D2.1

Report on safety requirements

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Partners short names

ENVI	Parco Scientifico Tecnologico Per L'ambiente Environment Park Torino Spa
IMI	Institute For Methods Innovation
IME	Fundacion IMDEA Energia
APRE	Agenzia per la Promozione della Ricerca Europea
CNH2	Centro Nacional Del Hidrogeno
RIGP	Regionalna Izba Gospodarcza Pomorza
CLUSTER TWEED	Cluster Tweed
BH2C	Balkanski Vodoroden Klaster

Abbreviations

APQ	Almacenamiento de Productos Quimicos
BPVC	Boiler and Pressure Vessel Code
BRA	Building Risk Assessment
CGA	Compressed Gas Association
EIGA	European Industrial Gases Association
FCEV	Fuel Cell Electric Vehicle
FERA	Fire and Explosion Risk Assessment
FMECA	Failure Mode, Effects & Criticality Analysis
ISO	International Organization for Standardization
HRS	Hydrogen Refuelling Stations
HAZID	Hazard Identification
HAZOP	Hazard and Operability Analysis
LOPA	Layers of Protection Analysis
MIE	Ministerio de Industria y Energia
NFPA	National Fire Protection Association
PSV	Pressure Safety Valve
QRA	Quantitative Risk Assessment
RD	Real Decreto
SIL	Safety Integrity Level
UNE	Asociación Española de Normalización

Executive Summary

The primary aim of this report is to outline the safety requirements for hydrogen projects, detailing both prescriptive and performance-based approaches across different countries involved in the HYPOP project for mobility and residential applications. This report supports the aim of the project, i.e., raising public awareness and trust towards hydrogen technologies and supporting decision-makers in integrating hydrogen into local economies and communities. To do so, the results here described will be the basis for the future guidance to be issued as final output of HYPOP project.

In general, HYPOP project focuses on stakeholder engagement through surveys, interviews, and participation in events to collect information on safety, permitting, and certification requirements for hydrogen technologies.

In this deliverable the following information is shared:

- Description of the safety approaches and requirements identified for different Hydrogen Technologies: Prescriptive and Performance based approaches;
- Best practices and approaches classified for mobility and residential application (i.e., Hydrogen Refuelling stations - fixed, mobile, containerised layouts; micro-CHP based on Fuel Cell technologies, etc);
- Analysis of Regulatory Frameworks in HYPOP countries affecting hydrogen mobility and residential.

HYPOP consortium worked to gather information on three different groups of Countries:

- The so called HYPOP countries, i.e., the Countries represented within the consortium: Belgium, Bulgaria (also part of the EU-13 group), Italy, Spain, Poland (also part of the EU-13 group);
- The so called frontrunner countries/ frontrunners Germany, France, the Netherlands, Switzerland
- The EU-13 countries: Bulgaria (also part of the HYPOP countries) , Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland (also part of the HYPOP countries), Romania, Slovakia, and Slovenia.

The collection of information for some of the above Countries is continuing to ensure the best possible coverage of the safety approach in the EU, thus supporting the drafting of a useful guidance. However, strength and weaknesses of the different country approaches were identified together with some best practices.

1 Introduction

HYPOP project aims to raise public awareness and trust towards hydrogen technologies and their systemic benefits. To do this, stakeholders' engagement is a pivotal aspect that has been taken into account for this project. Work package 2 (WP2) methodology involved tools to gather information from stakeholders through surveys, interviews and participation to events (engagement activity useful also for WP1). WP2 activities are crucial to provide the basis for the final guidelines that will support decision makers in introducing hydrogen in the local communities and economies. Specifically, technical data gathered about safety, permitting and certification requirements will be used for the workshops that will involve HYPOP's stakeholders and thus providing decision makers with valuable information coming from sharing real experiences and technical know-how. The stakeholder's engagement methodology followed for the Deliverable 2.1 (D2.1) included the following steps:

- Identification of the categories of stakeholders involved in safety issues (Technology manufacturers, early adopters and public authorities involved in the evaluation of safety);
- Organization of surveys, interviews, and participation to events to engage stakeholders;
- Mapping of the existing regulations on safety in each Country to highlight the main requirements and approaches;
- Comparison and similarities related to safety aspects between different H2 projects in each Country.

The research activity for D2.1 has covered:

- the HYPOP countries, i.e. the countries of the partners involved in WP2 (Italy, Spain, Poland, Belgium and Bulgaria).
- frontrunner countries, i.e., Germany, France, the Netherlands, Switzerland; and
- the EU-13 countries (except Bulgaria and Poland , already covered above): Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Romania, Slovakia, and Slovenia.

Collection of information from the EU 13 Countries not included within the HYPOP consortium is continuing due to the difficulties in accessing information within the time initially allocated for this work. An update of this information will be presented as part of the guidance document on safety to be issued at the end of the project.

This deliverable is structured around the two main approaches to safety that emerged during the stakeholders' engagement activity: **prescriptive and performance based**. The information provided exemplifies current approach to safety by the technology manufacturers, the early adopters and the authorities, and their correlation.

Both approaches aim to ensure the implementation of European Regulations and Directives on safety as well as the specific requirements by National Regulations.

The prescriptive approach to safety provides detailed safety requirements that must be met and which are generally produced by legislators and authorities at a central (national) level. These apply to certain categories of hydrogen installations, with the prescription of safety measures defined according to a range of possible applications. **Typical requirements of a prescriptive approach may concern, for example, safety distances between different components of a system or facility, maximum working pressures and the use of specific components manufactured under certain technical standards.** Detailed information on hydrogen-specific technical safety regulations, identified within HYPOP's research, will be provided in the Appendix text, showing an example of the type and level of prescription required in this kind of regulations.

The minimum safety requirements to be met according to the European Regulations and Directives and the specific requirements by National Legislation can also be ensured by applying **a performance-based approach to safety**. A **performance approach**, the definition of which is not unique and derives, in the case of this project, from the shared experiences of HYPOP stakeholders, is applicable to the specific hydrogen project, it **refers to the use of risk analysis methodologies to ensure minimum safety, makes reference to European and national legislation and international and national technical standards, and finally, follows common practices derived from the experience of stakeholders in their sectors of competence**. For this reason, through application of the performance-based approach, different hydrogen facility designs may emerge for the same type of applications, due to the presence of innovative technologies and/or different features of installation site. The main features of the performance-based approach emerge through the description of projects within a selection of European Countries where it has been applied.

2 Methodology

The methodology behind WP2 considered different key elements that reflect the typical features of a stakeholders' engagement activity aimed at gathering information about the perception from institutions towards hydrogen technologies and approaches followed by project developers to fulfil the national or local safety requirements. This methodology is replicated for the analysis of permitting requirements described in Deliverable 2.2 as it is based on the centrality of the role of institutions to boost hydrogen economy and ensure trust in hydrogen technologies.

2.1 HOW

ENVI supported the partners developing a common guide to map and update the state of the art of the available regulatory framework around EU and to identify pilot and commercial projects under development (i.e. as best practices) and the relevant stakeholders. The common guide was developed as a set of flowcharts (see figures in the next page). The starting point were the results of the HyLaw project, from which to start the evaluation of changes in regulations and procedures.

The added value of WP2 activity was to implement the overall picture provided by HyLaw project showing the application in practice and therefore understanding how institutional authorities and project interacted on the basis of the existing regulations or to achieve a solution when regulations were not available or fully applicable.

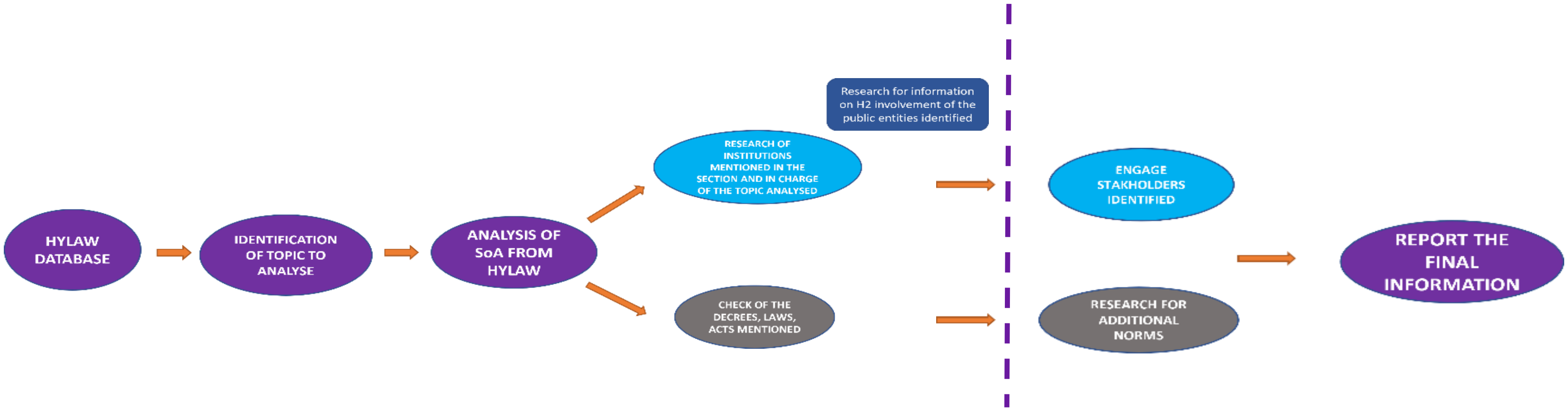

Figure 1 Flowchart guiding the information retrieval

First path is mainly related to institutions' engagement activity, participation to events, dissemination of HYPOP, legislation and research of other initiatives around EU. A more detailed guideline was also developed, as shown below:

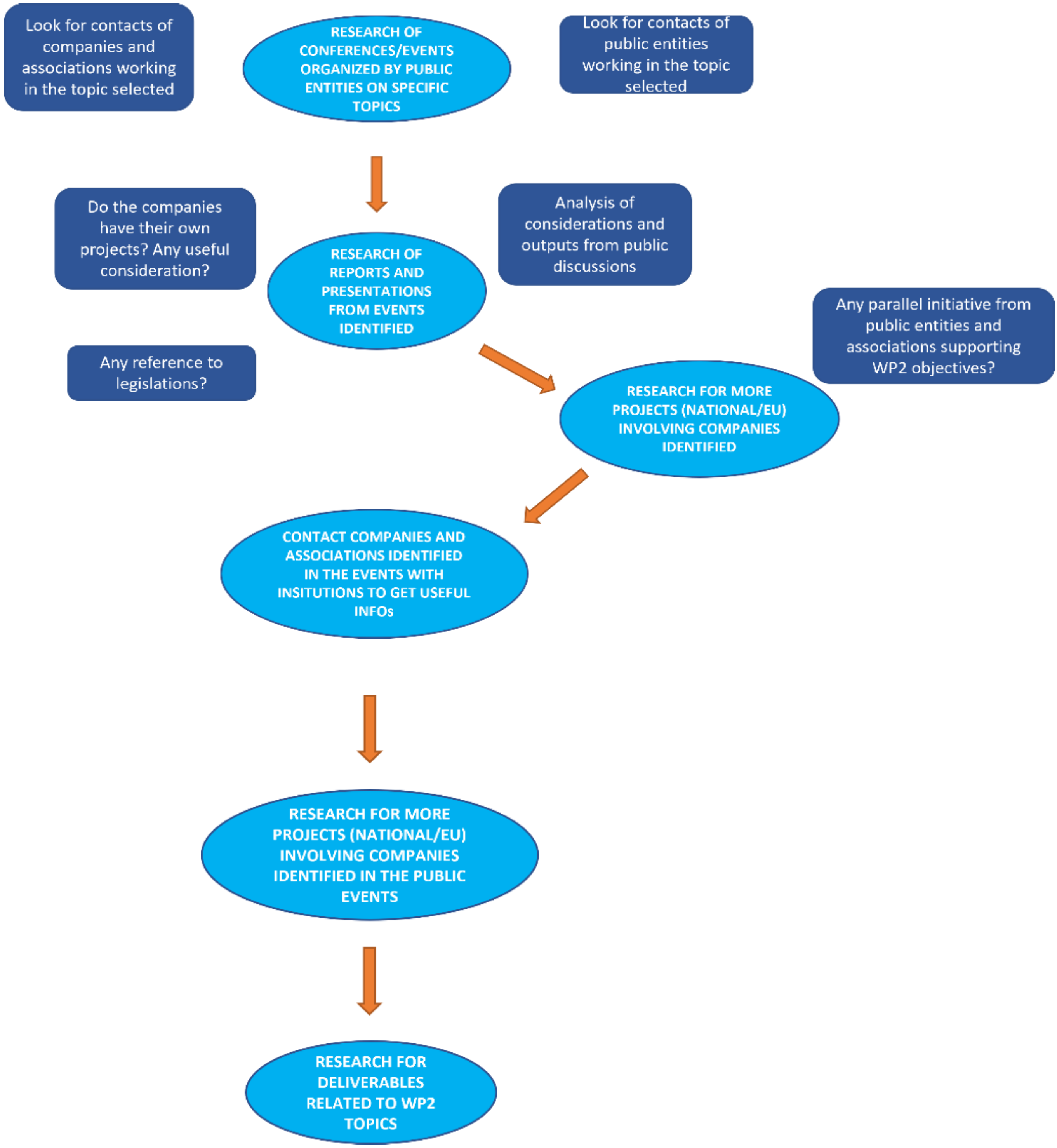

Figure 2 Detailed flowchart for information gathering from projects/ events

The second path is about the mapping of regulations available for hydrogen and hydrogen technologies (linked to previous research path) and potential gaps to be pointed out. Below is a representation of how the partners could go about finding information, with a specific support in expanding their research to reference technologies when H2- specific regulations did not appear to be available.

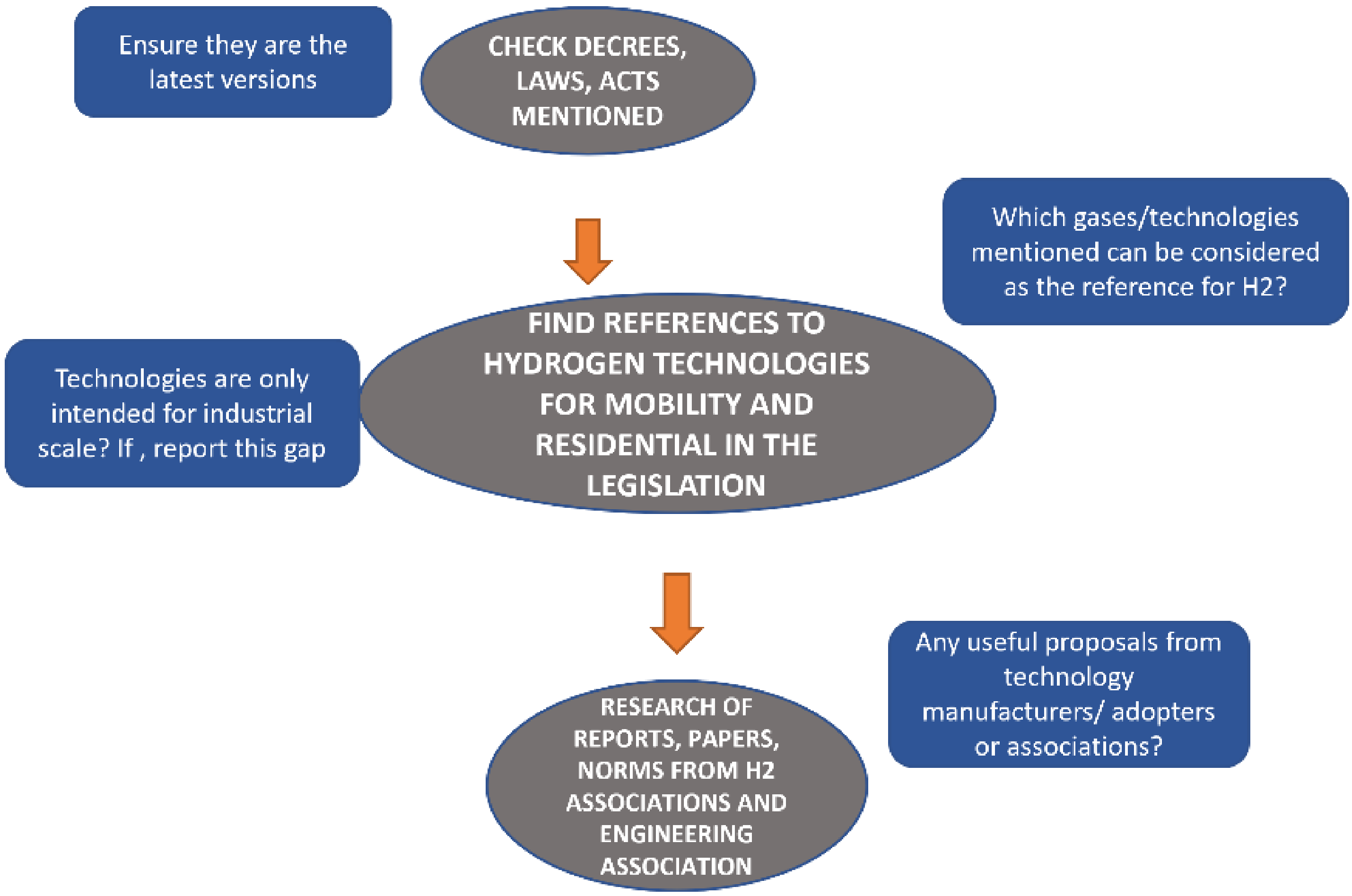

Figure 3: Detailed guidance about finding relevant regulations

When the above approach would not yield any result, web searches were implemented; failing that, the HyLaw baseline, if available, has been considered while the search for information is continuing.

2.2 WHO

HYPOP partners collected more than 140 contacts among companies, universities and research centres, hydrogen clusters and public entities.

The main contacts for stakeholders' engagement, finalised to the gathering of information on safety, permitting and certification comprised:

- Contacts with projects implementing new hydrogen installations, including Hydrogen Valleys, and /or innovative technologies;
- Network of industrial/institutional contacts of each partner in the HYPOP consortium, contacted personally for and interview or through surveys – these surveys also were used as a trace to guide any in-person discussion;
- Contact with National Contact Points (NCPs) through partner APRE, who is the Italian NCP and therefore is part of the network of organisations supporting R&I throughout Europe.

HYPOP project covers different groups of Countries and aims to increase knowledge about EU13-countries involvement in the hydrogen economy in general (Poland and Bulgaria are HYPOP's partners). On the other hand, Countries with the longest and most successful history of hydrogen installations are to be involved. To gather this information, a subdivision of work among the consortium, was agreed, with each partner tasked to find information about different Countries, as shown in the table below.

Table 1 EU-13 and Frontrunner Countries targeted for WP2 research and related HYPOP owners

HYPOP partners	Targeted countries
ENVI	Latvia, Slovenia, Switzerland
CNH2	Croatia, Lithuania, Malta
RIGP	Czech Republic, Estonia, Slovakia
TWEED	France, Germany, Netherlands
BH2C	Cyprus, Hungary, Romania

The details of the approach followed to find contacts supporting the integration of HyLaw information are explained below.

Projects

The HYPOP database was developed starting with the research of commercial, pilot and other funded projects generating and using renewable hydrogen, mainly for mobility and residential sectors. These projects entail a degree of innovation (first time installation, or novel technology) and dealt with safety and permitting issues, therefore experimenting, with the local authorities, different approaches leading to the implementation of the technology.

The projects reached were more than 35 and the following table refers to those hydrogen projects used as best practices or engaged for synergies with HYPOP project or related to events joined to disseminate and collect information about safety aspects.

Table 2 HYPOP Connections with projects for safety requirements

Projects	Connection
AMETHyST	Synergy/Event
e-SHyIPS	Synergy
Everywh2ere	Synergy
FCH2RAIL	Best Practice
FuelSOME	Synergy
GRASSHOPPER	Synergy
GREENHYSLAND	Synergy
H2iseo VALLEY	Best Practice
H2ports	Best Practice
H2VALCAMONICA	Best Practice
HEATING SYSTEM FOR BUILDING	Best Practice
HEATING SYSTEM FOR SCHOOL	Best Practice
HRS BELGIUM (commercial)	Best Practice
HRS BULGARIA (prototype)	Best Practice
HyCARE	Synergy
HYPER	Best Practice
HYRESPONDER	Synergy
HyTecHeat	Synergy
HYTRUCK	Best Practice/Event
MultHyFuel	Synergy
NORTH ADRIATIC HYDROGEN VALLEY	Synergy
OLGA	Synergy
PROMETEO	Synergy
REFLEX	Best Practice
SWITCH	Synergy
THyGA	Synergy
TULIPS	Best Practice/Event

<u>Surveys and personal contacts</u>

Further stakeholders' engagement activity was carried out through customized surveys aimed at gathering information about regulatory frameworks, the type of project, the stakeholders involved, the approaches followed and the barriers. They have been set up considering the potential points of view of two types of target groups: the Technology Manufacturers and Adopters and the Authorities. It is possible to still see and take part in the surveys through the following links:

- Survey for Technology Manufactures and Adopters[1];
- Survey for Authorities[2].

[1] https://docs.google.com/forms/d/e/1FAIpQLSdt2CfeFWWR6DgSLookAXTnyJPb-H2iAHBbV6kgnaKIdzB3cg/viewform
[2] https://docs.google.com/forms/d/e/1FAIpQLScTDZpfAUFpJM4wSdyZx2eWlPX7m0naaZcRsxCDhXQE7PNoQg/viewform

The surveys were also used as trace to lead a discussion with stakeholders during sector-specific events or through ad hoc meetings (e.g. with national hydrogen industry clusters/organisations).

NCP network

For those Countries where no information could be gathered through the above two methods, help was sought through the support of APRE as bridge for the other EU National Contact Points (NCP). Each NCP received an email explaining the goal of the project and asking directly information on the hydrogen regulatory framework or the name of an organisation/contact who could support the gathering of such information.

2.3 WHAT

The next sections report the technical analysis of the regulations and conventional regulations applied in the countries where information could be found. It must be disclosed that the work undertaken within the fist 12 months of project HYPOP has reached only part of the EU-13 countries, as shown below.

Table 3 Geographical coverage of the information gathered

		Regulations on safety found?
HYPOP Countries	Belgium	Y
	Italy	Y
	Spain	Y
EU-13 Countries	Bulgaria (also HYPOP country)	Y
	Poland (also HYPOP country)	Y
	Croatia	To be collected
	Cyprus	To be collected
	Czech Republic	To be collected
	Estonia	Y
	Hungary	Y
	Latvia	Y
	Lithuania	To be collected
	Malta	Y
	Romania	Y
	Slovakia	To be collected
	Slovenia	Y
Frontrunner Countries	France	Y
	Germany	Y
	Netherlands	Y
	Switzerland	Y

As HYPOP is based on a continuous engagement activity, missing or initial information will be the focus for the remaining duration of the project. Moreover, the stakeholders' engagement workshops to be organized within the scope of the Work package 4 are aimed to cover as much as possible these gaps involving the EU-13 countries to show their best practices and to point out requirements and barriers.

For the EU-13 Countries, first contacts with National Contact Points have been achieved but there is missing information about safety approaches for Industry, Mobility and Residential sectors for Croatia, Cyprus, Czech Republic, Lithuania and Slovakia. These EU-13 countries will be reached within the framework of WP4 activities, searching information following the methodology described so far and exploiting the database of stakeholders' contacts built in WP2 activities.

The next sections, after a preamble on the distinction between prescriptive and performance based approach to safety, reports a comparison of requirements, barriers, strengths and weaknesses of the regulations analysed as well as a first collection of best practices. These will be the basis for the guidance documents to be issued as a final outcome of project HYPOP.

Given the technical density of the safety regulations, the full analysis is reported in Section 9, which, for each country of the three groups, reports the regulations for the different sectors: industry, mobility and residential. However it must be noted that, particularly within the frontrunners countries, **industry and mobility** both include technologies for hydrogen production, storage, compression and use. For this reason, safety requirements can refer to multiple regulations. In the Frontrunner countries the combination of a sound regulatory framework for the safety design, installation and operation of hydrogen technologies and a high level of know-how and experience in the sector is supporting the integration of hydrogen technologies as drivers for decarbonization. Nevertheless, issues due to the novelty of the applications of renewable hydrogen can bring to different interpretations, especially at local level.

Regarding the **residential sector**, there are not specific requirements or barriers to the implementation of FC solutions or other H_2 ready systems except for the ones that can be defined by the distributor operators at local level. FC systems are considered as electrical appliances and common standards procedures apply. Where identified, specific safety requirements for hydrogen technologies implemented in residential environment that can refer to storage systems are needed.

3 Preamble: Prescriptive and Performance based Approaches: general definitions and features aimed to safety

Hydrogen is a very low density, highly flammable gas. Also, because of its small molecule size, it is highly diffusive. These properties need to be taken into account to approach safely its use. The properties most relevant to the safety aspects of using hydrogen, and consequently the use of hydrogen technologies, are density, flammability and diffusivity.

Hydrogen has a low ignition energy and a wide flammability range. It gives rise to a high temperature, invisible flame, and it forms explosive mixtures with air in concentrations from 4 to 74%. Furthermore, it has a very low density, which is 14 times lower than that of air, hence it diffuses very rapidly. For these reasons, risks of its release in air need to be carefully prevented or at least controlled, with appropriate ventilation systems avoiding any accumulation. Leakages are an issue, and, beside the correct joining technologies, materials resisting to hydrogen embrittlement need to be carefully selected. Furthermore, sources of ignitions need to be avoided. These and other properties of hydrogen influence public and stakeholder's perception compared to other conventional fuels, ending in (minimum) safety measures.

The **prescriptive approach to safety** is mainly based on requirements defined in advance in the regulatory framework specifically applied by the competent authorities assessing the hydrogen project under development. Such safety requirements can be referred to each hydrogen plant's component, to the plant itself and also to the surrounding elements that could be negatively affected by incident scenarios or be source of domino effects. **Typical requirements are safety distances** which can be required from a single component or from the perimeter of the plant to external elements. **Safety distances can vary according to different factors that can be for example: the quantity of hydrogen stored/present within the plant during the different operation phases (i.e charge, discharge, refuelling of vehicles…), the maximum allowed operating pressures, the flow rate of the dispensing systems or the type of hydrogen technologies itself**. Moreover, it can consider risk assessment methodologies, both quantitative or qualitative as a support for the achievement of the key elements of safety. In general, a prescriptive regulatory framework can ensure safety without clashing with techno-economic feasibility of hydrogen projects depending on its flexibility to cover as much as possible project configurations and applications.

The performance-based approach is mainly related to the concept of risk assessment. The application of advanced tools for risk identification can support decision-making on application of safety measures and management of risks. Both quantitative and/or qualitative tools, used for risk management across different stages of a facility/installation/plant lifecycle, have been developed. For example, these tools can include HAZID, HAZOP, SIL Analysis, LOPA, FMECA, QRA, BRA, FERA, ATEX, among others (see Abbreviations). Interaction with authorities is another pillar at the base of the performance-based approach to safety as it can help to overcome approval barriers thus achieving the best and safest solutions during project design phase. Different safety requirements can apply in the same country according to the type of competent authority in charge to evaluate safety and its grade of knowledge and confidence towards new hydrogen end uses. For this reason, this is a complex aspect to consider and furthermore, EU countries do not share the same administrative organisation.

The EU Directives governing safety framework can be synthetized as follows:

- SEVESO Directive;
- ATEX Directive (e.g. ATEX equipment and ATEX workplace);
- Industrial emission Directive (IED);

- Pressure equipment Directive (together with the Transportable Pressure Equipment Directive);
- Machinery Directive;
- Low Voltage Directive;
- Electromagnetic Compatibility Directive;
- International Carriage of Dangerous Goods by Road, by Rail and by Inland Waterways (ADR, RID, ADN);
- Classification, Labelling and Packaging of Substances (CLP);
- Registration, Evaluation, Authorization and Restriction of Chemicals (REACH).

Both the prescriptive and the performance-based approach to safety aim to fulfil the requirements of EU legislation as implemented by national regulations, with the prescriptive approach providing a fixed set of rules to be followed to ensure the safety of people and structures, and the performance-based analysing the single case for establishing how to do it.

In general, key steps involved in the safety evaluation for both approaches are:

- **Identification of hazardous situations** that could originate internally or externally and potentially lead to an accident;
- **Evaluation of the damage potential from such accidents** by quantifying their impact on vulnerable targets, such as people, the environment, and physical assets;
- **Evaluation of the likelihood of occurrence** of initiating events and of their possible outcomes;
- Risk containment measures and barriers.

4 Summary of the requirements and barriers of the approaches adopted by the different countries

For the different countries (group HYPOP Countries, EU-13 and Frontrunners), HYPOP performed an in-depth analysis of the hydrogen specific regulations and conventional regulations applied when gaps are present – see section 9. The following tables summarise the information collected, whilst also already presenting a synopsis of the requirements and barriers found from the analysis of the current regulations, by Country and country group.

Table 4: Requirements and barriers for Industry, Mobility and Residential sectors – HYPOP COUNTRIES

HYPOP Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
Belgium	*(requirements)* Performance-based approach; quantitative risk assessment; ATEX zoning; technical standards ISO, EN; gas and fire detection systems; engagement fireman organization *(barriers)* lack of guidelines; regulatory gaps; variety in interpretations	No specific requirements or barriers identified as residential sector is lagging behind as hydrogen application
Italy	*(requirements)* Safety prescriptions like distances and pressure limits; H_2 technologies as for industrial use; ATEX zoning; PED application; technical standards ISO, EN; engagement local fire brigades; conventional fuel regulations *(barriers)* Strict safety distances; H_2 technologies as for industrial use; poor use of risk assessment; perception; regulatory gaps and time demanding procedures; different interpretations; lack of guidelines	*(requirements)* Safety prescriptions; technical standards ISO, EN; common procedures for electric appliances; conventional fuel regulations *(barriers)* Lack of knowledge; scarce perception towards FC micro-CHP systems; conventional regulations; different interpretations; lack of guidelines
Spain	*(requirements)* Performance-based approach for HRS; prescriptions for storage quantities and industry sector; technical standards ISO, EN; H_2 technologies as for industrial use; engagement of local authorities; conventional fuel regulations; safety guidelines *(barriers)* regulatory gaps for compressed and fixed storage systems; safety prescriptions; lack of experience; H_2 technologies as for industrial use	no specific requirements have been identified for residential H2 technologies *(barriers)* regulatory gaps; conventional fuel regulations; FC micro-CHP systems not included in legislation

Table 5: Requirements and barriers for Industry, Mobility and Residential sectors – EU-13 COUNTRIES

EU-13 Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
Bulgaria (also HYPOP country)	*(requirements)* Technical standards ISO, EN; engagement local fire brigades, safety prescriptions *(barriers)* Regulatory gaps; lack of knowledge; safety prescriptions; low perception for storage of H_2	*(requirements)* Technical standards ISO, EN; engagement local fire brigades, safety prescriptions *(barriers)* Safety prescriptions; low perception for storage of H_2
Poland (also HYPOP country)	*(requirements)* performance-based approach; risk assessment; technical standards ISO, EN; conventional fuel regulations *(barriers)* regulatory gaps; conventional fuel regulations	No information available at the moment. Further research is needed
Croatia	Only first contacts through the NCP	Only first contacts through the NCP
Cyprus	Only first contacts through the NCP	Only first contacts through the NCP
Czech Republic	Only first contacts through the NCP	Only first contacts through the NCP
Estonia	*(requirements)* conventional fuel regulations *(barriers) regulatory gaps; lack of knowledge*	Further research is needed. Synergies with other EU projects have been started
Hungary	*(requirements)* Safety prescriptions; ATEX zoning; PED application; H_2 technologies as for industrial use; gas and fire detection systems; quantity of hydrogen stored *(barriers)* Regulatory gaps; lack of knowledge; H_2 technologies as for industrial use; perception towards stored hydrogen and on-site production	No information available at the moment. Further research is needed
Latvia	*(requirements)* technical standards ISO, EN; safety prescriptions; quantitative risk assessment; conventional fuel regulations *(barriers)* conventional fuel regulations; regulatory gaps; lack of knowledge; safety prescriptions	There are not specific safety requirements or barriers for the installation of FC-based systems as they are considered as micro-CHP systems
Lithuania	Only first contacts through the NCP	Only first contacts through the NCP
Malta	(barriers) main focus on other solutions for decarbonization; lack of knowledge; regulatory gaps	No information available at the moment. Further research is needed
Romania	*(requirements)* ATEX zoning; technical standards ISO, EN; conventional fuel regulations; safety prescriptions *(barriers)* conventional fuel regulations; regulatory gaps; lack of knowledge	No information available at the moment. Further research is needed
Slovakia	Only first contacts through the NCP	Only first contacts through the NCP
Slovenia	*(requirements)* conventional fuel regulations *(barriers)* regulatory gaps; lack of knowledge; conventional fuel regulation	No information available at the moment but significant pilot projects are starting

Table 6: Requirements and barriers for Industry, Mobility and Residential sectors – FRONTRUNNER COUNTRIES

Frontrunner Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
France	*(requirements)* Flexible prescriptions for safety (dispensing flow rate, HRS); performance-based approach; mitigation measures to reduce safety distances Not specific barriers have been identified	*(requirements)* H_2 specific regulation for indoor and outdoor installations; focus on safety of storage systems; flexible prescriptions for safety Not specific barriers have been identified
Germany	*(requirements)* Performance-based approach; ATEX zoning; risk assessment methodologies; guidelines for HRS implementation; technical standards ISO, EN; gas and fire detection systems Not specific barriers have been identified	No specific requirements and barriers have been identified from the safety point of view
The Netherlands	*(requirements)* Performance-based approach; quantitative risk assessment; official guidelines for risk assessment; flexible safety prescriptions No specific barriers have been identified	No specific requirements and barriers have been identified from the safety point of view
Switzerland	*(requirements)* ATEX zoning; official guidelines for hydrogen production; engagement local fire brigade; risk assessment methodologies No specific barriers have been identified	Further research needs to be carried out for residential applications

5 Strengths and weaknesses with comparison of safety approaches in EU countries

This section aims to highlight strengths and weaknesses, similarities and differences between the various safety approaches of the countries for which information has been collected. The areas of comparison ranged from hydrogen production to infrastructure for mobility and residential applications.

5.1 Strengths and weaknesses

The following table provides the strengths and weaknesses for hydrogen technologies implementation in industry, mobility (research on HRS with on-site hydrogen production is linked to industrial applications) and residential sectors. Missing information will be the focus for the remaining duration of the project where the stakeholders' engagement workshops to be organized within the scope of the Work package 4 are aimed to cover as much as possible these gaps.

The parameters against which the strength/weakness analysis has been performed are:

- Availability of guidelines for safety evaluation
- Evidence of implementation/adoption of risk assessment methodologies
- Evidence of regulations, codes and standards guiding the safety approach to hydrogen
- Application/adoption/evidence of performance-based approach and consequent requirements
- Application/adoption/evidence of prescriptive approach and consequent requirements.

These parameters represent the main characteristics of a safety regulatory framework and approach hence their availability/application/ evidence is considered in general a positive element. However, the association between parameters and colours (hence positivity or negativity) has been decided according to the main elements found during the regulatory frameworks and best practices analysis, and as output of the stakeholders' engagement activities in terms of perception and opinions. Nevertheless, it does not intend to reflect fully the current situation for each country as case-by-case situations should be considered.

The table can be read as follows:

- Where information is missing, "n/a" (not available) is reported (red colour if missing information is a weakness)
- If the chosen parameter does not reflect the country specific safety approach and yet it does not represent a weakness, "n/r" (not relevant) is reported;
- If the chosen parameter refers to the regulatory framework or to the safety approach followed in the country and if it corresponds to a positive experience/ best practice or to negative experience/gap in the regulatory framework, green or red colours are associated respectively to indicate a strength or a weakness.

Table 7 Strengths and weaknesses identified according to the main safety factors influencing the implementation of hydrogen in Industry, Mobility and Residential sectors

HYPOP Countries	Guidelines for safety evaluation	Risk assessment methodologies	Regulations, codes and standards	Performance-based requirements	Prescriptive requirements
Belgium				n/a	n/r
Italy					
Spain					
EU-13 Countries	Guidelines for safety evaluation	Risk assessment methodologies	Regulations, codes and standards	Performance-based requirements	Prescriptive requirements
Bulgaria (HYPOP country)				n/a	
Croatia	n/a	n/a	n/a	n/a	n/a
Cyprus	n/a	n/a	n/a	n/a	n/a
Czech Republic	n/a	n/a	n/a	n/a	n/a
Estonia		n/a	n/a	n/a	
Hungary		n/a	n/a	n/a	n/a
Latvia				n/a	
Lithuania	n/a	n/a	n/a	n/a	n/a
Malta		n/a	n/a	n/a	n/a
Poland (HYPOP country)					n/a
Romania		n/a		n/a	n/a
Slovakia	n/a	n/a	n/a	n/a	n/a
Slovenia		n/a	n/a	n/a	n/a
Frontrunner Countries	Guidelines for safety evaluation	Risk assessment methodologies	Regulations, codes and standards	Performance-based requirements	Prescriptive requirements
France	n/a				
Germany					n/r
The Netherlands					
Switzerland					n/a

The above table can also be represented visually with a coloured map, where each of the green cells has been counted as one point of strength, with 5 being the maximum (the Netherlands).

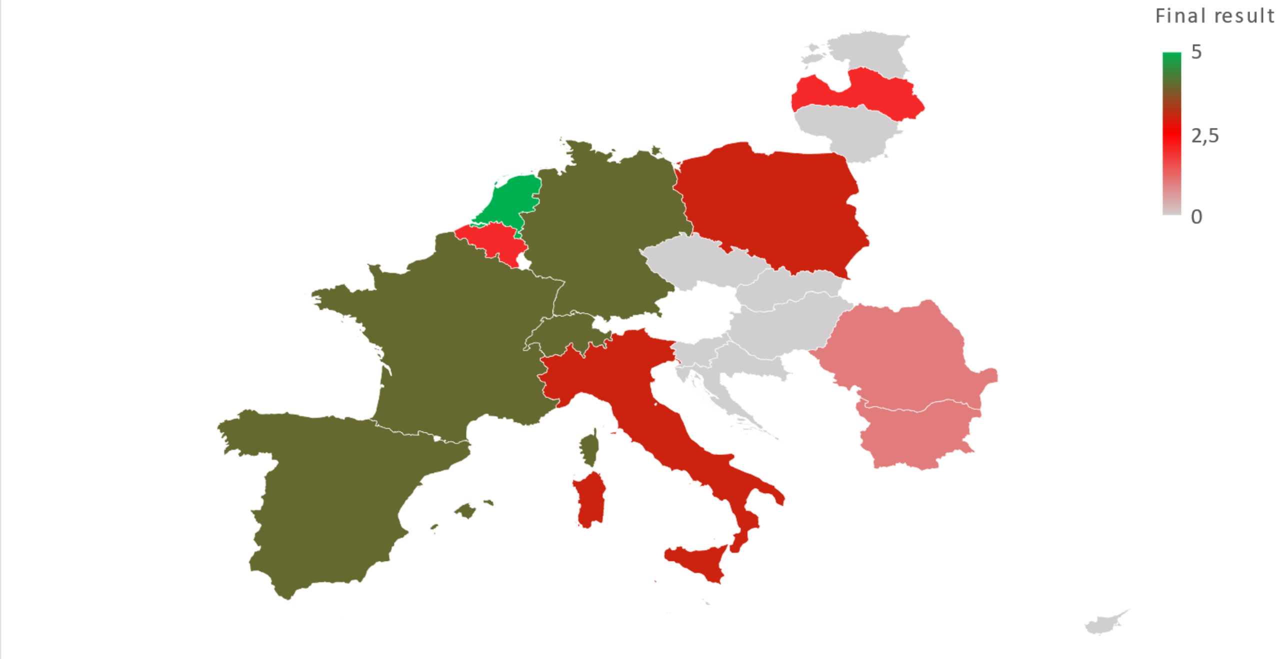

Figure 4 Map of the safety approaches by Country, with the greenest countries representing those where the safety approach has the most elements from the list in section 5.1.

5.2 Similarities among Countries analysed

The administrative organization of a country, from which competent safety authorities arise, is a factor to consider for both prescriptive and performance-based approaches. In particular, multiple interpretations can emerge in the absence of common guidelines and knowledge about renewable hydrogen use and hydrogen technologies in new sectors such as residential and mobility. This becomes even more critical in the case of the prescriptive approach where the innovative features of a hydrogen project may struggle to fit within the existing regulatory framework and requirements for safety. Indeed, it has been possible to demonstrate how the use of specific risk analyses to support a hydrogen project is functional in achieving minimum safety conditions and increasing the knowledge and awareness of competent authorities regarding new hydrogen projects.

An example involves the **mobility sector** with the HRS. In this case, the use of a risk analysis has been a common element for HRS project planning in Belgium and Poland (references are made about the need to increase public awareness and education), and it has been an instrument to spread knowledge to firefighting authorities in Italy (HRS in Bolzano).

Moreover, for countries like Poland, Belgium, Bulgaria, Germany, as well as for EU-13 countries, risk assessment methodologies, guidelines from the industry sector, technical reports for fire prevention, technical standards and reference to general safety management elements are taken into account. Similar tools are taken into consideration also in the Italian regulatory framework for safety of hydrogen technologies, but generally the approach is to apply existing prescriptions from technical rules for HRS and Hydrogen production plants as well as the ones borrowed by other conventional fuels and technologies – with the consequent limitations.

5.3 Differences among Countries analysed

Some comparisons can be done regarding the safety approaches and among the HYPOP countries, especially for the HRS but extended also to **Hydrogen production plants and residential sector**:

Regarding the **hydrogen production facilities**, even the ones conceived to be integrated in HRS (on-site hydrogen production), the following differences among countries and approaches emerged:

- The safety requirements for the hydrogen production plant designed for the ammonia production in Spain (example of the performance-based approach) is based on the **combination of risk analysis, recommendations from official guidelines published at national level for the safety management** (including technical reports, safety reports, references to technical standards) and the **application of conventional national regulations regarding storage systems** (e.g. distances between storage and public roads, buildings from 6 to 10 meters…);
- On the other side, the example of prescriptive approach from Italy for production and distribution facilities (under the technical rule for hydrogen produced by water electrolysis) showed **specific requirements like the need for a containment structure for <u>each</u> hydrogen technology and safety distances according to the working operating pressures but highlighted also a gap as differences among the different type of technologies are not taken into account (e.g. storage has the same requirements of a compressor, for instance).** For one of the projects applying this Italian regulation, the **switch from prescriptive to performance-based approach** was identified and some of the safety distances could be reduced through a preliminary risk assessment (from 15 meters to 7 meters). It has been used also as a tool to increase safety authorities' acceptance.

Specifically for **HRS safety**, the following comparisons among the approaches are showed.

- The German performance-based approach is considered as the reference and the following winning characteristics emerged:
  - official documentation for explosion protection,
  - recommendations and technical reports from the industry sector for evaluation and fire prevention are generally the base of the safety approach.
  - Safety distances can be recommended but not mandatory in general.
  - Stakeholders rely on risk assessment methodologies.

Instead, for the HYPOP countries, the following findings are reported:

- For the HRS designed in Belgium, quantitative risk assessment and specific technical standards have been considered by the stakeholders. On top of that, the minimum safety distances from sensitive elements of the surrounding environment, such as the neighbourhood, derived only from the calculation of thermal radiation generated by an explosive event (request of the regional safety authority);
- For the **HRSs which are going to be built in Poland** by one of the stakeholders, some basic consideration for safety are shared like the applications of certain **EU directives and regulations** like ATEX and **pillars for the general safety** of the HRS: leak detection, ventilation and emergency systems, standards for construction, operation and maintenance, hydrogen purity and quality etc;
- the Italian technical rule for HRS is characterized by prescriptions, especially for the safety distances needed between compressor systems, storage units, containments structures for the hydrogen delivery vehicle, dispensing units etc. For example, **the safety distances between those hydrogen technologies and the elements outside the facility can vary from a minimum of 15 meters to 30 meters and are defined without taking into account the differences between the technologies installed on site** (if on site H2 generation is present, electrolysers technical rule could be applied with safety distances ranging from a minimum of 5 meters to 30 meters). Furthermore, multifuel HRS are allowed if certain safety distances

ranging in general from 12 to 30 meters are respected. In the case of one of the hydrogen projects described for an Italian HRS, the switch from this prescriptive to performance-based approach has been possible through the combination of risk analysis, description of incident scenarios and the comparison with the safety approach of another country allowed for the acceptance by the fire fighters of certain modifications to the technical rule.

Hydrogen technologies can also be employed **in the residential sector**. This end use of hydrogen is even newer compared to the mobility and industry and public acceptance is one of the main hotspots. To date, from a safety regulatory perspective, there are no particular new developments within the countries of the HYPOP consortium, except for the official definition of threshold limits for the injection of renewable hydrogen into the gas network (blending with natural gas up to 2% for Italy and 5% for Spain, Appendix A).

- **The two projects concerning the hydrogen heating system and natural gas blending for the utilities of public buildings, as described in the cases of Poland and Bulgaria, exhibit the typical elements of the performance-based approach.** In fact, **best practices** for the safe installation of the described systems and the use of **industry technical standards** are shared.
- In the case of the Italian project described in the prescriptive approach, a different technology has been used, a reversible SOFC cogeneration system capable of meeting electrical and thermal needs. In this case, **the Italian technical rule for the storage of natural gas has been borrowed for this hydrogen project and the related prescriptions have been applied fully. For the residential application of this project, required safety distances went from 20 to 30 meters if no specific containment structures for protection were designed**. On the other side, if containment structures were envisaged to protect both sideways and upward or only laterally, the safety distances could have significantly decreased into a range from 5 meters to 30 meters. To define the exact safety distance, also the geometric capacity of the storage system needed to be taken into account (more details in the Appendix A).
- If we compare the regulation applied in France but in this case specific for hydrogen storage systems (potentially also for the residential sector), safety distances go from **8 meters (outdoor installation) to 5 meters (indoor installation)** from property boundaries or any building. It is also allowed to have **multiple fuels stored in the same site with a safety distance of 8 meters that can be reduced even more with additional safety measures.**

Furthermore, comparisons between the safety requirements within the two different prescriptive approaches of Italy and Bulgaria for the HRSs are proposed. A short comparison is also made with the prescriptions for the HRS built in France.

- In the Italian technical rule for HRS, there are specific safety distances to be respected between hydrogen technologies that can range from 15 to 30 meters (similar approach for the technical rule of hydrogen production by water electrolysis). Instead, within Bulgarian prescriptions, hydrogen technologies which constitute the HRS facility can be integrated within the hydrogen production area (if envisaged in the HRS project);
- In the Bulgarian regulation, delivery of hydrogen to the HRS is not conceived through pipelines. Instead, in the case of the Italian technical rule, supply through pipelines, under certain requirements about storage capacity (e.g. storage < 500 nm^3; no hydrogen bundles and H2 production on site), is allowed;
- Compared to Italian technical rule for HRS, in the case of Bulgarian regulation hydrogen processing procedures other than renewable hydrogen production from water electrolysis are not allowed (conventional fuel processing like steam methane reforming etc not allowed);

- In the Bulgarian regulation, other types of storage technologies than the ones regarding compressed hydrogen are possible. In this case, specific standards are required. For example, for metal hydride storage systems, standard required is ISO 16111 "Portable gas storage devices. Hydrogen absorbed in reversible metal hydride". In the case of Italian technical rule for HRS, only electrolysis and steam methane reforming are mentioned (together with the standards required).
- In France, safety distances between the hydrogen technologies and the facility boundaries, the ventilation devices and the storage of flammable gases varies from a **minimum of 6 meters to 14 meters**. These distances can be reduced if a solid wall high at least 3 meters is built. **The prescriptions depend on the flow rate and thus the capacity of the HRS.**

The next section presents a first collection of best practices identified during the work, i.e., experiences that have brought about successful installation of hydrogen technologies in the industry, mobility and residential sectors. Where possible, “winning” approaches and lessons learned have been highlighted.

The identification of best practices will continue during the next phase of the project , as they will feed the Guidance documents to be issued at the end of project HYPOP.

6 Best practices for safe implementation of Hydrogen in Industry and Mobility

The following section shows the best practices identified showing the safety approaches applied for:

- Hydrogen production and storage for mobility applications;
- hydrogen refuelling station with on-site production;
- fixed hydrogen refuelling station;
- mobile hydrogen refuelling stations;
- railway mobility.

This distinction is aimed to highlight safety perception among these HRS configurations due to factors like safety distances, pressure thresholds and the related risk assessments methodologies that can differ significantly.

Hydrogen is a chemical product well known and used in different industrial processes. For this reason, industrial applications are generally more used to safety regulations and related permitting procedures. Since renewable hydrogen is going to be exploited as an alternative and integrated fuel for decarbonization of multiple end-uses, safety requirements from industrial applications can be transferred to many mobility and residential applications. The presence of on-site hydrogen production in a HRS, for instance, links directly to industrial applications and crosslinked safety perception, and for this reason industry and mobility are analysed together.

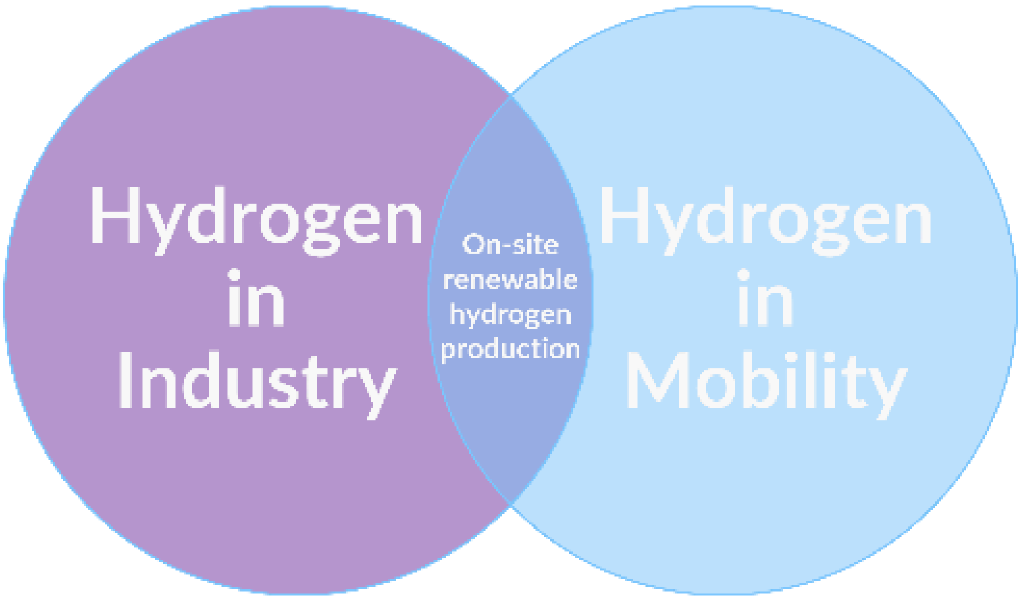

Figure 5 Interconnection between safety requirements in Industry and Mobility sectors

In Deliverable 2.2 the distinction between Industry and Mobility is more emphasized. This is because permitting procedures which include also environmental, urban/land and other types of permits. are quite different when it comes to an industrial site and a public site.

6.1 Hydrogen production and storage for mobility applications:

6.1.1 ITALY: Performance based approach

An example of the performance-based approach adopted in Italy and explained below is given by a project which is still under development and called HYPER (Hydrogen valley in Mantova)[3]. **Risk assessment methodologies are valuable tools for safety compliance and, in cases like these, can modify the prescriptive provisions of the regulations.**

Figure 6 Layout of the HYPER project (Italy)

Among its different components, the project envisages an electrolysis unit, a compressor system, an innovative tube trailer (@ 500 bar) solution to reduce the environmental impact of hydrogen transport and end uses like H_2 trains. For this case, the stakeholders involved in the project aims to apply the Italian regulation for hydrogen production through electrolysis and related storage systems (details of the technical rule in Appendix). Taking into account the safety distances required and the hazardous components of the production and distribution facility, barriers have already arisen in the design phase.

Main barriers and mitigation measures:

- **mandatory containment structures for each component of the hydrogen facility** (except the HRS dispenser) and the piping, considered as hazardous component and requiring to respect safety distances;
- the stakeholder intends to follow a performance-based approach to meet the same minimum safety requirements but reducing the distances of the regulation;
- To optimise the design of the facility through a risk assessment consisting of:
  a) HAZOP analysis to eliminate or reduce process accidental events;
  b) Statistical-historical analysis for plant optimisation for random events by means of special anti-breakage flanges to reduce likely of explosion events;
  c) Domino effect mechanism evaluations of secondary accidents/scenarios that induced the displacement of piping due to interference of damage areas with cryogenic oxygen tank.

WINNING APPROACH: The risk analysis was accompanied by the use of a software to estimate the effects and consequences of accident scenarios ("conical" model and "Unified Dispersion Model"). **In addition, the risk analysis made it possible to address an issue such as the interference between**

[3] https://assogastecnici.federchimica.it/docs/default-source/default-library/eventi/xvii-rns/michela-capoccia-e-giovanni-romano.pdf?sfvrsn=a8b10158_1

hazardous elements such as the loading and unloading bays and the compressor area and to propose an alternative solution by reducing the minimum internal distance between the two elements mentioned by halving it from 15 metres to 7 metres.

LESSON LEARNT: The following scheme synthetizes the factors that can be cause of switch from prescriptive to performance-based approach to safety in those cases (also for other type of HRS or hydrogen plants) where the regulatory framework is not able to meet the techno-economic feasibility of the hydrogen project.

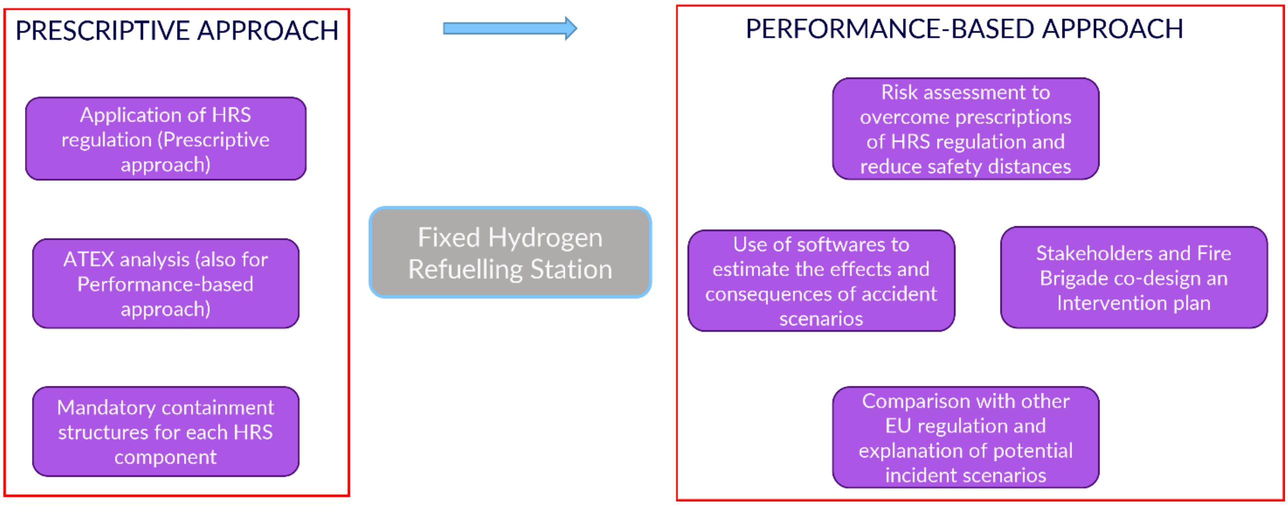

Figure 7 Prescriptive approach and Performance-based approach for safety of Fixed HRS configurations

6.2 HRS with on-site production

6.2.1 ITALY: Production and distribution plants (HRS) for railway mobility

Another evidence of the performance-based approach applied in Italy as a combination of risk assessment methodologies and interactions with the safety authorities is provided. It is the case of the **Production and distribution plants (HRS) for railway mobility in H2iseo Hydrogen Valley** through which hydrogen is gaining more prominence in the railway sector.

An interview was conducted with one of the main partners involved in the project for the hydrogen production and distribution plant in the province of Brescia. The electrolysis plant will be located next to the HRS to avoid hydrogen transport and it will be connected to a renewable electricity source through an electric pipeline crossing the city. The project has not achieved the construction phase yet, and therefore technical documentation related to safety and permitting aspects is under development. The plan of actions is:

- to refer to the technical rule for hydrogen refuelling stations (described in detail in Appendix) **applying the prescriptive approach to safety;**
- to start discussions with the Provincial Fire Brigade of Brescia, bringing a preliminary risk assessment study that could be used by public authorities to better understand the main characteristics of the project;
- **to evaluate the application of the performance-based approach**, presenting a study on how, with certain measures, safety distances can be reduced.

WINNING APPROACH. **Continuous communication and interaction with safety authorities showing how the performance-based approach can guarantee high level of safety**.

6.2.2 SPAIN: guideline for safety installation of HRS and Hydrogen technologies

HYPOP project believes that a sound regulatory framework is pivotal for the implementation of a hydrogen economy. Nevertheless, it is often associated to the perception of institutions and their knowledge about hydrogen technologies. The transition phase towards hydrogen technologies for novel sectors like mobility and the uncertainties due to a not mature regulatory framework can be both faced through a deep cooperation between public stakeholders and hydrogen key players like technology manufacturers and adopters. **The following best practice is a tool developed by the Asociación Nacional de Normalizacion de Bienes de Equipo y Seguridad Industrial "Guía técnica: Seguridad del Hidrogeno" to support and to spread knowledge towards public authorities and to all those early adopters interested to unlock the hidden potential of hydrogen.**

It describes:

- the physical and chemical features of hydrogen;
- the different technologies for production, storage, compression, transport and distribution of hydrogen;
- the most relevant risk analysis methodologies, their function and goals and the stage of application in the project;
- the identification of potential regulatory gaps at national level, recommendations from experts and presentation of international regulations, codes and standards (RCS) for safety of hydrogen installations.

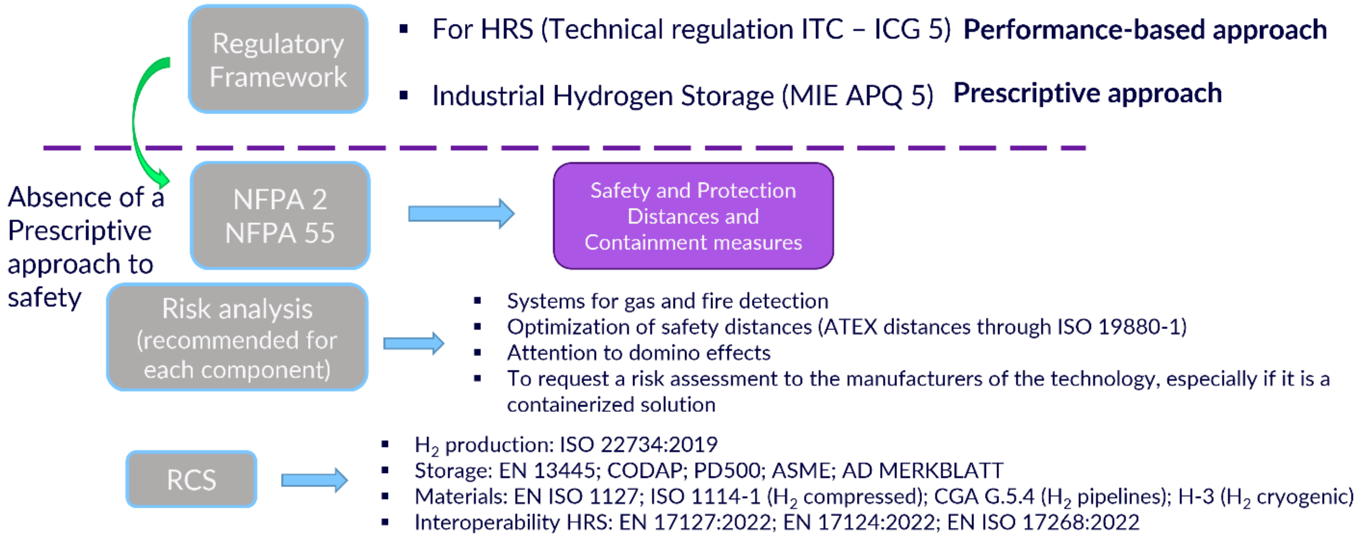

Figure 8 Scheme to comply with Public Safety authorities' requirements for HRS (Spain)

In the case of Hydrogen refuelling stations, Spain has a performance-based approach to safety. The technical regulation developed for this purpose describes all the requirements to fulfil for those hydrogen technologies functional to the refuelling of hydrogen fuelled vehicles.

The guide provides information for safety of HRS considering the presence of standard components like the electrolysis unit, the storage systems, the compressors and the dispensers. Moreover, as hydrogen refuelling stations are integrated systems, all the safety analysis done for each component must be implemented for the connection between systems during their operation and the related hazards (according ISO 19880-1, Part 11 Instrumentation and Control and Part 13 Operation).

Hydrogen production through electrolysis is mentioned as well and the regulation does not exclude this type of configuration. Nevertheless, the guideline recommends higher safety standards in case of on-site hydrogen production that together with storage and compression are the main dangerous elements of a HRS. **The safety distances need to be justified by a risk analysis**, whereby the distances where the effects of overpressure do not affect other installations are determined. It is recommended to simulate the overpressure waves in case of explosions or even projections, to determine safe distances for both fixed and mobile storage of hydrogen gaseous fuels. In general, there is no reference to constraints for containerized solutions with on-site production but risk assessments, a part from the ones produced during the base and the detailed engineering phases, must be asked to the manufacturer of the solution to integrate all the information available and define the safest plant's layout.

The following are the key elements to be taken into account for HRS with on site production, especially if containerized solutions are envisaged.

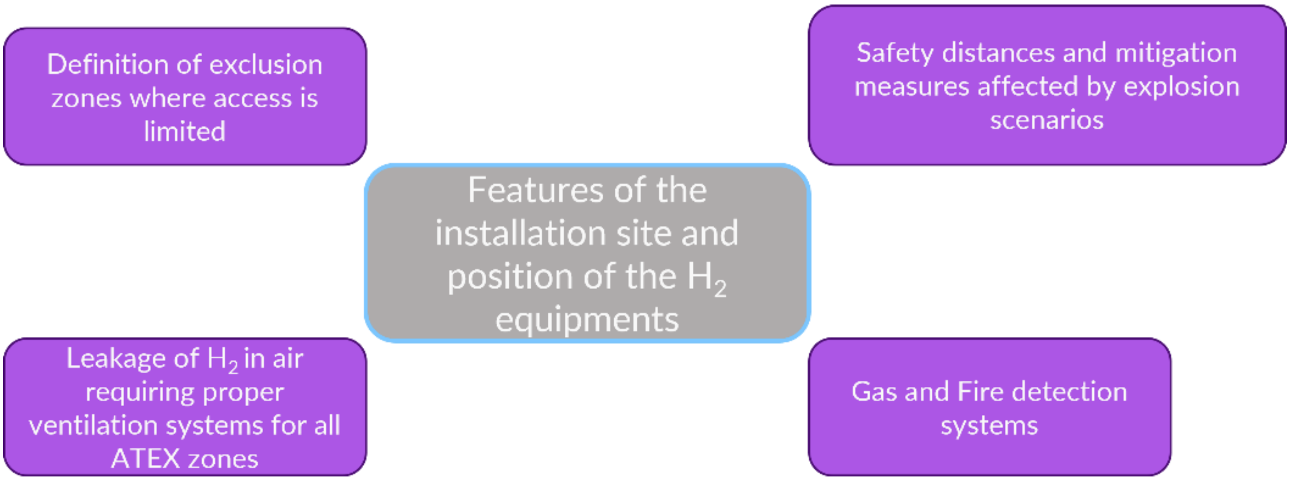

Figure 9 Influence of features of H2 components and of the installation site on the safety of a HRS

The guide gives significant space to inform about the choice of the right **storage technology** that depends on different elements as follows:

- **material** (i.e., consider embrittlement phenomena, structural discontinuities as potential leakage sources, geometry as mechanical stress element, manufacturing process of the component);
- operation pressures;
- **type of application** (i.e., stationary or mobility);
- **the state of hydrogen** (i.e., gaseous, liquid, cryogenic);
- volume/quantity of hydrogen stored;
- **type of cylinders used** (i.e., type 1,2,3,4);
- **configuration of the system** (i.e., vertical recommended with lower volumes, safe configuration as potential leakages due to valves ruptures are discharged upwards; horizontal ideal for high volume configurations like for tube trailers).

For storage systems, risk assessment should be developed according to recommended standards like ISO 3100:2018, IEC 31010 and EN ISO 12100:2012.

The following guidelines and reference documents are suggested for a safety management of the production and storage systems:

- NFPA-2 – Hydrogen technologies code;
- NFPA 55 – Compressed Gases and Cryogenic Fluids Code;
- BPVC Section VIII -1 “Reglas para la construcción de recipientes a presión”;
- UNE – EN 13445 “Recipientes a presión no sometidos a la acción de la llama”;
- CGA 5.4 “STANDARD FOR HYDROGEN PIPING SYSTEMS AT USER LOCATIONS”;
- CGA 5.5 “Standard for Hydrogen vent systems”;
- EIGA 033/14 “HYDROGEN CYLINDERS AND TRANSPORT VESSELS”;
- ISO/TR 15916:2015 “Basic considerations for the safety of hydrogen systems”.

WINNING APPROACH: the guideline has been developed through a cooperation between public stakeholders and hydrogen key players like technology manufacturers and adopters, so that a concerted approach could be defined. Furthermore, the guideline produced analyses all the different elements of a HRS considering therefore their possible integrations.

6.3 Fixed hydrogen refuelling stations

6.3.1 ITALY: Prescriptive approach vs Performance-based approach

WINNING APPROACH. If the use of regulations, directives and technical standards is an effective way to achieve safety requirements, also **communication and interaction with safety authorities is fundamental to the adoption of the performance-based approach**.

An example of how this interaction has been fruitful to overcome barriers and ensure a fast deployment is the case of the first HRS built and operated in Bolzano (Italy).

This case study was considered relevant as it refers to the first **HRS for road mobility of both light and heavy FCEV**. To date, thanks to funds from the Italian National Recovery and Resilience Plan (PNRR), about 47 refuelling stations have been approved for funding and are expected to be built by 2026.

The regulatory framework valid at the time of design and installation phases (2014) allowed only 350-bar dispensing mode as previous to the regulation developed in 2018 for HRS in Italy (Ministerial Decree of October 18, 2018, see Appendix for more details). To introduce also 700-bar dispensing mode for light duty vehicles, an amendment was requested to the Fire Brigade by the stakeholders involved. **The technical documentation submitted to the Fire Brigade included:**

- a risk assessment demonstrating the safety of a 700-bar plant;
- a detailed ATEX evaluation of the surrounding area.

The discussion with the Fire Brigade then allowed for a second amendment regarding the possibility of self-service refuelling for both bus drivers and motorists. This was made possible by providing:

- an analysis of incidents that occurred in similar facilities operating at 700 bars in other countries;
- analogy with the Austrian regulation that governs the possibility of performing self-service refuelling after having conducted a test of at least 6 months on the facility.

The stakeholder also shared the experience of co-designing an intervention plan that involved the Institute for Technological Innovations Bolzano (which manages the facility) and the Provincial Fire Brigade of Bolzano. This approach showed the effects of constant interactions between project owners and safety authorities.

6.3.2 POLAND: regulation for Hydrogen mobility

More than 30 HRS are foreseen to be implemented in the coming years in Poland, showing its commitment to fulfill the new Alternative Fuel Infrastructure regulation (AFIR).

The following list shows the different pillars for the safety of HRS in Poland and they can be taken as examples of good practices to ensure safety both for fixed, mobile and containerized configurations:

1. Hydrogen Storage and Handling:
    - Leak Detection: Install hydrogen sensors to promptly detect any leaks;
    - Ventilation: Proper ventilation is essential to disperse any released hydrogen;
    - Emergency Shut-off Systems: Implement emergency control valves to isolate hydrogen flow during emergencies;
    - Excess Flow Valves (EFV): EFVs to stop hydrogen flow when it reaches a certain level.
2. Infrastructure Safety:
    - Hydrogen Refuelling Station (HRS):
        - HRS should adhere to safety standards for construction, operation, and maintenance;
        - Proper signage and safety instructions must be visible for users;
        - Emergency response plans should be in place.
    - Hydrogen Pipelines:
        - Pipelines transporting hydrogen should meet safety criteria;
        - Regular inspections and maintenance are crucial;
        - Emergency shut-off valves should be strategically placed;
3. Fire Safety:
    - Fire Suppression Systems: Install fire suppression systems (e.g., water mist, foam) at HRS and other hydrogen facilities;
    - Firefighting Training: Staff should be trained in handling hydrogen-related fires;
4. Electrical Safety:
    - Electrical Equipment: Use explosion-proof electrical equipment;
    - Electrolysers and Fuel Cells: Ensure safe electrical connections;
5. Hydrogen Purity and Quality:
    - Certification: Regulations define acceptable hydrogen purity levels for different applications (e.g., fuel cells, industrial processes);
    - Quality Control: Ensuring consistent quality through monitoring and testing;
6. Emergency Response Plans:
    - Incident Preparedness: HRS and other facilities should have emergency plans for leaks, fires, or other accidents;
    - Coordination: Collaboration between industry stakeholders, emergency services, and local authorities;
7. Public Awareness and Education:
    - Educate the public about hydrogen safety;
    - Promote awareness of safe practices.

WINNING APPROACH: clear mapping of requirements and roles.

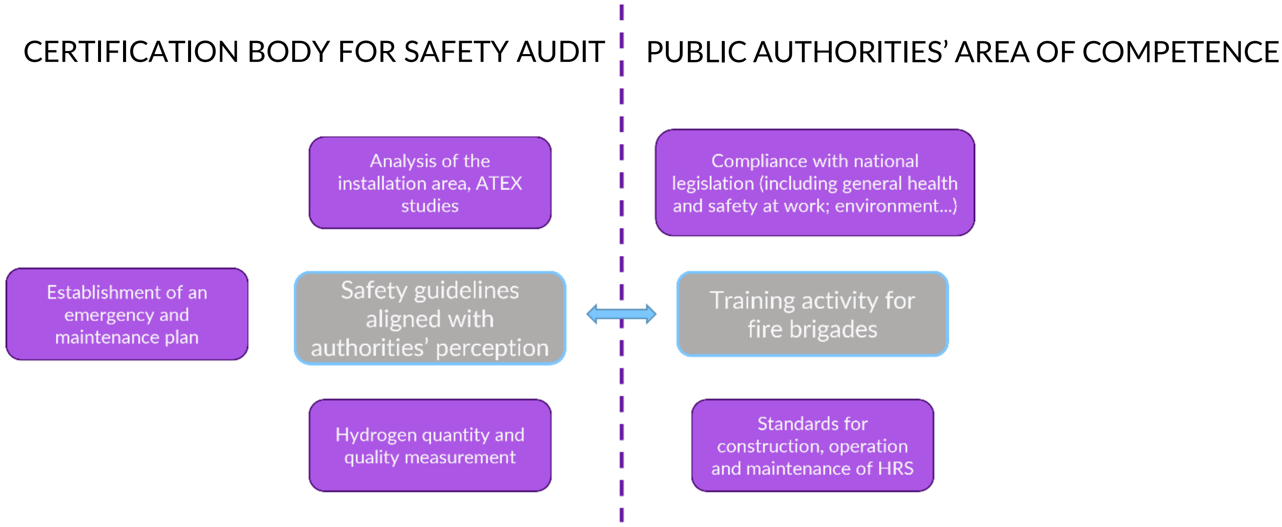

Figure 10 Key elements for certification bodies and public authorities

WINNING APPROACH: Stakeholders' engagement is fundamental to ensure a smooth and sound development of the hydrogen economy. Knowledge can be spread also through training initiatives that go from hydrogen key players like technology manufacturers or certification bodies to the institutions in charge of safety and permitting procedures. For example, **cooperation between certification bodies and fire brigades allows for an improvement of the public perception and consciousness and certification bodies can develop internal guidelines for safety audits which consider the point of view of institutions.** In the case of safety assessment, the procedure is facilitated. This initiative could be replicated also for other permitting procedures and the related stakeholders involved.

For more details about the main requirements of the Polish Law on Electromobility and Alternative Fuels that introduces the definitions and requirements for Hydrogen Refuelling Stations construction and operation, check the Appendix below.

6.3.3 GERMANY: guidelines for hydrogen refuelling stations

The following information has been gathered both through the analysis of a permitting guidelines for HRS and through an open, virtual and still ongoing initiative under the INTERREG funded project called HyTruck[4] whose main goal is to support public authorities from Baltic regions in steering the development of a transnational network of renewable hydrogen refuelling stations (HRS) suited for heavy duty vehicles.

Germany is known for the developed HRS system with a network of HRS exceeding 80 units (more under development). Hydrogen refuelling station system can rely on a developed regulatory framework that supports and ensure clarity to the German hydrogen mobility sector. This is also given by the existence of guidelines granted at national level and produced by relevant hydrogen associations where the different permitting procedures that stakeholders must follow to allow their HRS vary according to the quantity of hydrogen stored and the presence of on-site hydrogen production unit.

[4] https://interreg-baltic.eu/project/hytruck/

The German hierarchical permitting framework implies more complex procedures with increasing amounts of hydrogen flowing within the HRS perimeter and a consequent higher number of authorities involved. The guideline provides an in-depth description of the permitting procedure for Hydrogen refuelling stations without on-site production and with a quantity of hydrogen lower than 3 tonn. As the majority of plants developed in Germany have a maximum hydrogen throughput per day of 1 tonn[5], the permitting procedure described in the guidelines provides a useful picture of the safety and permitting elements considered at national level for fixed but also for mobile layouts (specific factors due to the type of mobility application or local regulations are out of the scope of the guideline).

The safety philosophy applied in Germany is the performance-based approach. What emerges from the analysis of the permitting procedure is that safety requirements are based on the following principles:

- Safety distances are usually defined by the technology manufacturer of the hydrogen component;
- Stakeholders rely fully on risk assessment methodologies, technical standards like ISO 19880-1:2020 "Gaseous hydrogen — Fuelling stations Part 1: General requirements" and recommendations;
- Safety approach should be integrated with the analysis of the official national documentation for explosion protection like "Explosionsschutz-dokument";
- As a part of the project development, recommendations from the document TRBS 3151 "Prevention of Fire, Explosion and Pressure Risks in Petrol Stations and Gas Filling Stations for Refuelling Land Vehicles - Technical Rule for Operational Safety" (ATEX zone classifications) are considered important;
- Technical Report as ISA TR 84.00.07:2018 "Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness";
- International Fire Code (IFC) which establishes the minimum requirements for fire prevention and fire protection systems. It is fundamental for emerging energy applications like the ones where renewable hydrogen can be conceived.

One element considered as fundamental to ensure safety through performance-based approach and risk assessment methodologies is the early detection of gas leakage. Indeed, Ultrasonic detection, Catalytic Bead Sensor and Flame Multi-IR systems are needed when working with compressed hydrogen as the majority of the accidents happened at HRS facilities are caused by human factors, for example, during maintenance, revision, restart procedures. This implies both the need of a higher knowledge about the Hydrogen Safety professionals and high-quality detection systems as one of the pillars necessary to ensure that performance-based approach is consistent and safe for public health and for environment.

WINNING APPROACH: National guidelines comprising:

- best practices;
- a checklist of relevant documents;
- expert opinions;
- information on important stakeholders to be involved in the procedure.

[5] https://h2-mobility.de/wp-content/uploads/sites/2/2021/08/H2-MOBILITY_Overview-Hydrogen-Refuelling-For-Heavy-Duty-Vehicles_2021-08-10.pdf

6.4 Mobile hydrogen refuelling station

6.4.1 BELGIUM: Safety approach for HRS implementation in Belgium

Regarding safety requirements for hydrogen projects construction and operation in Belgium, the following experience about a new hydrogen refuelling station for practical training on hydrogen cars is reported here as a best practice. It provides an example of the performance-based approach that can be followed for mobile but also fixed Hydrogen refuelling stations as shows the basic requirements for safety and permitting compliance.

Table 8 Set of EU directives and standards for HRS safety and permitting in Belgium

Type of regulation	Scope	Reference	Subject	Description
Directive	Europe	2014/94/EU	Alternative fuel infrastructure directive (AFID)	Common directive to deploy alternative fuel infrastructure
Standards	International	ISO/TS 19880-1	General requirements for refuelling station	Technical specifications for public and private refuelling stations
	Europe	EN 17127	General requirements for refuelling station	European transposition of ISO/TS 19880-1
	International	ISO 14687-2 + ISO 19880-8	Quality conformity and Hydrogen purity	Quality specification for hydrogen use for mobility
	Europe	EN 17268	Hydrogen purity	European transposition of ISO 14687-2 and ISO 19880-8
	International	ISO 17268	Recharging connectors	Standards for the design, the security and the operations of refuelling connectors
Sector standards	International	SAE J2601-1 SAE J2601-2 SAE J2601-3 SAE J2601-4	Refuelling protocols for: Light vehicles Hight vehicles Forklift Slow refuelling	Security and performance limits for refuelling stations (350 bar and 700 bar)
	International	SAE J2799	Communication between vehicle and refuelling station	Description of infrared communication between the vehicle and the refuelling station (350 bar and 700 bar). This communication system must also correspond to the SAE J2601 standard.

Together with the European and International legislation, also the regional safety requirements for this HRS have been collected as obtained through the **interactions with the competent regional authority**.

The DGO3 (General Operational Directorate for Agriculture, Natural Resources and Environment) is the competent authority at regional level to issue an environmental permit necessary for the construction of the hydrogen station.

A specific interview with the competent staff of the DGO3 made it possible to specify the operating conditions to be taken into account for the installation of a hydrogen refuelling station according to the features of the site (Francorchamps Automotive Campus):

- The hydrogen station studied does not imply SEVESO classification. The storage quantities for a station corresponding to the specifications are well below the SEVESO thresholds;
- The safety distances to be respected from buildings, the neighborhood and parking lots must be greater than the thermal radiation in the event of an explosion (risk of fire propagation);
- This distance in the case of a non-SEVESO classified site is calculated by the DGO3 using a simulation tool in the case of the environmental permit application. An exception can be made so that this is done upstream of the request;
- The DGO3 can also issue operating conditions to **prevent possible "domino effects".** In the case of this specific project, there is no equipment deemed dangerous around site. Therefore, the station should not be subject to any particular operating conditions.

WINNING APPROACH: communication with the permitting authority

6.4.2 SPAIN: mobile and modular system for the refuelling of rail and light vehicles

The first Spanish best practice about mobile hydrogen refuelling station is a EU funded project called FCH_2RAIL where a fuel cell hybrid power pack for rail applications was developed. What is relevant for the scope of WP2 activity is the mobile, modular and compact system developed for refuelling light vehicles and trains in Spain. The system is modular as it can consist of 1 to 4 containers, each of which contains a hydrogen refuelling station component (compressor, 2 storage systems and dispenser). Each container is then individually transported by road to its new destination once the refuelling of the vehicle is completed. The system does not include on-site production of hydrogen by means of an electrolyser. Hydrogen is transported to the refuelling station by a gas supplier that refills the two storage containers.

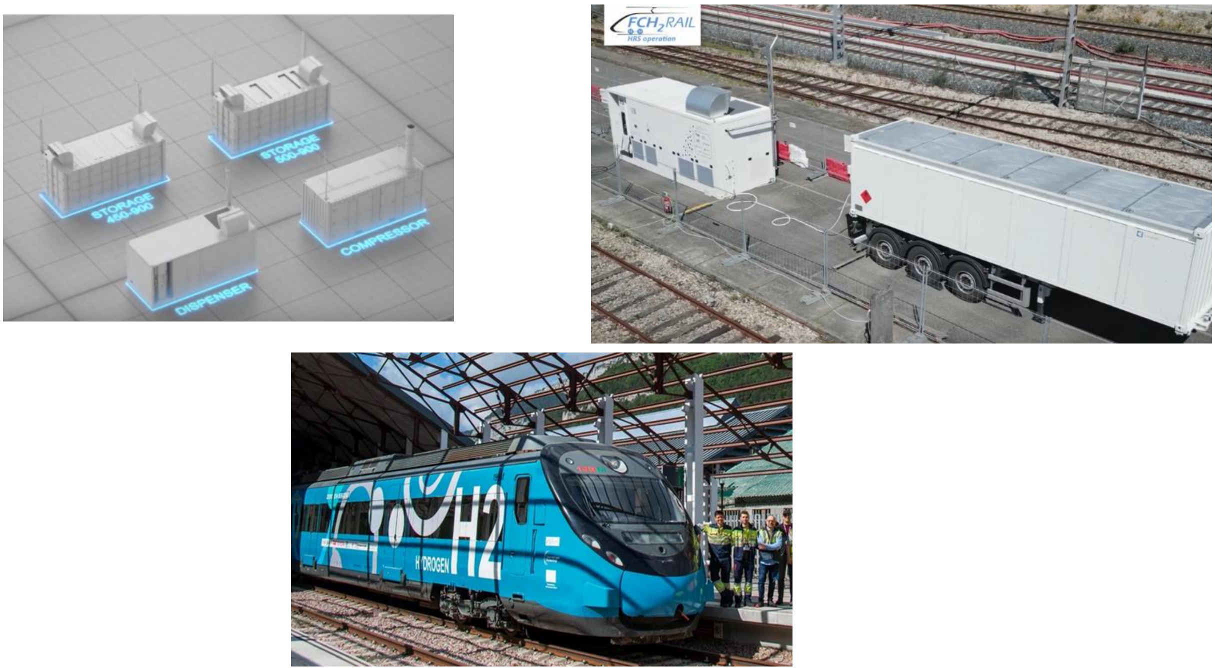

Figure 11 HRS layout for refuelling of H_2 rail vehicles

Interaction and communication with the public local authorities (i.e., 3 different local authorities from the 3 different regional refuelling sites of Galicia, Aragon and Madrid) and fire brigades were fundamental to overcome any critical urban planning, environmental and safety issue.

A customized permitting procedure was created to overcome the current gap of Spanish framework that does not consider the refuelling of such innovative Fuel cell-based vehicles. This process was time demanding but provided a first case in Spain spreading knowledge and increasing perception both from authorities and stakeholders' points of view.

Table 9 Customized protocol for safety and permitting of mobile HRS for H_2 rail vehicles (FCH2rail)

1) Preparation of the technical documentation for the HRS prototype
Development of the Project according to the regulation "ITC-ICG-05 Refuelling stations for gas vehicles;
The Project must include a green light from an engineering college;
Development of a maintenance plan;
Technical project for the fire brigade
2) Declaration of conformity and installation
Installation of the prototype on the selected site;
Obtaining a work certificate from an authorised engineer;
Installation of pressurised gas and low voltage. The certification is issued by a competent company;
Inspection of the installation by a control body, which issues an inspection certificate;
3) Paperwork for permitting procedure
Collection of all documentation and certifications;
Initiation of the IT procedure to validate the installation and payment of the fee for uploading the documentation produced.

Some of these steps are also reported in the Spanish regulation for HRS.

In terms of safety requirements, the key elements were the ATEX study linked to risk assessment methodologies for the identification of potential explosive atmospheres associated to potential ignition sources. Then, proper ventilation systems were designed. These tools and the application of technical standards like ISO 19881 "Gaseous hydrogen - Land vehicle fuel containers" defined the right safety distances between the different HRS components to any external buildings.

The Spanish legislative framework does not exclude the design, construction and operation of mobile and compact refuelling stations as the update of the regulation ITC-ITC 5 defines the hydrogen refuelling systems in general terms. Specifically, the regulation focuses on the importance of applying the risk assessment, ATEX and certain technical standards ending in a performance-based approach that provides general provisions without a priori safety distances. In terms of perception, high attention is paid towards the quantity of hydrogen stored.

WINNING APPROACH: working together with the local authority and creating a protocol that can be replicated

6.4.3 SPAIN: hydrogen mobility in a port envirionment

The H_2Ports European project demonstrates and validates two innovative solutions based on FC technologies and a hydrogen mobile supply station. The systems have been installed within the environment of the port of Valencia.

The overall system consists of a container with the compressor and control panel and a semi-trailer on which the buffer and dispensing system are installed. Hydrogen gas is refuelled by an external truck at 200 bar and unloaded in a 50,000 L storage tank at 33 bar. Since the HRS is installed on a semi-trailer equipped with wheels and can therefore move on the road, the international ADR regulation was applied. The systems safety was considered to be compliant to the regulation. This regulation required all pressure lines connecting the different components of the system to be depressurised.

The permitting restrictions were dictated and agreed together with the Port of Valencia's ownership body and management authority.

Safety requirements were fulfilled applying risk assessment methods, ATEX study and considering safety barriers and mitigation measures preventing any access to not allowed and trained personnel. This best practice opened to the possibility to implement safely decarbonization routes based on hydrogen technologies for port operation activities. Moreover, it has been an opportunity for institutions and fire brigades to understand the behaviour and potentiality of hydrogen.

Figure 12 HRS system installed in the Port of Valencia (courtesy of H_2Ports)

WINNING APPROACH: working with the authority in charge.

6.5 Other findings: Rail vehicles

For homologation of hydrogen-powered vehicles, specific tests are required to ensure the safety of hydrogen systems and components. Although the type approval requirements for these vehicles are harmonized throughout the European Union, challenges may arise due to differences in the interpretation of regulations by national authorities.

Specific **service and maintenance requirements** and procedures for hydrogen-powered vehicles are defined in guidelines published by **manufacturers**. Additionally, a limited number of national instructions are issued on this matter. There is a **regulatory gap in the service and inspection of**

FCEVs due to the lack of clear standards. The development of unified standards and procedures for servicing and inspecting specific components of hydrogen-powered vehicles, such as high-pressure hydrogen storage, fuel cells, and high-voltage components of FCEVs, and the hydrogen gas leak detection system, are fundamental to the safety performance of hydrogen-powered vehicles and could help achieve a high degree of practice harmonization. Having qualified service and maintenance personnel, as well as properly equipped inspection and maintenance facilities, could increase workplace safety and avoid exposing workers to greater risks.

Regarding hydrogen mobility and FCEVs deployment, steps forward have been made in defining safety requirements for the railway sector. In this regard, in Italy, Guidelines for the authorization of hydrogen-powered railway vehicles have been recently published. These guidelines were developed by the National Agency for the Safety of Railways and Road and Highway Infrastructures (ANSFISA) and propose an initial approach to safety for this sector. These official guidelines are interesting because they explain once more how the performance approach, based on risk assessment procedures and interaction between the different stakeholders, can be used in this transition phase towards an alternative mobility.

The document distinguishes between generic risks due to the mere presence of hydrogen and specific risks related to its use for railway traction, and also provides applicable mitigation measures. What appears to be particularly relevant is the performance-based approach applied for the safe use of hydrogen for railway traction and for the authorization of related vehicles. The guidelines recommend conducting risk analyses both regarding the general and usual railway risks associated with the introduction of the vehicle in the intended sector of use and in relation to the specific risks that hydrogen determines within the vehicle itself, towards the infrastructure, and vice versa. Given the complexity and variety of elements that make up the railway system, a "system risk" analysis is discussed, meaning an approach for which the risk analysis is the result not only of specific risks and scenarios of each stakeholder involved (vehicle manufacturer, railway company, infrastructure manager) but also of their interaction. In particular, it requires considering in the risk assessments the worst possible scenario in which critical events occur simultaneously (for example, release events). Moreover, laboratory experiments to be conducted on mock-ups or in the field (specific infrastructure) on real vehicles are considered tools for the validation of predictive models (for example, "computational fluid dynamics" CFD) used in the simulation phase.

As described in D2.3, safety can be also ensured applying the technical standards provided (and under development/revision) by Standardization Bodies at European and International level and by industries itself (technology manufacturers). For this reason, standardization is useful both for certification and safety requirements confirming their correlation. For more information about the standards suggested in the mentioned guidelines as tools to certify but also ensure safety of H2-fuelled trains and H2 mobility in railway sector for the Italian institutions it is possible to check the related section in D2.3.

7 Best practices for safe use of hydrogen in residential sector

The following section provides information about the best practices identified and the requirements and barriers for the implementation of hydrogen technologies in the residential sector, i.e.:

- Reversible fuel cells;
- Fuel cell based CHP with on -site production via electrolysis
- Boilers with on -site production via electrolysis.

Through the section, applications using H_2-ready heating systems (with combustion) as alternatives to FC-based systems are considered expressing the potential perception from public authorities of these technologies for power and heating supply. These evidences relate to small applications, which are often below the radar of the safety authorities, so it is not possible to identify consistently lessons learnt or winning approaches.

7.1 Reversible Fuel Cells: hydrogen production and power generation

7.1.1 ITALY: Reversible SOFC for cogeneration for Residential application

ENVI directly participated in REFLEX project (GA No779577), a European demonstrative project where a reversible solid oxide fuel cell, capable of operating both for the production of hydrogen and for the production of electricity, was to be installed and tested in a real environment. Specifically, it was a compact system that also integrated the hydrogen storage system and batteries.

The project followed a prescriptive approach to safety as the HAZOP risk analysis regarding the safety of the technologies used for compression, storage and piping was intended only as a support instrument for the safety evaluation process of the Fire Brigade. This choice was given to the specific plant features below certain threshold values and thus out of the scope of Fire Fighters competence. Moreover, the regulations applied (described in Appendix) are not specific to hydrogen and hydrogen technologies but derive from the regulatory framework typical of the residential sector and conventional fuels such as natural gas. This more convenient choice was therefore dictated by a regulatory gap present at the time of the project where the only technical rule in Italy available was the one for HRS. In fact, the technical rule for electrolysers was only published on 7 July 2023 (just a year before the publication of this deliverable and after the end of the REFLEX project).

In the REFLEX project, two European directives for safety were considered: the Seveso Directive and the ATEX Directive. The Seveso Directive did not apply because the quantities of hydrogen stored were less than 5 tons, while, due to the presence of hydrogen, there was a certain probability of forming explosive atmospheres, and therefore the ATEX Directive was considered for the classification of the aforementioned areas into zones.

The regulations to be followed included the Decree of the Ministry of the Interior February 3, 2016, "Approval of the technical fire prevention rule for the design, construction, and operation of natural gas deposits with a density not exceeding 0.8 and of biogas deposits, even with a density above 0.8".

In this case, **the most relevant parameter for safety was the geometric capacity of the storage system**. The installation of the hydrogen storage system thus becomes subject to the evaluation of the Fire Brigade if the geometric capacity is greater than 0.75 m^3. Given certain geometric and pressure characteristics, the designed hydrogen storage system fell exactly within category 4 (the less restrictive in terms of safety requirements). **Despite that, in the design phase it was not possible to consider a containment structure for protection from risks of explosion. This brought the final configuration to be the stricter in terms of safety requirements (4^{th} category storage system with no safety degrees).**

The general approach is: the greater the safety conditions, the shorter the distances but the higher the economic commitments (more details about the safety requirements in Appendix).

Table 10 Safety distances for storage systems with safety degree 1

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	5 m	\	10 m
3rd category	5 m	\	20 m
2nd category	5 m	\	25 m
1st category	5 m	\	30 m

Table 11 Safety distances for storage systems with safety degree 2

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	5 m	7,5 m	15 m
3rd category	10 m	10 m	20 m
2nd category	10 m	15 m	25 m
1st category	10 m	15 m	30 m

Table 12 Safety distances for storage systems of 4th category with no safety degree

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	20 m	20 m	30 m

Regarding the **cogeneration system to be used in the residential context**, a technical fire prevention rule for cogeneration groups powered by natural gas was also applied in this case (Ministerial Decree July 13, 2011). In the case of the reversible fuel cell to be installed in this project, **the technical fire prevention rule did not require evaluation by the Fire Brigade Command because the net power produced was less than 25 kW, and therefore the provisions of the decree were considered to comply with standard safety conditions but without the obligation of project evaluation**. The additional provisions in this case concern the assumption of responsibility that passes to the installer.

LESSON LEARNT: the Italian regulations have since evolved; however, this case demonstrates how using non-hydrogen specific regulations might lock both the authority and the installer in prescribing/adopting safety measures that might be disproportionate to the actual application.

7.2 Fuel cell-based CHP with on -site production via electrolysis

7.2.1 ITALY: smart grid with Hydrogen-based cogeneration system for Fire Brigade station at Turin airport

Airports are cooperating to introduce hydrogen as a sustainable fuel for aircrafts and as a decarbonization mean for operations both airside and landside. TULIPS project, funded under Horizon 2020, aims to support innovative projects in airports to reduce their carbon emissions in atmosphere. Turin airport, managed by SAGAT s.p.a, achieved a full operational and innovative smart grid for the supply of energy to the Fire Brigade station serving the airport. This best practice refers to the installation of a renewable hydrogen production plant composed by an electrolyser, a storage of 700 L at 15 barg, a blending station capable to work with 100% of H_2 and with different H_2/CH_4 blends, and 2 solid oxide fuel cells for Combined Heat and Power.


Figure 13 Storage system of gaseous hydrogen and containment structure required (Italy)

Figure 14 Hydrogen production system (left) and Fuel Cells (right) for energy supply to the Fire Station of Turin Airport (Italy)


Regarding the safety approach, the following elements were considered to allow the plant and to satisfy all the fire fighters requirements:

- Matching between project features and applicable regulations:
    - Hydrogen storage < 0,75 m^3 (same regulation of REFLEX project);
    - Flammable gases produced and used < 25 Nm^3 (Italian regulation for hydrogen production plants, see Appendix);
    - Cogeneration system (fuel cells) with net power < 25 KW (same regulation of REFLEX project).

The project did not fall within these regulations. For this reason, fire fighters were only informed of the project receiving a formal communication. Moreover, as the Fire Brigade station is directly connected to the smart grid, testing and operation phases have represented the opportunity for training activities.

- Quantitative risk analysis (bow tie) as requested by the national regulation (Ministerial Decree 03/09/2021) for the electrolyser, blending unit and containment structure for the hydrogen storage;
- Identification of safety requirements recommended by NFPA2 for the storage and piping systems; NFPA55 for "Compressed Gases and Cryogenic Fluids Code";
- Standards for qualitative safety considerations (i.e., UNI ISO/TR 15916:2018);
- ATEX study;
- Pressure Equipment Directive for storage systems;
- Risk assessment for the Fuel Cells room;
- Calculation of people density in the Fire Brigade Station and in the contiguous area;
- Installation of gas detection systems for electrolysis unit and fuel cells room;
- Proper ventilation systems.

LESSON LEARNT: Both residential best practices involving fuel cell hydrogen technologies highlight the different elements characterising prescriptive and performance-based approach to safety. Here different considerations from safety aspects to the authorities' point of view is described.

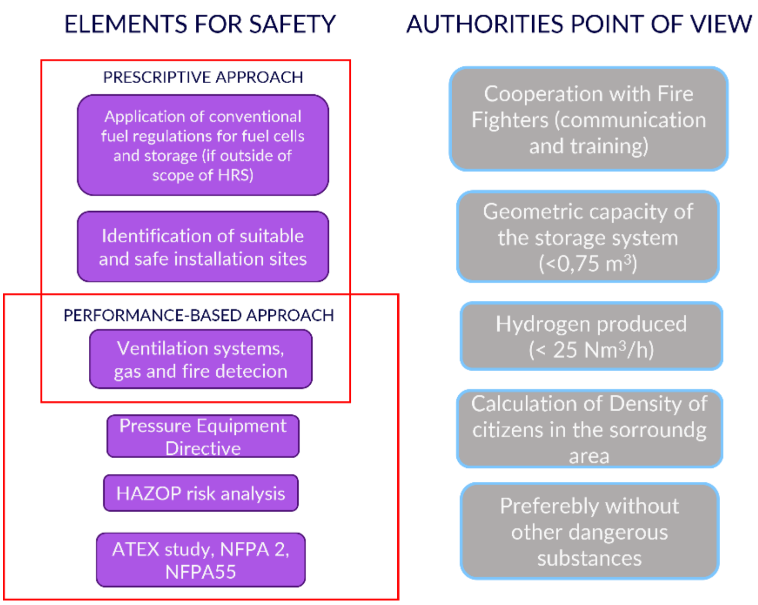

Figure 15 Connections between Prescriptive and Performance-based approaches for safety and requirements from Fire Fighters (Italy)

7.3 Boilers with on -site production via electrolysis

7.3.1 POLAND: Hydrogen Heating System

In the case of Polish project, the company SES Hydrogen Energy has completed functional tests of a prototype of a 0.5 MW **hydrogen-oxygen boiler** and has simulated the work on a real installation. The innovative technology is going through the certification process but it is intended to be used to heat apartments in the housing estate in Śrem with hydrogen.

The planned hydrogen boiler plant will be part of a diversified heating system supplying heat to 195 apartments under construction at the Srem TBS housing estate. It will serve to provide central heating and central water for the buildings. The entire system envisages the installation of a hydrogen boiler room based on the combustion of hydrogen and oxygen, as well as a heating system including ground-based brine-to-water heat pumps. The focal point of the boiler plant will be a hydrogen-oxygen boiler with gas preparation systems. In addition, the infrastructure will include: a hydrogen and oxygen generation module using electrolysers, an electrolysis water preparation system, a hydrogen and oxygen storage module, and power and control systems for technological processes and heat exchange.

The stakeholders involved are SES Hydrogen Energy and the Śrem Social Housing Society (TBS), the Municipality of Śrem and Con-Project.

In Poland, safety regulations for hydrogen heating systems are essential to ensure the safe implementation of this technology. Technical supervision of equipment for handling, transporting, and storing hydrogen, fire protection, occupational health and safety, and emergency services are present because in this transition phase the existing regulations in Poland can apply broadly to gaseous and hazardous fuels including hydrogen. Anyway, **while specific safety requirements for hydrogen heating systems are not explicitly outlined in the available framework, it is essential to adhere to general safety practices (similar safety practices and considerations are present in the previous section for HRS in Poland):**

- Hydrogen Leak Detection: Install sensors to detect any hydrogen leaks promptly;
- Ventilation: Ensure proper ventilation in areas where hydrogen is used or stored;
- Emergency Shut-off Systems: Implement emergency control valves to isolate hydrogen flow during emergencies;
- Excess Flow Valves: Fit excess flow valves (EFV) to stop hydrogen flow when it reaches a certain level.

7.3.2 BULGARIA: Hydrogen Heating System

Another evidence of the performance-based approach in the **residential sector** comes from Bulgaria where one of the stakeholders interviewed by BH2C partner brought its experience in a similar case. **A project for the construction of a facility for green hydrogen production for the heating needs of Otets Paisii Primary School, Lozen, Sofia City has been developed**. This project is under development but it will represent the **first public building in Southeast Europe to use on-site production of renewable hydrogen for its heating needs**.

Figure 16 Hydrogen production, containment structure and Heating system for School heating (Bulgaria)

Main goal of this demonstrative project is to analyse, design and install a green hydrogen production system (left) connected to a hydrogen boiler to optimize the school's heating system (solar panels will be used to provide electricity for the equipment operation). As it has been shared by the stakeholder, **storage on site is not envisaged and this aspect has significantly decreased the risk perception by the authorities and reduced the burden of requirements to be fulfilled for the safety compliance.** Indeed, an electrolyser for the heating needs of the school was designed and produced with a capacity of 5 kW. **The installation of the electrolyser has followed the appropriate technical parameters and instructions of the Fire Safety Service that assessed the hydrogen production unit as safe thanks to the tests conducted and ended with a validating protocol for the tests developed for this type of application.**

Moreover, the following technical standards and documents have been considered for the production unit and the boiler system to receive the approval from the authorities (the Main Directorate "Fire Safety and Civil Protection", the National Security Agency, and the State Agency for Metrology and Technical Supervision) involved in the process due to the specific risks related to a facility like a school.

The only main instructions received from the Fire Safety Office were to use rigid connections to connect the produced hydrogen to the boiler burner.

Table 13 Documentation required by safety authorities and technical standards applied for electrolysers safety assessment in Bulgaria

Documents received from state institutions
Certificate of Conformity for our equipment from the State Agency for Metrology and Technical Supervision
"Fire Safety and Civil Protection - Protocol for instructions on how the connections between the existing heating appliance and the electrolyser should be built
National Security Agency - Letter of Eligibility for the construction of hydrogen equipment, complying with the instructions of the Fire Safety Service
Standards for the electrolyser
Low Voltage Directive (LVD) (2014/35/EU)
ISO 22734:2019: Hydrogen generators using water electrolysis for industrial, commercial and residential applications:
ISO/TR 15916:2015 Basic considerations for safety of hydrogen systems
EN 61511-1:2017 Functional safety - Safety systems for the manufacturing industry sector - Part 1: Framework, definitions, system, hardware and application
ISO 12100:2010 Safety of machinery — General design principles — Risk assessment and risk mitigation. It is important to add that this deliverable is under revision and it will be replaced by ISO/CD 12100
ISO 13850:2015 Safety of Machinery – Emergency stop function – Principles for design
IEC 61326-1:2012: Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1: General requirements
EN 55011:2016+A1:2017+A11:2020+A2:2021: industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement
EN 1593:2004 : Non-Destructive testing- Leak testing – Bubble emission techniques

8 Conclusions

The analysis conducted by the HYPOP consortium within Task 2.1 has yielded the following conclusions, which can serve as a starting point for further discussions with stakeholders to develop comprehensive guidelines on safety approaches to hydrogen technology – installation and operation:

- Hydrogen and hydrogen technologies are well known in an industrial setting and therefore there is an opportunity to capitalise on that experience also for regulations and legislation applying to other sectors. Spreading the knowledge could **mitigate the perception of risk by the safety authorities**;
- **Technical practices shared by industry experts** should be more widely shared with authorities to understand how to safely implement a facility
- The **performance-based approach** can be considered as a means of transition to acquire more knowledge and standardize safety requirements for those countries that normally apply it or wish to approach this method, while simultaneously aligning and improving the required conditions in the prescriptive regulations for those countries that have a different approach. Moreover, all those countries without hydrogen specific safety regulation can benefit from this approach (like the EU 13 countries);
- The **importance of communication** between safety authorities and project designers to overcome barriers and avoid negative feedback from the public;
- **Guidelines issued at national or local level including also other EU experiences and approaches** should be created as a driver for more cooperation between the stakeholders of the hydrogen value chain and the public authorities.
- **Sharing of information amongst Countries 'authorities could support** a quicker implementation of rules and regulations also in countries with less experience in hydrogen technology.

During this transition phase, the following **possible scenarios for the application of safety approaches** have been identified:

- The prescriptive approach is functional when there is already solid prior experience with certain fuels or technologies, as in the case of natural gas. This sound knowledge is then reflected in regulatory prescriptions more aligned with the specific needs and characteristics of the project, expanding the related audience without the constant need for modifications through risk analysis (which remains a valid support tool to ensure minimum safety requirements);
- The transition from a prescriptive to a performance-based approach occurs in some cases when a risk analysis is applied that allows for overcoming obstacles imposed by the specific regulatory prescriptions for hydrogen (if present). This case is particularly common in contexts where the project is highly innovative or where there is a lack of knowledge about hydrogen/hydrogen technology by safety authorities, making it difficult to strictly apply the prescriptions;
- The shift from a prescriptive to a performance-based approach can also occur when there is no prescriptive norm for hydrogen, and traditional fuel standards are applied, which must be adapted to the needs of an alternative fuel like hydrogen. This is mainly done through risk analysis;
- The performance-based approach can be the reference procedure for meeting safety and public health requirements. This approach is versatile and applicable even in the absence of specific regulatory references, and it primarily, but not exclusively, relies on industry and manufacturers' guidelines and detailed risk assessment methodologies.

In this transition phase towards a hydrogen economy, prescriptive hydrogen regulations rules are not necessarily the best solutions because a too prescriptive approach to safety can hinder the development of projects where innovative technologies or new end uses like the ones involving renewable hydrogen are deployed. Anyway, prescriptive approach can become more aligned to the technical needs of this new fuel and new end uses once more experienced is acquired in the following years. On the second hand, a performance approach based on industry guidelines and regulations commonly followed may not be enough to fulfill safety requirements asked by authorities at different levels and in different countries. Despite that, during this transition phase the performance-based can be the best compromise as it can ensure minimum safety requirements by means of the sector knowledge of stakeholders on conventional fuels even if this does not fully prevent hydrogen projects and technologies from obstacles. Risk assessment methodologies, technical standards, technical reports and manufacturers guidelines can be valuable tools to achieve minimum requirements of safety authority and at the same time to provide a scientific approach that can facilitate the deployment of the innovative hydrogen projects and its related technologies. Finally, case by case analysis is needed, both for prescriptive and performance-based approach in order to meet safety and public health requirements associated to the project and environment characteristics.

The following figure represents the starting point for the future safety guidelines as a support to the implementation of hydrogen projects in Industry, Mobility and Residential sectors.

So far, these pillars have been identified through the information shared by stakeholders engaged, with the exploitation of data from best practices and the analysis of requirements and barriers of the different regulatory frameworks available at EU level. Nevertheless, HYPOP is a continuous project where additional or missing information will be targeted within WP4 framework and stakeholders' engagement activity to validate this first assessment.

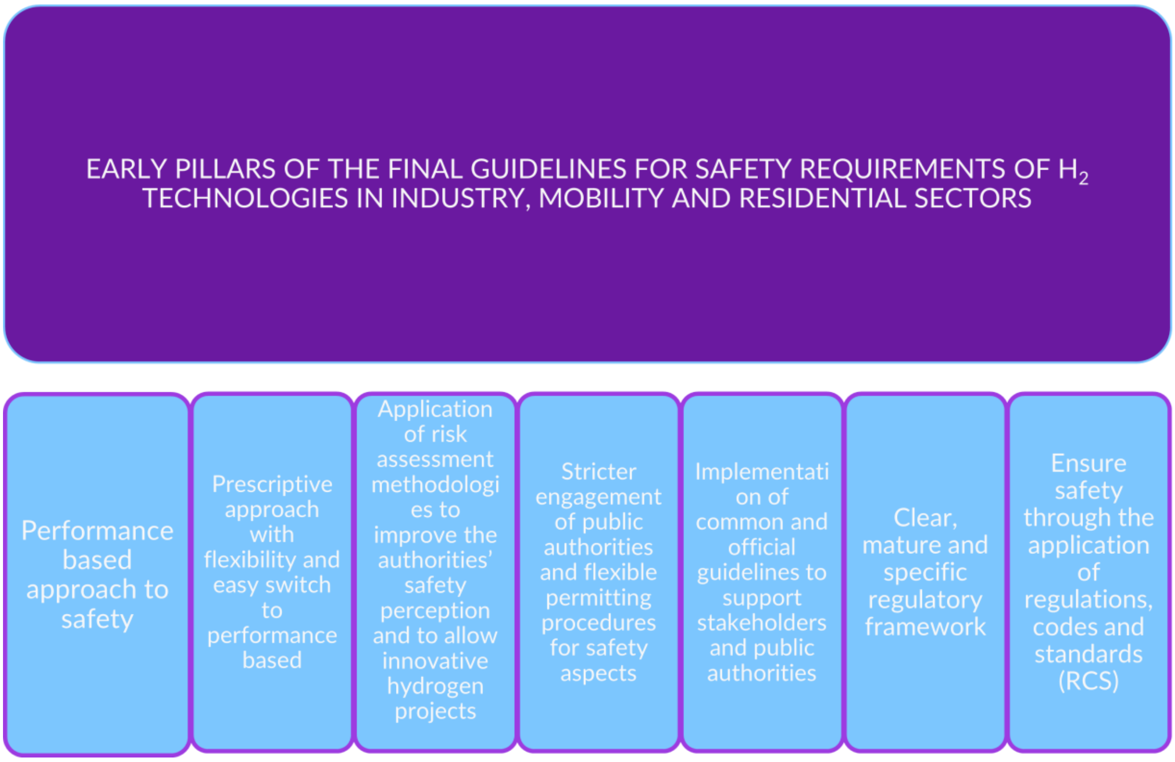

Figure 17 *Early pillars for the final HYPOP guidelines on safety requirements for Industry, Mobility and Residential sectors*

LINK BETWEEN PRESCRIPTIVE AND PERFORMANCE-BASED APPROACHES

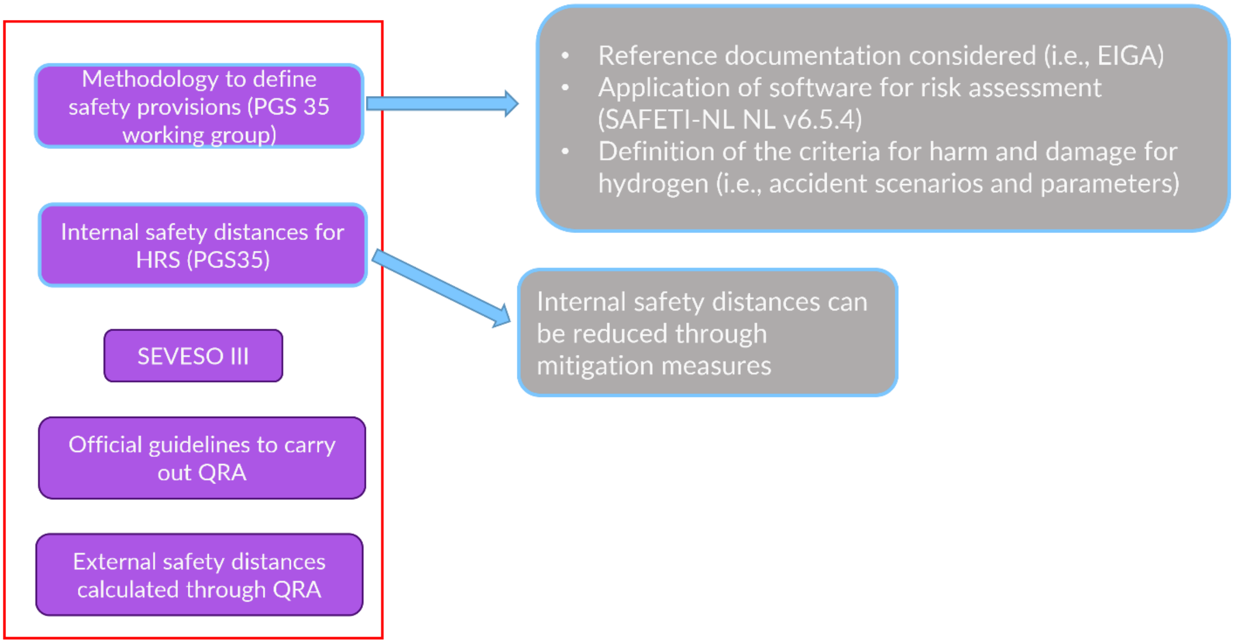

Figure 18 *Key elements of the performance-based approach to safety for HRS and their link with the prescriptive approach*

9 APPENDIX: Technical analysis of Regulatory Frameworks for Safety of Hydrogen Technologies: requirements and barriers

This Section provides an in-depth analysis of hydrogen specific regulations and conventional regulations applied when gaps are present. The description of the regulations allows to perceive and visualize the requirements and barriers existing in EU-13 countries, HYPOP and Frontrunner countries. The following table (already reported at the beginning of the document) serves as a guide through the section to identify the information collected. Being an ongoing project, HYPOP is open to all stakeholders interested to fill the gaps.

Table 14: Requirements and barriers for Industry, Mobility and Residential sectors.

EU-13 Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
Bulgaria (HYPOP country)	*(requirements)* Technical standards ISO, EN; engagement local fire brigades, safety prescriptions *(barriers)* Regulatory gaps; lack of knowledge; safety prescriptions; low perception for storage of H_2	*(requirements)* Technical standards ISO, EN; engagement local fire brigades, safety prescriptions *(barriers)* Safety prescriptions; low perception for storage of H_2
Croatia	Only first contacts through the NCP	Only first contacts through the NCP
Cyprus	Only first contacts through the NCP	Only first contacts through the NCP
Czech Republic	Only first contacts through the NCP	Only first contacts through the NCP
Estonia	*(requirements)* conventional fuel regulations *(barriers) regulatory gaps; lack of knowledge*	Further research is needed. Synergies with other EU projects have been started
Hungary	*(requirements)* Safety prescriptions; ATEX zoning; PED application; H_2 technologies as for industrial use; gas and fire detection systems; quantity of hydrogen stored *(barriers)* Regulatory gaps; lack of knowledge; H_2 technologies as for industrial use; perception towards stored hydrogen and on-site production	No information available at the moment. Further research is needed
Latvia	*(requirements)* technical standards ISO, EN; safety prescriptions; quantitative risk assessment; conventional fuel regulations *(barriers)* conventional fuel regulations; regulatory gaps; lack of knowledge; safety prescriptions	There are not specific safety requirements or barriers for the installation of FC-based systems as they are considered as micro-CHP systems
Lithuania	Only first contacts through the NCP	Only first contacts through the NCP
Malta	(barriers) main focus on other solutions for decarbonization; lack of knowledge; regulatory gaps	No information available at the moment. Further research is needed
Poland (HYPOP country)	*(requirements)* performance-based approach; risk assessment; technical standards ISO, EN; conventional fuel regulations *(barriers)* regulatory gaps; conventional fuel regulations	No information available at the moment. Further research is needed

Romania	*(requirements)* ATEX zoning; technical standards ISO, EN; conventional fuel regulations; safety prescriptions *(barriers)* conventional fuel regulations; regulatory gaps; lack of knowledge	No information available at the moment. Further research is needed
Slovakia	Only first contacts through the NCP	Only first contacts through the NCP
Slovenia	*(requirements)* conventional fuel regulations *(barriers)* regulatory gaps; lack of knowledge; conventional fuel regulation	No information available at the moment but significant pilot projects are starting
HYPOP Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
Belgium	*(requirements)* Performance-based approach; quantitative risk assessment; ATEX zoning; technical standards ISO, EN; gas and fire detection systems; engagement fireman organization *(barriers)* lack of guidelines; regulatory gaps; variety in interpretations	No specific requirements or barriers identified as residential sector is lagging behind as hydrogen application
Italy	*(requirements)* Safety prescriptions like distances and pressure limits; H_2 technologies as for industrial use; ATEX zoning; PED application; technical standards ISO, EN; engagement local fire brigades; conventional fuel regulations *(barriers)* Strict safety distances; H_2 technologies as for industrial use; poor use of risk assessment; perception; regulatory gaps and time demanding procedures; different interpretations; lack of guidelines	*(requirements)* Safety prescriptions; technical standards ISO, EN; common procedures for electric appliances; conventional fuel regulations *(barriers)* Lack of knowledge; scarce perception towards FC micro-CHP systems; conventional regulations; different interpretations; lack of guidelines
Spain	*(requirements)* Performance-based approach for HRS; prescriptions for storage quantities and industry sector; technical standards ISO, EN; H_2 technologies as for industrial use; engagement of local authorities; conventional fuel regulations; safety guidelines *(barriers)* regulatory gaps for compressed and fixed storage systems; safety prescriptions; lack of experience; H_2 technologies as for industrial use	no specific requirements have been identified for residential H2 technologies *(barriers)* regulatory gaps; conventional fuel regulations; FC micro-CHP systems not included in legislation
Frontrunner Countries	Requirements and barriers for Industry/Mobility	Requirements and barriers for Residential
France	*(requirements)* Flexible prescriptions for safety (dispensing flow rate, HRS); performance-based approach; mitigation measures to reduce safety distances Not specific barriers have been identified	*(requirements)* H_2 specific regulation for indoor and outdoor installations; focus on safety of storage systems; flexible prescriptions for safety Not specific barriers have been identified

Germany	*(requirements)* Performance-based approach; ATEX zoning; risk assessment methodologies; guidelines for HRS implementation; technical standards ISO, EN; gas and fire detection systems Not specific barriers have been identified	No specific requirements and barriers have been identified from the safety point of view
Netherlands	*(requirements)* Performance-based approach; quantitative risk assessment; official guidelines for risk assessment; flexible safety prescriptions No specific barriers have been identified	No specific requirements and barriers have been identified from the safety point of view
Switzerland	*(requirements)* ATEX zoning; official guidelines for hydrogen production; engagement local fire brigade; risk assessment methodologies No specific barriers have been identified	Further research needs to be carried out for residential applications

9.1 HYPOP COUNTRIES - Belgium: Safety approach in Hydrogen Mobility

Belgium is facing this transition phase towards hydrogen economy through a cross linked approach where technical standards (more detail in D2.3), the consultation with the competent authorities and the risk assessment analysis are the pillars needed to accompany the implementation of hydrogen projects in the country as well as the to demonstrate the compliance to the minimum safety requirements asked at local and European level from the administrations. The main requirements asked by local authorities of Belgium involved at different levels are the ones included in the EU directives. Additional requirements are followed when specific project features require them.

As Belgium is divided into different regions, legislations for hydrogen technologies can vary:

- for the Hydrogen refuelling Stations built in Flanders region, the existing VLAREM legislation for storage and handling of dangerous gases can be used. In cases where this legislation is not specific enough, the Dutch directive PGS35 is used to define the necessary requirements;
- In Wallonia region, some private actors use the French Guide for the general hydrogen systems[6].

The approach is composed by the application of:

- EU legislations;
- Local regulatory framework (not necessarily referred to hydrogen and hydrogen technologies);
- Guidelines and best practices (also from other surrounding countries).

Moreover, the fireman organisation (FRCSPB) needs to be consulted and it generally requires to put a significant hydrogen detector network to identify potential leakages within the facility and for the hydrogen transported.

Quantitative risk assessment is the common practice in Belgium (as in Netherlands) and the related guidelines on how to perform it for HRS but also for other applications are under development.

[6] GUIDE POUR L'EVALUATION DE LA CONFORMITE ET LA CERTIFICATION DES SYSTEMES A HYDROGENE, 2021 written by France Hydrogen and INERIS

Hydrogen production on site and its storage are indeed the main concern in HRS but in general also for other facilities for industrial and residential sectors. Several technical standards, codes and regulations are needed to ensure the safe, efficient and sustainable operation of all the installations. The outputs of the performance-based approach also depend on the authorities and the type of administrations involved in the project approval.

9.2 HYPOP COUNTRIES -Italy: Regulations for Safety of Hydrogen Technologies in Industry, Mobility and Residential sectors

This section will provide information about 4 different regulations for:

- Hydrogen Refuelling stations (HRS);
- Hydrogen production through electrolysis;
- Natural gas storage (for storage applications outside HRS);
- Cogeneration groups (for fuel cells).

Other regulations applicable to hydrogen technologies are mentioned in the table below representing all the potential matches between the different hydrogen technologies. This result was obtained through an analysis conducted on national and European projects involving Italian stakeholders. The majority of the technical rules are not hydrogen specific and this reflects the regulatory gap existing in Italy.

In Italy, the authority responsible for evaluating compliance with safety regulations (in this section also called technical rules by the competent Italian safety authorities) and for allowing the installation of hydrogen technologies in various applications such as industry, mobility, and residential, is primarily the Fire Brigade (other entities may be involved according to the specific case). The national Fire Brigade is the authority designated by the Ministry of the Interior to ensure, throughout the national territory, public rescue service and prevention and extinguishing of fires, including forest fires.

The main normative references are given within the "Fire Prevention Technical Rules of the Fire Brigade." In some cases, when it is not possible to associate a project and its technologies with a specific fire prevention technical rule, a more general normative text, always drafted by the Fire Brigade, called the **Fire Prevention Code (D.M August 3, 2015), can be applied**. The different production activities (installations/projects) that potentially employ hydrogen and that could be subject to control by the Provincial Fire Brigade for compliance with safety requirements are listed in the D.P.R 1/08/2011 n. 151 (ex DM 16/02/1982).

Table 1 Fire Fighters' legislative framework for safety installation of hydrogen technologies in Italy

Annex I Activities Presidential Decree 151/2011		Hydrogen Technologies	Italian Technical rules for fire prevention
1 C	Facilities and plants where flammable and/or oxidizing gases are produced and/or used with total quantities in the cycle exceeding 25 cubic meters per hour	Electrolysers	DM 07/07/2023: Technical fire prevention rule for the identification of methodologies for risk analysis and fire safety measures to be adopted for the design, construction, and operation of hydrogen production plants by electrolysis and related storage systems; DM 03/02/2016: Approval of the technical fire prevention rule for the design, construction, and operation of natural gas storage facilities with a density not exceeding 0.8 and biogas storage facilities, even if their density is above 0.8.
2 B	Compression or decompression plants for flammable and/or oxidizing gases with a capacity > 50 Nm³/h and up to 2.4 MPa	Compressors	DM 07/07/2023 (see 1 C); DM 16/04/2008: Technical regulation for the design, construction, testing, operation, and monitoring of works and systems for the distribution and direct lines of natural gas with a density not exceeding 0.8; DM 17/04/2008: Technical regulation for the design, construction, testing, operation, and monitoring of works and plants for the transportation of natural gas with a density not exceeding 0.8.
2 C	Compression or decompression plants for flammable and/or oxidizing gases with a capacity > 50 Nm³/h		
3 B (Considered only compressed gaseous H2)	Storage of compressed flammable gases in mobile containers with an overall geometric capacity from 0.75 to 10 cubic meters	Bundles, tube trailers	DM 07/07/2023 (see 1 C); DM 03/02/2016 (see 1 C).
3 C (Considered only compressed	Storage of compressed flammable gases in mobile containers with an overall geometric capacity greater than 10 cubic meters		

Annex I Activities Presidential Decree 151/2011		Hydrogen Technologies	Italian Technical rules for fire prevention
gaseous H2)			
3 C (Considered only compressed gaseous H2)	Facilities for filling compressed flammable gases into mobile containers with a total geometric capacity greater than 0.75 cubic meters	Filling of bundles or tube trailers	DM 07/07/2023 (see 1 C); DM 03/02/2016 (see 1 C).
4 B (Considered only compressed gaseous H2)	Storage of compressed flammable gases, in fixed tanks with a total geometric capacity from 0.75 to 2 cubic meters	Buffer tank	DM 07/07/2023 (see 1 C); DM 03/02/2016 (see 1 C).
4 C (Considered only compressed gaseous H2)	Storage of compressed flammable gases, in fixed tanks with a total geometric capacity greater than 2 cubic meters	Storage	DM 07/07/2023 (see 1C); DM 03/02/2016 (see 1C).
6 A	Transport and distribution networks for flammable gases, including those of petroleum or chemical origin, with a relative density < 0.8 and pressure from 0.5 to 2.4 Mpa	Hydrogen pipelines or blending into the natural gas network	DM 07/07/2023 (see 1 C); DM 16/04/2008 (see 2B and 2C); DM 17/04/2008 (see 2B and 2C).
6 B	Transport and distribution networks for flammable gases, including those of petroleum or chemical origin, with pressure > 2.4 Mpa		
13 C	Fixed distribution plants for gaseous fuels and mixed type (liquid and gaseous)	Hydrogen refuelling station	DM 23/10/2018: Technical regulation of fire prevention for the design, construction and operation of hydrogen distribution systems for motor vehicles; DM 24/05/2002 and related decrees: Natural gas stations; DM 30/04/2012: Natural gas vehicle refuelling appliance;

Annex I Activities Presidential Decree 151/2011		Hydrogen Technologies	Italian Technical rules for fire prevention
			DM 30/06/2021, LNG mobility: LNG refuelling appliance and compressed natural gas refuelling appliance.
49 A	Groups for the production of auxiliary electric power with internal combustion engines and cogeneration plants of total power between 25 kW and 350 kW	Fuel cells	DM 13/07/2011: Technical rule for fire prevention for the installation of internal combustion engines coupled with electric generators or other operating machines and cogeneration units serving civil, industrial, agricultural, artisanal, commercial, and service activities.
49 B	Groups for the production of auxiliary electric power with internal combustion engines and cogeneration plants of total power between 350 kW e 700 kW		
49 C	Groups for the production of auxiliary electric power with internal combustion engines and cogeneration plants of total power > 700 kW		
74 A	Plants for heat production fuelled by solid, liquid, or gaseous fuel with a capacity greater than 116 kW and up to 350 kW	Boilers	DM 08/11/2019: Technical fire prevention rule for the design, construction, and operation of heat production plants fueled by gaseous fuels.
74 B	Plants for heat production fuelled by solid, liquid, or gaseous fuel with a capacity greater than 350 kW and up to 700 kW		
74 C	Plants for heat production fuelled by solid, liquid, or gaseous fuel with a capacity greater than 700 kW		

The main national regulations for fire prevention (safety) of hydrogen technologies in Italy are:

1. **Decree of 23 October 2018 by the Ministry of the Interior:** "Technical rule for fire prevention for the design, construction, and operation of hydrogen distribution plants for motor vehicles;
2. **Decree of 7 July 2023 by the Ministry of the Interior:** "Technical rule for fire prevention for identifying risk analysis methodologies and fire safety measures to be adopted for the design, construction, and operation of hydrogen production plants through electrolysis and their storage systems."

These technical rules for fire prevention are mainly applicable to the industry and mobility sector but, in absence of other regulations (technical rules) for fire prevention, their application to the residential sector cannot be excluded and can be integrated with risk assessment methodologies and the safety requirements borrowed by other technical rules for conventional fuels like natural gas.

The general objectives of these technical rules are:

- To reduce the causes of fire and explosion;
- To limit, in the event of an accidental event, the damages to people;
- To limit, in the event of an accidental event, the damages to buildings and the surrounding environment;
- To allow first responders to work safely.

9.2.1 Technical rule for Hydrogen Refuelling stations

The technical rule for fire prevention for hydrogen refuelling stations (HRS) "Decree of 23 October 2018 by the Ministry of the Interior" regulates the safety requirements that must be met for both new service stations and existing ones in case of modifications planned from the date of entry into force of the decree. Although the regulation may generally consider both gaseous and liquid fuels, it specifies prescriptions for gaseous hydrogen distribution facilities.

The application of the above safety requirements to other mobility areas than road mobility, such as inland waterway and railway, should not be excluded even if not directly specified. **In those cases where it is not possible to fully comply with the prescriptive requirements of the regulation, it is possible to request for a performance-based safety approach called "engineering approach to fire safety," whose provisions are detailed in the Ministerial Decree of 9 May 2007.** This technical rule opens up the possibility of constructing a HRS according to the international **standard ISO 19880-1 "Gaseous Hydrogen – Fuelling stations**".

Depending on the site of installation, the safety requirements can vary. **A HRS is forbidden when the construction area falls:**

a) within the **homogeneous territorial zone** that is fully built-up (identified as zone A in the general regulatory plan or in the building program), and **within the perimeter of the built-up area** in those municipalities lacking the aforementioned urban planning instruments. In both cases, **the existing building density within a 200 m radius from the perimeter of the hazardous elements of the plant cannot be higher than 3 m^3 per m^2;**

b) in the completion and expansion zones of the urban aggregate indicated in the general regulatory plan or in the building program, where a building density higher than 3 m^3 per m^2 is expected;
c) in areas, wherever located, designated as public green spaces.

However, there are some exemptions from the safety restrictions that can be granted by the territorially competent municipality. For example, if the installation site falls within the completion and expansion zones of the urban area (b), HRS powered by a pipeline system, are allowed when:

- The storage system is less than 500 Nm^3;
- The amount of hydrogen produced on site is less than 50 Nm^3/h;
- There are no hydrogen bundles (even emergency ones are not allowed).

The same exemptions apply if the building area of the HRS falls within areas designated as public green spaces but only when the municipal urban planning instruments already envisage the presence of fuel distributors in other green areas.

In all those cases not included in the previous list, it is possible to build a HRS for road mobility.

It is important to specify that the technical rule allows only trained personnel to perform hydrogen dispensing activities through the dispenser. There is an exemption only in the case of private HRS for company fleets where the facility is located within the company premises. In this case, if the employee personnel are properly trained and if the dispensing system is equipped with communication hardware and software between the vehicle and the station that ensures safe delivery, they can proceed with hydrogen dispensing in self-service mode. According to this fire prevention technical rule, the following are considered hazardous elements:

Table 2 HRS components considered as dangerous by Italian technical rule

Hazardous elements
Hydrogen production units (if present)
The gas hydrocarbon pressure reduction and metering cabin (only in the case of a production unit consisting of a reformer with hydrocarbons)
Compressors
Storage units
Tube trailers, if present
Dispensing units
Connecting elements between hazardous elements for hydrogen transfer (piping and connections)

All hazardous elements, except for the dispensing unit, must be fenced with a structure not less than 1.8 meters in height and placed at a distance from other elements of the plant to allow for safe operation.

In addition to fencing, the technical rule prescribes the need to create, for all elements defined as hazardous except for the dispensing unit, a solid containment structure. The containment is a structure made of reinforced concrete walls, or other non-combustible material with adequate mechanical resistance, with construction characteristics of the structures such that they only peripherally mitigate the effects of explosion and fire, including projectile debris. The containment structure can have one or two of the four sides completely open provided that such openings do not face areas open to the public. The height of the containment must be more than 1 m higher than the highest point of the hazardous elements contained therein. The technical rule recommends that, within the containment, suitable measures are adopted to prevent the formation and persistence of explosive atmospheres.

The technical rule defines the design characteristics of the HRS both where there is an on-site production unit or if hydrogen is supplied through an external pipeline or tube trailers:

- If the HRS includes, within its perimeter, a hydrogen production unit (via electrolysis or steam reforming of natural gas or another hydrocarbon), a specific risk assessment must be mandatorily provided, with the characteristics described in Annex I of the Ministerial Decree of 7 August 2012. Both types of hydrogen production units must be designed following international standards: ISO 16110-1 "Hydrogen generators using fuel processing technologies - Part 1: Safety (like steam methane reforming) and ISO 22734-1 "Hydrogen generators using water electrolysis - Part 1: General requirements, test protocols and safety requirements". These hazardous elements must be placed in solid containment.
- **Compressors**, along with any ancillary devices, **must be placed in solid containments** and must be designed according to the standard EN 1012-3 "Compressors and vacuum pumps - Safety requirements - Part 3: Process compressors". Multiple safety valves must be installed at the end of the compressors. **Vessels used to balance pressure variations must be installed in solid containment as well** and must be characterized by a geometric volume lower than 0.4 m^3;
- Storage systems must be designed to operate with a variable operating pressure of up to 1,000 bars and with a storage capacity of less than 6,000 Nm^3 according to the international standard ISO 19884 "Gaseous hydrogen — Cylinders and tubes for stationary storage" (this standard has been delated and a new draft is under development by ISO). Safety must also be ensured by installing a support structure for the system made of fire-resistant material R60 or similar (material capable of maintaining its mechanical integrity during 60 minutes of fire exposure), thermally actuated valves, and pressure monitoring valves. Only when the total hydrogen capacity exceeds 6,000 Nm^3, the containment envisaged can be composed of several smaller, solid, wall separated containments, one for each storage tank;
- **Tube trailers** for HRS must be designed following the ADR regulation (International Agreement on the Transport of Dangerous Goods by Road). During refuelling within the HRS perimeter, the piping is considered part of the overall plant, the parking area must ensure the absence of maneuvers for the d in case of emergency, and there must be no obstacles along the trajectory from the HRS plant entrance to the unloading area. The replacement of the tube trailers should not be carried out simultaneously with the unloading of other possibly containing fuels or substances other than hydrogen.

The previous hazardous elements must respect some **specific safety distances**. Below are the definitions of the distances indicated in the table (definitions according to D.M 30/11/83 coordinated with the modifications and integrations introduced by D.M 09/03/07):

- **Protection distances**: the minimum value of the distances measured horizontally between the perimeter in plan of each hazardous element of an activity and the fence (where prescribed) or the boundary of the area on which the activity itself is located;
- **Internal safety distances**: the minimum value of the distances measured horizontally between the respective perimeters in plan of the various hazardous elements;
- **External safety distances**: the minimum value of the distances measured horizontally between the perimeter in plan of each hazardous element of an activity and the perimeter of the nearest building outside the activity itself or other public or private works or with respect to the borders of buildable areas towards which such distances must be observed.

Table 3 Safety distances for Compressors, Storage systems and Containment structure for Tube Trailers in HRS (Italy)

Hazardous elements	Protection distances	Internal safety distances	External safety distances
Compressors	15 m	\	30 m
Storage units	15 m	15 m	30 m
Containment structure of the tube trailer	15 m	15 m	30 m

For the compressor containment structure, the external safety distance, except for that computed from buildings for public use, can be reduced by 50% if it is proved that between the openings of the compressor containment and the buildings external to the plant, suitable continuous screening with concrete walls or other non-combustible material of adequate mechanical strength are realized, such as to ensure the containment of any fragments projected towards the external constructions.

Table 4 Safety distances for Dispensers in HRS (Italy)

Hazardous element	Protection distance	Internal safety distance	External safety distance
Dispensing unit	15 m	12 m	30 m

The external and protection distances of the dispensing unit can be reduced by 50% if appropriate non-combustible material barriers of adequate mechanical resistance are placed between them and the external constructions to the plant, except those for public use.

Additional safety distances must be provided to separate the hazardous elements from spaces designated for auxiliary services like:

- Manager's office, warehouse, toilets, workshop without the use of open flames, and washing plant: the same internal safety distances defined in the previous tables apply;
- Electric power cabin: 22 m;
- Manager's dwelling: external safety distance;

- Dining and/or sales areas:
  - Up to 50 m^2 of total covered area: the internal safety distances from the previous tables apply;
  - Up to 200 m^2 of gross area accessible to the public (an additional area for services and storage not exceeding 50 m^2 is also allowed): 15 m from the hydrocarbon gas reduction and measurement cabin and 22 m from the other hazardous elements of the plant;
  - For areas larger than those indicated above: 30 m.

Furthermore, the technical rule prescribes a double external safety distance from buildings intended for community uses such as schools, hospitals, offices, worship buildings, public entertainment venues, sports facilities, tourist-hotel complexes, supermarkets and shopping centers, barracks, and places where people frequently gather such as public transport stations, fairgrounds, markets, etc. The calculation of external safety distances can include the widths of roads, rivers, streams, and canals. Moreover, when the external safety distance refers to buildable areas, it is allowed to include the prescribed setback distance, in cases where local building regulations prohibit construction on the boundary.

Between the hazardous elements and overhead electric lines, with voltage values greater than 1000 V AC and 1500 V DC, a distance of 45 m must be observed, measured horizontally from the overhead projection.

The technical rule provides specific requirements for HRS of company fleets. Requirements are set in the case of a hydrogen production less than 50 Nm^3/h. For those aspects not directly mentioned, the provisions previously indicated for the safety distances must be respected. **The main differences compared to public HRS are as follows**:

- Hazardous elements do not necessarily have to be fenced if the company structure within which the HRS is built has a fence not lower than 1.8 meters;
- If only personnel involved in refuelling are allowed, and containment structures and fences are designed according to the technical specifications mentioned before, the HRS for the company fleet can be built within the company's perimeter;
- The internal safety distances indicated in the previous tables must be respected, except for the distance between dispensing units which can be reduced to 6 m;
- The external safety distances indicated in the previous tables must be respected without any exception. These distances apply to any other productive activity located within the company perimeter.

Exceptions are also defined in the case where the refuelling station consists of different fuels. This is possible by respecting safety distances:

Table 5 Safety distances between hydrogen and other conventional fuels (Italy)

Hazardous elements vs other fuels related elements	Safety distances
HRS vs Gasoline and diesel tanks	15 m
HRS vs Liquefied petroleum gas tanks (from HRS Dispensing unit)	30 m (15 m)
HRS vs liquefied petroleum gas tanks	15 m
HRS vs Natural gas refuelling plant (from HRS Dispensing unit)	22 m (12m)

Between the different dispensing units	12 m

9.2.2 Technical rule for Hydrogen Production through electrolysis and related storage systems

The new Italian technical rule, Ministerial Decree of July 7, 2023, from the Ministry of Interior: "Technical fire prevention rule for the identification of risk analysis methodologies and fire safety measures to be adopted for the design, construction, and operation of hydrogen production plants through electrolysis and related storage systems" is potentially applicable into different sectors even if they are not directly specified in the document.

In this regulation, the risk assessment is required to provide an additional level of safety but not as a substitute or a mean for modifications of the main provisions (e.g. safety distances etc) described within the document. Anyway, its application to modify the prescription and achieve the same minimum safety is possible but a longer permitting process is needed (see Deliverable 2.2). Risk assessment is a support for the electrolysis units, the tanks aimed to store hydrogen gas, the compressors and for the areas involved in the operation of hydrogen technologies that needs to be designed according the ATEX Directive to fulfill the European requirements.

The technical rule provides different ranges of allowed working pressures up to 1000 barg. For working pressures above 1000 barg or in the case of adopting storage systems different from those indicated in the technical rule, the designer must implement a risk assessment and adequate fire safety measures, also determined through the "engineering approach to fire safety" as required by the decree of the Minister of the Interior of May 9, 2007.

According to the present technical rule, the following are considered **hazardous elements subject to safety distances and fire prevention**:

a) Electrolyser;
b) Buffer tank;
c) Compression system;
d) Storage system;
e) Pressure reduction and stabilization unit;
f) Loading station (loading bays);
g) Connecting pipes (connection elements between items a), b), c), d), e), and f) for hydrogen distribution);
h) Parking area for tube trailers;
i) rooms intended for auxiliary services.

If the production unit is connected to tube trailers for supplying HRS or other applications, a specific area for their location must be identified.

The areas where the hazardous elements are located need to be fenced, with a height of not less than 1.8 m, or otherwise made so as to make these elements inaccessible and prevent tampering.

If the hydrogen technologies are within sites already equipped with their fencing, the said fencing is not necessary. Where provided, such a fence or any other measure adopted to make these elements inaccessible needs to be placed at a distance from the plant elements that allows their safe operation and maintenance.

The electrolysis area must follow specific external safety distances so that the Fire Brigade vehicles can access and move without any obstacles, especially in case of emergency. Below are the minimum requirements applied to at least one entrance of the plant:

- Width: 3.50 m;
- Height clearance: 4 m;
- Turning radius: 13 m;
- Slope: not exceeding 10%;
- Load capacity: at least 20 ton (8 on the front axle, 12 on the rear axle, wheelbase 4 m).

For all tanks for hydrogen storage, the maximum allowed pressure is 1,000 barg, and they must be placed inside a containment structure (except for buffer tanks) with the same characteristics as for the HRS plants. For the safety of the area, when the storage has a capacity of more than 6,000 Nm^3, the same containment structure needs to be divided by partition walls to mitigate effects due to incidents (each portion containing storage with a capacity of less than 6,000 Nm^3). Also in this case, the materials used must be fireproof (R60 materials or similar).

Compressors must be equipped with tanks capable of damping pressure fluctuations above 150 barg and with a geometric volume of less than 0.4 m^3. Otherwise, if the geometric volume is greater than 0.4 m^3, **a risk assessment is necessary**. The compressor must be contained within a reinforced concrete containment structure.

The distances to be respected for the hazardous elements of the facility are:

Table 6 Correlation between operating pressures and minimum safety and protection distances for hazardous elements in a renewable hydrogen production facility (Italy)

Hydrogen operating pressure (barg)	External safety distance	Protection safety distance	Internal safety distance
700 < P ≤ 1000	30	15	15
500 < P ≤ 700	25	15	15
300 < P ≤ 500	20	15	15
100 < P ≤ 300	17	12	12
50 < P ≤ 100	12	8	8
30 < P ≤ 50	8	6	6
10 < P ≤ 30	7	5	5
P ≤ 10	5	3	3

If the working pressures are higher than those indicated, the stakeholder must apply the provisions of the "Engineering approach to fire safety" as per the Ministerial Decree of May 9, 2007 (it refers to the performance-based approach). **For the compressor, the external safety distance, except for the one calculated with respect to buildings intended for community use, can be reduced by 50% if between the openings of the compressor containment structure and the constructions outside the plant, suitable continuous screening with concrete walls or other incombustible material of adequate mechanical**

resistance is realized. In any case, such distance cannot be less than the minimum internal safety distance and the protection distance, provided for the same pressure value.

Pipelines, both high and low pressure, are considered hazardous elements, and the safety distances indicated in the table apply to them, except for the internal safety distances from closely connected process elements. According to the technical rule, buildings intended for community use such as schools, hospitals, offices, places of worship, public entertainment buildings, sports facilities, tourist accommodation complexes, supermarkets and shopping centers, barracks, as well as places where people tend to gather such as public transport stations, fair areas, markets, etc., lead the external safety distances reported in the Table 6 to the double of the base value.

The following internal safety distances are observed between hazardous elements and the below-mentioned buildings intended for auxiliary services:

a) buildings intended for auxiliary services: safety distances as indicated in the previous Table 6;
b) Electrical energy delivery cabin: 22 meters.

Other relevant distances refer to power lines. Between hazardous elements and overhead power lines, with voltage values greater than 1,000 V in alternating current and 1,500 V in direct current, a distance of 45 meters from the plant projection must be observed.

This fire prevention technical rule for hydrogen production plants prevents access to individuals not properly trained.

9.2.3 Technical rule for the installation of cogeneration units serving civil, industrial, agricultural, artisanal, commercial activities and services

The technical rule for the safe installation of cogeneration units and/or groups provides common provisions for all the various cases reported in the document within Title I, while the other Titles are more specific:

- **Total power up to 25 kW** (not subject to fire brigade control): Title IV;
- Total power between 25 kW and 50 kW: Title I and Title III;
- Total power between 50 kW and 10,000 kW: Title I and Title II.

The provisions of the Fire Prevention Technical Rule apply to both fixed and mobile installations and also for installations with a total power of less than 25 kW, which, however, from an authorization standpoint, are not subject to fire brigade control.

When the productive activity exceeds a total power of 10,000 kW or concerns installations included, for example, in industrial production processes, fire-fighting systems, stations and power plants, this technical rule offers only useful reference criteria which are not mandatory provisions.

Given the chemical-physical characteristics of hydrogen, the common safety provisions reported in the Fire Prevention Technical Rule referring to gaseous fuels with a density lower than 0.8 and to liquid fuels with a flash point lower than 55 °C were considered. In the case of gaseous hydrogen, the ratio between its density (0.084 kg/m^3) and the density of air (1.22 kg/m^3) is less than 0.8, and therefore only some of the provisions reported along the decree apply. The same goes for liquid hydrogen which falls among the liquid fuels with a flash point lower than 55 °C.

Relevant safety aspects for the design of a hydrogen cogeneration systems, which are important within the common provisions, involve:

- incorporated tanks;
- service tanks;
- storage tanks.

and their respective fuel supply systems for all three mentioned types. A parameter to consider for distinguishing the different provisions of the technical rule is the **geometric capacity of the tanks**.

For liquid fuels with a flash point lower than 55 °C like liquid hydrogen, each cogeneration unit and/or group can have both **incorporated and service tanks**, even divided into multiple compartments or several single tanks provided that the total capacity does not exceed 120 dm^3.

The technical rule specifies that the overall geometric capacity is to be understood as the sum of both incorporated tanks and service tanks possibly present to fuel the units and/or cogeneration groups but only if these are installed inside the same room where the units and/or cogeneration groups are located. The supply of the incorporated or service tank, not fuelled from the storage tank and with a total capacity of less than 120 dm^3, is allowed with portable containers of the type approved according to current regulations.

Concerning **storage tanks** for liquid fuel with a flash point lower than 55°C, these cannot be placed within rooms or on terraces. The installation of such tanks is governed by the regulations of the decree of the Minister of the Interior July 31, 1934, published in the Official Gazette September 28, 1934, no. 228.

For all types of installation, a risk assessment related to explosive atmospheres in accordance with current regulations is needed.

The installations of groups and/or cogeneration units, with a total nominal power of up to 25 kW, are carried out by the installer according to the prescriptions provided by the manufacturer of the group and/or cogeneration unit, reported in the instruction manual for use and based on good technical standards. For such installations, it is the installer, once the installation is completed, who attests under his own responsibility that the group and/or cogeneration unit is installed according to the rules of the art.

Considering all the valid provisions in general for tanks and fuelling from gaseous and liquid fuels, the technical rule also defines the characteristics for the safe construction of rooms containing different types of groups and/or cogeneration units with different nominal powers.

All these three types of installation can envisage **three types of installation locations**:

- outdoors;
- in external rooms;
- in rooms included in the volume of a building.

The technical rule provides a set of common provisions that generally apply to groups and/or cogeneration units with a total nominal power greater than 50 kW and up to 10,000 kW. These provisions are mainly related to the construction of the room containing the cogeneration group and any heat production system connected to it.

Specific limits related to the total power of the cogeneration groups and the maximum allowable geometric capacity of the various tanks also change depending on the function of the buildings in which they are installed. These limits are generally reduced in the presence of activities with high people attendance or with specific functions for the community.

In general, in the same room, multiple groups and/or cogeneration units with different fuels can be placed as long as the total installed nominal power does not exceed 8,000 kW. Instead, groups and/or cogeneration units fuelled with liquid fuel having a flash point lower than 55°C, such as liquid hydrogen, can coexist in the same room only with groups and/or cogeneration units fuelled with the same type of fuel.

Similar constraints also apply in the case of integrating cogeneration groups and/or units with heat generation systems (subject to the technical rule Ministerial Decree of November 8, 2019). **Groups and/or cogeneration units with heat production systems are allowed in the same room provided that they are fuelled by the same type of fuel**. Furthermore, the coexistence in the same room of one or more groups and/or one or more cogeneration units with heat production systems fuelled with the fuels reported in the following table is also permitted:

Table 7 Cases where cogeneration units are coupled with heat generation systems using "similar" fuels (Italy)

Thermal unit / Group or cogeneration unit	Liquids with a flash point lower than 55°C	Liquids with a flash point equal or higher than 55 °C	Gas with a relative density to air greater than 0.8	Gas with a relative density to air lower than 0,8	Solid fuels
Liquids with a flash point lower than 55°C	Yes	Yes	No	No	No
Liquids with a flash point equal or higher than 55 °C	Yes	Yes	Yes	Yes	Yes
Gas with a relative density to air greater than 0.8	No	Yes	Yes	No	No
Gas with a relative density to air lower than 0,8	No	Yes	No	Yes	No

In reference to scenarios where cogeneration units are coupled with heat generation systems using "similar" fuels, there are **additional common conditions to comply with**:

- The sum of the total thermal power of the cogeneration units and the capacity of the heat production plants does not exceed 10,000 kW;

- Any incorporated or service tanks of the cogeneration units altogether do not exceed 120 dm^3;
- The cogeneration units do not perform safety functions;
- The cogeneration units are equipped with a metal enclosure;
- The lateral distances between the cogeneration units and the heat production plants must not be less than 0.6 m;
- For the aspects like access, communication, fire resistance and ventilation, the fire safety measures provided by the current fire prevention standards of the heat production plants, applicable according to the type of fuel used, must be applied if more restrictive than the ones indicated in the cogeneration unit technical rule.

Given the previous common provisions for outdoor installations there are a series of safety distances to be respected between the cogeneration unit and storage systems. These distances can be reduced in case of interposition of an adequate protective structure made of incombustible material and of dimensions sufficient to protect the entirety of the storage system. The cogeneration units must be surrounded by an area not less than 3 m deep and free of materials or vegetation that may constitute a fire hazard.

Table 8 Safety distances between the cogeneration unit and storage systems in Italy

Total nominal power	Distance	Reduced distance
Up to 2.500 kW	3 m	3 m
Up to 5.000 kW	4 m	
Up to 7.500 kW	5 m	4 m
Up to 10.000 kW	6 m	5 m

The provisions described so far are an example of what is required for cogeneration units with a total nominal power between 50 kW and 10,000 kW. Then, the fire prevention technical rule provides specific construction-related guidelines for cogeneration groups and/or units with a total nominal power greater than 25 kW and not exceeding 50 kW, while most of the provisions related to geometric capacity and total nominal power mentioned are similar to those described previously.

9.2.4 Technical rule for the design, construction, and operation of natural gas storage facilities with a density not exceeding 0.8

Provisions of the Fire Prevention Technical Rule for the design, construction, and operation of natural gas storage facilities with a density not exceeding 0.8 and biogas storage facilities, even with a density exceeding 0.8, published in the Decree of the Ministry of Interior on February 3, 2016, has been taken into account for the approval of safety of the hydrogen storage systems.

The technical rule mentions different types of storage systems:

- storage in fixed tank;
- storage in mobile containers.

Fixed storage safety requirements

For storage in fixed tanks, the technical rule defines the maximum operating pressures allowed, different according to the type of storage:

- for **pressostatic accumulators**: 0.05 bar (0.005 MPa);
- for **gasometers**: 0.5 bar (0.05 MPa);
- for **tanks**: 30 bar (3 MPa) for the geometric volume of a single tank over 50 m^3 and 50 bar (5 MPa) for the geometric volume of a single tank equal to or less than 50 m^3;
- for **pipeline-tanks**: the maximum pressures provided for pipelines, up to a maximum of 120 bar if buried (12 MPa); pipeline-tanks possibly above ground are assimilated to medium-pressure tanks (Pmax operation = 50 bar).

Each of these types of storage is also classified respectively as:

- low;
- medium;
- high.

The technical rule then provides a further classification of storages in fixed tanks based on the global storage capacity, intended as the sum of the individual storage capacities and measured in m^3 as follows:

C = V x P/Po

where:

V = geometric volume of the tanks or pipeline-tanks, expressed in m^3;

P = maximum absolute pressure, expressed in bar;

Po = absolute barometric pressure, expressed in bar and conventionally assumed to be equal to 1 bar. For gasometers and pressostatic accumulators, the maximum geometric volume is assumed. For maximum absolute pressure, it means the maximum operating pressure as declared by the operator.

Table 9 Maximum storage capacity allowed (Italy)

Category	Maximum storage capacity (m^3)
1st	over 120,000
2nd	over 20,000 and up to 120,000
3rd	over 1,000 m^3 and up to 20,000
4th	up to 1,000

The technical rule considers hazardous elements of a storage with fixed tanks:

a) containers intended to contain gas (pipeline-tanks, tanks, gasometers, pressostatic accumulators, digesters);
b) compression stations and decompression cabins;
c) any other element presenting a danger of explosion or fire under normal operating conditions, including the transfer point, components, and fixed pipelines with an operating pressure exceeding 5.0 bar (0.5 MPa).
For all elements referred to in points b) and c), with operating pressures lower than 5.0 bar (0.5 MPa), the provisions of the DM April 16, 2008 "Technical rule for the

design, construction, testing, operation, and supervision of natural gas distribution systems and direct lines with a density not exceeding 0.8" must be respected.

Storage systems can be installed in areas compatible with urban planning instruments. The installing area of the storage must be delimited by a specific fence, at least 1.80 m of height, placed at a distance from the hazardous elements not lower than the protection distance set for the elements themselves and indicated in the tables below.

The fire prevention technical rule provides a set of general provisions for assessing safety distances in the case of storages in fixed tanks.

Table 10 Safety distances between Pipeline-tanks (high pressure) and internal buildings

Maximum operating pressure [bar]	24 < P ≤ 60	12 < P ≤ 24	P ≤ 12
Distance (m)	10	7	5

For operating pressures above 60 bar, distances must be increased proportionally to a maximum of double.

Additional distances to be respected:

- Protection distance: 10 m (reduced by 50% if referring to storages consisting of 4th category underground pipeline-tanks);
- Internal safety distance: 15 m (reduced by 50% if referring to storages consisting of 4th category underground pipeline-tanks);
- External safety distance: 20 m, (reduced by 50% if referring to storages consisting of 4th category underground pipeline-tanks).

Table 11 Safety distances for Tanks (medium pressure)

Tanks with individual storage capacity	Internal building	Protection distance	Internal safety distance	External safety distance			
				1st cat.	2nd cat.	3rd cat.	4th cat.
Up to 5.000 m^3	15 m	10 m	12 m	45 m	40 m	35 m	30 m
Over 5.000 m^3 and up to 10.000 m^3	20 m			50 m	45 m	40 m	\
Over 10.000 m^3	30 m			60 m	50 m	45 m	\

For all types of fixed storages, unless specific exceptions are reported in the technical rule, the external safety distance must be increased by 50% if the buildings to be protected are used for activities:

- with the presence of the public, with a crowd exceeding 100 units;
- intended for communities, included in Annex I to the DPR 1 August 2011 n. 151;
- characterized by the detention and use of flammable, inflammable, or explosive products, included in category C of the said decree.

Mobile storage safety requirements

The fire prevention technical rule also specifies safety requirements for **storage in mobile systems**.

Hazardous elements are:

- Buildings, structures, and areas designated for the storage of storage containers;
- Containment structures, where present, or the area designated for the parking of vehicles used for the transportation of natural gas;
- Natural gas compression plants and decompression cabins;
- Any other element that presents a risk of explosion or fire under normal operating conditions.

In general, the same provisions described for storage in fixed systems apply.

For mobile storage, the possible capacity ranges are:

- 1st category: more than 10,000 m^3;
- 2nd category: more than 5,000 up to 10,000 m^3;
- 3rd category: more than 850 m3 up to 5,000 m^3;
- 4th category: more than 75 up to 850 m^3.

Depending on the construction characteristics of the storage buildings, the mobile storage and the containment structures designated for the parking of vehicles used for gas transportation can have **two different degrees of safety:**

- **1st degree of safety**: if the construction characteristics of the structures ensure containment, both laterally and upwards, of fragments or other materials projected in case of an explosion;
- **2nd degree of safety**: if the construction characteristics of the structures ensure containment, only laterally, of fragments or other materials projected in case of an explosion.

4th category storages can be made outdoors or under a canopy even without containment elements.

Fences to be used for the pertinent area of the storage follow the same provisions described for fixed storage systems.

The safety distances required between the storage systems and the other hazardous elements or buildings are reported in the following tables. Protection, internal and external safety distances are defined regarding the Italian technical rules for HRS and electrolysis plants.

Table 12 Safety distances for storage systems with safety degree 1

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	5 m	\	10 m
3rd category	5 m	\	20 m
2nd category	5 m	\	25 m
1st category	5 m	\	30 m

Table 13 Safety distances for storage systems with safety degree 2

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	5 m	7,5 m	15 m
3rd category	10 m	10 m	20 m
2nd category	10 m	15 m	25 m
1st category	10 m	15 m	30 m

Table 14 Safety distances for storage systems of 4th category with no safety degree

Storage capacity	Protection distance	Internal safety distance	External safety distance
4th category	20 m	20 m	30 m

9.3 HYPOP COUNTRIES Spain: Regulatory Framework for Safety of Hydrogen Technologies in Mobility and Residential

These subsections represent two regulations generally followed in Spain to deal with hydrogen projects for mobility and residential applications as a mature regulatory framework for hydrogen technologies is still missing at national level:

- **For HRS**: Real Decreto 919/2006, de 28 de julio (ITC-ICG 5);[7]
- **For residential**: Real Decreto 656/2017, de 23 de junio, por el que se aprueba el Reglamento de Almacenamiento de Productos Químicos y sus Instrucciones Técnicas Complementarias MIE APQ 0 a 10 [8] (MIE APQ-1 "almacenamiento de líquidos inflamables y combustibles en recipientes fijos"; MIE APQ-5 "almacenamiento de gases en recipientes a presión" móviles"; MIE APQ-10 "almacenamiento en recipientes móviles".

As a general rule, the following pieces of legislation must be taken into account for Spain when safety of hydrogen facilities must be ensured:

- **Low Voltage Electrical Regulations**: Royal Decree 842/2002, of 2 August, which approves the Low Voltage Electrotechnical Regulations;
- **High Voltage Electrotechnical Regulations**: Royal Decree 337/2014, of 9 May, approving the Regulation on technical conditions and safety guarantees in high voltage electrical installations and its Complementary Technical Instructions ITC-RAT 01 to 23;
- **Pressure Equipment Regulation**: Royal Decree 809/2021, of 21 September, approving the Pressure Equipment Regulation and its complementary technical instructions;
- **Chemical Product Storage Regulations**: Royal Decree 656/2017, of 23 June, approving the Chemical Product Storage Regulations and its Complementary

[7] https://www.boe.es/buscar/act.php?id=BOE-A-2006-15345#itcicg05
[8] https://www.boe.es/buscar/act.php?id=BOE-A-2017-8755

Technical Instructions MIE APQ 0 to 10 (BOE 25/07/17). **A focus on this Regulation is provided as hydrogen storage is one of the main issues perceived by safety authorities;**

- **Regulation of installations for the supply of gaseous fuels**: Royal Decree 919/2006, of 28 July, which approves the technical regulation for the distribution and use of gaseous fuels and its complementary technical instructions ICG 01 to 11. **A focus on this Regulation is provided as hydrogen refuelling stations, especially if with on-site hydrogen production, are one of the main issues perceived by safety authorities;**
- **Fire Protection Regulations**: Royal Decree 2267/2004, of 3 December, approving the Fire Safety Regulations in industrial establishments and Royal Decree 513/2017, of 22 May, approving the Fire Protection Installations Regulations;
- **Regulation of Refrigeration Installations**: Safety regulation for refrigeration installations and its ITCs approved by RD 552/2019;
- **Major Accident Regulation**: Royal Decree 840/2015, of 21 September, approving measures to control the risks inherent to major accidents involving hazardous substances.

9.3.1 Safety requirements for Hydrogen Refuelling Stations

The Spanish approach to safety for hydrogen refuelling stations refers to the regulation "Real Decreto 919/2006, de 28 de julio (ITC-ICG 5)". **This regulation is characterised by a performance-based approach.**

The regulation aims to establish the essential technical requirements and minimum safety measures to be observed when designing, constructing and operating installations for the storage and supply of hydrogen in the gaseous phase for use as motor fuel.

In general, the design, construction, assembly and operation of hydrogen refuelling stations shall comply with the technical specifications set out in Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure and its delegated regulations from the time of its date of application.

As this EU directive represents a qualitative guide, safety requirements needed for the compliance procedures can be achieved following the provisions of national and international technical standards like ISO 19880-1.

For this type of facilities, useful standards are:

- the **ISO/TS 19880-1:2020** "**Gaseous hydrogen - Fuelling stations - Part 1: General requirements"** standard. It defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty road vehicles (e.g., fuel cell electric vehicles);
- the **ISO 14687:2019 "Hydrogen fuel quality - Product specification"** standard establishes the minimum quality characteristics of hydrogen fuel as distributed for utilization in vehicular and stationary applications.

The overall documentation to be collected and submitted to the competent authorities at national and local level in charge of the evaluation of the safety of the hydrogen plants are summarised as follows:

- Object of the project;

- Location and ownership;
- Author of the project;
- Owner of the installation;
- Applicable regulations;
- Description, plans and calculations justifying the installation;
- Detailed layouts;
- Flow, connection and electrical circuit diagrams;
- Tests and trials to be carried out;
- Operation of the installation;
- Operation of the installation;
- Maintenance and revision of the installation;
- Safety documentation and emergency plans;
- General budget.

The standards mentioned will be the reference documentation to carry out the tests of the HRS under the supervision of an inspection body, assisted by the installation company and the project supervisor.

9.3.2 Safety Requirements for Hydrogen Storage Systems

Residential sector is still facing deep gaps in the regulatory framework, both from safety and permitting points of view. Moreover, the few pilot initiatives of application of hydrogen in urban environments hinders the increase of practical experiences fundamental to allow public authorities to develop a sound regulatory framework.

In Spain, outside the hydrogen refuelling stations where specific guidelines, technical standards and the ITC-ICG05 regulation are available, the storage of hydrogen for residential applications is regulated by **Chemical Product Storage (APQ)** (all part from 1 to 10) regulations. These Regulations, even if not specific for hydrogen technologies and facilities, can be applied in the absence of an updated regulatory framework.

The regulations **MIE APQ (from 0 to 10)** apply a prescriptive approach to safety establishing the safety conditions for storage, loading, unloading, and delivery facilities for hazardous chemicals. All the safety distances indicated in the regulations refer for all compressed and flammable gases, thus including hydrogen in its gaseous and liquid forms. The regulations referring to hydrogen are:

- **MIE APQ-1 directive "Storage of flammable and combustible liquids"** laying down technical requirements for the storage, loading, unloading and transfer of flammable and combustible liquids and flammable liquefied gases in fixed containers;
- **MIE-AQP 5 directive "Gas storage in mobile pressure vessels"** establishes the safety distances for hydrogen storage and sets out the technical requirements for the storage and use of mobile pressure vessels containing compressed, liquefied and dissolved gases under pressure and their mixtures;
- MIE APQ-10 directive "Storage in mobile containers" sets out the technical requirements for storage, loading, unloading and transfer of hazardous chemicals in mobile vessels.

This regulatory framework is not specific for hydrogen storage systems and in addition these storage facilities are designed for industrial applications. Moreover, some gaps exist as only liquid or compressed H_2 storage on mobile systems are considered. Fixed gaseous hydrogen systems are totally excluded. As mentioned in the previous Spanish guideline Bequinor on safety of hydrogen, this issue could be overcome applying the international technical standard EN 17533:2021 “Hydrogen Gas. Storage and pipelines for stationary storage”.

Further details and information about these regulations can be gathered in the official documentation.

In this subsection, a specific focus on mobile hydrogen storage systems is provided as it is more likely to be used in residential sectors during this first stage of transition towards a hydrogen economy.

According to MIE-APQ 5, five categories of storage are stablished based on the stored gases. As a general rule, higher are the hazards associated to a fuel (gas, liquid, compressed state etc) more restrictive are the safety requirements applied. **The following indicators refer to hydrogen for its flammability and the compressed state: H220 and H280 respectively (they specify the safety requirements).** The values exported from the Regulation, given in the following table, are applicable only to gases which do not present any hazard other than those indicated.

Table 15 Categories of storage, indicators and limits for Storage Quantity in MIE APQ5 Regulation (Spain)

Storage Category	Type of Danger	Hazard indicator	Storage quantity (Nm^3)
1	Flammable	H220	Q≤ 50
	Compressed gas	H280	Q≤ 200
2	Flammable	H220	50 < Q ≤ 175
	Compressed gas	H280	200 < Q ≤ 1,000
3	Flammable	H220	175 < Q ≤ 600
	Compressed gas	H280	1,000 < Q ≤ 2,400
4	Flammable	H220	600 < Q ≤ 2,000
	Compressed gas	H280	2,400 < Q ≤ 8,000
5	Flammable	H220	Q> 2,000
	Compressed gas	H280	Q> 8,000

Having done this classification, the safety distances for hydrogen storage are established consequently.

Table 16 Location and safety distances according to MIE APQ5 Regulation

Storage category	1	2	3	4	5
The storage area may accommodate within it an activity other than the storage of containers provided that it does not affect the safety of the containers	Yes	Yes	No	No	No
Distances (metres) between vessels of flammable gases to other gases	6 m or separation wall				
Distances (metres) between vessels of flammable gases to inert gases	3 m or separation wall				
Distances (metres) between vessels of flammable gases to any source of ignition or open fire	6 m or separation wall				

Table 17 Requirements for closed area warehouses according to MIE APQ Regulation

Storage category	1	2	3	4	5
Flammable, oxidising or inert. Distances (metres) to					
Public roads	–	2	3	4	6
Inhabited buildings or third parties	–	3	6	8	10
Activities with risk of fire and explosion	–	3	6	8	10
Internal warehouse services	–	–	–	2	6

Table 18 Requirements for open area warehouses according to MIE APQ Regulation

Storage category	1	2	3	4	5
Flammable, oxidising or inert. Distances (metres) to					
Public roads	–	4	6	8	10
Inhabited buildings or third parties	–	6	8	10	15
Activities with risk of fire and explosion	–	6	8	10	15
Internal warehouse services	–	–	–	2	6

This is evidence of the application of conventional regulations for safety to hydrogen projects. Hydrogen is conceived as a dangerous and flammable gas but safety requirements are not defined according to the technologies used. Not only in Spain but also in other countries like Italy the regulatory gap for certain applications and for the specific hydrogen project's features may bring to the use of not hydrogen specific regulations and the need of interpretation of the consequent safety requirements to know, risk assessment has been used as one of the instruments to comply with the safety authorities requests but not to modify their provisions.

9.4 HYPOP and EU13 COUNTRIES -Bulgaria: Regulation for Safety of Hydrogen Refuelling Stations

Bulgaria is one of the few countries in EEA that has a prescriptive regulation for Hydrogen Refuelling stations: Regulation No RD-02-20-2 of September 28, 2020 on the "Conditions and Procedure for Design, Construction, Commissioning and Control of Hydrogen fuel vehicle filling stations"[9] (Issued by the Minister of Regional Development and Public Works, the Minister of Transport, Information Technology and Communications, the Minister of Interior, the Minister of Economy, the Minister of Environment and Water).

The Regulation defines the technical requirements for the design, construction and commissioning of charging stations for hydrogen-powered vehicles (cars, buses and trucks from 350 to 700 bar), providing stakeholders of minimum requirements to build an HRS safely.

All the information provided in the Regulation are intended for **three types of infrastructures for the supply of HRS**:

- Off-site hydrogen production: hydrogen supplied from outside the perimeter of the HRS **by a truck towing a battery trailer from 250 kg to 280 kg of compressed hydrogen** under pressures from 16.55 to 21.37 MPa;
- Off-site hydrogen production: hydrogen supplied from outside the perimeter of the HRS by a truck carrying hydrogen bottles in a compressed gaseous state, each with a capacity of up to 50 l, under pressure of up to 30 MPa and a temperature of 20 °C (subject to the requirements of the European Agreement on the International Carriage of Dangerous Goods by Route (ADR));
- **On-site hydrogen production through water electrolysis** (electricity can be supplied by the power grid or from another energy source).

Moreover, it is possible to supply the HRS with transportable pressurized gas storage equipment containing hydrogen absorbed in a **metal hydride storage** system. In such cases, the requirements of **BDS ISO 16111 "Portable gas storage devices. Hydrogen absorbed in reversible metal hydride"** are needed to ensure the safety. Regarding the connection between the HRS and vehicles, the hydrogen dispenser should be protected in a housing that contains the process pipelines, dosing system, fuel hose, measuring, control and auxiliary equipment. **The dispenser must meet the requirements of BDS EN ISO 17268 "Connection devices for refuelling road vehicles with gaseous hydrogen (ISO 17268:2012)".**

Other technical standards mentioned by the Regulation and that stakeholders needs to follow are**:**

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[9] https://lex.bg/bg/laws/ldoc/2137206003

- BDS EN 17127 "Outdoor hydrogen refuelling points, dispensing gaseous hydrogen and including filling protocols";
- Each area of the hydrogen charging station should be evaluated for the presence or formation of an explosive gas atmosphere according to **BDS EN 60079-10-1 "Explosive atmospheres. Part 10-1: Classification of areas. Explosive gas atmospheres".**

All the HRS components need to comply with the requirements of the corresponding harmonised standards and should be reported in the technical documentation of the project of the facility. If it is not possible to apply such standards, each technology used in the facility should meet the minimum safety requirements determined in the Law on the Technical Requirements for Products (ZTIP) and/or the European regulations adopted in the specific product area.

This regulation opens to multifuel HRS configurations where the HRS can be integrated in an existing conventional refuelling station.

Nevertheless, the Regulation prescriptions do not apply in the following situations:

- when compressed hydrogen is supplied to the **HRS by pipelines**;
- when liquid hydrogen is delivered by truck to the HRS and it also present an on-site storage of **liquid hydrogen**;
- with hydrogen generators using technologies for the processing of other types of fuel on site (natural gas, biogas, etc.);
- for hydrogen refuelling mobile charging stations;

For the construction of the HRS, the Regulation provides safety distances determined on the basis of the facility capacity. Safety distances refer to the hydrogen supply or hydrogen production area, the storage area, the compression area and the area for dispensing of hydrogen to vehicles. Each zone of the HRS should be designed on a foundation of reinforced concrete, which is calculated for the corresponding structural loads caused by the planned facilities for the zone.

When designing a HRS with the supply of hydrogen produced off-site and delivered by trucks with trailers, a design area for a full trailer parking and maneuvering area and a design area for an empty trailer parking area are provided. The length of the parking areas is from 18 m to 23 m, and the vehicle is also provided with a turning radius that is sufficient to ensure free maneuvering in the trailer delivery/exchange area.

The on-site hydrogen generation area, the low-pressure hydrogen storage area and the high-pressure hydrogen storage area shall be provided with a safety fence with a height of at least 2 m.

The Regulation provides a guide for the parameters of the hydrogen technologies that stakeholders want to implement in HRS:

- in the case of **on-site hydrogen production**, the main parameters to consider are the flow rate, the output hydrogen pressure range, the hydrogen temperature range and the qualitative characteristics of hydrogen, which must comply with the technical specifications of **standard EN 17124 "Hydrogen fuel - Product specification and quality assurance for hydrogen refuelling points dispensing gaseous hydrogen - Proton exchange membrane (PEM) fuel cell applications for vehicles".** Moreover, all the prescriptions of the manufacturer of the electrolyser should be taken into account. **The dimensions of the on-site hydrogen generation area are determined depending on the capacity of the electrolyser**. It needs to be manufactured according ISO 22734 "Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications";

- in the case of the **storage systems**, the base under the **tube trailers, hydrogen bundles or under the metal hydride system** which remain on the charging station site, should be made of reinforced concrete or other suitable product with a fire reaction class not lower than A2. Moreover, the site intended for the supplying of hydrogen to the HRS should be protected along the entire length on both sides of the platform with reinforced concrete walls with thickness in their narrowest part not less than 0,3 m and with a height of not less than 3.5 m;
- **compressor systems** should be provided for installation in a factory-built module (container). If on-site hydrogen production is foreseen, **the compressor can be integrated (coupled) into the hydrogen generation area.** Each compressor shall be equipped with a pressure release device to prevent overpressure, as well as with means of complete release of the pressure of all parts of the compressor system for maintenance purposes;
- dispenser can be integrated within the hydrogen production area. Moreover, it needs to meet the requirements of the standard ISO 16964 "Gas cylinders — Flexible hoses assemblies — Specification and testing". Instead, the connections devices follow the standards ISO 17268 "Gaseous hydrogen land vehicle refuelling connection devices".

Then, the Regulation provides prescriptions regarding the minimum geometric volume of the storage system according to the capacity of the facility. Safety distances vary if the geometric volume of the storage increases. For one-day charging of HRS some provisions are defined. The minimum geometric volume in this case is:

- 450 L, for low pressures up to 250 bar;
- 105 L, for high pressures (cars refuelling at 700 bar);
- 4,000 L, for high pressures (bus refuelling at 350 bar).

If more than one daily charging is considered, the minimum geometric volume of the storage systems and the safety distances increase accordingly.

The minimum safety distances from the elements of the HRS to other facilities on the territory of an integrated hydrogen charging station (HRS integrated within another fuelling station) and other relevant safety distances from the Ordinance n. № Iz-1971 of 29.10.2009 for civil-technical rules and norms for fire safety are presented in the following tables.

The distance between adjacent columns (dispensers) for the refuelling of hydrogen vehicles shall be at least 5 m. The distance from the facilities of the hydrogen charging station to the property limit of the charging station is at least 5 m.

Table 19 Safety distances between different elements of an integrated HRS in Bulgaria

By №	Buildings and facilities on the territory of the complex auto supply station	Tanks (underground) for light fuels	Above ground propane-butane tanks	Underground with a volume of up to 25 m3 or equivalent to underground LPG tanks with a volume of no more than 10 m3	Bottle group for natural gas	Site for a mobile platform with a gas bottle installation for natural gas	Compressor for natural gas	Column for charging motor vehicles (including combined vehicles)	Service building
1	Tanks (underground) for light fuels	0.5	the diameter of the larger one	0.5	5	5	5	5	according to Art. 619
2	Above ground propane-butane tanks	the diameter of the larger one	Art. 584, para. 1, tab. 55	the diameter of the larger one	5	5	5	10	15
3	Underground with a volume of up to 25 m^3 or equivalent to underground propane-butane tanks	0.5	2	0.5	5	5	5	5	7.5

By №	Buildings and facilities on the territory of the complex auto supply station	Tanks (underground) for light fuels	Above ground propane-butane tanks	Underground with a volume of up to 25 m3 or equivalent to underground LPG tanks with a volume of no more than 10 m3	Bottle group for natural gas	Site for a mobile platform with a gas bottle installation for natural gas	Compressor for natural gas	Column for charging motor vehicles (including combined vehicles)	Service building
	with a volume of no more than 10 m^3								
4	Bottle group for natural gas	5	5	5	-	-	-	5	15
5	Site for a mobile platform with a gas bottle installation for natural gas	5	5	5	-	-	10	5	15
6	Propane-butane cylinder filling points	5	5	5	5	5	5	10	10
7	Equipment for filling tanks for light fuels	1.5	5	5	5	5	5	5	according to Art. 619

By №	Buildings and facilities on the territory of the complex auto supply station	Tanks (underground) for light fuels	Above ground propane-butane tanks	Underground with a volume of up to 25 m3 or equivalent to underground LPG tanks with a volume of no more than 10 m3	Bottle group for natural gas	Site for a mobile platform with a gas bottle installation for natural gas	Compressor for natural gas	Column for charging motor vehicles (including combined vehicles)	Service building
8	Vehicle charging station (including combined vehicles)	5	10	5	5	5	5	5	according to Art. 619, 629, 636

Table 20 Other safety distances within HRS in Bulgaria

№		Minimal distances, m

order	Buildings and facilities on the territory of the charging station	Tanks for light fuel	Equipment for filling tanks for light fuels	Above ground tanks for propane-butane	Under-ground tanks with volume up to 25 m^3 or equivalent to underground tanks for propane – butane with volume no more than 10 m^3	Filling points for propane-butane bottles	Bottles for natural gas	Site for a mobile platform with a gas-bottle installation for natural gas	Compressor for natural gas	Column for refuelling motor vehicles with light gas, propane-butane or natural gas (including the combined ones)	Service building	Boundaries of the property
1.	Buildings/facilities where is positioned the hydrogen generator	10	10	10	5	10	5	5	5	10	10	5
2.	Warehouse (metal container or bottles) for hydrogen storage under law pressure	8	8	8	8	8	8	8	8	10	15	10
3.	Compressor module for hydrogen	10	10	10	10	10	10	10	10	10	10	10
4.	Warehouse/buffer metal vessel for hydrogen storage under high pressure	10	10	10	10	10	10	10	10	10	15	10
5.	Systems for hydrogen pre-cooling	10	10	10	10	10	10	10	10	10	10	5

6.	Column (dispenser) for refuelling vehicles with hydrogen (including the combined ones)	5	5	10	5	10	5	5	5	5	10	5

9.5 HYPOP and EU-13 COUNTRIES - Poland: Regulatory Framework for Safety of Hydrogen Refuelling Stations

In Poland, the regulatory framework for hydrogen mobility sector has been recently updated. The Regulation of the Minister of Climate and Environment of 21 October 2022 on detailed technical requirements for hydrogen stations (Journal of Laws 2022, item 2158) **introduces a definition of a hydrogen station and basic requirements for its construction and operation.**

Design, construction, approval for operation and operating rules are regulated by numerous normative acts on construction, technical, safety or environmental aspects. In addition to generally applicable regulations, **there are technical standards - national and international, which systematize the available technical knowledge on an ongoing basis and set the highest standards for the construction of such facilities. These key elements are also indicated in the regulation for HRS.** The project owner has a certain discretion limited by other regulations and the obligation to exercise due diligence and appropriate standards, which suggests, for example, the use of technical standards for hydrogen technologies certification and technical standards for safety installation. These are in addition to:

- **Hazard Identification**: Identifying potential hazards associated with hydrogen production, storage, and usage;
- **Risk Assessment**: Evaluating risks based on factors like quantity, location, and exposure;
- **Mitigation Strategies**: Implementing safety measures to reduce risks, such as using explosion-proof equipment and ensuring proper ventilation.

The most important elements from the regulation to ensure safety of Hydrogen refuelling stations are:

- It is mandatory to be compliant with the international technical standards ISO 1988-1 and EN ISO 17127;
- The dispensing unit must be compliant with the international technical standards ISO 19880-2 and EN ISO 17268;
- As hydrogen will be used for hydrogen mobility purposes, high standards for hydrogen quality and measurements for hydrogen quantity must be considered;
- The hydrogen refuelling stations must consider two independent electricity sources;
- All the procedures and types of tests for the safety of operation, repair and upgrading of hydrogen refuelling stations must be carried out by national inspection authorities.

9.6 EU-13 COUNTRIES - Estonia: Current gaps in the regulatory framework for hydrogen implementation

Within HYPOP activity, the stakeholders' engagement activity through the cooperation with the National Contact Points allowed to collect some information about the current initiatives in Estonia. At national level, policies to support the hydrogen economy, including incentives for hydrogen production and infrastructure development (Government Energy Policies) are still under development. As for other EU-13 countries, different hydrogen projects encompassing hydrogen production, storage, distribution and use are still ongoing and waiting for a more mature framework. The following projects are the one that will be monitored to get information for the final HYPOP guidelines if results will be available.

- **Tallinn Hydrogen Refuelling Stations:** Estonia's capital is setting up its first hydrogen refuelling stations to support the introduction of hydrogen vehicles in public and private transport [EREF][10];
- **Estonian Hydrogen Valley:** A comprehensive project aimed at creating a full hydrogen supply chain from production to consumption, including industrial applications (Energy Sector Innovations);
- **Hydrogen Buses in Tartu:** Integration of hydrogen buses into the public transport fleet to test and optimize hydrogen fuel technology in real-world conditions (Local Transport Authority Announcements).

9.7 EU-13 COUNTRIES - Hungary: Regulatory framework for industry and mobility applications

Hungary has installed the first public Hydrogen refuelling station in 2024 for the refuelling of buses. This is a step forward the increase and the transfer of experiences about hydrogen technologies. Safety regulatory framework is not mature enough and this could affect all the permitting procedures.

The general approach to safety followed for Hydrogen refuelling stations in Hungary is prescriptive as different prescriptions like distances are indicated in the national regulation available (even if not Hydrogen specific, Ministerial Decree 2/2016). Moreover, the hydrogen production through electrolysis was considered as affecting both mobility and industrial applications. Project developers should contact the Fire Protection Authority.

The EU directives and regulation considered in the regulatory framework are: PED, ATEX, CLP and SEVESO.

Plant distances (i.e., safety, installation and protection distances), specific features of the installation site and the required containment structures for protection of other facilities, equipment and citizenship are the main elements of the safety approach.

Specific attention is paid to the storage and the hydrogen production where the installation of fire and gas detection systems and safety or protection distances are generally the outputs of the risk and safety assessment.

Safety requirements and perception towards Hydrogen facilities, independently if the HRS is with or without on-site production, is greatly influenced by the quantity of stored hydrogen. Above 1,25 ton of hydrogen stored on-site, a disaster protection permitting is needed. The complexity of safety requirements increases with the amount of hydrogen, including the SEVESO directive requirements, like risk assessment methodologies, above 5 tonn. Even if the risk assessment is not mandatory, except in the previous case, it is highly recommended as safety and its distances should come independently from the application of SEVESO directive.

The safety distances, which are not hydrogen specific but they refer to dangerous gases, vary according to the volume of hydrogen stored, as showed in the table. Distances can be reduced to some extent when they cannot be satisfied and additional protective measures are needed.

Tabella 15 Link between distances and volumes of hydrogen stored for safety of industry and mobility installations in Hungary

Volumes of H_2 stored (m^3)	Distances required
5	5 m

[10] https://www.eref-europe.org/

5 < V < 100	10 m
100 < V < 500	15 m
> 500	20 m

9.8 EU-13 COUNTRIES - Latvia: Regulatory framework for hydrogen application in Industry and Mobility sectors

9.8.1 Hydrogen mobility and hydrogen production

Latvia does not have a specific hydrogen regulatory framework. Safety is ensured through the application of risk assessments, mainly of quantitative-based, that are generally required by the building authorities in charge of the evaluation of the hydrogen project, independently from the presence or not of on-site hydrogen production, including HRS. Due to the gap in the regulatory framework for hydrogen, regulations for conventional fuels are considered. Safety requirements can also come from the application of SEVESO directive if hydrogen quantity overcomes the 5 ton stored on-site. Especially for public HRS, the compliancy towards competent authorities can be achieved through the application of international technical standards that define the minimum safety requirements and distances needed:

- ISO/TS 19880;
- ISO 17268:2012 for the connection between the refuelling station and the vehicles.

Storage of hydrogen is the main concern from the regulatory point of view (i.e., distances can reach 100 meters and must be respected between the storage system and other buildings and structure). Safety approach followed in Latvia show key elements of the performance-based one but some prescriptions coming from other regulations exist and reflect a prescriptive approach with strict safety distances.

9.8.2 Safety approach for Residential applications

There are not specific safety requirements for the installation of FC-based systems or hydrogen heating systems. They are associated to conventional appliances as micro-CHP systems for building energy supply.

9.9 EU-13 COUNTRIES - Malta: Current gaps for hydrogen implementation

Malta is working on two innovative hydrogen projects at national level which are at early stage of development: **Melita TransGas Pipeline (MTGP)**, connecting Delimara (Malta) and Gela (Italy), and **HydroGenEration**, a project carried out by the university of Malta and FLASC B.V., which is seeking to investigate various technical aspects to enable the coupling of offshore wind generation and a co-located Hydrogen production plant. So far, hydrogen has only been considered within the scope of the National Transport Strategy but the national hydrogen economy still suffers the gaps of the regulatory framework and a competition with the battery electric mobility which currently takes priority over the installation of a hydrogen refuelling network. At the moment there are not specific information on safety requirements for hydrogen applications but additional insights about the overall permitting procedures and requirements for Melita TransGas Pipeline (MTGP) project are provided in Deliverable 2.2 as output of the engagement activity with the National Contact Point of Malta.

9.10 EU-13 COUNTRIES - Romania: Regulatory framework for hydrogen implementation in Industry, Mobility and Residential applications

9.10.1 Hydrogen mobility and hydrogen production

In Romania there is not a specific hydrogen regulatory framework and safety requirements are similar to the ones for conventional fuels. Being an explosive gas, competent authorities require, especially for hydrogen production and storage systems, to assess the risks as inspection for explosion prevention are carried out on field. Indeed, the regulation for explosion prevention requires the application of technical standard EN 60079, related to ATEX directive.

Hydrogen refuelling stations are not specified in the regulations and, as for the hydrogen production and storage, conventional fuel and technology requirements are followed. Due to the gap of regulations the following technical standards are applied for the safety of the HRS and the safe connection between HRS components and vehicles:

- ISO/TS 19880-1:2016 Gaseous hydrogen — Fuelling stations;
- ISO 17268 :2020 Gaseous hydrogen land vehicle refuelling connection devices defines the design, safety and operation characteristics of gaseous hydrogen land vehicle (GHLV) refuelling connectors.

Tabella 16 Distances required within and from the HRS for safety in Romania

Elements from HRS	Distances required
Within the HRS	2 - 15 m
To external buildings	10 - 35 m

9.10.2 Safety Approach for Residential applications

There are not specific safety requirements for the installation of FC-based systems or hydrogen heating systems. They are associated to conventional appliances as micro-CHP systems for building energy supply. The main issues are related to the procedures that the authorized technicians should follow.

9.11 EU-13 COUNTRIES - Slovenia: Current gaps for hydrogen implementation

According to KSSENA, the Energy agency for national affairs in Slovenia, the implementation of hydrogen technologies in different sectors is significantly hindered by the regulatory gaps present so far. As a national hydrogen strategy (which is going to be included in the next National energy and climate plan) is still missing, all the hydrogen value chain is waiting for more clear guidelines to start pilot and commercial projects and to identify solutions to align demand and offer of hydrogen technologies.

Existing framework of pilot projects for hydrogen production and distribution follow **permitting procedures not specifically related to Hydrogen but mainly to natural gas.**

Hydrogen is mentioned mainly in strategic document for transport, as reported by H2MA project leaded by KSSENA organization,

The following are the projects which could in the future support the creation of a solid permitting framework for hydrogen technologies in Slovenia:

- **North Adriatic Hydrogen valley (NAHV)** coordinated by a state-owned power generation company, Holding Slovenske elektrarne (HSE);

- at the moment there is only one **Power to Gas plant at pilot scale in Slovenia**. Green hydrogen is produced to fuel the internal needs of a glass industry (Steklarna Hrastnik glassworks company);
- There are **3 pilot Hydrogen refuelling stations in Slovenia**. One of these HRS is located at Salonit Anhovo and its purpose is to refuel a cement factory. At the moment the HRSs are not operational and designed only for internal uses.

9.12 FRONTRUNNERS - France: insights from legislative framework for Safety of Hydrogen technologies for Industry, Mobility and Residential

In this Section some of the main elements of the French legislative framework for safety of HRS and storage systems outside of the HRS are provided. The following description is not intended to be exhaustive but it aims to provide some terms of comparison. France has a developed HRS network which is supposed to increase further in the following years. For this reason, the experience gained is an added value for this project.

9.12.1 Safety for Hydrogen Refuelling Stations

In France safety distances in HRS depend on the dispenser max flow rate and the general approach to safety varies starting from a minimum value of hydrogen stored equal to 1 ton of hydrogen.

As reported by the Association France Hydrogene[11], the safety distances between the hydrogen technologies and the facility boundaries, the ventilation devices and the storage of flammable gases vary according to the features of the HRS (e.g., the flow rate).

Table 21 Safety distances between H2 technologies in HRS for France

Max flow rate	Distances	Distances reduced
120 g/s	14 m	10 m
60 g/s	10 m	8 m
20 g/s	6 m	6 m

The safety distances can be reduced in two cases:

- The anti-snatch system of the distribution hose is designed to ensure an upward orientation of the gas flow by more than 45°; or
- If technical means are provided and automatically ensure that the gas flow is stopped at the potential breakage point of the hose within less than 2 seconds (this is the solution most often implemented in installations).

If these distances cannot be maintained, the operator must install a solid wall without openings, made of REI120 fire-resistant materials, which must be taller than the highest point of the distribution area (excluding the vent) but at least 3 meters high.[12] Moreover, HRS built in France require safety distances between hydrogen dispensers and other fuels (5 m) but in some cases authorities can allow stakeholders to install the hydrogen dispenser on the same island as other fuels. Instead, the allowed distance between two hydrogen dispensers is 2 meters.

9.12.2 Safety for Hydrogen Storage Systems for Residential

In France there is also a Regulation that applies specifically for hydrogen storage "Arrêté Ministériel du 12 février 1998 relatif aux Prescriptions Générales (AMPG) applicables aux installations classées pour la protection de l'environnement soumises à déclaration sous la rubrique n° 4715". According to this document, there are some prescriptions to follow for **storage systems installed outdoor and indoor**. These prescriptions mainly refer to safety distances that go from **8 meters (outdoor installation) to 5 meters (indoor installation)** from property boundaries or any building. These

[11] https://s3.production.france-hydrogene.org/uploads/sites/5/2023/02/Fiche-ICPE-1416-Distribution-dhydrogene.pdf
[12] MultHyFuel project: https://multhyfuel.eu/progress

distances are not needed if the building and the gaseous hydrogen storage are separated by a wall that is:

- Solid without openings;
- Built with non-combustible materials, with fire-resistant characteristics of 2 hours;
- With a minimum height of 3 meters;
- Extended from the storage by a canopy constructed with non-combustible and 1-hour fire-resistant materials;
- With a minimum width of 3 meters in horizontal projection.

This wall must be extended on both sides and on the storage side by return walls without openings, built with non-combustible and 1-hour fire-resistant materials, with a height of 3 meters and a length of at least 2 meters. Moreover, also **other flammable or combustible substances are considered and can be stored in the room or in the storage area of the installation if they are separated from the hydrogen storage systems** by:

- Either a distance of 8 meters;
- Or a solid wall without openings with a 1-meter extension, built with fire-resistant materials with a 2-hour fire rating, rising to a height of 3 meters or to the roof unless more stringent requirements are specified by other regulations.

9.13 FRONTRUNNERS - Germany: Performance-based approach to Safety for Hydrogen Refuelling Stations

The following information was gathered through the participation to HyTruck Breakfast Briefing initiative with the topic "Hydrogen safety regulations and compliance HRS & Risk assessment for planning and operation of HRS".

Safety measures are based on:

- Legally binding requirements coming from:
    - legislation concerning health and safety at work, emissions, social;
    - government regulations;
    - accident prevention regulations.
- Voluntary requirements referring to:
    - standards and principles for insurance;
    - technical standards from ISO, NFPA, CEN/CENELEC, SAE standardization organization. Specific mention is made to the technical committees: ISO/TC 197 "Hydrogen Technologies" and ISO/TC 22 "Road vehicles" (for more details about TC activity check D2.3);
    - technical rules (e.g. hazardous substances);
    - government action plants.

In Germany there are not mandatory safety requirements prescribed in the official documents like pressure limits or safety distances. **The main issue for HRS but also for industrial or residential applications that brings to more strict safety requirements is the volume of hydrogen stored on-site.** In particular, as already mentioned along the text, above 5 ton the directive SEVESO is applied but HRS are more used to store around maximum 1 ton thus avoiding its application. Nevertheless, **for this type of facilities, in Germany stakeholders completely rely on risk assessment procedures, technical standards and technical recommendations** because even if not required in the regulatory framework, the same risk assessment can result into physical restriction and prevention systems as well as minimum safety distances according to the specific characteristics of the planning site. **Concerning safety distances, there are general recommendations from the TRBS 3151 document "Prevention of fire, explosion and pressure hazards at petrol stations and gas filling systems for filling land vehicles - Technical rule for operational safety"** (this document is also relevant for permitting during building and operation of HRS). **However, safety distances are often defined by the manufacturer, typically based on regulations of their country of origin or international documents**. If the operator decides for shorter distances than the ones recommended in the guidelines TRBS 3151, he does it on his own risk. The manufacturer is then out of liability claims. Within the TRBS 3151, **also ATEX zones classifications is linked to risk assessment and represents a reference document that govern safety of HRS as well as their integration in existing infrastructures intended also for end uses others than mobility.**

One of the main official documents that needs to be taken into account in Germany for safety, and relevant for different hydrogen technologies and application fields, is the **Documentation of explosion protection "Explosionsschutz-dokument".** Moreover, the following list of documents (not exhaustive) intends to provide a base for safety framework using both prescriptive and performance-based provisions:

- **International Fire Code (IFC)** which establishes the minimum requirements for fire prevention and fire protection systems. It is fundamental for emerging energy applications like the ones where renewable hydrogen can be conceived;
- Relevant national regulations such as the Ordinance on Industrial Safety and Health, Hazardous Substances Ordinance and Workplace Ordinance;
- **Technical standards** like ISO 19880-1:2020 "Gaseous hydrogen — Fuelling stations Part 1: General requirements" followed in Germany as guidelines for the risk assessment. It defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty road vehicles (e.g. fuel cell electric vehicles). **This standard also has a section related to gas detection systems which are considered as one of the main safety aspects to be evaluated within HRS (but not limited to it).** Other useful technical standards for safety planning and operation can be EN 61511 "Functional safety - Safety instrumented systems for the process industry sector" and EN 1127-1 "Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology". Several technical standards useful for HRS planning and construction as well as also for other hydrogen technologies and sectors are reported in D2.3 (within it a short selection has been provided just for documentation and according to the type of project evidences analysed in the framework of HYPOP activities);
- **Technical reports** like ISA TR 84.00.07:2018 "Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness" which has been developed to analyse chemical processes and hazards in Energy, Chemical and other industrial facilities. It allows to conceive the system design from a performance-based perspective and provides methods of estimating Risk Reduction Factors.

One element considered as fundamental to ensure safety through performance-based approach and risk assessment methodologies is the early detection of gas leakage. Indeed, Ultrasonic detection, Catalytic Bead Sensor and Flame Multi-IR systems are needed when working with compressed hydrogen as the majority of the accidents happened at HRS facilities are caused by human factors, for example, during maintenance, revision, restart procedures. This implies both the need of a higher knowledge about the Hydrogen Safety professionals and high-quality detection systems as one of the pillars necessary to ensure that performance-based approach is consistent and safe for public health and for environment.

Multifuel facilities are allowed in Germany. Moreover, hydrogen dispenser can be installed on the same island as other fuels. Anyway, they are typically installed separately from the non- hydrogen dispensers as it includes specific components relevant to hydrogen dispensing (same approach in Belgium). In the case of a combination of a dispenser for hydrogen with other dispensers, all parts of the system must be designed for explosion group IIC (or IIB+H2) and for temperature class T3, as defined in Directive 2014/34/EU. The possible release quantity in the event of leaks from refuelling hose lines for gaseous fuels shall be limited to a harmless level. This is fulfilled for hydrogen if:

- there is an automatic check of the connection of the refuelling hose to the refuelling connection of the motor vehicle so that refuelling is not started in the event of a leak;
- there is automatic monitoring of the refuelling so that refuelling is stopped immediately in the event of a leak;
- the hose is safely depressurised via a blow-off line by discharging the hydraulic fluid via the vent mast/chimney; and
- after refuelling, the refuelling hose is pressure-free.

9.14 FRONTRUNNERS - Netherlands: Regulatory Framework for Hydrogen implementation in Industry and Mobility sectors

Safety requirements for hydrogen production facilities derive from EU Industrial Emissions Directive as they are considered as integrated chemical plants. **SEVESO III directive is applied** and transposed at national level with the BRZO 2015 (Besluit Risico's Zware Ongevallen), Decree on the risks of serious accidents. The safety requirements in Netherlands are linked to the Land Use plans and thus the competent authorities can be the municipality or provinces. A part from prescribed distances included in the regulatory framework encompassing Land use and environmental laws and acts, **quantitative risk assessment and manufacturing risk assessment are the tools required to ensure safety.**

Quantitative risk assessment is the main tool followed in Netherlands to ensure safety of hydrogen installations for industry and mobility applications. Indeed, official guidelines explaining how to do it are issued at national level[13]. This is one of the drivers of the deployment of a hydrogen economy where both stakeholders and public authorities can take advantage of this kind of references.

Classification of allowed industrial installations and the related safety distances are collected within a uniform permitting procedure where, similarly to other EU frontrunner countries, the Omgevingswet regulation provides a single authority in charge of the overall process. Storage of hydrogen follows regulations which are connected to the ones valid for hydrogen production facilities.

In the case of **HRS**, the safety approach is also linked to other types of permits like the environmental impact assessment procedure which, according to the **regulation PGS35**, defines if the HRS layout can be built in a certain location. Specifically, the regulation PGS35 "Waterstofinstallaties voor het afleveren van waterstof aan voertuigen en werktuigen"[14] **provides provisions about the safety installation of hydrogen refuelling stations for vehicles and equipment.** The provisions indicated in

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[13] https://content.publicatiereeksgevaarlijkestoffen.nl/documents/PGS3/PGS3-1999-v0.1-quantitative-risk-assessment.pdf

[14] https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs35/

the document as result of the activity of a working group composed by a team of hydrogen experts are the ones showed in the table.

The external safety distances are calculated applying the quantitative risk assessment methodology. The document does not mention ATEX zoning.

Internal safety distances, defined as separation distance between a potential hazard source (e.g. equipment involving dangerous substances) and an object (human, equipment or environment), which will mitigate the effect of a likely foreseeable incident and prevent a minor incident escalating into a larger incident (also known as domino effect). The provision of adequate internal safety distances is thus a fundamental consideration for safe layout of hydrogen refuelling stations.

Table 22 Internal safety distances according to the PGS35 regulation for HRS in Netherlands

Accident scenario	Applicable effect	Leakage flow	Protection value	Internal safety distance (meters)
Leakage scenario, 10% of piping diameter DN50 at 10 bar, for onsite production – steam reforming or electrolysis	Flare	12 g/s	3 kW/m^2	2.2
	Flare	12 g/s	10 kW/m^2	2.1
	Flare	12 g/s	35 kW/m^2	0
Leakage scenario, 10% of piping diameter 1” at 85 bar, for onsite production – electrolysis	Flare	23 g/s	3 kW/m^2	3.1
	Flare	23 g/s	10 kW/m^2	2.9
	Flare	23 g/s	35 kW/m^2	n/a
Leakage scenario, hose failure of tube trailer, 1 mm at 200 bar	Flare	8 g/s	3 kW/m^2	2.9
	Flare	8 g/s	10 kW/m^2	1.8
	Flare	8 g/s	35 kW/m^2	n/a
Leakage scenario, hose failure of tube trailer, 3 mm at 200 bar	Flare	75 g/s	3 kW/m^2	5.5
	Flare	75 g/s	10 kW/m^2	5
	Flare	75 g/s	35 kW/m^2	4.7
Leakage scenario, hose failure of tube trailer, 1 mm at 500 bar	Flare	20 g/s	3 kW/m^2	2.9
	Flare	20 g/s	10 kW/m^2	2.7
	Flare	20 g/s	35 kW/m^2	n/a
Leakage scenario, hose failure of tube trailer, 3 mm at 500 bar	Flare	178 g/s	3 kW/m^2	8.5
	Flare	178 g/s	10 kW/m^2	7.8
	Flare	178 g/s	35 kW/m^2	7
Leakage scenario, downstream compressor, 10% of piping diameter 1 mm at 450	Flare	18 g/s	3 kW/m^2	2.7
	Flare	18 g/s	10 kW/m^2	2.6
	Flare	18 g/s	35 kW/m^2	n/a
Leakage scenario, downstream compressor, 10% of piping diameter 1 mm at 1000 bar	Flare	36 g/s	3 kW/m^2	3.9
	Flare	36 g/s	10 kW/m^2	3.6
	Flare	36 g/s	35 kW/m^2	3.3
Leakage scenario, 10% of piping diameter 0.75” at 100 bar, for gaseous hydrogen through piping	Flare	16 g/s	3 kW/m^2	2.5
	Flare	16 g/s	10 kW/m^2	2.4
	Flare	16 g/s	35 kW/m^2	n/a

The document also clarifies the methodology followed to calculate the provisions, especially the internal safety distances, through a specific **software (SAFETI-NL NL v6.5.4)**, application of definitions and safety concepts from the European Industrial Gases Association (EIGA) in their 2007 report, IGC Doc 75/07/E "Determination of safety distances" and indicating **the criteria for harm and damage for hydrogen** like the thermal radiation from jet fire relating to the different targets (i.e., people, buildings…)

The regulation also recommends to consider mitigation measures like firewalls to reduce escalation, or the alteration of equipment design and/or operating conditions to reduce the severity and/or likelihood of the incident if the resultant safety distances are too large.

The following figure summarises the key elements identified in the regulatory approach to safety and shows the interconnection between prescriptive provisions (i.e., internal safety distances) and a performance-based approach (i.e., external safety distances, QRA application etc).

9.15 FRONTRUNNERS - Switzerland: Safety approach for the implementation of Hydrogen production plants

The following information have been collected analyzing the official guidelines for the permitting of hydrogen production plants issued at national level in Switzerland (more details in Deliverable 2.2).

The key elements characterizing the safety approach are:

- the safety requirements are aligned with the Labor law and its regulations and the Fire prevention ordinance;
- fire prevention prescriptions VKF of the Association of Cantonal Fire Insurance Companies constitute harmonized standards at the intercantonal level for the preventive protection against the dangers and effects of fires and explosions in buildings and installations;
- risk assessments if required by competent authority for surveillance aspects, FOEN;
- application of the ATEX 1999/92/EC directive.

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