent communication with authorities, landowners and the public is essential to ensure acceptance and smooth approval procedures. Where required, technical solutions such as trenchless installation methods may be applied to minimise environmental or urban impact.

Property rights, land use constraints and local infrastructure interfaces can significantly influence route selection and construction planning. These aspects should be assessed at an early project stage to avoid delays and redesign efforts.

In addition, project schedules should account for the fact that approvals may be granted for **clearly defined districts or sections** rather than for entire large-scale zones. While many authorities have experience with permitting individual pipeline sections, procedures for approving complete hydrogen “conversion or supply districts” may not yet be fully established in all countries. Early clarification of expected documentation, safety assessments, system boundaries and verification concepts is therefore recommended.

2.4.3 Lifecycle management: planning, construction, commissioning, operation and maintenance

Beyond design and permitting, hydrogen infrastructure requires a structured approach to safety management and integrity management over the full lifecycle. Operators should establish clear responsibilities and processes covering planning, construction, commissioning, operation and maintenance, reflecting hydrogen-specific hazards and operational requirements (e.g. dispersion behaviour, concentration-dependent ignition characteristics, and gas quality sensitivities). [4]

Construction and cleanliness management

During construction, the system is typically not yet filled with hydrogen. Nevertheless, the build phase should already ensure that all materials, components and workmanship are compatible with the intended hydrogen service. Particular care is required for detachable connections, sealing concepts and joining quality. Contamination during construction should be avoided, as residues, debris or ingress of foreign substances may adversely affect hydrogen quality and downstream applications. Cleanliness requirements, handling procedures and flushing concepts should therefore be specified early (see Chapter 2.2 on hydrogen quality).

Commissioning and verification

Commissioning should follow clearly defined procedures, including pressure testing, functional testing of safety devices, and documented verification of installation quality. Where national rules require independent inspection, the involvement of qualified third parties should be planned from the outset. Commissioning plans should also address purging sequences, avoidance of hydrogen-air mixtures, and the management of temporary venting or blow-off activities.

Operational safety and monitoring

In operation, hydrogen-compatible equipment and operational procedures are required, including safe isolation concepts and, where appropriate, gas detection and emergency shutdown logic (especially in enclosed installations). Personnel training and competence management are critical to ensure that routine operations and interventions are executed safely and consistently.

Maintenance and intervention procedures

Maintenance procedures should explicitly cover leak detection, safe purging and venting, controlled opening of systems, and intervention techniques such as hot tapping or line stopping where these are used. Tools and temporary equipment used during inspections and maintenance must be suitable for hydrogen service and for the relevant hazardous area classification. Documentation of interventions, repairs and modifications should be maintained throughout the asset's lifecycle and integrated into the operator's integrity management processes.

2.4.4 Overview of new-build activities in Ready4H2 countries

Table 4 shows that European countries are at very different stages of development in the planning and implementation of hydrogen infrastructures and are pursuing strategies that in some cases diverge significantly. While some countries prioritise the construction of new 100% hydrogen pipelines, drawing on existing regulatory frameworks, others focus specifically on converting existing gas infrastructures or on regionally limited, cluster-based solutions. What many approaches have in common is a strong focus on industrial applications and the use of pilot and demonstration projects for technical and regulatory validation. The table also shows that standardisation issues, safety requirements and operational concepts – such as flaring and blowdown procedures – have not yet been conclusively clarified in several countries and that there is still a need for research and coordination at the European level.

Table 4: Overview of new build activities in Ready4H2 countries

Austria	The planning, construction and testing of hydrogen pipelines are subject to comprehensive ÖVGW regulations, which set out specific requirements for hydrogen. First new hydrogen pipelines are in the planning phase. Explosion protection and safety measures, e.g. flaring and venting concepts, are under technical discussion.
Czech Republic	Priority given to use of existing infrastructure. At technical universities, intensive technical discussions are taking place on the

	suitability of existing network components for the transition to 100% hydrogen. Against this backdrop, the GasNet project Pardubice Polygon was initiated to test selected network components, in particular valves and control stations from long-term operation, at a special test site under 100% hydrogen conditions. The aim is to evaluate the practical suitability of these components and to compare the test results with theoretical analyses.
France	Geographically limited hydrogen networks for industrial clusters. Focus is primarily on industrial applications (existing customers). The reasons for this are the currently lower maturity of electrolysis technologies, the higher cost of hydrogen and still limited mobility hydrogen options. At the same time, “hydrogen valleys” remain an active field. Projects with industrial customers and, in some cases, individual mobility projects are being developed there. However, there is a clear guideline for 100% hydrogen distribution in France: unlike in the long-distance transmission sector, only new pipelines are being considered for this purpose, because the existing natural gas network is considered important for the expansion of biomethane and other methane-based, low-CO_2 gases.
Germany	Planning, construction and testing of hydrogen pipelines are subject to comprehensive DVGW regulations that define specific requirements for hydrogen. Approval and testing processes are governed by national regulations (High-Pressure Gas Pipeline Ordinance, Pipeline Ordinance, DVGW worksheets and VdTÜV information sheets). The safety concept in Germany is comparatively strict: the requirements are high and include detailed specifications for explosion protection, material selection and labelling. When constructing new hydrogen pipelines, the design differs from that of conventional natural gas pipelines primarily in that the specific properties of hydrogen must be taken into account to a greater extent. A key issue is the choice of materials and impermeability (permeation): hydrogen can diffuse through certain materials that are largely impermeable to air or methane. Therefore, materials and seals must be specifically tested for hydrogen compatibility and selected accordingly. A second focus is on explosion protection and safety measures. Hydrogen has a wide explosion range and requires only a very low ignition energy. This means that protection concepts and operational safety measures must be adapted to these specific risks – for example, by taking into account the heat input and the special nature of an (almost) invisible flame in the hazard and application concept.
Netherlands	The national backbone network is currently being constructed, with the first section already completed. The *rollout plan* envisages the creation of a fully functional national hydrogen system by 2033, covering import, transport, storage and export. Around 30% of the network will be newly built, while around 70% will consist of repurposed existing networks. In parallel, distribution network operators are developing several *regional hydrogen networks*, some of which will be operated independently, while others will be connected to the backbone network. In addition, special distribution networks are being planned for industrial clusters. New pipelines are being designed for these industrial applications; three projects are currently in the (detailed) planning phase. The first hydrogen distribution network for smaller industrial companies in Deventer is scheduled to go into operation in 2027. *Home | GROHW*

	In contrast to the transmission network, only new pipelines are being considered for the short-term supply of 100% hydrogen to industry, as the existing networks are still needed for the expansion of biomethane.
Slovakia	DSO involvement in development of Hydrogen Valleys around Industrial clusters that aim to decarbonise the top emitters of GHG in Slovakia. 2 projects are currently being developed – one completely new build (10 km pure hydrogen pipeline connecting Slovak Hydrogen Backbone and Steel plant) and one repurposed pipeline (70 km pure hydrogen pipeline connecting to the Hydrogen Backbone and a refinery). 3 DSO corridors are planned (covering 20% of total network) but only if hydrogen becomes affordable for mass use. For remaining 80% of the network the methane-based distribution is still expected also in long-term (biomethane, other low emissions gases and hydrogen blending up to 20 vol.%). The Slovak Hydrogen Backbone is being developed by national TSO – most of it repurposed. Start date of operation is planned on 2032-2034.
Spain	Focus on hydrogen production for valleys and clusters (bottom up). Basic rules for pure hydrogen exist in the current legal framework. Numerous valley and cluster projects are already underway, several at an advanced stage, supported at the hydrogen production level by substantial national and European funding programmes. Spain has already mobilised over €3 billion under the *PRTR (Recovery, Transformation and Resilience Plan)* for green hydrogen, covering both CAPEX and OPEX support, and has recently launched public consultations for an additional €465 million in direct subsidies for projects participating in the European Hydrogen Bank and the Industrial Decarbonisation Bank under the AaaS scheme. Spain has also secured over €0.5 billion in the first and second EU Hydrogen Bank auctions. However, many projects are still awaiting the final investment decision. In the long term, a larger hydrogen network will be created either by converting existing natural gas pipelines or by building new ones and will later be connected to future hydrogen corridors, ultimately resulting in the creation of a national hydrogen backbone.
Switzerland	When building new network sections, the differences between hydrogen and conventional natural gas pipelines are highlighted first. In Switzerland, the principle is that new network sections are planned and implemented to be H_2-ready from the outset. It is expected that, despite the need for some new construction, the roll-out of the hydrogen infrastructure will be based largely on existing or former gas pipelines, through the use and repurposing of existing routes and assets. It is emphasised that Switzerland has national standards for the construction of new hydrogen pipelines, which serve as a basis for planning and implementation.
United Kingdom	Focus is on new 100% hydrogen pipelines (*HyNet, East Coast*). It is assumed that two parallel infrastructures will emerge in the long term: a methane network (possibly with additives and up to 20% hydrogen blending) and a 100% hydrogen network (which will require the construction of new hydrogen pipelines). Many hydrogen projects are already in the planning stage, and an initial tender/bidding opportunity in the region of UKP500 million is expected in 2026. Currently, a prerequisite for participation is that the project connects the pipeline directly to storage facilities.

2.5 Blending natural gas with hydrogen

This section describes blending hydrogen into natural gas networks, including boundary conditions and limitations (including input from various countries) as well as distinction/differences from a complete conversion to hydrogen (including safety aspects).

EN 16726 [49] is currently being updated and includes requirements that increasingly take into account the use of hydrogen (up to 20 vol.% hydrogen) in fuel systems. This standard harmonises gas quality requirements for Group H natural gas across Europe.

2.5.1 Fundamentals of gas quality

DVGW worksheet G 260 specifies average gas compositions for various fuel gases, which are listed in Table 5: Gas compositions according to DVGW worksheet G 260. Actual gas compositions fluctuate around these values over time, and there are also regional variations for end customers, depending on the gas purchased by network operators from upstream networks and the origin of the gases in the grid.

Table 5: Gas compositions according to DVGW worksheet G 260

Combustible gas	Gas composition in mol-%										
	CH	N_2	CO	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	CnHm	O_2	CO	H_2
Methane	100	-	-	-	-	-	-	-	-	-	-
Natural gas H Russian	96.96	0.86	0.18	1.37	0.45	0.15	0.02	0.01	< 0.001	-	-
Natural gas H North Sea	88.71	0.82	1.94	6.93	1.25	0.28	0.05	0.02	< 0.001	-	-
Natural gas H Denmark	90.07	0.28	0.60	5.68	2.19	0.90	0.22	0.06	< 0.001	-	-
Biomethane H	96.15	0.75	2.9	-	-	-	-	-	0.2	-	-
Biomethane H + LPG	90.94	0.69	2.68	-	5.0	0.50	-	-	0.19	-	-
Natural gas L Germany	86.46	10.24	2.08	1.06	0.11	0.03	0.01	0.01	< 0.001	-	-
Natural gas L Holland	83.64	10.21	1.68	3.56	0.61	0.19	0.04	0.07	< 0.001	-	-

Table 6 shows the average substance values for the calorific value, Wobbe index and relative density corresponding to the gas compositions shown.

Table 6: Material values for natural gases according to DVGW worksheet G 260

Gas type	Calorific value	Wobbe index	Relative density
	kWh/m³	kWh/m³	-
Methane	11.0634	14.8526	0.5548
Natural gas H Russian	11.1858	14.7636	0.5740
Natural gas H North Sea	11.6420	14.6831	0.6286
Natural gas H Denmark	12.1285	15.2816	0.6299
Biomethane H	10.6382	13.8834	0.5871
Biomethane H + LPG	11.6259	14.5222	0.6408
Natural gas L Germany	9.8203	12.4281	0.6243
Natural gas L Netherlands	10.2345	12.7747	0.6418

For the second gas family (methane-rich gases), *DVGW worksheet G 260* defines limit values for relevant substance values, as listed in Table 7.

Table 7: Limit values for substance values according to DVGW worksheet G 260

Substance value		Unit	Lower limit	Upper limit
Calorific value		kWh/m³	8.4	13.1
Wobbe index	H gas	kWh/m³	13.6	15.4
	L gas	kWh/m³	11.0	13.0
Relative density		-	0.55	0.75

When adding hydrogen to these natural gases, it must therefore be ensured that the limit values are complied with. Table 8 lists the maximum hydrogen proportions above which the respective substance values violate the limit values.

Table 8: Limit values for hydrogen content in accordance with DVGW worksheet G 260

	Calorific value	Wobbe index	Relative density
Gas type	mol.	mol.	mol.
Methane	35	34	21
Natural gas H Russian	36	31	24
Natural gas H North Sea	39	28	31
Natural gas H Denmark	43	40	31
Biomethane H	31	8	26
Biomethane H + LPG	39	25	33
Natural gas L Germany	22	98	31
Natural gas L Netherlands	27	98	33

2.5.2 Billing

When hydrogen is added to natural gas, it must be ensured that gas volumes can be billed to customers in accordance with regulations. In accordance with *DVGW worksheet G685* (relevant for German market, but similar approach can be taken in other EU countries), gas volumes are measured at the customer's premises using calibrated meters and billed using the billing calorific value and the respective gas price. Network operators determine the billing calorific value $H_{S,eff}$ at each exit point using values from measuring devices or methods that are subject to the Measurement and Calibration Act. Each billing calorific value must be traceable to calorific value measurements that comply with calibration law. To this end, network operators measure feed-in calorific values at the feed-in points into their networks or obtain them from upstream network operators. The feed-in calorific values are based on hourly, daily or monthly average values. For calorific value measuring devices that comply with calibration law, the hourly value $H_{S,h}$ is used. This is calculated from the values measured within one hour by arithmetic averaging. Reconstruction systems that comply with calibration law provide daily values $H_{S,d.}$ If gases with different calorific values are mixed before or during feed-in to the network, resulting in the distribution of a mixed gas, the feed-in calorific value at this feed-in point is determined:

- by measuring the calorific value after mixing or
- by calculating the mixed gas calorific value as a quantity-weighted average based on the quantity flows and calorific values of the gases being mixed

If calorific value measurement or calorific value reconstruction in accordance with calibration law is economically unreasonable, the following alternative methods may be used to determine billing calorific values:

- gas quality tracking
- quantity-weighted averaging of the feed-in calorific value (average value method)
- other recognised methods

In the mean value method, the monthly billing calorific value $H_{S,m,eff}$ is calculated using the quantity-weighted average of the feed-in calorific values $H_{S,m}(i)$ and the feed-in quantities $V_{n,m}(i)$, with i representing the feed-in points. In principle, the smallest available time unit of the feed-in calorific values must be used to determine the billing calorific value. The following values apply:

- from discrete measurements: hourly values
- from reconstruction systems: daily values
- from substitute methods: monthly values

For each feed-in point, the monthly quantity-weighted average is calculated as follows.

$$H_{S,m} = \frac{\sum_{i=1}^{L} H_{S,h}(i) * V_{n,h}(i)}{\sum_{i=1}^{L} V_{n,h}(i)}$$ Equation 21

Index m	Monthly basis
Index h	Hourly basis
Running index i	Hour 1 to L
L	Number of hours in the month

In the case of single-sided feed-in, the calculated monthly average already corresponds to the monthly billing calorific value.

In the case of multi-sided feed-in, the monthly billing calorific value is calculated from the quantity-weighted average of the feed-in points.

$$H_{S,m,eff} = \frac{\sum_{i=1}^{N} H_{S,m}(i) * V_{n,m}(i)}{\sum_{i=1}^{L} V_{n,m}(i)}$$ Equation 22

Index m	Monthly basis
Run index i	Feed-in points 1 to N
N	Number of feed-in points

An annual or sub-annual billing calorific value $H_{S,a,eff}$ is calculated by weighting the monthly billing calorific values and feed-in quantities.

$$H_{S,a,eff} = \frac{\sum_{i=1}^{M} H_{S,m,eff}(i) * V'_{n,m}(i)}{\sum_{i=1}^{L} V'_{n,m}(i)}$$ Equation 23

Index a	Annual basis
Index m	Monthly basis
Running index i	Month 1 to M
M	Number of months in the billing period

The averaging method is only permissible if no feed-in calorific value $H_{s,m}$ differs by more than 2% from the billing calorific value $H_{s,m,eff}$. This therefore only applies to multi-site feed-ins. In order to comply with this "2% limit", the following inequality must therefore be satisfied.

$$-0{,}02 \leq \frac{H_{S,m}(i)}{H_{S,m,eff}} - 1 \leq +0{,}02$$ Equation 24

Compliance with the 2% limit for hydrogen feed-in to the example natural gas with a calorific value of 11.2 kWh/m³ (i.N.) was checked using a two-sided feed-in as an example. A natural gas-hydrogen mixture is fed in at feed point 1 and pure natural gas at feed point 2. Since the average value is calculated on a volume-weighted basis, all possible volume flow ratios were considered for different hydrogen proportions.

In the following figures, the volume flow ratio of the two feed points is plotted on the x-axis as a proportion of the volume flow at feed point 1 to the total volume flow. The dotted lines on the secondary y-axis show both the volume flows of the feed points (blue & yellow) and the total volume flow (purple) of the feed points in m³/h (i.N.), assuming a constant energy demand of 10,000 kWh for all consumers in the network. The left edge of the diagrams corresponds to a single-sided feed via feed point 2 with pure natural gas and thus a (total) volume flow of 893 m³/h (i.N.). Moving to the right on the x-axis, the share of feed-in point 1 with the natural gas-hydrogen mixture in the total volume flow increases until it corresponds to a one-sided feed-in via feed-in point 1 at the right edge. Therefore, the total volume flow continues to increase towards the right edge as the share of the mixed gas with the lower calorific value increases. The greater the proportion of hydrogen in the mixed gas, the greater the increase in the total volume flow required to meet the constant energy demand of the consumers.

The solid blue line shows the deviation of the feed calorific value at feed point 1 and the solid yellow line shows the deviation of the feed calorific value at feed point 2 from the volume-weighted average calorific value. If these two lines are within the 2% limit (red lines), this is marked with a green dot on the x-axis for the respective volume flow ratio. If one or both feed points do not comply with the 2% limit, the green dot is missing.

In the first example, 2 vol.% hydrogen is added at the first feed point and pure natural gas continues to be fed in at the second feed point. The calorific value of the mixture drops to 11.047 kWh/m³ (i.N.). As can be seen in Figure 11, the 2% limit is maintained for every volume flow ratio.

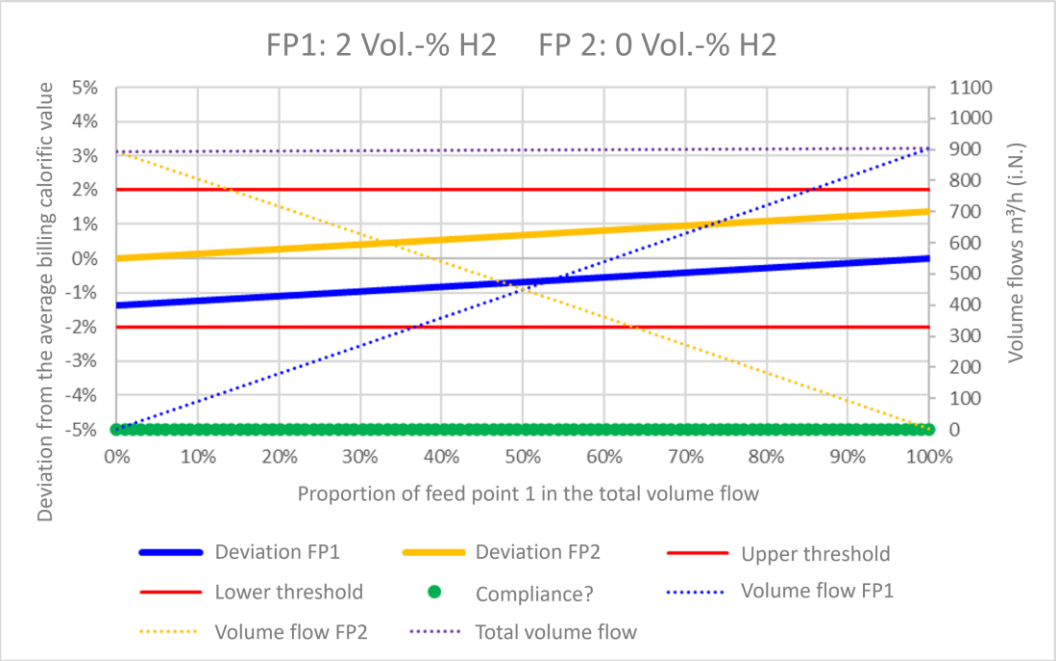


Figure 11: Compliance with the 2% limit at 2 vol.% hydrogen admixture [50]

In the second example, 4 vol.% hydrogen is added at the first feed point and pure natural gas continues to be fed in at the second feed point. The calorific value of the mixture drops to 10.894 kWh/m³ (i.N.). This means that the 2% limit is only complied with if the proportion of feed-in point 1 in the total volume flow is between approx. 30 and 70%, as can be seen in Figure 12. Some networks have a summer operating mode, whereby the network is largely supplied via a single feed-in point. In these cases, if the other feed-in point only has a small share of the total volume flow, the 2% limit would no longer be complied with. Here, it would be necessary to completely block the feed-in point with the lower volume flow and switch completely to one-sided feed-in so that the 2% limit can be complied with.

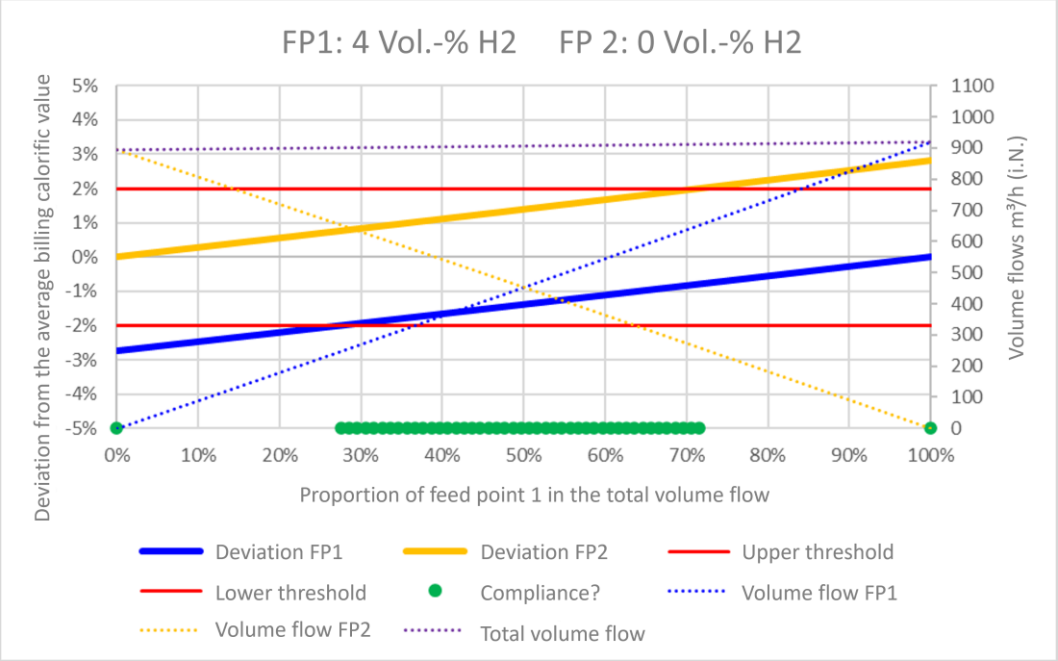


Figure 12: Compliance with the 2% limit at 4 vol.% hydrogen admixture [50]

This would also be necessary at a hydrogen content of 3 vol.%, as the 2% limit could no longer be complied with at very low volume flow rates of 3 to 4% at a feed-in point.

In the third example, 6 vol.% hydrogen is added at the first feed-in point and pure natural gas continues to be fed in at the second feed-in point. The calorific value of the mixture drops to 10.740 kWh/m³ (i.N.). This means that the 2% limit can no longer be complied with at any volume flow ratio, as can be seen in Figure 13.

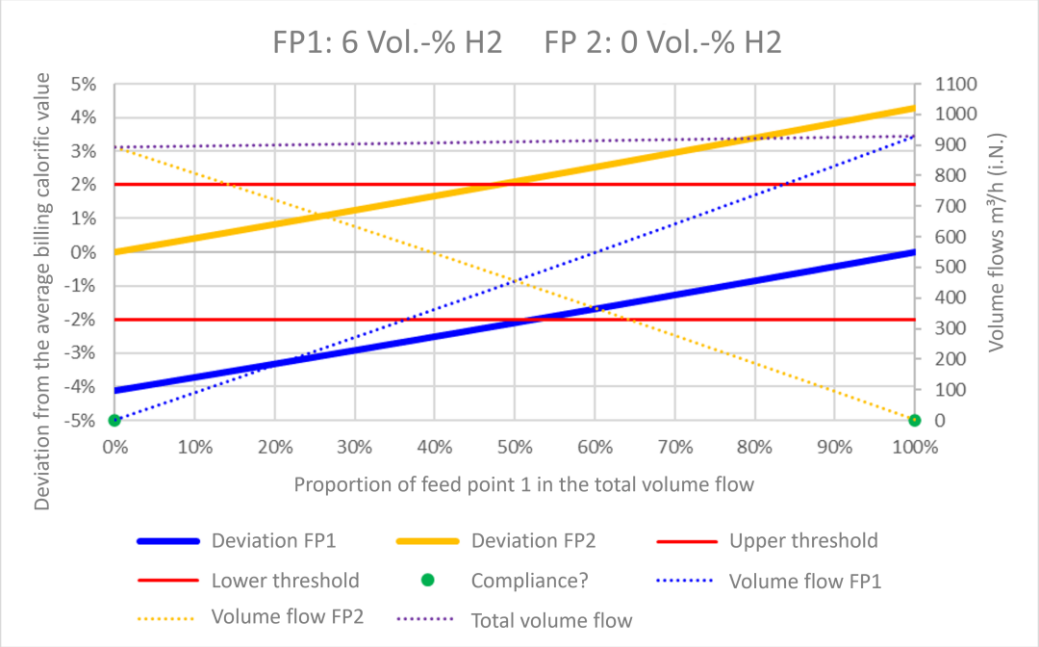


Figure 13: Compliance with the 2% limit at 6 vol.% hydrogen admixture [50]

This means that the 2% limit cannot be maintained at even higher hydrogen proportions in the mixed gas. At 20 vol.% in the mixed gas, its calorific value drops to 9.668 kWh/m³ (i.N.) and the significantly greater deviation is shown for comparison in Figure 14.

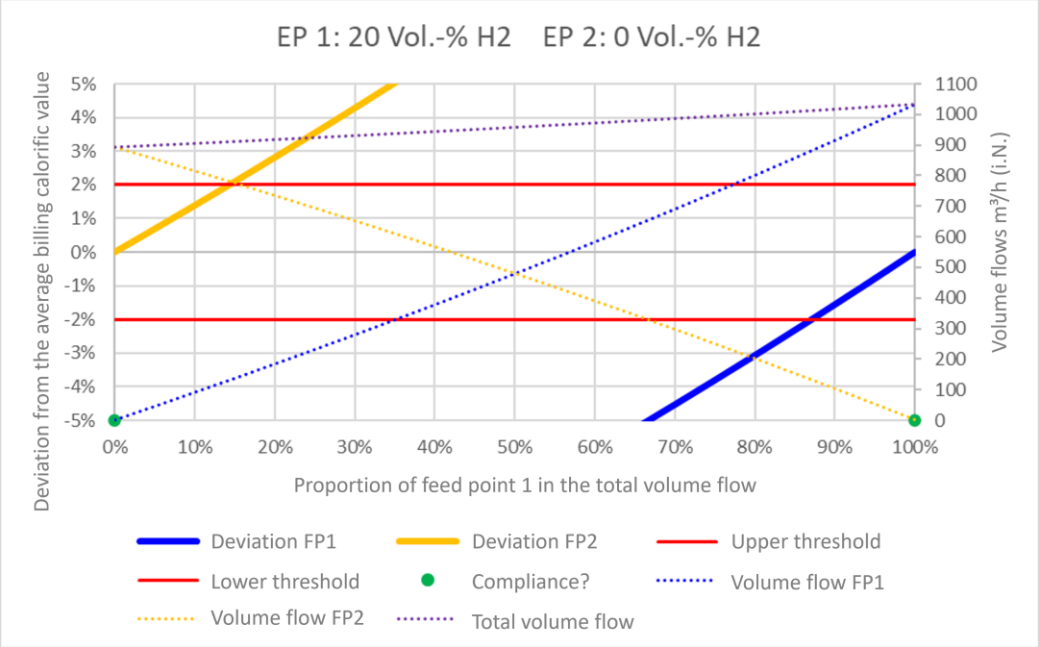


Figure 14: Compliance with the 2% limit at 20 vol.% hydrogen admixture [50]

2.5.3 Hydrogen tolerance of gas infrastructure and end devices

Material suitability of many components in the gas distribution network for hydrogen admixtures has already been confirmed in various studies. Up to certain hydrogen proportions, no significant adjustments are usually necessary, while at higher proportions, further testing or modifications may be necessary in isolated cases.

Figure 15 provides an overview of the current status of the assessment. Figure 15 shows the technical readiness of the gas infrastructure and end-user appliances for hydrogen-natural gas mixtures. This was developed based on ongoing research and the expertise and experience of operators and experts, and was last updated in November 2023. The study shows that the most important infrastructure elements and end devices can generally be operated without modification with a hydrogen admixture of 0–10 vol.%, while concentrations of up to approximately 30 vol.% can be achieved after replacement and modification measures.

In the long-distance transport sector (>16 bar), the main elements can accommodate up to 10 vol.% hydrogen without modification, while higher proportions require individual mitigation measures, particularly for steel pipelines, depending on respective operating and pipeline conditions.

For storage, admixtures of up to 5 vol.% are possible without modifications; after modifications, many storage facilities can even accommodate up to 100 vol.% hydrogen. However, above 10 vol.%, flare and burner components in particular must be significantly modified or replaced, and further research is needed for higher concentrations and special types of storage.

For compression, pressure regulation and metering, most elements are suitable for up to 10 vol.% hydrogen without modifications. However, turbo and piston compressors are considered a limiting factor, as they can only achieve higher proportions with minor modifications. Process gas chromatographs are considered problematic, so that significant technical modifications are necessary for mixtures up to about 25 vol.% hydrogen.

In distribution (<16 bar), the main components can transport mixtures of up to 30 vol.% hydrogen without any modifications in most cases. After modifications, it is assumed that almost all components could also be suitable for up to 100 vol.% hydrogen, although additional research is required, particularly for overflow valves.

In terms of end devices, domestic appliances are likely to be suitable for up to 20 vol.% hydrogen.[6, 7] In Germany, domestic installations can accommodate up to 100% hydrogen, but the integrity of the installation must be proven. Additionally, meters must be changed to the correct dimensions, and pressure regulators must come with a manufacturer's declaration for hydrogen[8].

Industrial processes can usually only handle small admixtures of up to around 5 vol.% without conversion measures being necessary, whereas power plant gas turbines, processes using natural gas as a raw material, and CNG steel tanks are sensitive even to small amounts of hydrogen. With conversion measures, the hydrogen tolerance of industrial combustion processes can be increased by up to 20% by volume[9]. This involves adapting the gas and air amounts or making minor changes to the burner controls, for example. Even higher mixing rates are possible for industrial combustion processes, but they require more extensive conversion measures. Typical industrial processes such as heat treating steel or melting glass/aluminium can be fully converted to pure hydrogen combustion.

[6] Abschlussbericht DVGW Roadmap Gas 2050: G201824-D 3.3: „Bewertung der H2-Verträglichkeit von Gasanwendungen bis zu einer Grenze von 40 Vol"
[7] Project THyGA Testing Hydrogen admixture for Gas Applications
[8] DVGW Merkblatt G655: „H2-Readiness"
[9] Abschlussbericht DVGW Roadmap Gas 2050: G201824-D 3.3: „Bewertung der H2-Verträglichkeit von Gasanwendungen bis zu einer Grenze von 40 Vol"

Industrial grids are suited for the use with pure hydrogen. Components such as meters, pressure regulators or valves must come with the manufacturer declaration for use with hydrogen.[10]

Before converting any industrial grid, appliance or domestic installation to pure hydrogen, a statement from an expert regarding the DVGW rules or a designated body is required.

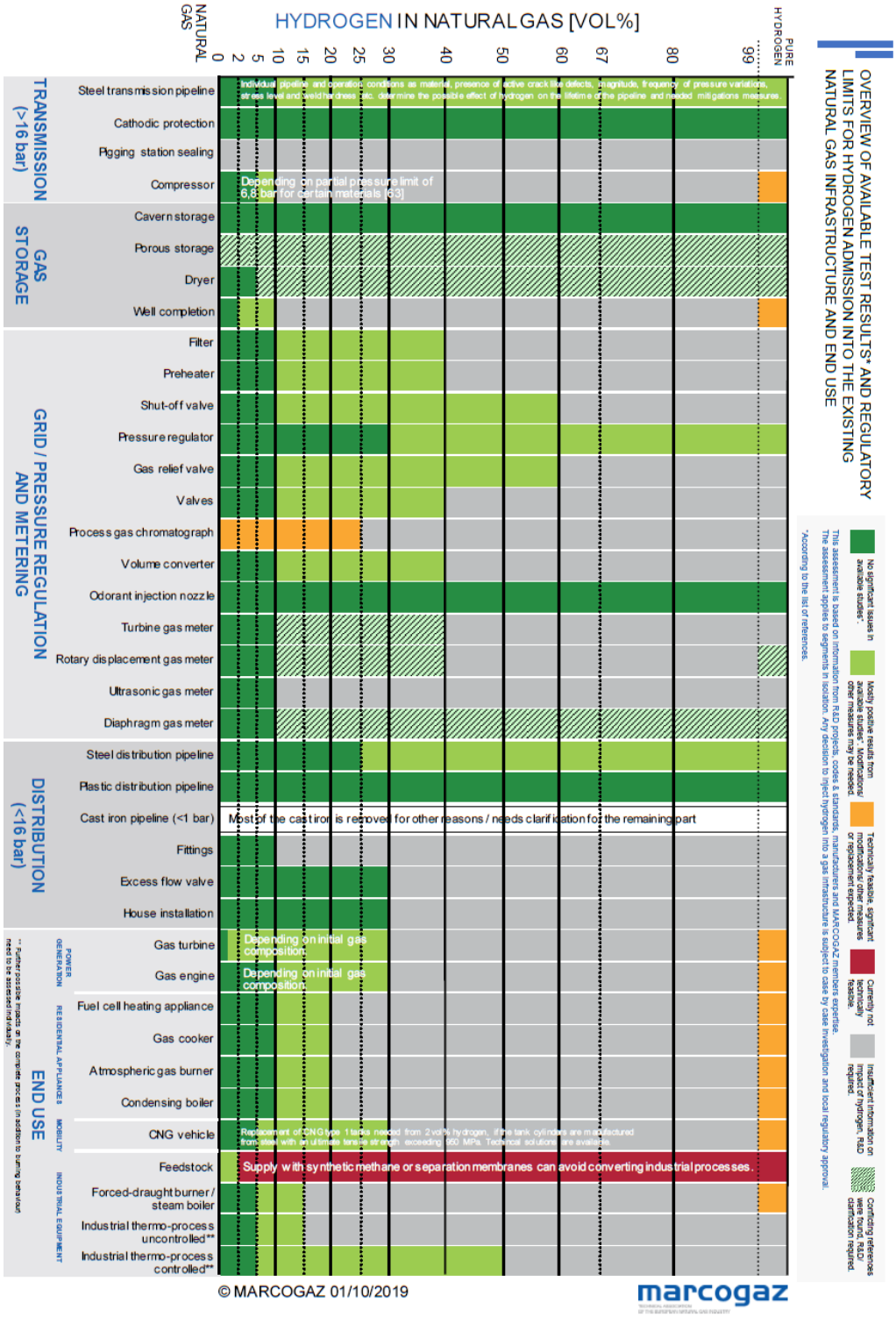


Figure 15: Infographic on the hydrogen tolerance of gas infrastructure and end devices, Nov. 2023 [51]

[10] DVGW Merkblatt G655: „H2-Readiness“

2.5.4 Overview of blending activities in Ready4H2 countries

The following table provides a comparative overview of the current status of hydrogen blending in gas distribution networks in Ready4H2 countries. It shows both the hydrogen content permitted by regulations and practical experience from pilot and demonstration projects. The overview illustrates that blending is assessed and used very differently across Europe, ranging from a targeted instrument for market ramp-up to a purely transitional solution to an approach with currently low strategic significance or as an alternative in a multi-molecule gas system.

The country contributions presented show that hydrogen blending, which is technically feasible in principle, is often limited by non-technical factors. In particular, end-device compatibility, gas billing, gas quality requirements and national funding and regulatory frameworks determine whether and to what extent blending is implemented in practice. At the same time, ongoing projects are providing important insights into grid compatibility, gas quality monitoring and dealing with fluctuating hydrogen content in grid operation.

Table 9: Overview of blending activities in Ready4H2 countries

Austria	In the Austrian DSO grid, up to 10% blending is technically feasible. Blending is seen as an important instrument for market ramp-up. A research project is underway to simulate and measure the concentration of hydrogen in a gas network with multiple entry and exit points, as well as a hydrogen feed-in station. The project aims to develop a reliable simulation tool that can forecast the maximum hydrogen concentration within the network and ensure that this limit is not exceeded. At the moment an essential limiting factor for the ramp-up of hydrogen blending is RFNBO certification.
Czech Republic	Legislation allows i) up to 2 vol.% without further conditions and ii) up to 20 vol.% based on DSO approval (technical standards development is currently in progress). Limiting factors: end devices, billing. DSO grid compatibility up to 20 vol.%. Ongoing nationwide blending project in *Hranice u Aše* to investigate the resistance of distribution network components to hydrogen. Initial results: • a defined section of the gas distribution network is being tested during ongoing operation with a hydrogen admixture of up to 20 vol.%. The tests are being carried out in stages, with increases to 5 vol.%, 10 vol.% and 20 vol.% hydrogen content • the network under consideration has a typical medium pressure of up to 4 bar and is used in live operation to supply end customers The hydrogen is continuously produced by electrolysis from renewable electricity sources and stabilised by hydrogen buffer storage. Key components of the project are the blending technology used and the remote monitoring of all relevant operating parameters via a SCADA system. Gas quality is monitored using gas chromatograph and H_2 analyser technologies, among other measures. Feed-in and feed-out data are also processed for mathematical balancing and time-dependent network load forecasts, in particular to map calorific value fluctuations (*Simone*). In addition, a project is being carried out in the field of gas quality and measurement technology, which includes measurement evaluation and the development of a software tool (*Simone*) for calorific value calculation. Challenges currently exist in the following areas, in particular:

	• the behaviour of standardised customer end devices when operating with CH_4-H_2 mixtures and the evaluation of operating experience and feedback • mapping of seasonal flows via control stations and the balancing of hydrogen production and consumption, particularly production and storage strategies and the reaction speed of distribution technology to changing network loads
France	Regulations and DSO specifications generally allow up to 6 vol.% hydrogen. In practice, however, the proportion is often limited to 2 vol% in order to protect sensitive consumers, in particular natural gas vehicles and certain industrial processes. The technical feasibility of significantly higher admixtures was demonstrated in the *GRHYD* project. There, the injection of up to 20 vol.% hydrogen into a distribution network was demonstrated, with new domestic and commercial appliances. Nevertheless, there is no funding or support model specifically for hydrogen injection into the natural gas network. The national strategy focuses more on the direct use of pure hydrogen.
Germany	Theoretically high blending ratios are possible but current focus is on ≤ 20 vol.% in practice. Three key limiting factors: • Combustion properties: The maximum permissible amount of hydrogen is determined by the limit values for the Wobbe index, calorific value and relative density of the gas mixture. These specifications are laid down in the *DVGW G 260* regulations (including associated tables) and describe how much hydrogen can be added to the base gas without exceeding the permissible combustion properties for methane-rich gases (2nd gas family). • Fluctuations in volume flow: The gas flow of the base gas is subject to daily and seasonal variations. In extreme cases, the volume flow can approach zero or the flow direction can reverse. In this case, the hydrogen feed must be reduced or interrupted to prevent impermissible enrichment beyond the limit values. • Technical limitations of the infrastructure and gas use: It must be checked whether the network infrastructure, materials used, measurement/measuring methods, and connected gas appliances/applications are suitable for the respective hydrogen blending. This also includes requirements for interoperability and compatibility, which must be verified by appropriate tests in case of doubt.
Netherlands	Technically possible. Current regulations and DSO specifications allow up to ≤ 0.5 mol% hydrogen in the network. [52] The technical feasibility of injecting up to 20 vol.% hydrogen into the distribution network has been demonstrated in *the Ameland pilot project* (new appliances, 10-15 households). Admixing up to ~5 vol.% hydrogen into natural gas is technically feasible in the DSO network. [46] There is no drive to blend in the Netherlands; it is difficult to maintain a stable percentage with the enormous swing in the gas grid compared to countries in the south of Europe. The end goal is 100% hydrogen, blending means two conversions which may be expensive. Blending in niche areas for offtakers as a last resort may be possible. There is currently no support scheme to support injection of hydrogen into the network in the Netherlands. The national strategy focuses on pure hydrogen utilisation and maybe 1 vol.% or 2 vol.% hydrogen in natural gas at a national level.

Slovakia	Very restrictive (≤ 2 vol.%) due to end uses and billing. There is a practical pilot project from which experience has been gathered. A key limiting factor is low to non-existent gas flows in summer, particularly when hydrogen production from renewable energies (RES) is high and there would actually be a particularly strong interest in feeding hydrogen into the grid. In addition, bidirectional gas flows can occur in the high-pressure network, which increases the risk of multiple blending (undesirable overlaps/enrichment). Against this background, SPPD has identified four preferred ("go-to") zones for blending in Slovakia, located at interfaces with the TSO, characterised by high and continuous gas flows (even in summer) and that offer potential for large-scale electrolysis and sector coupling. From an operational perspective, a 2 vol.% admixture is considered uncritical. However, above 2 vol.%, there is a need for gas quality tracking to ensure fair billing based on "real" kWh (rather than purely volumetric approaches). For household customers, up to 10 vol.% is described as unproblematic, supported by tests in a network with around 300 consumption points. For larger consumers, on the other hand, it becomes more challenging from around 5 vol.%: in principle, this is often still feasible, but beyond that, de-blending may be necessary – which is expensive and raises the question of who bears the costs.
Spain	*Ministerio para la transición ecológica y el reto demográfico* (MITECO) has already integrated feed-in rules into the existing legal framework. A threshold value of 2 vol.% is planned, which can be raised to up to 5 vol.% under certain conditions; namely, if there is a positive hydraulic simulation and no sensitive customers will be affected. The technical feasibility of significantly higher admixtures was demonstrated in the *H2Sarea project*, where the injection of up to 20 vol.% hydrogen into a distribution network was demonstrated. Overall, blending is seen as a real option for the ramp-up of hydrogen in the country. Network access and connection for hydrogen is regulated in specific regulation *"circular de acceso y conexion 2/2025 de 9 de abril de la Comision Nacional de los Mercados y la Competencia"* and via an auction system; the first auction is scheduled to run from 1 October 2025 and is accompanied by high expectations. Firsts real feed-in projects have been announced. The *green Hysland project* in the Balearic Islands has been testing a 2 vol.% hydrogen blend since 2024.
Switzerland	Hydrogen blending into H-gas in Switzerland is governed by the SVGW G18 guideline, which is referenced in Swiss legislation (RLSV, SR 746.12) as a recognised rule of technology. For hydrogen contents of up to and including 2 vol.%, no additional safety assessment of the gas grid and connected users is required. For hydrogen contents above 2 vol.% and up to and including 20 vol.% within a defined network area, the gas network operator must carry out a safety assessment of the hydrogen compatibility of the grid and its connected users. Compliance with the remaining H-gas limit values is also required. In particular, the effects on the Wobbe index and other combustion-related parameters must be taken into account, as these may further restrict the permissible hydrogen content. In addition, it must be ensured that the gas is fully consumed within the defined area and that no backfeeding into upstream networks occurs. Blending in Switzerland is therefore a regulated option that may serve either as a transitional solution or, depending on regional conditions, as a longer-term approach.
United Kingdom	Considered as a transitional and hedging instrument.

	It has been demonstrated that pipelines in the national transmission network can transport hydrogen admixtures of 2 vol.%, 5 vol.% and 20 vol.%, as well as 100% hydrogen in the future (as demonstrated by NGT, among others). The *HyDeploy* project has demonstrated that hydrogen can be safely added to an existing natural gas network at concentrations up to 20 vol.% (initially at a university, later in a village) without modifications to customers' standard gas appliances. It is expected that hydrogen admixtures in distribution networks will not exceed 5 vol.%. Challenges include customer concerns about billing (as hydrogen changes the calorific/heating values), network-related issues regarding pressure control, and compliance with blending ratio stability when feeding in hydrogen. National expertise is particularly strong in the area of conversion on the demand side (via the Towns Gas Transition). At the same time, there is extensive know-how from North Sea pipeline projects.

2.6 Operational considerations

Differences in the operation of hydrogen pipelines compared to natural gas pipelines

Based on a completed research project on operational and safety aspects of gas distribution networks converted entirely to hydrogen (100%) with design pressures up to 16 bar [53] initial practical experience from existing hydrogen networks was systematically evaluated. The aim was to analyse both safety and organisational requirements for ongoing operation as well as for maintenance and repair measures.

The study was based on a comprehensive analysis of national and international regulations and on structured exchanges with experts from the gas industry and other industries. Document analyses, guided interviews and standardised questionnaires were used as methods to obtain as broad and practical a picture as possible of the current operating reality of hydrogen-carrying networks.

The following table presents a summary of the systematic classification of operational, organisational and safety requirements for the operation of gas pipelines with different hydrogen contents. It serves as a practical guide and highlights areas where adjustments may be necessary compared to natural gas pipelines. The measures presented are not exhaustive but rather form a condensed selection of relevant aspects for the planning, construction and operation of hydrogen pipelines.

Table 10: Adjustments to operating procedures and equipment with changes in hydrogen concentration [53]

Category	**H_2 content <30 vol.%**	**H_2 content from 30 vol.% to ≤ 60 vol.%**	**H_2 content ≥ 60 vol.%**
Clothing	No change compared to natural gas pipelines	No change compared to natural gas pipelines	It is essential to ensure that clothing cannot become electrostatically charged. No change compared to natural gas pipelines.
Tools	No change compared to natural gas pipelines	Use of low-spark tools recommended	Use of low-spark tools recommended
Electrically powered tools	No change compared to natural gas pipelines	Must be suitable for use in at least ATEX protection class IIb.	Must be suitable for use in ATEX protection class IIc.
Gas detection	No change compared to natural gas	Must be suitable for use in at least ATEX	Must be suitable for use in ATEX

		protection class IIb and calibrated for hydrogen.	protection class IIc and calibrated for hydrogen.
Construction site equipment Underground pipes	No change compared to pipelines carrying natural gas	Provide technical ventilation for trench work	Provide technical ventilation during trench work. Use of a fire watch recommended.
Shut off pipes	No change compared to pipelines carrying natural gas	Double shut-off with interstitial space ventilation and continuous pressure monitoring	Double shut-off with intermediate space ventilation and continuous pressure monitoring
Squeezing	Only at max. 5 bar and PE pipes	Only at max. 5 bar and PE pipes. Use gas sensors and reduce pressure if necessary	Only at max. 5 bar and PE pipes. Use gas sensors and reduce pressure if necessary
Blowback	No change compared to pipes supplied with natural gas	Double bubble setting with intermediate space ventilation and continuous pressure monitoring	Double bubble setting with intermediate space ventilation and continuous pressure monitoring
Vent/depressurise pipe sections	No change compared to pipelines supplied with natural gas.	Larger EX zones may occur. Extend the safety area.	Risk of potential self-ignition. This can lead to banging noises, heat radiation and explosion overpressure. Check and adjust protective measures if necessary.
Odorisation	No change compared to pipelines supplied with natural gas	Other Odorants in use	Other odorants in use, if applicable
Pipeline inspection	No change compared to pipelines supplied with natural gas	Ensure that measuring devices are suitable. If necessary, they must be specially calibrated for the mixing ratio	Ensure that measuring devices are suitable.

Results show that existing technical regulations and certification concepts provide a robust basis for safe operation, but should be further developed and harmonised internationally. In particular, better coordination with occupational health and safety requirements at the European level is considered necessary.

With regard to network operation and maintenance, it is apparent that many measures are fundamentally comparable to those for natural gas operation, but must be supplemented by hydrogen-specific requirements. These include qualified training of personnel, the use of fire and safety posts, adapted welding and joining procedures, and measures to prevent electrostatic charging.

Another safety-related aspect concerns the classification of potentially explosive areas. As the hydrogen concentration in natural gas-hydrogen mixtures increases, the underlying explosion groups change, which has a direct impact on the permissibility of the equipment used. This underlines the need for clearly defined limit values and unambiguous specifications for the operation of mixed and transitional states in European networks.

Odorisation of hydrogen remains a key unresolved issue. While its relevance to safety is undisputed, suitable odorants are still under development. However, initial approaches show that both sufficient perceptibility and compatibility with hydrogen-sensitive applications, such as fuel cells, appear to be achievable in principle.

Overall, the results show that the safe and compliant operation of hydrogen-carrying gas distribution networks is technically feasible. This requires targeted adjustments to existing regulations, consistent training of operating personnel, and the further development and harmonisation of technical and organisational standards at the European level.

Training and qualification requirements

The introduction and operation of hydrogen-carrying networks require targeted awareness-raising and qualification of operational personnel. Training content should convey both a basic understanding of the role of hydrogen in the energy transition and the specific physical and safety differences compared to natural gas.

Key training topics include:

- changed propagation and ignition behaviour of hydrogen
- effects on potentially explosive areas
- typical sources of danger such as heat radiation, explosion overpressure, spontaneous combustion and electrostatic discharges
- operational measures to prevent ignition sources
- proper use of detection and measurement systems
- organisational protective measures such as work instructions, clothing requirements and emergency procedures

Particular emphasis should be placed on practical exercises, such as detecting leaks, handling gas detectors, safely carrying out pressure relief and blow-off procedures, and how to behave in malfunction and emergency situations. Training should be seen as an ongoing process that becomes increasingly important as the proportion of hydrogen increases

3 Overview of projects and experiences

The development of a hydrogen infrastructure in the distribution network sector is in a dynamic phase in Europe. While concrete conversion and demonstration projects are already being implemented in some countries, others are still in the early stages of strategic and regulatory preparations. Practical experience from pilot projects, regional conversion projects and the first hydrogen valleys is providing important insights for the future transformation of existing gas networks.

The following subchapters compile the contributions of the Ready4H2 countries and provide a comparative overview of the current project status and key technical and organisational challenges. First, a country-specific project database was compiled that shows which infrastructure approaches are currently being pursued (conversion of existing pipelines, new construction or hydrogen blending). Second, historical conversions of European gas supply systems were reviewed in order to derive transferable lessons learned for today's hydrogen transformation.

Based on this, the respective national framework conditions and the status of implementation strategies were analysed. The compilation illustrates that the transformation of gas distribution networks is heavily dependent on regulatory requirements, technical starting conditions and strategic priorities, and is at very different stages in different countries. Finally, the results were evaluated comparatively, and key universal planning modules were identified that are necessary for a successful conversion, regardless of the chosen transformation path.

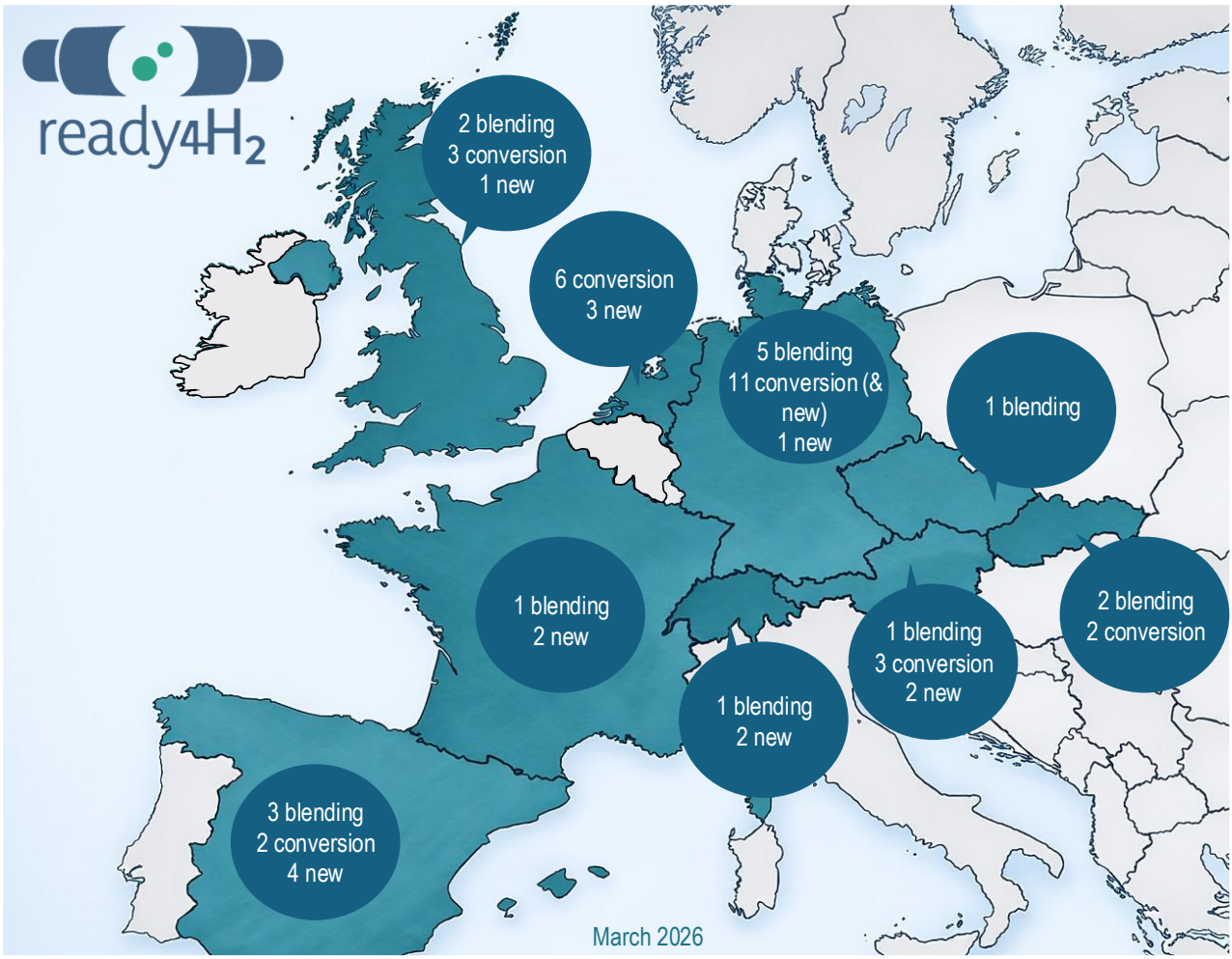


Figure 16: Ready4H2 project overview (March 2026)

3.1 Ready4H2 project database

Figure 16 shows the current implementation status of selected hydrogen projects in the countries of the Ready4H2 partners (as of March 2026). It shows projects in the categories of **blending** (adding hydrogen to existing natural gas networks), **conversion** (converting existing infrastructure to 100% hydrogen) and **new build** (building new hydrogen-only infrastructure). The graphic overview illustrates the geographical distribution and the number of projects by country and category.

Supplementary Table 11 lists the individual projects per country in detail and assigns them to the respective categories. Further information can be found in the detailed table in *Appendix 4: Ready4H2 project database*.

The overview clearly shows that the European ramp-up of hydrogen infrastructure is in a dynamic implementation phase. While blending projects often serve as an entry-level solution for using existing gas networks, conversion and new build projects mark the transition to a long-term, fully hydrogen-based infrastructure network.

Table 11: Ready4H2 project database

	Blending	**Conversion**	**New build**
Austria	HyBS (AGGM, ÖVGW)	Green Lime H2Start Network HyGrid2 (Energienetze Stmk)	Green Refractory CemChem
Czech Republic	Hranice u Aše		
France	GRHYD		IMAGHyNE H2ZONE
Germany	Energiepark Mainz 2.0 H_2 -20 H2-MiX wind2gas Windgas Haßfurt	H2-Coastlink (+new) Energiepark Bad Lauchstädt Hydro Net H_2HoWi GET H2 (+new) Rh_2 Main Connect (+new) H_2 Direct H_2 Linnich H2Gersthofen (+new) H2-Insel Öhringen HH-WIN (+new)	H2-GeNeSiS
The Netherlands		Hoogeveen Uithoorn Lochem Wagenbogen Hoogeven Stad aan 't Haringvliet	LIFE NEW HYTS H2avennet GROWH
Slovakia	H2Pilot 5-10% certification	HP Steel testing H2Demo	
Spain	Sa i lH2 Turn 2X H2Sarea	Madrid i lH2blending H2 Retrofit Project in Madrid	BH2C Benorth2 Green Hysland HUB LA ISLA H2
Switzerland	Energie 360, Bülach		H2 Bois Iwb Basel, Birsfelden
United Kingdom	HyDeploy Spadeadam	H21 Spadeadam Hy4Heat	H100 Fife

3.2 Historical conversions in Europe

Since the late 1960s, some European countries have switched gas supply from town gas to natural gas. Compared to town gas, natural gas has twice the calorific value, meaning that half the amount of gas provides the same heat output. [54] Town gas is a toxic gas mixture produced by coal gasification, which can lead to carbon monoxide poisoning if inhaled.

Since 2018, several European countries have also switched gas supply due to the decline in production of natural gas production in Groningen (Netherlands) triggered by earthquakes in the region as a result of extracting the gas. The Dutch authorities decided to reduce gas production from the field, planning to phase out completely by 2030. Gas produced in Groningen is a low-calorific "lean" gas, abbreviated to L-gas. Many countries, however, are currently dependent on imports of high-calorific "rich" gas, or H-gas. [55]

Austria – Switch from town gas to natural gas (Vienna)

Between 1970 and 1978, Vienna switched from town gas to natural gas. This was one of the largest projects undertaken by Wiener Stadtwerke in the 1970s [54] During this period, around 1.5 million gas appliances were converted from town gas to natural gas. The main challenges during the conversion were cost issues, tender procedures and practical implementation. [56] Adaptation or replacement of appliances therefore require long-term planning and a systematic approach, as well as the gradual conversion of individual network areas. Other Austrian cities were also gradually converted from town gas to natural gas.

Belgium – conversion from lean gas to rich gas

Since 2018, Belgium has been converting several regions from low-calorific ("lean") to higher-calorific ("rich") natural gas, which is no longer sourced from the Netherlands but from Norway, the United Kingdom or Qatar, for example. [55] The Brussels region, for example, was divided into three zones for this purpose, which were converted successively in 2020, 2021 and 2022. [57] Nationwide, the last conversions were completed in September 2024. A total of approximately 1.6 million private households and commercial customers were affected. Outdated gas appliances and appliances from abroad had to be inspected and, if necessary, adapted or replaced to comply with Belgian standards.

France – conversion from L-gas to H-gas

In northern France, the so-called "Gaz-B zone" was supplied with low-calorific gas, including from the Netherlands. Since 2016, this zone has been gradually converted to high-calorific H gas. The process is expected to be completed by 2029 at the latest, as the supply contracts for natural gas from the Netherlands will end by then. The conversion is taking place on a regional basis, divided into 20 sectors. The "Gaz-B zone" represents 10% of French consumption, which corresponds to approximately 1.3 million households. In France, too, in addition to adapting the transport and distribution networks, interventions are necessary for each individual customer. [58]

Germany – conversion from L-gas to H-gas

In north-western and western Germany, the so-called market area conversion from low-calorific L-gas to high-calorific H-gas has been underway since around 2015. This is triggered in particular by the decline in Dutch L-gas production, but L-gas production in Germany is also declining. The conversion is therefore to take place at an early stage and will be carried out in stages until 2030. Approximately 25% of German household customers are affected. This includes inventory, adjustment and random quality checks of gas end devices. [59]

Netherlands – production of pseudo-L-gas by adding nitrogen

In the 1960s, the Netherlands rapidly expanded its national gas transport system. Gasunie has built a nationwide network that enabled households and industry to quickly switch from coal (and other energy sources) to natural gas. Also, in Netherlands a widespread conversion from town gas to natural gas was done. Besides Gasunie, regional distributors expanded their networks at the same time. Dutch gas distribution network covers virtually the entire country, and natural gas has historically played a dominant role in heating buildings. [60] This system was largely built using Groningen gas, which has a low calorific value (L-gas). Over

time, the Netherlands developed two parallel gas systems with different gas qualities and operates separate transport networks for L-gas and H-gas. H-gas comes from other Dutch gas fields and imports. [60, 61]

In recent years, gas consumption in the Netherlands has fallen significantly, including in private households. The reasons for this are better building insulation, more sustainable heating solutions and more efficient energy use. [62] These factors contribute to a continuous, steady decline, but do not explain the sharp drop. This is due to sharp price rises after Russia invaded Ukraine; prices rose from 1.2 euros to 2.5 -3.5 euros per cubic metre of L-gas. As a result, volumes of gas transported in the Dutch transmission network are currently declining. [63]

The Netherlands plays a special role in the transition of gas supply as part of the phase-out of gas production in Groningen. Instead of a widespread switch from L-gas to H-gas in the distribution network, the focus is on the production of so-called pseudo-L-gas. This involves adjusting the calorific value of imported high-calorific natural gas to a lower level by adding nitrogen. The aim is to continue supplying existing consumers with low-calorific gas for the time being without having to carry out widespread appliance conversions. The Netherlands intends to phase out the use of natural gas completely by 2050. This approach differs fundamentally from the market area conversions in Germany, Belgium and France.

United Kingdom – conversion from town gas to natural gas [64]

In the early 1960s, heat supply in the United Kingdom was initially gradually converted from coal and gas to town gas (which was produced from coal or oil). However, in 1965, large deposits of natural gas were discovered in the North Sea. Between 1967 and 1977, the gas supply was converted from town gas to natural gas nationwide, affecting 13 million households and 650,000 commercial and industrial users. [65] Under the *"Conversion Day programme"*, 35 million appliances in households and commercial facilities were converted. [66]

Spain – switch from town gas to natural gas

Once the natural gas arrives to Spain in 1969, the main Spanish cities switched from town gas to natural gas. During this period, around millions of gas appliances were converted from town gas to natural gas. The main challenges during the conversion were cost issues, tendering procedures and practical implementation. The adaptation or replacement of the appliances therefore required long-term planning and a systematic approach, as well as the gradual conversion of individual network areas

Summary

In the countries under review, conversion from town gas to natural gas and later from L-gas to H-gas was carried out predominantly on a regional basis and staggered over time. Technical conversion of the distribution networks resulted in considerable logistical effort, particularly in terms of adapting consumers' gas appliances. The Netherlands is an exception in that the gas quality was adjusted for existing household appliances by adding nitrogen, thus avoiding the need for large-scale adaptation of appliances.

3.3 Framework conditions

The following table provides a structured overview of the key technical and organisational steps involved in converting existing gas distribution networks to hydrogen. It shows the extent to which individual measures are necessary, what national differences exist and how these are justified.

The overview is based on practical project experience, national regulations and country-specific assessment approaches, and illustrates that conversion processes depend on respective technical, regulatory and infrastructural framework conditions.

Table 12: Overview of framework conditions in Ready4H2 countries

Austria	National guidelines (ÖVGW) on the construction, operation and organisation of hydrogen, such as *H E200 "Hydrogen pipelines", H E210 "Conversion of gas pipelines", H B210 commissioning, decommissioning and work on hydrogen pipelines and stations*. *Integrated Austrian Network Infrastructure Plan (ÖNIP)* for the future development of energy and gas networks to achieve climate targets. First conversion and blending projects in implementation.
Czech Republic	Hydrogen specified in the Energy Act as an energy carrier; ongoing implementation of Gas Package. Focus on transition of TSO grids to hydrogen and hydrogen delivery to several key industrial sites. *Czech Hydrogen strategy* prepared in 2024.
France	Strong focus on welcoming new low-carbon gases, particularly those produced by pyro-gasification (pyrolysis), hydrothermal gasification or power-to-gas.
Germany	Comprehensive, technically and scientifically sound set of rules (DVGW). *Gas Grid Transformation Plan (GTP)* as a strategic path to climate neutrality. Clear regulatory framework (EnWG, GasNZV, technical rules). Extensive experience with conversion projects and blending.
Netherlands	Very active DSO role, numerous real-world trials. High level of political and social support. More support for industrial end use, less support for residential use in recent years, although this may change. Low-calorific gas is used in the Netherlands, meaning that switching to 100% hydrogen would increase network capacity by a few percent and, as such, a capacity analysis is therefore not necessary. In addition, the existing gas networks are mostly 30 to 50 years old, generously dimensioned and supply well-insulated buildings, providing sufficient capacity reserves. Grid Package transposed and is planned to be operational on 1 July 2027. *Hydelta* research programme jointly by TSOs and DSOs.
Slovakia	Initial strategic positioning, limited experience. The Slovakian network is connected to the EU Hydrogen Backbone. Two networks are planned in the future: • a pure hydrogen network, which accounts for approximately 20% and distributes more than 50% of the gas to consumers • a methane-based network, which accounts for approximately 80% and provides for the addition of biomethane and hydrogen
Spain	Regulatory framework under development with strong orientation towards European standards. Strong focus on blending and pure hydrogen in clusters and valleys.
Switzerland	26 DSOs and TSOs have jointly founded a national initiative called "*CH42*" for a coordinated grid transformation plan.

	No traditional gas market regulation, focus on security of supply. Switzerland has an existing pipeline that is intended to be part of the European Hydrogen Backbone and primarily serves south-north transit, with a planned conversion point along the route. In the north, there are local connections to the German hydrogen core network, while the future role of these connections and the use of hydrogen still need to be clarified. Regulatory requirements are governed by the Pipeline Safety Ordinance (RLSV), which permits the transport of hydrogen. At the same time, hydrogen demand is being assessed through surveys, while the Swiss government is pursuing a reduction in the size of the gas network as part of its decarbonisation efforts.
United Kingdom	Extensive feasibility studies, mainly conducted for the *H21 project*. Politically cautious stance on widespread conversion.

3.4 Gas distribution grid conversion status

Table 13 provides a comparative overview of the current status of the conversion of gas distribution networks to hydrogen in the Ready4H2 countries. It shows different national approaches, ranging from research and pilot projects to regional conversions and long-term planning.

The overview illustrates that countries are at very different stages of implementation and that the conversion of gas distribution grids is taking place gradually, on a project-specific basis or within regional limits. National priorities, regulatory frameworks and the respective state of technical knowledge are decisive factors in this regard.

Table 13: Overview of gas distribution grid conversion status in Ready4H2 countries

Austria	Detailed technical regulatory framework available. First conversion projects in implementation. Ongoing research projects on technical feasibility.
Czech Republic	Technical study has been prepared on DSO grid compatibility with hydrogen; testing polygon currently under development.
France	Conversion of existing distribution networks is not currently prioritised.
Germany	Highly detailed, technical and scientific regulatory framework from the DVGW. Planning is based on the *Gas Grid Transformation Plan (GTP)*, which describes a standardised transformation path from the current state to climate neutrality. In terms of content, the conversion refers to the network assets of the distribution network operators and expressly excludes customer installations. Conversion in clearly defined sub-networks with defined gas qualities. Material databases and service life assessments for steel and plastic pipes. Specific DVGW rules for steel and plastic pipes (including *G 407* and *G 408*). The main best practices for the transition to hydrogen are systematic assessment, clean databases and graduated testing processes. The starting point is a detailed

	network analysis and documentation, supplemented by the introduction of damage statistics and the individual assessment of conspicuous fault locations. Another important technical aspect is the integration of cathodic corrosion protection and the implementation of regular pipeline network inspections – both before and after the feed-in or conversion. For the conversion, gradual (phased) testing and evaluation procedures are recommended, the depth and scope of which depend on the planned hydrogen content and the documentation status of the network. If there are significant technical changes, the mandatory involvement of experts is also planned. Practical examples include projects with additions of up to 20% (*H2-20 Schopsdorf* and *H2Mix Hürth*) as well as approaches with 100% H_2 supply (*H2Direkt Hohenwart* and *H2HoWi Holzwickede*).
Netherlands	Multi-year pilot projects with 100% hydrogen in existing networks (residential areas). Technical feasibility confirmed. *Hydelta programme* on technical, safety, social and conversion aspects across 90 reports. Plans for the construction of a national transport network for hydrogen by Hynetwork (*the roll-out plan*).
Slovakia	Planning to repurpose existing high-pressure pipelines. High demand for methodological support.
Spain	Conversion of existing distribution networks not currently prioritised.
Switzerland	Most existing networks are already H_2-ready. Conversion happens in clearly defined zones/subnetworks and the transition is expected to be stepwise and regionally differentiated, with conversions carried out section-by-section in topologically self-contained subnetworks (“conversion zones”), rather than nationwide at once. *(CH42)*
United Kingdom	Individual projects (currently *H100*) demonstrating technical feasibility.

3.5 Comparison and evaluation of hydrogen readiness in Ready4H2 countries

Despite differing national conditions, the country contributions presented in the workshop show a high degree of consistency in terms of content regarding key challenges and approaches to solutions in the planning of hydrogen distribution networks. At the same time, clear differences in strategic prioritisation, regulatory design and the role of network operators are apparent. The following evaluation summarises these results in a comparative manner.

3.5.1 Key challenges in a country comparison

Conversion of existing networks

An active and systematically regulated conversion of existing gas distribution networks to hydrogen can be observed in Germany, the Netherlands and Switzerland in particular. These countries either have an established technical regulatory framework or extensive practical experience from pilot and real-world projects. In Austria, the United Kingdom and Slovakia, the conversion is taking place selectively and on a project-by-project basis. In France and Spain, it currently plays a minor role.

Construction of new hydrogen networks

Construction of new hydrogen pipelines is the central strategic approach in France, Spain and the United Kingdom, particularly for connecting industrial clusters and hydrogen valleys. In Germany, the Netherlands and Switzerland, new construction is seen more as a supplement to converting existing networks.

Blending of hydrogen

Blending hydrogen into natural gas networks an provide a practical and low-threshold pathway to scale up hydrogen to compatible end users and facilitate hydrogen ramp-up. It allows existing gas infrastructure to be used immediately, reducing the need for large upfront investments while supporting early hydrogen demand and supply. Approaches to the use of blending differ between countries: some actively promote blending as a transition tool, while others are more cautious due to technical limits and impacts on end users. Despite these differences, blending is important as a bridge solution that helps accelerate hydrogen deployment until dedicated hydrogen infrastructure is fully developed.

Regulatory maturity

A high degree of regulatory clarity exists in Germany and Switzerland in particular. In the Netherlands and Austria, corresponding frameworks are currently being developed in a structured manner. In several countries (including France, Spain, the United Kingdom and Slovakia), responsibilities, approval processes and technical specifications are still in transition.

3.5.2 Universal planning modules

Regardless of the chosen transformation path (conversion, new construction or blending), the following elements are necessary in all countries:

- **Strategic embedding**: alignment with energy, grid and regional planning, and definition of long-term target gas concepts.
- **Stakeholder and governance structure**: clear distribution of roles between network operators, authorities, politicians, industry and end customers.
- **Basic technical analyses**: systematic inventory of network infrastructure, feed-in and demand analyses, and evaluation of capacities and pressure maintenance.
- **Safety and operational concepts**: risk assessments, emergency concepts, qualification of personnel and emergency services.
- **Implementation planning**: project planning, logistics, testing and commissioning planning.
- **Monitoring and learning**: continuous data collection, verification and feedback into standards and processes.

3.5.3 Context of differing national options

The design of these core components varies, depending on the national context, including in relation to:

- **Regulatory framework**: from strongly standards-based systems to evolving legal frameworks.
- **Strategic path selection**: conversion of existing networks, construction of new hydrogen networks or blending as a transitional solution.
- **End customer and end device regime**: degree of regulation, availability of device data and conversion logistics.
- **Blending limits**: national thresholds and dealing with sensitive customers.
- **Flushing and commissioning concepts**: nitrogen inertisation versus direct flushing with hydrogen.

4 Further research and investigation requirements

4.1 Open research questions and optimisation potential at European level

Overall, there is a need for further research and clarification on technical, operational and safety-related issues in connection with the conversion of existing gas networks to hydrogen and new building of hydrogen networks. These include:

- Optimisation potential in the design and safety of separation and shut-off procedures.
- The suitability of flare and blow-off equipment.
- Required flushing speeds.
- Need for practicable and standardised connection points and processes for flushing house connections and installation pipes.

These issues should be investigated, tested in practice and validated in the context of demonstration or pilot conversions that are as realistic as possible in order to create a robust pre-norm basis for incorporation into technical/safety standards.

In addition, there is still a considerable need for clarification and research at the European level on the following issues.

- **Assessment of hydrogen and hydrogen admixing compatibility with end-use connections and gas burner devices**. This particularly affects pipes and installations between the end point of the distribution network (namely house connections with a pressure regulator and meter) and the connected end device in the building. Distribution network operators generally do not have a systematic overview of the technical condition of these end systems; there is a lack of established monitoring and control mechanisms for operational safety, as well as a clear legal and regulatory framework that defines responsibilities, testing requirements and procedures for preparing these systems for future hydrogen use. The H2-Ried project in southern Germany is currently investigating different data acquisition approaches for domestic appliances in the context of mixing up to 20% hydrogen by volume into the natural gas grid.
- **Grid contamination and hydrogen quality in the context of converting existing natural gas infrastructure**. Ongoing national and European research projects (including initiatives in the Netherlands and Germany [7], and EU-funded projects such as *HyQualNet*) are investigating [67], among other aspects, the effects of residual odorants and potential contamination originating from legacy pipelines. Particular attention is being paid to the behaviour of odorant residues, deposits and material-related impurities when switching from natural gas to high hydrogen concentrations or pure hydrogen operation.

  While initial studies prepared for the European Commission have provided a preliminary assessment of hydrogen quality requirements and contamination risks, further results from current research projects are still pending. A systematic evaluation of these findings will be essential to define harmonised European requirements for hydrogen purity, acceptable contamination levels and corresponding mitigation measures. This topic therefore represents an open research field with direct implications for operational safety, gas quality management and cross-border interoperability of hydrogen networks.
- **Minimum technical requirements and standards for the construction of new hydrogen-compatible pipelines**. Uniform European specifications – based, for example, on existing standards such as *EN 1594* or hydrogen-specific regulations to be further developed – are necessary to create planning security and ensure consistent design practices, especially for transmission system operators.

Netherlands

There are currently no priority open technical research questions, after five years of *Hydelta* research, in the Netherlands. However, the implementation of national laws and regulations from the *European gas package* has been delayed, which is impacting the timing of the implementation of corresponding measures.

Czech Republic

There is a significant need for research into the operation of existing gas appliances with hydrogen admixtures of up to 20%. In particular, there is uncertainty regarding the suitability of older appliances for CH_4-H_2 mixtures. Inhouse investigations by GasNet indicate that existing test methods could also be applicable for 20% hydrogen. However, there is no generally accepted statement on this.

The main challenge is currently not the compatibility of new gas appliances with a hydrogen admixture of up to 20%. It is generally assumed that appliances placed on the market under the *Gas Appliances Regulation (GAR, EU 2016/426)* are designed to ensure compatibility with such blends. The uncertainty primarily concerns older appliances that were approved under the former *Gas Appliances Directive (GAD)* or even earlier national regulations. To date, no competent authority has issued a clear and generally binding statement confirming their suitability for operation with 20% hydrogen admixture. From an operational perspective, this creates a significant barrier: as long as there is even a single non-compliant appliance within a network area – or if access to the offtake point is not possible to verify the appliance type – the injection of hydrogen blends into that area cannot be considered permissible. This regulatory and practical uncertainty therefore represents a key obstacle to large-scale hydrogen blending and requires coordinated clarification at the European level.

Against this background, coordinated research across Europe would be helpful in order to arrive at a reliable conclusion that gas appliances tested in accordance with the *Gas Appliances Directive (GAD)* or *Gas Appliances Regulation (GAR)* are generally suitable for hydrogen admixtures of up to 20%. In addition, it would be useful to update the interchangeability and acceptance diagram (*DVGW G 260*) to explicitly take 20% H_2 mixtures into account.

Additional insights will be gained from the operational experience of the *Hranice u Aše* pilot project, in particular from end customer feedback on connected gas appliances. The experience of the current winter, in which consumption is expected to be higher than in previous years, will provide important data. Operating conditions are continuously monitored; so far, operation has been stable and without failures.

Another key area of research concerns the conversion of existing network components to 100% hydrogen across all pressure levels (above and below 16 bar). Accordingly, operational network components are being tested at a special test site under 100% hydrogen conditions, both in static operation and under dynamic medium loads. The investigations are being carried out in collaboration with technical universities and the Association of Gas Component Manufacturers in the Czech Republic.

Switzerland

The most important practical challenge mentioned is defining clear criteria for the demarcation of conversion zones and calorific value areas – possibly in the form of checklists. Open questions mainly concern the optimal sequence of the conversion: which clusters should be prioritised first, which blend levels make sense for each zone, and how are cross border interfaces taken into account?

Slovakia

From the Slovak perspective, further research and clarification is needed on the conversion of existing high pressure pipeline systems to hydrogen. In many cases, converting existing pipelines is considered the preferred option over completely rebuilding them.

There is a particular focus on the use of inline inspection (ILI) methods as a basis for decision making in conversion projects. However, there is currently a lack of detailed technical information on how to methodically perform ILI-based assessments for hydrogen applications, how meaningful the data obtained is, and what conclusions can be drawn from it in terms of the integrity, safety and suitability of the pipelines for operation with hydrogen. In terms of content, the focus is in particular on detecting cracks and defects in weld seams, for example using EMAT (electromagnetic acoustic testing) methods. In addition, it is necessary to assess how

components and fittings should be handled – in particular, whether valves need to be replaced as a matter of principle or whether selective upgrading is possible. Finally, before feeding in hydrogen, the internal cleaning or treatment of the pipeline must be taken into account to ensure a hydrogen purity of at least 98% and to reliably remove contamination.

Accordingly, there is a need for further studies, demonstration projects and a systematic compilation of best practices in order to create a robust basis for future conversion decisions.

The situation is generally considered less critical in low to medium pressure networks: no major problems are generally anticipated in the DSO network itself, while the situation in customer installations (i.e. behind the meter or main shut-off valve) is much more questionable. The specific focus is primarily on leak tests, physical inspections and, where necessary, the replacement or adaptation of appliances/consumption devices.

Germany

At the national level, the focus is primarily on legal uncertainty, lack of binding climate neutrality plans and uncertainties regarding market ramp up and hydrogen prices - in addition to technical challenges involved in converting existing networks. A robust financing scheme for DSOs is needed, as well as local political support and, finally, a political and regulatory "green light" for hydrogen in building heating. At the European level, there are also different regulatory frameworks and technical standards, and the harmonisation of hydrogen infrastructure has not yet been completed.

Spain

The final definition of the regulatory framework currently under development, as well as the implementation of national laws and regulations stemming from the European gas package, will play a critical role in the actual deployment of hydrogen as an energy commodity. Delays in this progress have had an impact on the timing of the implementation of the corresponding measures.

4.2 Need for clarification in the context of conversion processes to 100% hydrogen

In connection with specific conversion projects to 100% hydrogen [43], clarification is currently needed on the following points:

1. **Necessity of making customer pipelines inert**

   It has not yet been clarified whether it is necessary to make a distribution pipeline system inert. Due to low pipeline volumes, especially in domestic installations, and short periods of time during which pipelines are open to the atmosphere, the necessity of inertisation is currently being questioned. Further findings are expected from the *HyVent* project. Current findings show, that the inertisation of gas installation is not necessary and the flushing of natural gas directly with hydrogen is a valid option[11].

2. **Uniform procedure for flushing pipeline systems**

   A uniform procedure is needed to cover pipeline system flushing, for example with nitrogen or hydrogen. The following aspects in particular need to be clarified:

   - Should the gas be blown-out or flared and does the conversion process fall within the scope of the *EU Methane Regulation*?
   - At which opening should flushing take place? The flushing point should be as close as possible to the gas appliance.

[11] Roth, R.; Pietsch, P.: Wasserstoffumstellung von Gasinstallationen - Untersuchung notwendiger Umstellschritte bei der Umstellung von häuslichen Gasinstallationen von Erdgas auf Wasserstoff, Gaswirtschaftlicher Beirat 2025, DBI-Gastechnologisches Institut gGmbH Freiberg

- What technical and safety-related requirements apply to flaring processes?
- Is it possible to provide a defined flushing connection for new gas appliances as the end of the pipeline system or as part of the gas appliance and to standardise this via component standards and supplementary regulations?

3. **Leak test after conversion**

   According to the *German DVGW G 655* rule, if no changes have been made to the installation and it has been checked for tightness under natural gas, it is also valid for hydrogen, albeit with reduced leakage limits (0.5 l/h). If three parts or less of the installation have been changed, a visual inspection using a foaming agent or gas detectors on the changed parts is valid if the tightness of the installation has been verified under natural gas. For changes to more than three parts of the installation, a leak test of the entire installation is mandatory.

   The DVGW is currently investigating and regulating the necessary pressure levels and leakage limits for hydrogen, as well as new methods of testing.

4. **Approval procedure for conversion districts**

   Before any physical conversion of networks to 100% hydrogen can take place, the respective conversion districts must be formally approved by the competent authorities. It can be assumed that approvals will be granted for clearly defined individual conversion districts rather than for entire large-scale conversion zones. To date, regulatory experience is largely limited to the approval of individual pipeline sections; there is no established or standardised procedure yet for the approval of complete conversion districts or zones. Consequently, it remains unclear which documentation, safety assessments, certification, system boundaries and verification concepts will be required for such approvals in the future. The development of a transparent and harmonised approval framework for areas of hydrogen conversion therefore represents an important regulatory and procedural gap that needs to be addressed.

4.3 Gaps in information and regulations

Czech Republic

The Czech Republic currently lacks comprehensive technical regulations that fully cover the transition to 100% hydrogen, including technical, technological and safety-related aspects. GasNet is therefore actively involved in European standardisation and legislative processes, including within the *European Committee for Standardisation (CEN)* and initiatives such as *verifHy* (DVGW).

Early involvement of all relevant stakeholders is considered essential, in particular government agencies as the drivers of the national hydrogen strategy, network operators (transmission, distribution and storage), market participants and manufacturers of hydrogen technologies and gas appliances.

Switzerland

From a Swiss perspective, there are currently no relevant gaps in information or regulation.

Austria

In Austria, there is a particular need for clarification in the area of hydrogen certification for hydrogen admixtures. Two important laws on renewable energies and gas (as well as on gas infrastructure in general) are missing (as of spring 2026).

European level

In addition, there is a need for regulation at the European level to harmonise requirements for hydrogen quality in cross border pipeline systems.

5 Summary and conclusions

The Ready4H2 Planning Guide provides a structured framework for planning and implementing the transformation of gas European distribution networks to be compatible with hydrogen. Against the backdrop of the European market ramp-up of hydrogen and renewable gases, the Planning Guide addresses the key challenge of upgrading or expanding existing networks to be ready to transport hydrogen, whilst maintaining operations and enabling network operators to transform to hydrogen.

The Planning Guide shows how to make the transformation of gas distribution networks along three fundamental development paths: conversion of existing networks to hydrogen, construction of new hydrogen-specific pipelines, and blending hydrogen with natural gas as a transitional or supplementary option. These paths are not considered in isolation in the Planning Guide but are embedded in a common procedural framework that systematically links strategic classification, preparatory analyses, technical and organisational adaptation measures, and practical implementation.

A key finding is that, despite different national conditions – for example regulation, grid structure, material stocks or strategic priorities – there is a high degree of agreement on fundamental challenges and approaches to solving technical issues. Regardless of the chosen transformation path, recurring core components are seen in all countries, including clear strategic gas targets, robust basic technical analyses, coordinated safety and operating concepts, structured implementation planning, and continuous monitoring and learnings from project experience.

At the same time, the country comparisons make it clear that there is no uniform transformation strategy; while some countries are actively pushing ahead with the conversion of existing networks, others are primarily focussed on the construction of new hydrogen networks or on blending as an entry path. The Planning Guide takes this diversity into account by separating universally applicable planning elements from context-dependent options, thus enabling both comparability and flexibility.

The analysis of the planning and conversion processes also underlines the importance of preparatory work. In particular, delays or uncertainties in the following key success factors can have a significant impact on the entire transformation process: availability and quality of network data, assessment of material and operational suitability, early involvement of customers and stakeholders, and issues of safety, measurement and odorisation.

Furthermore, the Planning Guide makes it clear that further development of gas distribution networks for hydrogen is not solely a technical task. Organisational, regulatory and communication aspects – such as approval processes, stakeholder comms, role allocation, interfaces between network levels and dealing with different national regulations – have equal impacts on implementation. Greater European coordination and transparency can help to reduce complexity and accelerate knowledge transfer between countries – *something that the Ready4H2 project can facilitate.*

Overall, the Ready4H2 Planning Guide shows that the transformation of gas distribution networks to hydrogen-compatible systems is feasible and known, and requires a systematic, step-by-step and context-sensitive approach. The Planning Guide supports network operators identify suitable transformation paths, recognising risks at an early stage and making informed decisions. *Ready4H2 thus makes an important contribution to the practical implementation of the European hydrogen strategy and contributing to a flexible, resilient and decarbonised energy infrastructure in the long term.*

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Appendix 1: Calculation formulae for pressure loss

Parameter	Calculation formula
Density in operating state	$\rho_{b,r} = \rho_n * \frac{p_b}{p_n} * \frac{T_n}{T_b} * \frac{1}{K}$
Operating volume flow	$\dot{V}_b = w * \frac{\pi}{4} * {d_i}^2$
Standard volume flow	$\dot{V}_{n,r} = \dot{V}_b * \frac{p_b}{p_n} * \frac{T_n}{T_b} * \frac{1}{K}$
Compressibility factor	$K = \frac{Z_b}{Z_n}$
Amount of energy transported	$\dot{Q} = \dot{V}_n * H_{s,n}$
Reynolds number	$Re = \frac{w * d_i * \rho}{\eta}$
Pipe friction coefficient	$\lambda = \left[-2 * \log\left(2{,}7 * \frac{(\log(Re))^{1,2}}{Re} + \frac{k}{3{,}71 * d_i}\right)\right]^{-2}$ or $\lambda = \left[-0{,}868 * \ln\left(\frac{(\ln(Re))^{1,2}}{Re} + \frac{k}{3{,}71 * d_i}\right)\right]^{-2}$
Pressure loss per metre	$\Delta p_V = \frac{L}{d_i} * \frac{\rho}{2} * w^2 * \lambda$

Formula symbol	**Explanation**	**Unit**	**Formula symbol**	**Explanation**	**Unit**	**Index**	**Explanation**
ρ	Density	kg/m³	Z	Real gas factor	-	b	Operating condition
P	absolute pressure	bar	$\dot{Q}$	Energy transported	kW	n	Standard conditions
T	Absolute temperature	K	H_s	Calorific value	kWh/m³	r	Real gas
K	Compressibility factor	-	Re	Reynolds number	-		
$\dot{V}$	Volume flow	m³/h	μ	Dynamic viscosity	kg/(m*s)		
w	Flow velocity	m/s	λ	Pipe friction coefficient	-		
d_i	Pipe internal diameter	mm	κ	Isentropic exponent	-		
L	Pipe length	m					

Appendix 2: Comparison of flow velocities and pressure losses (hydrogen and natural gas)

		Operating pressure in bar						
		0.250	0.50	3.0	6	12	22	60.0
		Flow velocities in m/s						
Natural gas		5.0	5.0	10	10.0	10.0	20.0	20
H_2		15.8	15.8	31.8	32.1	32.6	67.2	75.0
		Increase in pressure losses in %						
d_i in mm	**25**	+ 39	+ 38	+ 28	+ 27	+ 28	+ 29	+ 44
	50	+ 38	+ 37	+ 28	+ 27	+ 27	+ 29	+ 44
	100	+ 37	+ 36	+ 28	+ 27	+ 27	+ 29	+ 44
	150	+ 36	+ 36	+ 28	+ 27	+ 27	+ 29	+ 44
	200	+ 36	+ 35	+ 28	+ 27	+ 27	+ 29	+ 44
	300	+ 36	+ 35	+ 28	+ 27	+ 27	+ 29	+ 44

Appendix 3: Calculation formulae for GPRMS capacity calculation

Component	Calculation formula	
Nominal inlet diameter	$\dot{V}_n = \frac{\pi}{4} * {d_{i,u}}^2 * w_u * \frac{p_b}{p_n} * \frac{T_n}{T_b}$	w_u recommended: max. 20 m/s
Filter	$\dot{V}_n = A_b * A_F * \frac{p_b}{p_n} * \frac{T_n}{T_b}$	A_b recommended: max. 200 $\frac{m^3/h}{m^2}$
Gas pressure regulator	$\dot{V}_n = K_G * \sqrt{p_d * (p_u - p_d)}$	à subcritical pressure ratio
	$\dot{V}_n = K_G * p_u * \frac{1}{2}$	à supercritical pressure ratio
SAV	$\dot{V}_n = \frac{\pi}{4} * {d_{i,SAV}}^2 * w_{SAV} * \frac{p_b}{p_n} * \frac{T_n}{T_b}$	w_{SAV} recommended: max. 50 or 70 m/s
Gas meter	$\dot{V}_n = G * \frac{p_b}{p_n} * \frac{T_n}{T_b}$	
Nominal outlet diameter	$\dot{V}_n = \frac{\pi}{4} * {d_{i,d}}^2 * w_d * \frac{p_b}{p_n} * \frac{T_n}{T_b}$	w_d recommended: max. 20 m/s
Preheating	$\dot{V}_n = \frac{\eta * W_{Kessel} * 3600}{\rho_n * c_{p\,m} * \Delta T_1}$	

$\frac{p_d + p_{amb}}{p_u + p_{amb}} \geq 0{,}53 <$	$\frac{p_d + p_{amb}}{p_u + p_{amb}}$
Subcritical	supercritical

Formula symbol	Explanation	Unit
$\dot{V}$	Volume flow	m³/h
d_i	Inner diameter	m
w	Flow velocity	m/s
p	Pressure	bar
T	Temperature	K
A_b	Max. filter load	$\frac{m^3}{h}/m^2$
A_F	Filter area	m

Formula symbol	Explanation	Unit
K_G	Standard flow rate Regulator	m³/h
G	Counter size	-
η	Efficiency	-
W_{Kessel}	Boiler output	kW
ρ	Gas density	kg/m³
$c_{p\,m}$	Specific heat capacity	$\frac{kJ}{kg * K}$
ΔT_1	Temperature increase	K

Index	Explanation
u	Upstream (inlet)
d	downstream (output)
n	Standard conditions
b	Operating condition
SAV	SAV

Appendix 4: Ready4H2 project database

Austria		
HI2 Valley	Within the Hydrogen Industrial Inland (HI2) Valley, 17 projects are being developed. The projects listed below include conversion, new building and blending.	
Green Refractory	new	DSO The gas distributor KNG-Kärnten Netz plans to locate new pipeline routes for H_2 transportation.
CemChem	new	TKNG, as the local gas DSO, KNG is working on a concept for a new hydrogen grid connection between the South Hydrogen Corridor and the project partners.
Green Lime	conversion	InterCal Austria will cooperate with the energy company Energie Steiermark Wasserstoff GmbH to repurpose existing gas pipelines to meet increasing H_2 H_2 demand.
H2Start Network	conversion	Conversion of a 30 km gas pipeline between Linz and Sattledt and construction of a new 7 km pipeline allowing for hydrogen transportation between the cities of Asten and Ebelsberg.
ÖVGW projects	Several green gas projects are (co-)funded by ÖVGW (more information available upon request)	
HyGrid2	conversion	Publicly funded project. The aim is to convert an existing pipeline and establish a demonstration facility. The project addresses challenges like pipeline inspection, hydrogen quality, and material readiness, while considering specific national conditions.
HyBS	blending	Project to simulate and measure the concentration of hydrogen in a gas network with multiple entry and exit points, as well as a hydrogen feed-in station. The project aims to develop a reliable simulation tool that can forecast the maximum hydrogen concentration within the network and ensure that this limit is not exceeded.
Czech Republic		
Hranice u Aše	blending	Pilot project using the existing gas network to distribute a blend of natural gas and renewable H_2 to households and smaller industrial offtakers. Level of blend currently at 10%, heading towards 20%.
Polygon Pardubice	blending, conversion	New training facility for training of personnel and for testing equipment and components (both new and those extracted from the existing network). It is designed to operate with natural gas, hydrogen blends and hydrogen.
France		
IMAGHyNE	new	Hydrogen Valley in Auvergne-Rhône-Alpes that will cover the entire value chain: production, storage, transport, distribution and uses for industry, energy and mobility. GRDF is a partner in this project.
GRHYD	new	Building a new supply chain based on hydrogen enriched natural gas. GRDF is in charge of GN-H_2-NG blend injection and distribution in the gas grid. Additional Information.[68]
H2ZONE		in 2024, this hydrogen experimentation and training platform has been set up on the Energy Formation campus near Nantes, by GRDF. With a surface area of 1,000 m2, it is designed around a H2 network organized into several

		functional and educational zones: injection, work, leak detection, etc.
Germany		
H2-Coastlink	conversion, new	Comprises five sections, each of which makes a key contribution to connecting the regional infrastructure to the German hydrogen core network. The five sections have a total length of 239 km. 62% of the pipelines already exist and will simply be converted. The first pipelines will go into operation in 2027. EWE is investing €250 million. The project will therefore cost significantly less than a new construction.
Energiepark Bad Lauchstädt	conversion	Flagship project producing GH_2 from wind power and transporting it via a converted 25 km natural gas pipeline to supply industrial customers.
Energiepark Mainz 2.0	blending	Blending into the local natural gas network.
Hydro Net	conversion	Project in the Sauerland region aiming to build a regional hydrogen market and infrastructure for industrial SMEs. A key element is the conversion of the 11 -km former natural gas pipeline between Arnsberg and Balve.
H_2HoWi (100%)	conversion	Conversion of part of the natural gas network for the transport of hydrogen in Holzwickede. Hydrogen is supplied to several commercial customers who use it for heating. Four hydrogen heating appliances from Remeha are in operation here. The replacement of natural gas, with the effects on materials, safety and operational feasibility is scientifically monitored.
GET H_2, TransHyDE consortium	conversion, new	GET H_2 TransHyDE is a German flagship hydrogen infrastructure project focused on converting existing natural gas pipelines and building new hydrogen networks. Using a real test pipeline in Lingen, the project develops practical methods for safe operation, inspection, cleaning, and leak detection to enable reliable long-distance hydrogen transport.
Rh_2 Main Connect	conversion, new	Building a regional hydrogen network to supply the Frankfurt Rhine-Main area with GH_2. Plans for an initial ~120 km starter grid, expandable later to meet growing industrial and mobility demand.
H_2 Direct (100%)	conversion	In Hohenwart, Vaillant supplied heating appliances for 100% hydrogen as part of the "H_2 Direkt" project. Starting in September 2023, an existing small gas network in a district of the town was converted to supply pure hydrogen instead of natural gas. The project supplies ten households and a small business. The natural gas heating appliances were replaced with new hydrogen heating appliances.
H_2 Linnich	conversion	Pilot project testing how an existing natural gas network can be converted to run fully on pure hydrogen. It supplies a local site entirely with hydrogen to prove safe, practical operation and gain insights for future climate-neutral heat networks.
H_2 -20	blending	A DVGW pilot project involving 350 households demonstrated that it is possible to blend up to 20% hydrogen into an existing natural gas grid without making any changes to pipelines or household gas appliances. It provides key evidence for the safe integration of hydrogen into today's gas infrastructure.
H2-MiX	blending	Blending of 20 vol.% hydrogen to the natural gas network and testing of around 100 household appliances over an extended period of time.

H2-GeNeSiS	new	Hydrogen system along the Neckar River as a basis for scaling up the hydrogen economy in the Stuttgart region. On site, surplus green electricity is converted into hydrogen and processed for use in the neighbourhood, in mobility and in industry.
H2Gersthofen	conversion, new	Approx. 1,200 m pipe network in pressure class DP 4, of which the last 250 m have been reclassified, including house connections; main pipe constructed in 1992–1993. Transport of hydrogen to four apartment buildings with around 250 residential units and a heat demand of 2.5 gigawatt hours per year (GWh/a). The project is in the implementation phase until autumn 2026.
H2-Insel Öhringen	conversion	The supply of 100% hydrogen was tested in a field trial lasting two months (in 2025). The hydrogen was used to heat the property's buildings. Safe and reliable operation with 100% hydrogen from the gas network, domestic installations and gas appliance.
HH-WIN	conversion, new	Hamburg hydrogen industry network covering around 60 km is set to supply hydrogen to the majority of Hamburg's industrial companies in future.
wind2gas	blending	Blending into the natural gas network of Schleswig-Holstein Netz AG.
Windgas Haßfurt	blending	Blending into the local natural gas network.
Ireland		
HyTest	blending	Study assesses how up to 20% hydrogen can be safely blended into Ireland's gas distribution network.
The Netherlands		
Hoogeveen	conversion	Pilot project repurposing the natural gas network for transport of hydrogen that be used to will heat 12 homes in Hoogeveen.
LIFE NEW HYTS	new	Demonstration project that builds and tests a local value chain for GH_2 (production, distribution, and refuelling) to accelerate hydrogen use in heavy road transport.
Amsterdam Port Area The name is H2avennet	new	Plan for a public hydrogen distribution network (pressure 15,5 bar) for port-area industry, designed to later connect to a high-pressure transmission backbone.
GROWH	new	Local hydrogen chain concept in Deventer covering the complete supply $_{H_2}$chain from generation and production to distribution and consumption.
Uithoorn	conversion	Temporary pilot project in the town of Uithoorn, where 14 vacant houses have been adapted to test domestic heating systems running on zero-emission hydrogen fuel. https://www.bdrthermeagroup.com/stories/hydrogen-homes-go-live-in-uithoorn
Lochem	conversion	Three-year pilot converting the existing town gas grid for 100% hydrogen. Pipelines made of PE and PVC were connected to 12 households (13 condensing boilers). No changes were made to the existing gas grid and the in-house installation, which are 5-80 years old, with the exception. A number of newly installed access flow valves and hydrogen meters were installed. In addition, two hydrogen sensors per house were installed. The

		project was live from 2022 - 2025.
Wagenbogen	conversion	Pilot project converting the existing gas grid to 100% hydrogen with pressures between 100 mbar (g) up to 8 bar(g), which is the highest pressure in existing natural gas grids. The project supplies 33 houses using a hybrid heat pump. It has been operational since 2023 and will run for another eight years.
Hoogeven	conversion	Upcoming conversion project in Hoogeveen with around 100 houses.
Stad aan 't Haringvliet	conversion	Upcoming conversion with 618 houses coming online in 2028. A multi-fuel boiler is being developed for this project.
Slovakia		
H2Pilot	blending	In 2022, the H_2 Pilot project tested a blend of 10% hydrogen blending in a village of 300 consumers. https://www.spnz.sk/wp-content/uploads/2024/09/Demec_P_Jesenna_konferencia_2024.pdf
HP Steel testing	conversion	In 2023, SPPD, the Slovak gas DSO, conducted a high-pressure steel testsing to examine the impact of hydrogen on HP steel pipelines typically used for natural gas distribution.
5-10% certification	blending	In 2024, the entire network was certified for hydrogen blending with 10% in city grids and 5% in high-pressure grids.
H2Demo	conversion	The H2Demo test polygon in 2025 aimed at 100% hydrogen tightness tests on conventional gas grid components.
Spain		
Sa i lH2	blending	Building a new electrolyser-based hydrogen hub and related facilities (refuelling station, industrial supply, future grid injection). Gedisol Energía distributes GH_2 using tube trailers for supply distribution. Herogra uses GH_2 blended with natural gas for fertilisers.
Madrid i lH2blending	conversion	Madrileña Red de Gas (a gas distribution company) and Pryconsa (a real estate developer) plan to supply 100 homes in Valdemoro with GH_2 instead of natural gas.
Turn 2X	blending	GH_2 produced and blended with natural gas (RNG) that is transported via the existing pipeline infrastructure to customer destinations (factories with high energy consumption).
BH2C	new	Until 2027: 100% H2 Pipeline in Biscay, connecting an electrolyser at Petronor refinery with ABANTOs Hydrogen Industrial Area. (Phase I) 100% H2 Distribution Pipeline within Bilbaos Harbour. (Phase II) 100% H2 Distribution Pipeline from Bilbao's Harbour, in paralell to the left side of Bilbao's river, connecting the main industrial areas. (Phase III) Until 2028: Other industrial projects in the area that will be connected to the valley. (Phase IV)
Benorth2	new	100% hydrogen Pipeline in Biscay, connecting an electrolyser in Amorebieta with industrial companies in the area all the way to Arrigorriaga.
H2Sarea	blending	Seeks to research and develop the necessary technological solutions for

		the safe distribution of hydrogen and its mixes with NG in the natural gas network. The scope covers the range of tests and studies carried out to validate using the existing network to distribute natural gas with 20% green hydrogen blends, and the end use of this fuel by users. Tests finished with successful results.
H2 Retrofit Project in Madrid	conversion	The final version of the project of gas network retrofit to hydrogen in a municipality (Madrid) is completed. This analysis has been presented to Madrid Authorities. Technical features: - 5,170 connection points (3.402 flats + 1,714 single-family house + 51 commercials; 11 institutions of public interest; 4 boiler rooms; 1 industry). - 36,650 m of existing gas network, in polyethylene. - Maximum natural gas consumption: 2,100 Nm^3/h.
Green Hysland	new	Aims to deploy a fully functioning hydrogen ecosystem in the island of Mallorca, Spain. It will be achieved by producing green hydrogen from solar energy and delivering it to the end users (island's tourism, transport, industry...), including gas grid injection.
HUB LA ISLA H2	new	The project consist of the production of green hydrogen by means of an electrolyser (1 MW) to be implemented in the facility of the SailH2 company and the infrastructure associated to make possible the injection of hydrogen produced in the gas network of Sevilla managed by Nedgia as DSO. Nedgia will manage the associated infrastructure, mainly the injection module and the construction of approximately 1 km of new steel pipeline and valves associated.
Switzerland		
CH42	new	CH42 is a joint initiative of Swiss gas network operators for the coordinated transformation of gas networks to enable the use of renewable gases such as biomethane, hydrogen, and hydrogen blends.
Hybridwerk	blending	Since 2016, Regio Energie Solothurn's Aarmatt hybrid plant has demonstrated how surplus solar and wind power can be converted via power-to-gas into hydrogen and, since 2018, additionally through methanation into storable methane for injection into the gas grid.
United Kingdom		
H100 Fife	new	Residential hydrogen heating demonstration project in Scotland. It will produce 100% GH_2 and deliver it through a new dedicated hydrogen gas network to around 300 homes.
HyDeploy	blending	The HyDeploy demonstrations in Keele and Winlaton, have shown that existing boilers and cooking appliances can run safely on a blend of up to 20% hydrogen with natural gas with no disruption to households at all. This project has also demonstrated that blended hydrogen can be used safely without any changes in industrial and commercial equipment too.
H21	conversion	UK programme testing whether the existing natural gas distribution network can be safely converted to carry 100% hydrogen for low-carbon home heating. It includes leak and safety trials, public research, and

		demonstration phases.
Spadeadam	conversion; blending	Test and demonstration site for hydrogen pipelines and gas network transition in Cumbria.
Hy4Heat	conversion	Replacing natural gas (methane) with hydrogen in residential and commercial buildings and gas appliances.