Fyrtårn Syd Project

Documentation demands for hydrogen infrastructure

August 2023

energy CLUSTER DENMARK

DGC
Dansk Gasteknisk Center

FORCE TECHNOLOGY

THE EUROPEAN UNION
The European Regional
Development Fund

Funded as part of the Union's response
to the COVID-19 pandemic

Investing in your future

Foreword

This report was prepared for the project *Documentation demands for hydrogen infrastructure* as part of the Lighthouse South: Green Energy and Sector Coupling, facilitated by Energy Cluster Denmark and funded by the European Union Regional Development Fund, as part of the Union's response to the COVID-19 pandemic.

Various sources were consulted for this report, including the industrial partners listed in Section 1.1 and the references stated throughout the document. The authors believe that the data presented in this report comes from reliable sources but are not able to guarantee its full accuracy or completeness. The situation regarding documentation demands for hydrogen is also developing and changes to the text in this document should be expected.

The target group who we envisage will read this document consists of designers, engineers, manufacturers, permitting authorities, procurement, and sales officers, as well as those stakeholders within the hydrogen industry in need of an overview.

This document is specifically addressed to provide guidance in the present situation where development of the hydrogen technologies occurs alongside the development of hydrogen standards. There is no legal requirement to follow this guideline, but it may serve as an aid in navigating the available information, as it provides the background and focus areas in a Danish and European context.

Our baseline assumption is that Danish legislations is closely aligned with European legislation. The guideline can therefore also be applied in a European context unless another reference is mentioned.

The report has been prepared by FORCE Technology and Danish Gas Technological Centre (DGC), in collaboration with industry partners.

Table of Contents

Aim

The aim of this report is to provide a general understanding of how European standards and guidelines are developed for hydrogen infrastructure and to summarise specific requirements related to safety and product integrity. Pathways to testing and certification for materials, components, and products will be suggested.

Scope

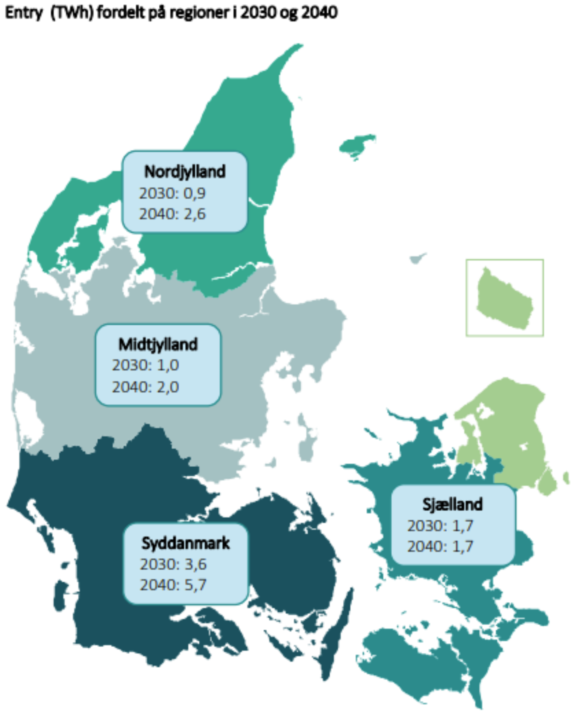
The scope of this report will provide the options to consider when working towards standardisation of documentation for hydrogen infrastructure, specifically for materials, components, and systems. It will do so by reviewing the requirements written in both harmonised and non-harmonised standards and in addition, present recent European activities that focus specifically on hydrogen standardisation.

PART 1

1.0 Project motivation

The motivation for this report was established in late 2021.

Hydrogen is Denmark's new export adventure. One Power-to-X (PtX) facility after another is being considered without the existence a solution being developed for the infrastructure necessary to enable this new type of energy supply. Many reports indicate that hydrogen infrastructure will be crucial for the green transition [1]. A 2021 report from Energinet [2] confirms that the need for this infrastructure will be the Southern Denmark, as shown in the image below. Here the electricity demand to produce hydrogen will be 3,6 TWh in 2030.


Entry (TWh) fordelt på regioner i 2030 og 2040

It is worth noting from the same report is that while Energinet previously aimed to establish a fully commercial hydrogen infrastructure by 2030, the majority of market actors have expressed a desire for a scaling that is fully established well before 2030. Some work has already begun to assess the possibility of converting parts of the existing natural gas infrastructure for hydrogen use, but this infrastructure will not be able to stand alone, and new infrastructure must therefore be established to meet the market demands for PtX.

Whether through conversion, or the construction of new infrastructure, the current approval requirements for hydrogen products are typically very strict or non-existent. In many instances, the requirements are vague, and it is up to the equipment supplier to determine what documentation should be provided. This leads to varying examples of hydrogen ready documents, complicating the establishment of an efficient national hydrogen infrastructure.

The underlying intention of this project was to develop input for a national guideline for documentation demands for hydrogen infrastructure. To try and work towards a common understanding, stakeholders in the hydrogen value chain (see 1.1) discussed how to document the suitability of pressurised gas equipment for safe storage and transportation of hydrogen. The stakeholders included infrastructure owners, authorities, equipment suppliers, and independent technical institutes, who assisted with defining what would constitute sufficient and acceptable documentation requirements.

The result of this project will provide input for a common guideline that can be evaluated and approved by all stakeholders in the hydrogen value chain. This project also collaborated with partners from Sweden and Germany on norms and regulations, so an international guideline could function collectively in the future. The project team considered it an advantage also to look outside of Denmark for inspiration and collaboration.

This project used the Frøslev-Egtved pipeline located in the South Denmark region as a basis. The pipeline has been in focus to support the export of green hydrogen to Germany, primarily from hydrogen-producing facilities in South Denmark. The project covered both local and national focus areas since the existing pipeline sections within Denmark would connect to the European Hydrogen Backbone [3].

1.1 Hydrogen infrastructure included in this report

The project was led by FORCE Technology and Danish Gas Technological Centre (DGC) with the support of the following partners:

- AVK International
- Energinet
- Evida
- Everfuel
- Elster-Instromet
- Euromekanik (SE)
- Fluoroseal
- Honeywell (DE)
- MS-Flowtechnic
- RMA (DE)
- Siemens Gamesa Renewable Energy
- Sikkerhedsstyrelsen (the Danish Safety Authority)

Interviews with all partners lead to a condensed list of components to be considered for analysis and to be implemented in the guideline. Some partners had a broader scope, and limitations in project budget did not allow for inclusion of all relevant components, nor did it allow for a sole focus on hydrogen pipelines. The following was established as the specific components and areas of interest for this project:

- Valves
- Meters
- Hydrogen sensors
- Gas chromatographs
- Filters
- Pressure regulators
- Insulation couplings
- Compressors
- System design

1.2 Generalised approach

The approach was to work towards a report that considered the general aspects that make up hydrogen infrastructure, such as the system, the product, the component, and the materials that make up that system. These general aspects were then condensed into 4 primary focus areas, namely: materials, safety (legislation), measurement, and functional performance of a test object in a hydrogen environment.

Materials

The material category evaluates the integrity of the materials utilised in pipelines, valves, compressors, and other components. The category sets up the parameters for testing and then relates the parameters to procedures mentioned in harmonized or not harmonised standards. The testing conduced in relation to the standards constitute the documentation required for integrating the specific component.

Safety

The safety category evaluates if the component or product interferes with the overall safety, as required by European essential requirements. The category states the risks associated with integration of the specific component or product accordance with European directives. The documentation within the safety category constitutes certifications of different accredited organisations or notified bodies, in addition to a risk analysis.

Measurement

The measurement category evaluates the performance-based parameters a product manufacturer must document before application in a regulative area. Such parameters include target gas compositions, calibrations gases, uncertainties, detection ranges and cross-sensitivities. Typically, the documentation constitutes accordance to a harmonized standard that is scoped within the specific product.

Post-functional

The post-functional category consists of an evaluation of the performance on the component or product after integration within the design. The evaluation inspects if the component or product satisfies the earlier-defined performance and safety requirements when it is operating in a hydrogen gas environment. The post-functional evaluation can be inspired by closely matching alternative standards if specific standards do not exist.

1.3 Partition of components related to documentation focus area

To assist with the literature search, evaluation and discussions, a standardised hydrogen component was created that had measurement, materials, safety, and regulation as its 4 baselines.

Measurement

- Hydrogen sensors
- Gas chromatography
- Metering

Materials

- Embrittlement of steel and metals
- Diffusion and or permeation of the gas through materials
- Non-metals

Safety

- Hydrogen characteristics
- ATEX requirements
- Risk assessment
- Risk analysis

Regulation

- Hydrogen infrastructure
- Harmonised standards
- Non-harmonised standards
- Conformity assessment
- Technical documentation

1.4 Properties of Hydrogen

The blending or substitution with hydrogen instead of methane-bases system entails an overall physical change of the energy carrier in the gas infrastructure, due the considerable difference of characteristics of hydrogen compared to methane.
In Table 1 important characteristics of hydrogen are compared to methane.

Compound	**Hydrogen**	**Natural gas**
Molar mass (g/mol)	2.02	16.04
Gas Density (kg/Nm^3)	0.09	0.72
Diffusion rate (cm^2/s)	0.61	0.16
Flammability range (vol%)	4-75	4-16
Minimum ignition Energy (mJ)	0.02	0.29
Autoignition temperature min (°C)	520	630
Flame velocity (m/s)	2.7	0.37
Lowe heating value (MJ/Nm^3)	10.8	36
Speed of sound (m/s)	1260	430
Global warming potential (CO_{2eq}/kg)	≈5.8	28

Table 1 Characteristics of hydrogen compared to methane.

The relatively low molar mass and density of hydrogen compared to methane, together with high diffusion rate of hydrogen may add to a higher probability of fugitive hydrogen emissions compared to methane. The higher flammability range and lower ignition energy and temperature of hydrogen compared to methane also adds to a higher risk of combustion. The different characteristics of hydrogen compared to methane will therefore contribute to different safety precautions, such as different potential hazardous zones in the vicinity of pressurized hydrogen components.

Additionally, hydrogen embrittles materials such as steel, which affects the integrity of the hydrogen infrastructure. Such precautions often give rise to additional testing of materials in gaseous hydrogen.

The characteristics of hydrogen as compared to methane is a key topic to consider, however not the focus of this report. Additional information is available in an abundance of sources, such as *ISO/TR 15916:2015: Basic considerations for the safety of hydrogen systems* [4] which is currently being updated by the ISO/TC197 technical committee.

1.5 Summary Part 1

The project was initiated based on a general lack of guidance within the hydrogen industry, as regards standards for components in hydrogen infrastructure. This was expressed by the project partners, and based on partner interviews, a list of components to be considered was derived. In the present guideline a division in the aspect of measuring components, material for hydrogen and safety is used. The characteristics of hydrogen as compared to methane is a key topic to consider, however the main focus of the present guideline is how this may cause different documentation demands and requirements.

PART 2

2.0 Regulation of the gas grid

The Danish Working Environment Act (LBK) no. 2062 of 16/11/2021 (and earlier editions) is a framework Act, which covers the general objectives and requirements in relation to the work environment. Amongst other things the act covers the design and safety of the workplace and requirements for technical equipment.

The LBK authorizes The Ministry of Employment (Beskæftigelsesministeriet) to define additional safety requirements on top of the existing EU regulations. These supplementary more detailed rules and requirements from the Ministry of Employment are laid down in executive order no. 1988 of 9/12/2020 *Executive order on safety requirements for natural gas facilities and biogas facilities under the Working Environment Act*[1] and covers pipelines, compressor stations, regulator stations and other supplementary equipment for the transmissions, storage and distribution of natural gas and upgraded biogas. The *Work Environment Denmark* (Arbejdstilsynet) is the authority on natural gas and biogas installations. Re-organisation early 2023 has changed the authority and merged part of Sikkerhedsstyrelsen (*the Danish Safety Authority*) and Arbejdstilsynet to cover hydrogen.

The executive order recognizes the *GPTC-guide* [5] as a suitable basis for compliance with the requirements related to the manufacture, construction, and operation of natural gas- and biogas installations in the executive order, provided the supplementary provisions specified in the *AT-Guide F.0.1* [6] prepared by the Danish Working Environment Authority are employed in conjunction with the guide (§2(2) in executive order no. 1988 of 9/12/2020).

The *GPTC-guide* has been developed based on American rules and conditions. A full recognition of the Guide would conflict with recognized (Danish) principles for calculation, construction, and surveillance of the pipeline (*GPTC-guide*) [5]. Therefore, the supplementary provisions in *AT-Guide F.0.1* sets out the necessary restrictions and supplements to the *GPTC-guide*, which are needed to adapt the guide to Danish conditions. Provided the *GPTC-guide* is employed with the supplementary provisions in *AT-guide F.0.1,* Work Environment Denmark will not take further actions.

The *GPTC-guide* [5] is not only recognized in Denmark but is employed as the design basis for natural gas grids in some European countries. As is the case in Denmark, the guide is sometimes supplemented with national supplementary rules and/or with the requirements provided in *EN 1594:2013 Gas infrastructure – Pipelines for maximum operating pressure over 16 bar – Functional requirements* [7]. This makes it simple to ensure interoperability, cross-border trade, and to provide uniform and consistent documentation across member states.

---

[1] The requirements were originally described in executive order no. 414 of 8/7/1988 under Work Environment Act no. 646 of 18/12/1985 and did not include biogas facilities.

2.1 Regulation of a (future) hydrogen grid

While existing national legislation refers to a specific recognized standard (supplemented by a national guideline) for the construction, manufacture and operation of infrastructure elements intended for the transport of natural gas (and biogas), no such reference to a recognized standard exists in the legislation for the transport of hydrogen, which makes it significantly more cumbersome to design a grid for hydrogen transportation. Infrastructure intended for the transport of hydrogen currently will needs to abide by the Working Environment Act no. 2062 of 16/11/2021.

It follows from the act, that recognized norms or standards, which are relevant to safety or health must be followed. Executive order 429 of 05/04/2022 on the design of technical equipment as well as Executive order 428 of 05/04/2022 on the use of technical equipment also applies. Work environment Denmark Authority[2] is the authority on the Working Environment Act and the associated executive orders.

Besides regulation of the work environment, the distribution of hydrogen is subject to the Gas Safety Law (Gassikkerhedsloven) no. 61 of 30/01/2018 and the five executive orders associated with the law. Of the five executive orders order no. 253 of 04/04/2018 on the safety of gas facilities (Gasanlægsbekendtgørelsen), which also applies to distribution pipelines intended for the transport of hydrogen (§ 2(9)), order no. 239 of 23/03/2018 on the safety of gas equipment (Gasmaterielbekendtgørelsen) and executive order no. 240 of 23/03/2018 (Gasdistributionsselskabsbekendtgørelsen) are considered of particular importance for the distribution of hydrogen. The Danish Safety Technology Authority (Sikkerhedsstyrelsen) is the authority on the Gas Safety Law and associated executive orders.

In general, the Gas safety law refer to the use of standards, which are recognized in the five executive orders (§7 and §8). In cases where these standards are not -or cannot be- used for the transported gas, it must be documented, in which way the safety requirements in the gas safety law are satisfied (§7(2) and §8(2)). Likewise, the safety requirements in the executive order on gas facilities can be satisfied, if the owner of the gas facility can document, that the chosen design meets a safety level which is at least equivalent to the safety level in the referred standards (§3(2)) (equivalent safety criteria). In general, most, if not all, the standards referred to in the executive order on gas facilities, consider gas which follows definitions in DS/EN 437 *Test Gases*. Hydrogen is not mentioned as a distinct gas in the scope of the standard. EU Regulation 2016/426 on appliances burning gaseous fuels (Gasapparatforordningen) annex II, states that the member states shall communicate criteria for gas that can be distributed to consumers in their territory – including hydrogen content. Suitable test gases shall be decided based on these criteria.

The documentation burden for each individual element in the infrastructure (pipeline, valves, gas chromatographs, etc.) falls to the equipment manufacturer, who must be able to document to the infrastructure owner, that the equipment is fit for purpose. Provided suitable recognized standards or suitable guidelines exist, the manufacturer may choose to

---

[2] Arbejdstilsynet

refer to compliance with their requirements, as part of documenting the fitness for purpose of their equipment.

In the absence of suitable recognized standards, the manufacturer may prove the fitness for purpose by designing suitable test programs or have such designed by a recognized test institute. Unfortunately, without any harmonized test standards to adhere to the requirements for such tests are not well-defined. This can lead to non-conforming procedures between the various test institutes around Europe. Furthermore, due to a lack of harmonized test procedures and well-defined acceptance criteria, a statement of conformity issued by one institution for certain conditions may not be accepted as sufficient documentation for demonstrating fitness for purpose in all member states across Europe.

Prior to any large-scale establishment of a hydrogen infrastructure, it should be clarified according to which norms and standards the authorities will approve the infrastructure. Such clarification should make the design, documentation, and approval process much more uniform and efficient for both infrastructure owners and authorities and will help ensure a consistent level of safety for all facilities. A possible solution could be a review of executive order 253 of 04/04/2018 on the safety of gas facilities, so that a suitable standard for hydrogen pipelines can be referenced. This could include the addition of national supplementary requirements, or as an alternative, that a new executive order, specific to safety requirements for hydrogen facilities is developed. To prevent dual jurisdiction between Work Environment Denmark and the Danish Safety Technology Authority, such a reference should not be incorporated into order 1988 of 9/12/2020.

2.2 Example guidelines and standards for hydrogen systems

Standards and guidelines for material selection, construction and operation of infrastructure intended for the transport of hydrogen do exist. Further, standards covering infrastructure components at present may be accommodated to include hydrogen. It is likely that these standards will be recognized as a partial basis for compliance with the requirements related to construction, operation, and maintenance of a hydrogen infrastructure. A condensed list of some of the relevant standards and guidelines described in the following include:

- ASME B31.12:2019: *Hydrogen Piping and Pipelines*
- ISO/TR 15916:2015: *Basic considerations for the safety of hydrogen systems*
- EIGA 121/14/E (2014) *Hydrogen transportation pipelines*
- IGEM/TD/1 Edition 6 Supplement 2: *High pressure hydrogen pipelines*
- IGEM/TD/13 Supplement 1: *Pressure regulating installations for hydrogen at pressures exceeding 7 bar, 2021*
- DVGW G 406: *Requirements for New Gas Valves in H2 Applications for Gas Transmission, Gas Distribution and Gas Installations*
- DVGW G 409: *Conversion of High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar for Transportation of Hydrogen*

Until we have sufficient experience with updated knowledge. It is expected that the Danish Safety Technology Authority, in many respects will refer to some of the requirements stated in ASME B31.12 *Hydrogen Piping and Pipelines* [8].

ASME B31.12 is considered one of the first standards for the transport of hydrogen in pipelines and it includes the requirements and guidelines for selecting materials, design, construction, maintenance, and operation of steel pipelines intended for the transport of hydrogen. Both ASME B31.12 and B31.8 (*Gas Transmission & Distribution Piping Systems*) on which the GPTC-guide is based, are part of the ASME B31-series for pressure piping. ASME B31.12 incorporates relevant parts of ASME B31.8 [9] with a focus on hydrogen. Resultingly, the standard largely follows the same terminology and structure as the GPTC-guide [5].

There are several differences between the two codes, for instance regarding material requirements, design options, as well as changes to the design factor in certain location classes. However, in most respects, the requirements in the code differ only marginally from those given in the GPTC-guide, which the authorities as well as the methane DSO and TSO already have prior experience with and which forms part of the Danish guidance for the construction, manufacture, maintenance, and operation of natural gas infrastructure.

The ASME standard is based on American conditions, and like the approach for the GPTC-guide, it is not expected, that the standard can be recognized without suitable restrictions and supplements. The Danish Safety Technology Authority is, however, not expected to develop a supplementary guideline similar to AT-guide F.0.1 [6]. This leaves it up to the infrastructure owner to propose suitable restrictions and supplements to the ASME code.

Hence, the main reference is ASME B31.12 which is a frequently referenced standard for hydrogen pipelines, and it is used in a broader sense than what may have been the intention. At present, standards for offshore pipelines are not yet developed, leading to a practice of using ASME B31.12 in combination with existing offshore pipeline standards.

In parallel, national guidelines within the European Union and European Economic Community are being developed. The European Industrial Gases Association (EIGA) has developed a publication on hydrogen pipelines [10]. This document resembles to some extent the UK Institution of Gas Engineers and Managers (IGEM) covering both hydrogen pipelines and IGEM/TD/13 Supplement 1: *Pressure regulating installations for hydrogen at pressures exceeding 7 bar*. The UK Institution of Gas Engineers & Managers (IGEM) has published two supplementary documents related to hydrogen infrastructure in November 2021 [11, 12].

One (communication 7849) is related to the IGEM standard TD/1 and is a supplement with additional requirements for transmission of Hydrogen, including blends of hydrogen and natural gas [11]. It covers high pressure hydrogen pipelines, whereas the communication 1850 is a supplement to the IGEM/TD/13 standard covering the safe design, construction, inspection, testing, operation and maintenance of pressure regulating installations (PRIs) for hydrogen at pressures exceeding 7 bar [12]. Both publications refer to the following document, as regards materials.

ISO/TR 15916: Basic considerations for the safety of hydrogen systems (Informative Appendix C) [4] rates materials and the risk of hydrogen embrittlement. It further emphasises the importance of the evaluation considering the service conditions. Current development of ISO/TR 15916 is ongoing at present, excluding the tabulated materials rating. It contains a general guidance on what to consider when designing for hydrogen.

Project partners from Sweden and Germany (see 1.1) were included in the present project to ensure alignment of the national guideline to be developed. Sweden is at a stage similar to Denmark, while the German partners are involved in development of standards and national guidelines, such as DVGW G 406: *Requirements for New Gas Valves in H2 Applications for Gas Transmission, Gas Distribution and Gas Installations, which was* issued early 2023 [13].

A similar document for pipelines exists, DVGW G 409 [14], which is largely inspired by ASME B31.12. In an American context the Specification for Pipeline valves, API 6D, which is relevant to many European manufacturers, is expected to be covered for hydrogen by API 6Z *Standard for Valves in Hydrogen Gas (H2) Service at Normal Temperature* which is being developed.

Hydrogen infrastructure components are also to be considered through the aspect of ATEX, PED (Pressure Equipment Directive), the Machinery Directive (Maskindirektivet 2006/42/EC) and possible new hydrogen specific CE-marking of components. As an example of how it all links together, ATEX-certificates are a part of the Danish Legislation in the Directive of Machinery §227, where e.g., electrical equipment must be marked accordingly to the agreements of ATEX.

Repurposing of existing components from methane to hydrogen requires evaluation of appropriate ATEX-zones and the requirements to follow, e.g., including equipment from ATEX group IIC above a certain blending percentage.

2.3 Denmark

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

Hydrogen in transmission networks is not yet defined in the ordinance nor in the Energinet requirements for gas quality and delivery specifications for shippers which refer to the gas ordinance. Thus, for the moment, it is not allowed to inject any amount of hydrogen or to transport pure hydrogen in the gas transmission network. Dialog between the parties is ongoing. Denmark intends to launch a national hydrogen strategy. There are suggestions in Denmark to establish a hydrogen industry with surplus of production of hydrogen using wind and solar power. Since the Danish demand is regarded as limited, the export to e.g., Germany is viewed as potential export destination for surplus hydrogen. The Danish Safety Technology Authority is the competent authority to set hydrogen blending limits in Denmark.

Energistyrelsen has published a stepwise guide in March 2023 to provide an overview of the authority approvals required to establish hydrogen facilities in Denmark. The guideline enacts a thorough framework from the planning phase to the operation phase.

For the purpose of documenting the appropriate procedures of a focused set of components the stepwise guideline from Energistyrelsen is relevant from 6 to 8 with some aspects from step 4.
Step 6 covers the application of the Danish "Sikkerhedsstyrelsen" requirements, with regards to the instalment of components. These requirements are stated in the Danish legalisation "Gassikkerhedsloven".

Step 7 includes the application send to the Danish "Forsynings tilsynet" regarding the network codes and guidelines. Step 8 involves the occupancy permit in which an application must be conducted with regards to pressure-bearing equipment. Step 6 covers documentation on ATEX and CE approvals, which may have some importance for components installed in potentially explosives zones.

The total framework from Energistyrelsen can be found in [15].

MR Helle
In collaboration with Energinet, Evida, DGC and IRD Fuel Cells a small closed-ring facility with capacity of 80 bar has been tested for blending of hydrogen up to 15 vol%. The closed ring facility originated from a real natural gas system with several natural gas components involved. The testing of gas quality, flow metering and leakages with periods of 3 months showed that no additional modifications of the closed-ring system were required for hydrogen content to 12 vol%. A phase 2 was initiated with addition of 20% hydrogen in natural gas.

2.4 Germany

The legal presumption clause that the gas system is designed, constructed, and operated in a safe, economic and environmentally friendly manner if the Codes of Practice of the German scientific and technical association for gas and water – DVGW (Deutscher Verein des Gas- und Wasserfachs) are applied, is extended for hydrogen. Accordingly, the application of DVGW Codes of Practice is extended for the field of hydrogen. Currently, as per DVGW G 262 from September 2011, clause 5.9, a hydrogen concentration in natural gas up to below 10 % is permitted with restrictions for some grid components such as gas turbines, underground gas storage and CNG stations that in many cases can be designed for hydrogen contents between 2 and 5 Vol%.

The new G 260, which also integrated DVGW G 262, presents the current state of the art regarding the injection of more than 10 Vol-% hydrogen content. As a prerequisite, hydrogen injection requires grid-specific investigations that also include downstream structures and consumers to confirm the actual suitability. The aim is to facilitate 10 Vol-% of hydrogen by 2030 for the whole gas system without restrictions.

DVGW G 409 [14], describes technical aspects and the procedure for determining the material-mechanical suitability of a pipeline. Furthermore, the update for gas transmission steel piping (G 463 and G 466-1) is in progress. On a component level, the DVGW G 406 was issued early 2023: *Requirements for New Gas Valves in H2 Applications for Gas Transmission, Gas Distribution and Gas Installations* [13].

In Germany, isolated hydrogen pipeline networks with 100 % hydrogen concentrations already exist for industrial purposes owned and operated by private network operators. These are built according to another legal regime, the rules for gas transmission pipelines.

Furthermore, several pilot projects are in progress for which agreements with authorities and other involved parties are made and for which DVGW codes of practices and other relevant codes and standards are applied, as far as possible.

2.5 Hydrogen offshore

In Denmark and other European countries hydrogen production facilities offshore in the vicinity of large offshore wind parks is discussed. It is relevant to mention the current efforts towards developing a standard for offshore hydrogen pipelines to supplement the current DNV-ST-F101. DNV initiated H2Pipe and launches several Joint Industry Projects (JIP) to include participants from industry in development within the hydrogen field. Extensive test programmes are expected to contribute to a new standard for offshore gas instead of the current approach of applying ASME B31.12 as a supplement to governing offshore standards.

The offshore industry is used to considering hydrogen, but in the context of sour service in oil & gas environments. Material qualification in this field is often in accordance with NACE MR 15156 which may be too harsh and rule out materials which would be suitable in a pure hydrogen gas system.

2.6 Summary Part 2

It is the responsibility of any owner of future energy infrastructure or manufacturer to provide necessary document for implementing components compatible with pure hydrogen systems. Each individual element must be documented to be fit for purpose by reference to suitable laboratory tests, manufacture declarations of conformity or third part verifications from a recognized test institute or standards, which are deemed relevant. However, in response for the increasing interest of hydrogen applications and the absence of recognised hydrogen standards, some organisations have initialised projects in search of more harmonized and recognized procedures for the documentation of the introduction of hydrogen in current infrastructure. Furthermore, it could be a solution to modify existing safety regulations and executive orders which will also include supplementary national requirements.

PART 3

3.0 Hydrogen Readiness

The intention of this chapter is to provide a brief discussion on what to consider when applying a hydrogen ready status to a specific product. Besides well-known material compatibility problems, the addition of hydrogen to natural gas will also have an impact on the original physical properties, such as gas density, the net calorific value (NCV), the Wobbe index, the methane number, and the combustion air requirement. New values for these may need to be derived in the hydrogen ready evaluation if specific values or ranges of were included in the design requirements of the original natural gas conditions. This illustrates that hydrogen readiness requires precise definitions.

A survey of different stakeholders will likely reveal that the term "*hydrogen readiness*" will have different meanings and each meaning will be based on factors such as how green it is, how marketable it will be and how much work is needed to make it suitable for specific legislative and technical conditions. Hydrogen readiness for example could therefore refer to the % of hydrogen blended with natural gas, specific operating pressures and temperatures, the gas purity, the ability of a meter to measure hydrogen accurately or the application of a label that gives the impression that the product is suitable for use in hydrogen technologies. makes

Any declaration of hydrogen readiness therefore needs to disclose what specific application and operational conditions the readiness is intended for and be supported by a technical document package to show what assessment has been conducted.

One existing definition of hydrogen readiness is given by the European Engine Power Plants Association (EUGINE), which breaks it into 3 main categories and 9 subcategories, as shown in Table 3.1.

LEVEL A (100%H2)	**LEVEL B (25% H2)**	**LEVEL C (10% H2)**
A1 – Minimal modifications	B1 – Minimal modifications	C1 – Minimal modifications
A2 – Minor modification	B2 – Minor modification	C2 – Minor modification
A3 – Advanced modification	B3 – Advanced modification	C3 – Advanced modification

Table 3.1: Categories for H2 readiness according to EUGINE [16].

A 2019 study from MARCOGAZ used a broad combination of technical and regulatory requirements, as well as industrial experience to assess the hydrogen readiness of the existing natural gas infrastructure and end user applications [17]. What they found is that different hydrogen technologies have different levels of hydrogen readiness. There were also a few products that were assessed as having no significant issues when that product would operate in a hydrogen gas environment. This has two implications, the 1st being that nothing is yet 100% hydrogen ready for all conditions without an evaluation, the 2nd is that more investigative work and standardisation activities are needed.

Product	Readiness Assessment	Comment
Steel transmission pipelines	Up to 10%	Should be Ok for 100% H_2
Steel distribution pipelines	Up to 25%	Should be Ok for 100% H_2
Compressors > 16bar	Up to 5%	Significant modification needed for 100% H_2
Valves > 16bar	Up to 10%	Impact of 100% H_2 not known
Valves < 16bar	Up to 30%	Impact of 100% H_2 not known
Gas turbines	Up to 1%	Significant modification needed for 100% H_2
Gas engines	Up to 1%	Significant modification needed for 100% H_2
Gas chromatograph	Feasible, but significant modification needed	Impact of 100% H_2 not known
Gas meters	Up to 10%	Impact of 100% H_2 not known
Gas cookers	Up to 10%	Significant modification needed for 100% H_2
H2 as a feedstock	Up to 1%	Was not assessed as being feasible for 100% H_2

Table 3.2: A modified summary of the MARCOGAZ hydrogen readiness report [17].

3.1 European Roadmap on Hydrogen Standardisation

The transition to a clean energy source and the need for energy independence is forcing the European Union to make a quick transition from pilot projects to large scale industrial applications. To make this quick transition, technical and legal standardisation will be required, because a lack of hydrogen standards will create barriers for new hydrogen solutions.

To assess the readiness of standards, the European Commission set up the ECHA, also known as the European Clean Hydrogen Alliance. A specific aim of this alliance is to link industry and other stakeholders, so that clean hydrogen technologies can be deployed on a large scale by 2030.

In March 2023 the ECHA published a *Roadmap on Hydrogen Standardisation* [18] which now gives an overview of the standardisation gaps, the challenges, and the forecasted needs of a developing hydrogen value chain. It provides recommendations for streamlining and accelerating the development of standards for clean hydrogen technologies (renewable and low-carbon hydrogen).

The roadmap has 121 pages and is structured along 7 clusters, shown below.
The technical needs and timeline to develop standards for these clusters are also discussed.

1. Hydrogen production
2. Infrastructure
3. Industrial applications
4. Mobility
5. Energy
6. Building
7. Cross-cutting

The information on infrastructure (number 2), is that for transmission pipelines and compressor stations, approximately 80% of the European technical requirements in existing standards for design, construction, operation, and maintenance of gas infrastructure are also applicable for hydrogen. Sin general, the specific focus areas identified by the roadmap for 100% hydrogen gas and blends that contain hydrogen gas are:

- materials and related effects
- safety aspects of hydrogen including explosion prevention and protection
- interoperability within the technical system, including injection
- gas quality
- volume in relation to energy content
- gas underground storage
- definition of hydrogen infrastructure

3.2 European Legislation for Hydrogen Technologies

The examples presented below in Table 3.3 are only one small part of the bigger picture and are included in this report only as a baseline. The European Roadmap for Hydrogen Standardisation [18] has chapters dedicated to the legal and regulatory frameworks for the 7 clusters listed in Chapter 3.1 and will provide more detailed text than what is presented here.

Abbreviation	Name	Directive
PED	Pressure equipment directive	2014/68/EU
ATEX	Equipment for potentially explosive atmospheres	2024/34/EU
ATEX 153	Worker protection directive	1999/92/EC
MD	Machinery directive	2006/42/CE
EMC	Electromagnetic compatibility	2014/30/EU
LVD	Low voltage directive	2014/35/EU
HFCV	Hydrogen fueled vehicles	(EU) 2019/2144
NA	Type-approval of vehicles	(EU) 2021/535
NA	Type-approval of hydrogen vehicles	(EC) 79/2009
GAR	Gas appliance regulation	2016/426/EU

Table 3.3: Examples of EU directives that will be relevant for hydrogen technologies.

It will be seen that some directives are at an advanced stage of standards development. For example, the requirements for hydrogen powered vehicles and filling stations have experienced several years of standards and legislative development and are likely to provide the inspiration for other hydrogen technologies. EU regulation 2021/535 includes hydrogen powered vehicles and has text for safety performance and material compatibility. EU regulation 79/2009 considered many pressurised hydrogen products, but it expired in July 2022 and was replaced by EU regulation 2021/535.

Associated EU policies and directives that will shape our hydrogen future are:

- *EU Hydrogen Strategy*
- *Renewable Energy Directive*
- *Offshore Renewable Strategy*
- *Fitfor55*
- *Directive for the Deployment of Alternative Fuels Infrastructure* and
- *REPowerEU Plan and the Hydrogen Accelerator*

3.3 EU Product Certification

Certification of products within the EU deals with assessing whether the product meets the EU regulatory requirements. The products mentioned in this report are considered certified when it can be documented that the products have reached high safety, health, and environmental protection requirements. Examples of European product legislation that define these requirements are shown in Table 3.3.

The European legislation specifies the results that are needed, but normally does not prescribe how those results should be achieved, or what standards need to be applied.
A guide to the certification process can be found on the European Commission's website [19] and is simplified below.

Typical EU product certification process

1. Establish which European product legislation should apply.
2. Search European Commission's website for guidance documents.
3. Determine the essential requirements, normally in the Annex of the legislation.
4. Select the standards to be used.
5. Determine the level of conformity that should be reached.
6. Find a notified body that will do a conformity assessment.
7. Create a test and validation plan.
8. Assemble the technical documentation.
9. Create a statement of conformity for the product.

3.4 European Essential Requirements – Compliance by Harmonised Standards

European Essential Requirements are part of specific EU legislation, and they state the conditions that must be met before a product can be placed in the EU market. The essential requirements are those that will be of public interest, and they deal with the hazards that need to be considered for things like:

- health
- safety
- environment
- property
- accuracy

Example or Essential Requirements can be found in ANNEX II of (ATEX) Directive 2014/34/EU and ANNEX I of (PED) Directive 2014/68/EU. These are freely accessible from EUR-Lex, a website for the European Union [20, 21]

European standards are created by one of the 3 European standardisation organisations, namely CEN, CENELEC and ETSI, while national standardisation bodies (i.e., Danish Standards) take care of specific national requirements. DS S-605 deals with hydrogen on a national level in Denmark.

Harmonised European Standards are requested by the European commission, mainly to help ensure the free movement of products. They typically have an "EN" to show that it is a European Norm. Examples are:

- EN ISO 17268:2020 *Gaseous hydrogen land vehicle refuelling connection devices*.
- EN 1594 *Gas infrastructure - Pipelines for maximum operating pressure over 16 bar - Functional requirements*.

When the product is designed and manufactured in accordance with harmonised standards, there is an automatic presumption of compliance with European Essential Requirements.

A list of harmonised standards is published in the "Official Journal of the European Union" (OJEU). Access to these standards can be found in [22].

3.5 European Essential Requirements – Compliance by Other Options

There are a few "hydrogen certification schemes" within Europe and they can be used to demonstrate that the product complies with specific standards used in that specific certification process, although it will not automatically mean an acceptance by the permitting authorities.

Until there is general standardisation for hydrogen technologies, the different national standardisation bodies will have the burden to create the required guidance, together with the national permitting authorities. The application of new (hydrogen) technologies also means that national guidance and permitting processes will also need to develop, together with industrial experience for those technologies. The fundamentals of the European essential requirements should however still be valid and those can be used as inspiration.

The text in the European Commission's "*Blue Guide*" tells us that the conformity of a product may also be demonstrated by other technical means [19], such as national standards, standards which are not harmonised, the manufacturer's own specifications or some other justifiable assessment. The manufacturer (or purchaser in certain cases) can therefore apply standards and technical specifications of their own choice, but the automatic presumption of conformity is then lost, and more effort is needed to demonstrate compliance with the European Essential Requirements. This is referred to as "no presumption of conformity" and should be a suitable path to follow while we wait for the development and harmonization of standards for hydrogen technology. See ANNEX 1 for a proposed method for pipeline valves.

For hydrogen technologies that pose a risk to safety, an in-depth risk assessment will be required when there is no harmonised standardisation for those technologies. The aim of the risk assessment is to define what additional testing and evaluation activities will be needed, so that the essential European safety requirements can be complied with. This will in many cases require the assistance of a 3rd Party Notified Body and a team of risk specialists.

The guide for the *Safety Planning and Management in Hydrogen and Fuel Cell Projects* [23] is seen by the authors of this report as a good resource to help evaluate what essential variables need to be assessed for new hydrogen technologies. All demonstrations of compliance can then be gathered in the technical documentation package for that product.

3.6 Technical Documentation

European legislation requires that technical documents are created to demonstrate the conformity of the product. These documents will provide information on the design, manufacture, operation, and traceability of the product, where traceability also applies to the parts contained within the product.

The technical documentation must support any statements of conformity, whether the conformity comes from harmonised standards or any other means.

3.7 Conformity Assessment

A conformity assessment evaluates if a product complies with the requirements of specific EU legislation during both the design and production phases. The assessment also evaluates whether hazards have been identified and whether risks are managed. For established EU legislation, it was often possible to provide a self-declaration that a product complies with EU regulations. Products which have a high risk to the public interest will require that a 3rd party Notified Body undertake the conformity assessment. The conformity assessment can then be added to the technical documentation, for review by the permitting authorities.

3.8 Risk Analysis

The risk analysis will also be included in the technical documentation. The aim of the risk analysis is to assess all possible risks that the product may pose and to determine the essential requirements relevant for that hydrogen product. To write it in another way, the risk analysis can be used as a gap analysis, to determine what additional measures are needed, so that compliance with essential safety requirements is demonstrated. It should not be limited to design and manufacture, but also include the use, inspection, maintenance and decommissioning of the product.

In addition to reference [23], there is a Hydrogen Incident and Accidents Database [24] and a European Hydrogen Safety Panel's analysis of this database [25]. Publications like these give us a better understanding of how to recognise and mitigate risk for hydrogen technologies.

3.9 Summary Part 3

Any declaration of hydrogen readiness needs to disclose what specific application and operational conditions the readiness is intended for and be supported by a technical document package to show what assessment has been conducted.

A "*Roadmap on Hydrogen Standardisation*" has been published by the European Clean Hydrogen Association and it now gives an overview of the standardisation gaps, the challenges, and the forecasted needs of a developing hydrogen value chain.

European directives for hydrogen powered vehicles and filling stations have experienced several years of standards and legislative development and are likely to provide the inspiration for other hydrogen technologies.

When a product is designed and manufactured in accordance with harmonised standards, there is an automatic presumption of compliance with European Essential Requirements. The text in the European Commission's "*Blue Guide*" tells us that the conformity of a product may also be demonstrated by other technical means, such as national standards, standards which are not harmonised, the manufacturer's own specifications or some other justifiable assessment.

For hydrogen technologies that pose a risk to safety, an in-depth risk assessment will be required when there is no harmonised standardisation for those technologies. The aim of the risk assessment is to define what additional testing and evaluation activities will be needed, so that the essential European safety requirements can be complied with.

PART 4

4.0 Measuring products for hydrogen

4.1 Hydrogen sensors

Definition

A hydrogen sensor is defined to be an apparatus that can sense the presence of hydrogen in air. The technology can range from stationary mounted hydrogen sensors for alarm systems to mobile sensors that can aid in leak detection. Different technologies are applied for the sensing material, where electrochemical, semiconducting, and catalytic combustion cells are among the most utilized.

Overview of documentation

Standards associated with hydrogen sensors can be divided into two parts. One part is consisting of the electrical hazards of applying the technology in potential explosive zones. The other part is covering the performance of the technology. The need for a hydrogen sensor arrives from a risk assessment, where a mounted gas detector is one way of establishing safety and surveillance.

Electrical equipment in hazardous zones

The IEC 60079 standard covers the general requirements, testing and marking of the electrical components used in explosives zones [26]. Hydrogen sensors that conform to the IEC 60079 part 1 to 4 standard receive an IECEx certificate. Countries participating in the IECEx scheme include Europa, Canada, Australia, Russia, China, United States and South Africa. However, in Europe there is also an ATEX-certificate, which consists of two directives.

An ATEX-certificate may be based on the IECEx documentation, however the ATEX documentation may not always support the IECEx documentation. Manufacturers of hydrogen sensors may therefore document both certificates to ensure that products can be traded across countries without being re-tested. Hydrogen sensors that are documented with both certificates are accepted to be intrinsically safe when installed in potential explosives zones/atmospheres. ATEX-certificates are a part of the Danish Legislation in the Directive of Machinery §227, where electrical equipment must be marked accordingly to the agreements of ATEX [20, 21].

Performance based documentation

The ISO 26142:2010 defines the performance requirements and test methods of hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations in stationary applications. Only the requirements applicable to a product standard are present in the ISO 26142:2010 standards, which are precision, stability, measuring range, selectivity[3], response time and poisoning[4].

The ISO 26142:2010 is intended to be utilized for certifications processes, however ISO does not provide certification. Manufacturers of hydrogen sensors that have an ISO-certificate must therefore contact an independent certifying body for certification.

---

[3] The affinity towards measuring the target gas

[4] Is the degradation of the sensing material by other specimens

Application of ISO 26142:2010 adds credibility, but the subsequent certification can be costly for manufacturers and is sometimes not seen as a priority.

Risk assessment

There are no standards that can be used to determine the amount, nor the instalment of hydrogen sensors required for monitoring and ensuring intrinsically safe environments. However, risk assessments must be conducted according to several standards. As an example, ASME B31.12 describes surface leak surveys; however, the standard does not specify the technology applied for the approach. ISO 12100:2010 covers identification, estimation, and evaluation of risks during the relevant phases of machine life cycle. Part 3.6 and part 3.7 describes elimination of potential hazardous atmospheres. In both standards it can be assessed that stationary hydrogen sensors are required for monitoring and avoidance of potential explosive atmospheres.

4.2 Gas chromatography

Definition

Gas chromatography is a stationary measuring instrument that determines the mole fraction of a component in a sample mixture. The technology enables together with defined methods determination of the gas quality of the sample. Gas quality covers terms as caloric value, density, relative density and wobbe indices from the gas composition.

Overview of Standards for Measurement

The current DS/EN ISO standards related to gas chromatography are based on the natural gas system. The requirement for a standardized gas chromatography analysis arises from Danish legislation; "Bekendtgørelsen om gaskvalitet", "Gas-sikkerhedsloven" and "Rules for transport of gas".

The gas chromatography standards can be divided into two groups. One group defining the methods of the gas chromatography analysis and another group defining the gas composition. ISO EN standards related to hydrogen for first group are under development, however, there exist ISO EN standards that covers gas quality for applications for fuelling stations and fuel cells. For safe application of the instrument there are directives implemented into the Danish legislation relevant to electrical equipment and instalment of electrical equipment. Some of these directives are based on DS/EN ISO standards.

Gas Chromatography Analysis

The DS/EN ISO 10715:2022 standard covers the representative sampling of natural gas and natural gas substitutes that are conveyed into the transmission and the distributions grids. The uncertainty related to online sampling is covered in the newest edition.

The DS/EN ISO 6974 part 1-3 covers methods of analysis of natural gas and methods for calculating component mole fractions and uncertainties. The ISO 6974 is intended to measure hydrogen (H_2), Helium (He), carbon dioxide (CO_2) and other hydrocarbons either as individual components or as a group. This approach is suitable for a range of applications such as calibration, calculation of calorific value or other physical properties of the gas that are important for the surveillance of the gas system.

The DS/EN ISO 6976 standard describes methods for calculating gross calorific value, net calorific value, density, relative density, gross Wobbe index and net Wobbe index of natural gases, natural substitutes, and other combustible gaseous fuel, where the composition of the gas is known by mole fraction. The methods described provide the means of calculating the properties of the gas mixture at commonly used reference conditions.

The mentioned standards are all based on naturel gas, however calculations covered in ISO 6976 are not limited to natural gas. The definitions and calculations can be applied to a gas composition consisting of pure hydrogen. The lack of documentation for hydrogen related analysis arises from the measurement of mole fractions and the representative sampling. Gas chromatography instruments designed according to mentioned ISO standards can operate with gas composites >0.5% mol hydrogen.

Gas quality

The foreseen increase in the use of renewable gases such as hydrogen or biomethane requires predictable conditions for the end users. In this context, pre-normative studies on the Wobbe Index and oxygen will be fed into a revision of EN 16726 on gas quality for H-gas.

Gas quality specifications originate from legislations, codes of practice, or contractual agreements and are generally national. In the European Union, all infrastructure operators publish the gas quality specifications to grant access to their systems.
The current Danish legislation for the quality of naturel gas is covered in "Bekendtgørelse om gaskvalitet". The legislation defines specifications for gas, which among others concern higher Wobbe index, relative density, and water content.

For hydrogen the Danish legislation in "Bekendtgørelse om gaskvalitet" paragraphs 26 and 27 define the minimum amount of hydrogen, that is distributed in naturel gas distribution grid and is supplied to stationary fuel cells, to be 98 % (vol.). However, the transmission grid in Denmark is not covered by above paragraphs. Additionally, connected streams of hydrogen to both the distribution grid and to stationary fuel cells must be approved by the Danish Technical Safety authority "Sikkerhedsstyrelsen".

The DS ISO 14687:2019 standard defines the hydrogen gas specifications that are governed by the Danish legislation. The standard defines different grades for the gas quality according to the amount of hydrogen present in a gas sample, however the standard does not set out the appropriate analysis for determination of hydrogen content.

In general, there is no standardized overlap between the defined gas specifications in the Danish legislation and the defined analysis methods in the naturel gas-based DS/EN ISO standards mentioned in section 4.2 "Gas Chromatography Analysis". According to an analysis conducted by the HIGGS project [27] a standard for gas quality of hydrogen used in converted/rededicated gas system is under development.

Electrical Equipment and Instalment of Electrical Equipment

There are different directives. For application of gas chromatography in potential explosives atmospheres the ATEX directive is implemented into the Danish Legislation by "Bekendtgørelse nr. 289". An ATEX certified instrument complies to ATEX-quality modulus, where the directive covers equipment, protective systems, and components within the instrument.

The Machinery Directive 2006/42/EC is also implemented in Danish Legislation by "Arbejdstilsynets bekendtgørelse nr 612". The directive sets out health and safety requirements related to the design of an instrument based on the content of the DS/EN 60204 part 1. According to the directive the manufacturers of gas chromatography instruments should retain full responsibility for certifying the conformity of their machinery to provision of the directive. The CE marking should be fully recognized as being the only marking that guarantees that the instrument conforms to the requirements of the directive.

The Danish legislation covers appropriate and safe installation of electrical equipment according to "Bekendtgørelse af lov om sikkerhed ved elektriske anlæg, elektriske installationer og elektrisk materiel". The legislation considers potential electrical dangers. The low voltage directive is also a part of the Danish Legislation, which covers appropriate work and installation for equipment with a defined voltage limit. Additionally, for radio equipment and electromagnetic compatibility, the "Bekendtgørelsen nr 1431" is covered by the Danish legislation.

4.3 Metering

Definition

The term metering refers to measuring and recording the quantity of gas by reference of volume, mass, or energy content. Metering is applied for two main reasons. One is for settling the gas consumption of customers connected to the gas grid. The second reason is system surveillance of the gas quantities distributed in the grid.

Several techniques can be utilized for metering, however for scope of this report the techniques discussed are the turbine flow metering, diaphragm metering and ultrasound flow metering. Typically, in the Danish gas grid the diaphragm technique is applied for setting the gas consumption of the customers, where the turbine flow is applied for system surveillance. The ultrasound flow metering is applied in areas, where neither the diaphragm nor the turbine flow technique can be utilized, due to the deviation of gas compositions or the presence of larger gas flows.

Overview of standards and legislation

An instrument for metering installed for settlement of gas consumption must follow the Danish legislation according to "Bekendtgørelse nr 582", which dictates the field of application of the instrument for measurement of water, gas, electricity, and heat. A metering instrument can only be applied if the manufacturer of the metering instrument has the required documentation of the performance, limitations, and uncertainty.

The required documentation is obtained by an application to the "EU-typeafprøvning", which must follow the legislation covered in "Gasapparatforordning (EU) 2016 & 426 annex 3". According to the legislation the application must include a set of relevant EU-harmonized standards. Additionally, if there are no relevant standards necessary for the application, a set of appropriate supporting documents must be attached. A supporting documentation could include a thorough evaluation of the performance of the instrument.

There are no limitations related to performance in the Danish legislation for metering instruments utilized for system surveillance. The performance of these instruments may be defined by the gas distributors and gas companies, however, there exist DS/EN standards, that define design, requirements, and performance.

The DS/EN standards for the turbine flow metering, diaphragm metering and the ultrasound metering are 12261:2018, 1359:2017 and 17089:2019 respectively. In general, the three standards cover the meter classification, metrological performance requirements together with design and material requirements, which is covered below by the term "Metering requirements".

Metering requirements

For the DS/EN standards 12261, 1359 and 17089, design, material and method requirements are covered to ensure a performance within a defined uncertainty interval together with an acceptable life expectancy. Additionally, the standards define gas families and operation parameters within the respective technology.

The turbine flow technique can only be applied to first and second gas families, which corresponds to town gas and natural gas. The turbine flow technique cannot be applied for pressures and flows exceeding 420 bar and 25000 m^3/h respectively. The diaphragm technique can do measurements on first, second and third gas families, where the third gas family corresponds to LPG (liquefied petroleum gas). However, pressure cannot exceed 0.5 bar and a maximum flowrate at 160 m^3/h. The ultrasound technique, being the most expensive, has no limitation towards gas compositions and operating parameters, however the uncertainty may give high flow rates, because of acoustic interference, see Table .

The gas families, that are defined in DS/EN 427:2021 coupled with the Wobbe calculations described in DS/EN ISO 6976:2016, do not account for pure hydrogen gas. This indicates a lack of standard documentation with the usage of flow metering for hydrogen. Therefore, it is necessary to provide additional documentation, before an approved "EU-typeafprøvning" can be obtained, in which a flow metering technique can applied for settling gas consumption.

Electrical Equipment and Instalment of Electrical Equipment

In general, for electrical flow metering techniques the Machinery Directive 2006/42/EC is implemented in Danish Legislation by "Arbejdstilsynets bekendtgørelse nr 612".
The directive sets out health and safe requirements related to the design of an instrument based on the content of the DS/EN 60204 part 1. According to the directive the manufacturers of gas metering instruments should retain full responsibility for certifying the conformity of their meters to the directive. The CE marking should be fully recognized as being the only marking that guarantees that the instrument conforms to the requirements of the directive.

Furthermore, if the electrical flow metering technology is applied in potential explosives atmospheres the Danish legalization "Bekendtgørelse nr 289" implements the ATEX directive. Additionally, the Danish legislation covers appropriate and safe installment of electrical equipment according to "Bekendtgørelse af lov om sikkerhed ved elektriske anlæg, elektriske installationer og elektrisk materiel". The legislation conforms to potential electrical dangers. The low voltage directive is also a part of the Danish Legislation, which covers appropriate work and instalment for equipment with a defined voltage limit.

Technique	Gas family	Max. Pressure and flow	Electrical documentation
Diaphragm	1st, 2nd, 3rd	0.5 bar and 160 m^3/h	Yes, if electrical
Turbine flow	1st, 2nd	420 bar and 25000 m^3/h	Yes, if electrical
Ultrasound	No limitation	No limitation	Yes

Table 4.1: Overview of requirements of metering

4.4 Gap analysis for measurement

In general, there is a lack of documentation that binds the standardized documentation together with the Danish legislation, see Table 2.

For hydrogen sensors there exist sufficient standardized documentation for design, safety, and performance, together with approved uncertainties, however the requirement of applied stationary hydrogen sensors is absent in the Danish legislation and is only assessed through a risk assessment.

For gas chromatography there exist sufficient standardized documentation of design, methods, performance together with approved uncertainties, however the standardized documentation is based on natural gas with a maximum hydrogen content of 2% (vol.). The Danish legislation requires standardized documentation, which entails further documentation is required for implementation of gas chromatography measurement of pure hydrogen distributed in the Danish grid.

For metering-instrumentation, there exist sufficient standardized documentation of design, methods, performance together with approved uncertainties, however the documentation only involves 1st, 2nd and 3rd gas families. According to the definition of gas families, pure hydrogen is not accounted for. Additionally, the Danish legislation sets out requirements for standardized documentation, which entails the need further documentation for metering-techniques, that are applied for settling gas consumption.

Component	**Sufficient standardized documentation**	**Required by Danish legislation***	**The need for further documentation****
Hydrogen sensors	Yes	No	Good to have
Gas chromatography	No	Yes	Need to have
Metering	No	Yes	Need to have

Table 2 An overview of required documentation for measuring-instrumentation applied for pure hydrogen.

**The need for electrical safety and CE-marking is assumed for all instruments and is therefore not included.*

*** Further evidence involves supporting documentation, in which the instrumentation is approved for application. For more details see section "*

4.0 Measuring products for hydrogen”

The references used across the other parts of this report, ASME B31.12, EIGA and IGEM [8-12] refer to metering and sensors in a vague context, i.e. sensors should be calibrated by “as appropriate”, or “in accordance with appropriate standards for hydrogen service”, and metering to be “checked to confirm accurate measurement for hydrogen service” without specific reference. Hence, a gap indeed does exist between available documentation and standards, and the current need in the hydrogen industry.

Summary Part 4

The measurement selection for the introduction of hydrogen into the Danish infrastructure cannot sufficiently be documented by standardised procedure. Most of the legally required documentation is based on a natural gas-based system, which only allow below a few precents of hydrogen content. This entails a heavy load of additional documentation before a measurement instrument can legally be utilized for a 100 (%vol.) hydrogen-based system. However, some measurement methods can be applied with current standards since the working principles can be applied on any gas-composition.

PART 5

5.0 Materials for hydrogen

Hydrogen service requires special attention for materials selection.

The effects of hydrogen embrittlement manifest itself as loss in ductility, reduction in strength, reduction in fracture toughness and enhanced fatigue crack growth even at stresses below specified minimum yield strength.

Hydrogen embrittlement occurs at a critical combination of hydrogen, stress, and material susceptibility. Sensitivity to hydrogen embrittlement depends on metallurgical factors such as chemistry, microstructure, and hardness. Further to evaluation of materials compatibility, ASME B31.12 (nonmandatory Appendix A) mentions a tendency to limit the wall stresses to between 30% and 50% of the specified minimum yield strength during system operation of pipelines [8] while EIGA [10] states a possible reduction to 30% of SMYS or 20% of SMUTS if the recommended material considerations cannot be met. The risk of hydrogen embrittlement damage is exacerbated by presence of pre-existing flaws in the pipe material, hard weld zones and weld defects.

Pressure fluctuations and gradients are an important parameter in terms of material compatibility as well as dry- and cleanliness of the hydrogen since components in the hydrogen gas may affect the hydrogen uptake in the metallic materials.

In addition to the materials evaluation of subcomponents, a more thorough evaluation, possibly including testing is needed to evaluate if a component is suitable for hydrogen use.

In the present situation where standardisation is work in progress, there are no general test methods to evaluate materials for hydrogen service. The opinion that tables and lists are not adequate for materials selection is present, as the same material may be delivered in different conditions as regards heat treatment, strength and hence hydrogen susceptibility. IGEM states a material may be qualified for hydrogen service by laboratory or demonstration scale testing, or field experience, further adding to the overall message concluded in previous sections, that there is no single way of documenting hydrogen suitability.

NASA/TM-2016-218602: *Hydrogen Embrittlement* [28] has been used as a solid reference for materials evaluation in hydrogen systems, however, most guidelines refer to ISO TR 15916 [4]. Both publications contain ratings on to which extent materials are embrittled by hydrogen.

Sandia National Laboratories have performed the most extensive test programmes for materials in hydrogen gas. Several of their publications have received acknowledgement and it was a test programme performed by them, which caused the revision of ASME B31.12 from 2014 to 2019, allowing the use of higher strength pipeline steels without a penalty factor, hence they are a credible source of material data for thorough evaluation.

ISO/TR 15916: Basic considerations for the safety of hydrogen systems [4] lists materials and their suitability, and work is ongoing on updating the 2015 version to exclude tabulated data, since this may cause confusion and risk of hydrogen embrittlement, if the user does not have a proper understanding of how composition, microstructure, heat treatment and impurities in metallic materials interact.

ASME B31.12 states a general guidance to materials compatible with hydrogen service in Non-mandatory Appendix A.

Based on the referenced sources above, the following general guidance for materials selection applies, however tables for material selection should in general be treated with caution. Below the table, a brief description of the materials is presented.

Material	**Hydrogen gas compatibility**	**Notes**
Austenitic stainless steels	Compatible	Beware of martensitic conversion at low temperatures
Carbon & low-alloy steels	Compatible	Too brittle for cryogenic service
Grey, ductile, or cast iron	Not Compatible	Not permitted for hydrogen service
Nickel and alloys (e.g., Inconel, Monel)	Not Compatible	Beware of susceptibility to hydrogen embrittlement
Aluminium and alloys	Compatible	
Copper and alloys	Compatible	
Titanium and alloys	Compatible	

Table 5.1: Overview of selected materials and their compatibility for use in hydrogen gas.

Austenitic stainless steels

Austenitic stainless steels generally provide the best resistance to hydrogen embrittlement of any structural metal in hydrogen gas service. Austenitic stainless steels are the most resistant to hydrogen embrittlement of the stainless steels but may be subject to martensitic conversion at low temperatures and areas of plastic deformation. Martensite is a phase much more prone to cracking in hydrogen environments [8]. Extensive laboratory experiments, field experience from critical installations with hydrogen above 1000 bar has proven the track record for austenitic stainless steels. Alloying with certain elements may stabilise the austenitic microstructure further improve properties.

Duplex stainless steels

Duplex stainless steels exhibit a two-phase microstructure with austenite and ferrite. The presence of ferrite reduces the resistance to hydrogen embrittlement significantly, hence if given the option, an austenitic stainless steel should always be chosen above a duplex stainless steel. In some cases, duplex stainless steel be chosen to provide greater strength while still maintaining some resistance to hydrogen embrittlement.

Nickel alloys

High nickel alloys such as Inconel is often the solution for components in corrosive and high temperature applications and are frequently considered for use in hydrogen environments. Many nickel alloys are susceptible to hydrogen embrittlement, which can reduce their ductility and toughness and lead to premature failure. According to EIGA [10] nickel alloys should be avoided unless the user verifies the alloy is suitable for hydrogen gas service. ASME B31.12 does not consider nickel and its alloys acceptable for use in hydrogen gas [8]. Modest strength levels and avoidance of high nickel levels are worth noting to prevent hydrogen embrittlement. Hence, austenitic stainless steels is to be chosen above the high nickel alloys for components in hydrogen infrastructure. The properties of specific alloys may be improved by e.g., heat treatment, but as a general rule, nickel alloys should be used with caution in hydrogen environments and their suitability for hydrogen gas service should be verified before use.

Low-alloy and carbon steels

This group of steels cover both pipeline steels and a is in general a widely applied material. Low-alloy carbon steels exhibit increasing risk to hydrogen embrittlement with increasing strength. Difficulty in welding these materials may cause hard zones, and general knowledge on microstructure, cold work, welding parameters and the need for e.g., post weld heat treatment is recommended. Some components are typically welded into a hydrogen infrastructure system, hence welding should be a key focus.

Setting upper bound hardness limits may help to preventing hydrogen embrittlement in carbon steels for hydrogen service applications. The maximum hardness limits for carbon steels are approximately 22 HRC or 250 HB [10] while the maximum hardness limit for carbon steel hardness measurements according to ASME B31.12 is 235 HV. Restricting the strength of carbon steels may be disruptive to industry and the authors of this report propose that further work is needed to establish the link between hardness, and hydrogen embrittlement of carbon steels that operate in a hydrogen gas environment.

Copper and aluminium alloys

Copper and its alloys are known to possess high ductility and are not embrittled by hydrogen gas. The same applied to aluminium alloys, although research on the materials in hydrogen is ongoing. Tubing in housing containing city gas was made from copper and rubber, at a time when the city gas contained up to 50% hydrogen in the previous century. Further, both ISO TR 15916, ASME B31.12 and EIGA state copper, aluminium and their alloys as suitable for use in hydrogen.

Cast iron

According to ISO/TR 15916 cast iron (including grey and ductile) is not considered suitable for hydrogen service. The same recommendation is stated in ASME B31.12, EIGA and IGEM. The main reason is the inherent properties of cast iron, such as low elongation at fracture, and an inhomogeneous microstructure. Little research has been conducted, but interest is growing in evaluating the properties in hydrogen, since cast iron possesses advantages when used in some components and in consideration of bringing down the cost of green hydrogen.

Non-metals

As stated in ISO TR 15916 [3] the application of non-metallic materials has a long history of use in hydrogen environments. Chemical degradation is not a known issue, however, permeation through polymers is to be considered. Further, if pressure cycling or decompression occurs while hydrogen is trapped in the non-metallic material, it may cause physical changes in the form of crack formation. This is a known phenomenon in some O-ring and gasket materials, however it does depend on pressure exposure and cycling. ISO 11114-2:2021: *Gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 2: Non-metallic materials* may provide guidance on non-metals although not complete as regards relevant data [29].

Coating

Long-term effects of hydrogen on coatings are yet to be evaluated. Current standards refer to established coating standards and tests, which may rule out inferior coating quality, but they do not consider the long-term effects of hydrogen. A review of current literature however does not report on damage to coatings from pipelines, valves or other components operating in hydrogen service.

5.1 Components

In the previous Part 1 the components derived from partner interviews were listed. The items related to measurement, i.e. meters, sensors and gas chromatographs were treated in Part 4. The additional components are presented below in context of concrete advice derived from the references.

5.2 Valves

Valves are an essential part of hydrogen infrastructure and cover a wide range of components, such as safety relief valves, control valves, automatic and manual valves, double block and bleed (DBB) valve arrangements.

As per ASME B31.12:2019 valves manufactured in accordance with the following standards may be used: ASME B16.34, ASME B16.38, API 6D, API 609, API 600, API 602.
But valves shall only be used in accordance with the service recommendations of the manufacturer. This leaves many stakeholders in a limbo where the manufacturer cannot guarantee performance in hydrogen for valves manufactures according to the above listed standards. Currently, a hydrogen version of API 6D is developed, API 6Z.

In addition to this, European manufacturers provide components according to both the American standards listed above, but also their European equivalents.

Similarly, DVGW has issued DVGW G 406: *Requirements for New Gas Valves in H2 Applications for Gas Transmission, Gas Distribution and Gas Installations* early 2023 with recommendation as to how to evaluate hydrogen suitability of a valve.

The UK and EU guidelines IGEM and EIGA [10, 13] provide guidance on seals, seats (i.e. metal to metal or soft seats) and the major focus is on preventing leaks. Some allow Helium to be used as a test medium, due to similar properties when leak testing and much less safety precautions needed, while others prescribe the use of hydrogen.

ISO 19880-3 on valves for fuelling stations provides guidance on test methods following the same methodology as other valve standards, including leak testing (external and internal), pressure cycling, hydrostatic strength test and testing of non-metallic materials [30]. As for materials selection it refers to the same references as used in previous sections.

In summary, no single standard is applicable for hydrogen valves at present, but efforts to provide guidance on how to navigate the field are present.

5.3 Filters

Filtering is important although the purity of green hydrogen from electrolysis is rather high. Contamination from the process, or from the coupled infrastructure, e.g. a repurposed pipeline may occur and filter installation is recommended to avoid contamination, particularly upstream of pressure control and metering devices, due to the high sonic velocity of hydrogen.

Filter blockage in hydrogen systems is a risk since differential pressures across a blocked filter behaves differently in hydrogen as compared to natural gas. Installation of a strainer/mesh in the system may mitigate this risk according to IGEM [11, 12]. Further, the choice of materials in the unit should be in consideration of hydrogen sensitivity. Filters may be implemented in the design for purposes of avoiding leaks due to contamination of e.g. valves or other critical components in a system.

5.4 System design

Knowledge on hydrogen system design was requested through partner interviews and although it is a rather large area to cover, some general design principles may be applied.

A safety management system must be in place, addressing the specific properties of hydrogen, i.e. flammable range, increased probability of ignition, higher volume leakage rate and ATEX requirements including equipment from group IIC [11].

Several sources recommend sensing and instrumentation pipework is to be designed to minimise leakage by limiting the number of compression fittings and preferably manufactured from austenitic stainless steel [11, 12]. This is supported by the practical experience with hydrogen testing at FORCE Technology.

5.5 Pressure regulator

Pressure regulators are an integral part of the present natural gas infrastructure but may be considered in design of future hydrogen design. As mentioned by IGEM the effect of high sonic velocity should be considered at when the pressure drop across a regulator is more than 10%. Materials, both metals and non-metals, may be affected by pressure drops as well.

5.6 Insulation coupling

An insulation coupling typically consists of metallic parts connected by non-metals to ensure insulation between the parts. Non-metals in hydrogen environments are not as easily rated on performance as metals. While some may exhibit great properties as regards low diffusion/permeation of hydrogen through the material, differences may occur when testing rapid decompression properties. Some diffusion of hydrogen through an insulation coupling may be expected over time.

5.7 Compressors

Through partner interviews and research, compressors have shown to be a rather complex component in hydrogen systems.

ASME B31.12 and EIGA provide guidance on the design, operation, and maintenance of compressors used in hydrogen gas service. Both standards emphasize the importance of safety in compressor design and recommend regular maintenance and inspection to ensure safe and reliable operation. EIGA [10] provides recommendations for the design, operation, and maintenance of hydrogen compressors, including requirements for materials, lubricants, and safety systems. The document also notes that compressors used in hydrogen service should be designed to minimize the risk of ignition or explosion, and should be equipped with appropriate safety devices, such as pressure relief valves and flame arrestors.

In general, compressors are considered a safety critical component in a hydrogen system, both because they cause a temperature rise when operated and because sealing materials are worn over time giving rise to leaks. Focus on leak testing prior to installation, performance over time in hydrogen environments as well as material selection should be in focus.

5.8 Summary Part 5

Materials selection for hydrogen applications is complex and is not easily tabulated. Knowledge on how microstructure, strength, and delivery condition (heat treatment) affect the sensitivity to hydrogen embrittlement is crucial.

Components derived from partner interviews are described in the context of relevant sources. It is not only a matter of the right material selection of subcomponents but also testing of function, leak tightness and other requirements, as will be necessary future work to be conducted. Annex 1 presents this approach.

PART 6

6.0 Concluding remarks

The present document serves as a guideline, a present approach as to how components may be evaluated as fit for service in hydrogen. Further work, paving the road for national and international standards still needs to be conducted. A summary of each part of the report is presented below, followed by considerations on future work.

Summary Part 1

The project was initiated based on a general lack of guidance within the hydrogen industry, as regards standards for components in hydrogen infrastructure. This was expressed by the project partners, and based on partner interviews, a list of components to be considered was derived. In the present guideline a division in the aspect of measuring components, material for hydrogen and safety is used. The characteristics of hydrogen as compared to methane is a key topic to consider, however the main focus of the present guideline is how this may cause different documentation demands and requirements.

Summary Part 2

It is the responsibility of any owner of future energy infrastructure or manufacturer to provide necessary document for implementing components compatible with pure hydrogen systems. Each individual element must be documented to be fit for purpose by reference to suitable laboratory tests, manufacture declarations of conformity or third part verifications from a recognized test institute or standards, which are deemed relevant. However, in response for the increasing interest of hydrogen applications and the absence of recognised hydrogen standards, some organisations have initialised projects in search of more harmonized and recognized procedures for the documentation of the introduction of hydrogen in current infrastructure. Furthermore, it could be a solution to modify existing safety regulations and executive orders which will also include supplementary national requirements.

Summary Part 3

Any declaration of hydrogen readiness needs to disclose what specific application and operational conditions the readiness is intended for and be supported by a technical document package to show what assessment has been conducted.

A "*Roadmap on Hydrogen Standardisation*" has been published by the European Clean Hydrogen Association and it now gives an overview of the standardisation gaps, the challenges, and the forecasted needs of a developing hydrogen value chain.
European directives for hydrogen powered vehicles and filling stations have experienced several years of standards and legislative development and are likely to provide the inspiration for other hydrogen technologies.

When a product is designed and manufactured in accordance with harmonised standards, there is an automatic presumption of compliance with European Essential Requirements. The text in the European Commission's "*Blue Guide*" tells us that the conformity of a product may also be demonstrated by other technical means, such as national standards, standards which are not harmonised, the manufacturer's own specifications or some other justifiable assessment.

For hydrogen technologies that pose a risk to safety, an in-depth risk assessment will be required when there is no harmonised standardisation for those technologies. The aim of the risk assessment is to define what additional testing and evaluation activities will be needed, so that the essential European safety requirements can be complied with.

Summary Part 4

The measurement selection for the introduction of hydrogen into the Danish infrastructure cannot sufficiently be documented by standardised procedure. Most of the legally required documentation is based on a natural gas-based system, which only allow below a few precents of hydrogen content. This entails a heavy load of additional documentation before a measurement instrument can legally be utilized for a 100 (%vol.) hydrogen-based system. However, some measurement methods can be applied with current standards since the working principles can be applied on any gas-composition.

Summary Part 5

Materials selection for hydrogen applications is complex and is not easily tabulated. Knowledge on how microstructure, strength, and delivery condition (heat treatment) affect the sensitivity to hydrogen embrittlement is crucial.

Components derived from partner interviews are described in the context of relevant sources. It is not only a matter of the right material selection of subcomponents but also testing of function, leak tightness and other requirements, as will be necessary future work to be conducted.

6.1 Future Work

The foundation for future work on documentation demands for hydrogen infrastructure is laid in the present project, which is a literature-based study of the available technical standards and guidelines with a focus on the development of decision-making. This enables stakeholders to navigate and find the right path for testing and validating their component, regardless of whether the focus is on procurement, specification, or sales.

This is a good starting point, but the work conducted through the present report does not contribute with learnings from physical tests and evaluations. It is a necessary prerequisite to supplement the literature-based approach with physical tests in order to create reliable test data, evaluate and share experiences to benefit the entire Power-to-X value chain. Future experimental work will thus contribute with new knowledge through testing and validation based on the theoretical test philosophies from the present report. Examples of testing to be explored include test of materials, sensors, density, function and risk aspects. Extensive experimental work will provide concrete input in the form of reliable test data to standards so that they can be developed on a secure basis, as was the case for the 2019-update of ASME B31.12.

Alongside the ongoing development of standards, extensive test programmes could help develop a concrete tool based on reliable test data, which can be used by Power-to-X stakeholders to specify, produce, procure and regulate the rapidly developing hydrogen infrastructure. Internationally, there is consensus that testing is needed to ensure a safe green transition.

References

[1] Anbefalinger til en dansk strategi for Power-to-X*, Dansk Energi, 2020, https://greenpowerdenmark.dk/udgivelser/anbefalinger-til-dansk-strategi-power-to-x*

[2] Markedsdialog om brintinfrastruktur, *Energinet, November 2021*, https://energinet.dk/om-nyheder/nyheder/2021/11/09/markedsdialog-viste-bred-interesse-for-brintinfrastruktur/

[3] European Hydrogen Backbone (EHB) initiative, EHB website, https://ehb.eu/

[4] ISO/TR 15916:2015: *Basic considerations for the safety of hydrogen systems*

[5] ANSI/GPTC Z 380.1 -1998, *GPTC Guide for Gas Transmission and Distribution Piping Systems*, 1998-2000, Volume One, latest revision 2022

[6] At-vejledning F.0.1: *Vejledning om konstruktion, fremstilling, vedligeholdelse og drift af naturgasanlæg som tillæg til GPTC-Guide for Gas Transmission and Distribution Piping Systems, July 2001*
https://at.dk/en/regulations/working-environment-legislation/

[7] *EN 1594:2013 Gas infrastructure – Pipelines for maximum operating pressure over 16 bar – Functional requirements*

[8] ASME B31.12:2019: *Hydrogen Piping and Pipelines*

[9] ASME B31.8: *Gas Transmission & Distribution Piping Systems*

[10] EIGA 121/14/E (2014) Hydrogen transportation pipelines

[11] IGEM/TD/1 Edition 6 Supplement 2: *High pressure hydrogen pipelines*

[12] IGEM/TD/13 Supplement 1: *Pressure regulating installations for hydrogen at pressures exceeding 7 bar, 2021*

[13] DVGW G 406: *Requirements for New Gas Valves in H2 Applications for Gas Transmission, Gas Distribution and Gas Installations*

[14] DVGW G 409: *Conversion of High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar for Transportation of Hydrogen*

[15] Energistyrelsen: Guide for establishing onshore Power-to-X systems https://veprojekter.dk/anlaeg/ptxanleag

[16] *Hydrogen-readiness of engine power plants – A common definition*, ENTSOG website, accessed August 2023. https://www.entsog.eu/sites/default/files/2021-11/2.3.%20EUGINE%20-%20H2-Ready%20Definition%20-%20September%202021.pdf

[17] *Overview of test results & regulatory limits for hydrogen admission into existing natural gas infrastructure & end use*, 2019, MARCOGAZ website, accessed August 2023. https://www.marcogaz.org/publications/overview-of-test-results-regulatory-limits-for-hydrogen-admission-into-existing-natural-gas-infrastructure-end-use/

[18] *Roadmap on Hydrogen Standardisation*, March 2023, European Clean hydrogen Alliance, CENCENELEC website, accessed August 2023. https://www.cencenelec.eu/media/CEN-CENELEC/News/Press%20Releases/2023/20230301_ech2a_roadmaphydrogenstandardisation.pdf

[19] *The Blue Guide on the implementation of EU product rules 2022*, Official Journal of the European Union, Volume 65, 29 June 2022

[20] *Equipment for potentially explosive atmospheres* (ATEX), Directive 2014/34/EU, Official Journal of the European Union, 29 March 2014

[21] *Pressure equipment and assemblies* (PED), Directive 2014/98/EU, Official Journal of the European Union, 15 May 2014

[22] *European Commission Harmonised Standards*, Website of the European Union, Accessed August 2023. https://single-market-economy.ec.europa.eu/single-market/european-standards/harmonised-standards_en

[23] *Safety Planning and management in EU Hydrogen and Fuel Cells Projects – Guidance Document*, September 2021, Clean Hydrogen Partnership Website, accessed August 2023. https://www.clean-hydrogen.europa.eu/system/files/2021-09/Safety_Planning_Implementation_and_Reporting_for_EU_Projects-Final.pdf

[24] *The Hydrogen Incident and Accidents Database*, European Commission Minerva Portal, accessed August 2023, EUROPA - MINERVA Home Page - European Commission - HIADPT

[25] Wen et al., *Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database, International Journal of Hydrogen Energy, Volume 47, Issue 38, 1 May 2022, Pages 17082-17096*

[26] DS/EN IEC 60079: *Explosive atmospheres.*

[27] The HIGGS Project, *Website/URL https://higgsproject.eu/, last visit 11-08-2023*

[28] NASA/TM-2016-218602: *Hydrogen Embrittlement* by Jonathan A. Lee

[29] ISO 11114-2:2021: *Gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 2: Non-metallic materials*

[30] ISO 19880-3: *Gaseous Hydrogen – Fuelling stations – Part 3: Valves*

ANNEX 1

European Essential Requirements
Compliance by Other Options
A Proposed Method for Pipeline Valves

The proposed option for pipeline valves in this Annex is for illustrative purposes only and shall not be considered as a certified solution. Although a valve was chosen for an example, the principle should work for most products that will be exposed to pressurised hydrogen gas.

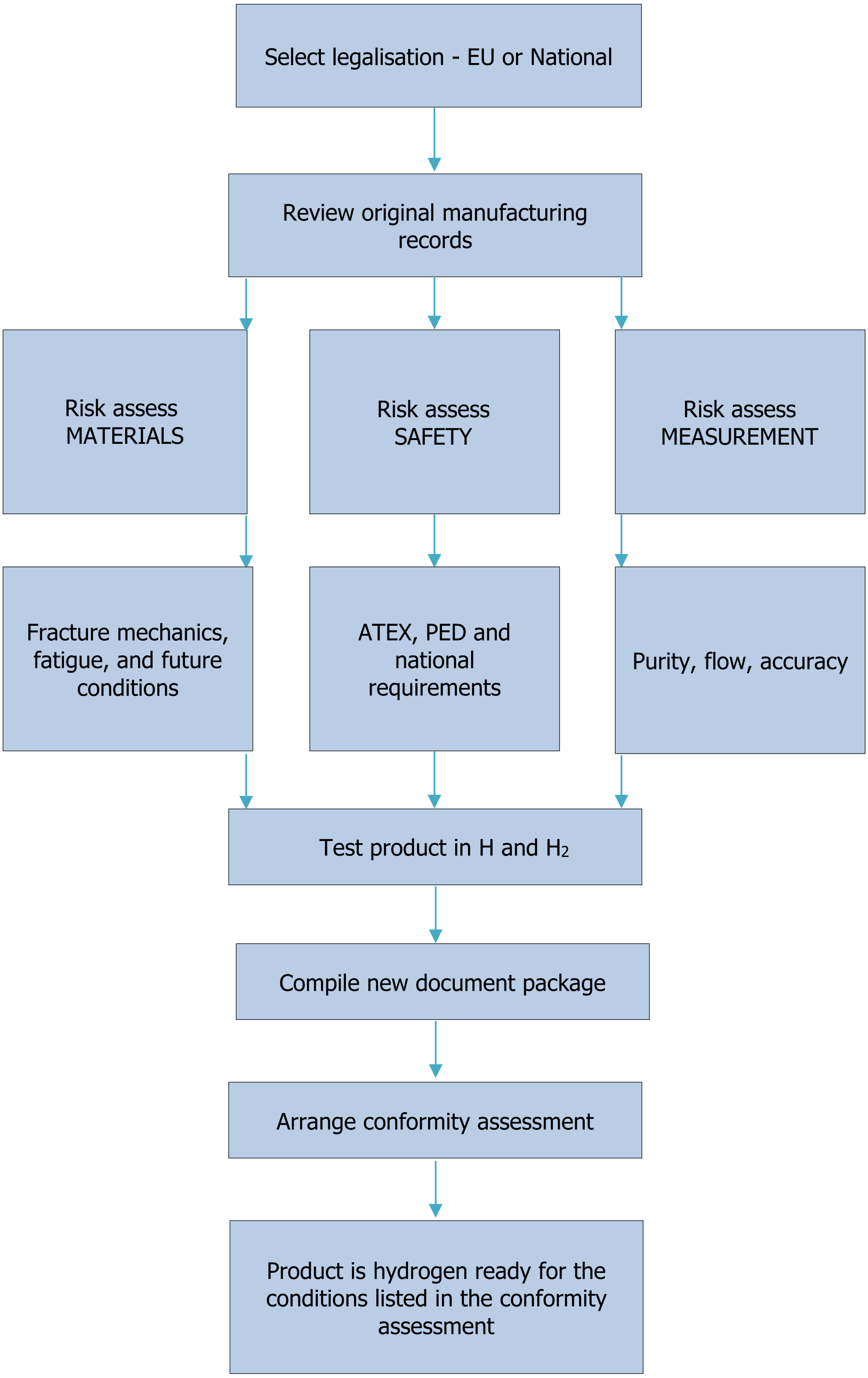
Where harmonised standards do not exist, the nearest alternative should be reviewed to establish if there are details that can be transferred. For the pipeline valves, this means reviewing standards for valves and fittings that are used for hydrogen vehicles, hydrogen fuels cells and hydrogen filling stations, with particular focus on (1) leak testing and (2) evaluating the long-term effect that hydrogen gas has on materials. It is expected that in many cases, conformity will be demonstrated by using a mix of harmonised and non-harmonised standards. In some cases (such as for leak testing) helium may be used instead of hydrogen gas.

The final conformity assessment will require that a Notified Body is involved, and that any hydrogen readiness statement (or non-standardised certification) refers to the conditions that were part of the assessment.

GENERAL APPROACH

1. Gather existing manufacturing records.
2. Assemble technical team.
3. Assemble risk assessment team.
4. Determine the essential requirements.
5. Establish where the gaps are.
6. Prepare new scopes of work.
7. Document outcomes of new work.
8. Arrange conformity assessment.
9. Involve a Notified Body.

The flowchart on the next page shows a general approach to demonstrate hydrogen readiness. It can be applied to any hydrogen product that also has a requirement to be part of a measurement system.


Select legalisation - EU or National
Review original manufacturing records
Risk assess MATERIALS
Risk assess SAFETY
Risk assess MEASUREMENT
Fracture mechanics, fatigue, and future conditions
ATEX, PED and national requirements
Purity, flow, accuracy
Test product in H and H_2
Compile new document package
Arrange conformity assessment
Product is hydrogen ready for the conditions listed in the conformity assessment