D1.3 – State of the art of safety standardisation framework

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Acronyms

ACRONYM	*MEANING*
AFIR	Alternative Fuels Infrastructure Regulations
ahG	Ad-Hoc Groups
ATENA	Atena scarl – Distretto alta tecnologia ambiente
CA	Conformity Assessment
CAB	Conformity Assessment Body
CCUS	carbon capture, utilization and storage
CDM	Clean Development Mechanism

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CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CER	Certified Emission Reductions
CFD	Computational Fluid Dynamics
CII	Carbon Intensity Indicator
DAFI	Directive on Alternative Fuels Infrastructure
DIN	German Standardization Body
DNV	DNV is an international accredited registrar and classification society
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EN	European Standard
ERU	Emission Reduction Units
ESBs	European Standardization Bodies
ETS	EU Emission Trading System
EU	European Union
FC	Fuel Cell
GHENOVA	Ghenova Ingenieria
GHG	Greenhouse gases
H2	Hydrogen
HAZID	Hazard Identification
IACS	International Association of Classification Societies
IEC	International Electrotechnical Commission
IET	International Emissions Trading
IGF Code	International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
ISBs	International Standardization Bodies
ISO	International Standardization Organization
JDP	Joint Development Project
JI	Joint Implementation Mechanism
JTC	Joint Technical Committee
LNG	Liquefied Natural Gas
NFPA	National Fire Protection Association
NG	Natural Gas
NSBs	National Standardization Bodies
OH&S	Occupational Health and Safety
PEM	Polymer Electrolyte Membrane (fuel cells)
POLIMI	Politecnico di Milano
PPE	Personal Protective Equipment
RCS	Regulations, Codes and Standards
RED	Renewable Energy Directive
RFNBOs	Renewable Fuels of Non- Biological Origins = renewable liquid or gaseous transport fuels for which none of the energy content of the fuel comes from biological sources
SC	Sub-committee
SDGs	Sustainable Development Goals
SEEMP	Ship Energy Efficiency Management Plan
SOLAS	International Convention for the Safety of Life at Sea
TBC	To Be Confirmed
TBE	To be explored
TBs	Technical Bodies
TC	Technical Committee
TS	Technical Specification
UNFCCC	United Nations Framework Convention on Climate Change
UNI	Italian Standardisation body (Ente Italiano di Normazione)
WG	Working Group
WP	Work Package

Executive Summary

The e-SHyIPS project aims to define the new guidelines for an effective introduction of hydrogen in maritime passenger transport sector and to boost its adoption within the global and EU strategies for a clean and sustainable environment, towards the accomplishment of a zero-emission navigation scenario. The goal of e-SHyIPS is to move from the idea to the application, filling the existing gap in normative and technical knowledge concerning all the related aspects on hydrogen in the maritime transport sector. By means of an ecosystem approach, e-SHyIPS proposes theoretical pre-normative research activities on standards, simulation and laboratory experiments, design of an appropriate certification process, spot future standardization activities to enhance the EU normative and regulatory landscape.

Task 1.3 “State of the art of safety regulatory and standardisation framework”, closed in December 2022, was part of the first work package of the project aimed at conducting a deep analysis about the use of fuels based on Hydrogen in the maritime sector.

The results of all the activities carried out within task T1.3 have been summarized in this public report, particularly relevant to standardization bodies, flags, but also companies who are striving to find normative and technical references.

1. Introduction

1.1 Scope and Objectives

Task 1.3 was aimed at reviewing the framework state of the art in terms of Regulations, Codes and Standards, pre normative documents, technical reports and specification, Interim Guidelines (IG) to code amendments at international (ISO/IEC) and European (CEN, EU states) level. The final aim was to start identifying initial standards and normative gaps and possibly define appropriate scenarios to study them.

This deliverable summarizes the findings coming from the activities done within task 1.3 that can be gathered in 3 building blocks:

1. Legislative framework state of the art: overview of the main relevant legislations;
2. Standardization framework state of the art: spotting of H2 (in non-maritime applications), natural gas and cryogenic vessels relevant standards. Mapping of technical bodies at Italian, European and International level which are developing standards relevant for e-SHyIPS scenarios;
3. IGF Code: identification of normative gaps for defining experimental scenarios to fill existing knowledge.

This deliverable has to be intended as the first step of a pathway which will be built up starting from 2023 and aimed at defining by the end of the project a strategic roadmap for an actual implementation of hydrogen on passenger ships, and for an update of relevevant normative and technical references.

1.2 Connection with other activities and contributions of partners

This report gathered inputs from several tasks of e-SHyIPS project. The results will feed the activities of other project tasks.

In particular, task 1.3 worked in parallel with task 1.1 to ensure that the state of the art framework was in line with the functional scenarios defined in the project. Task 1.3 also borrowed from task 1.2 in terms of tools and procedures to knowledge capture (e.g. in the workshop preparation and involvement of Advisory Board Members).

In terms of output, to be intended as where will the work go, the table below summarizes the main project activities which T1.3 results will feed.

Outputs
• T1.5 "Theoretical studies and ecosystem knowledge database creation": T1.3 results will feed the knowledge database inside the consortium and provide the starting point for the analysis of the gaps to be closed, the obstacle to do it and to update the general safety plan.
• Experiments Design: T1.3 has identified a preliminary list of normative gaps (IGF Code), some of them may be closed running experiments within e- SHyIPS project.
• WP6 "Pre-standard plan for IGF code update and other RCS improvements": T1.3 results will be the starting point to reach the goals of WP6, i.e. identifying existing gaps and barriers to improve existing regulatory and standardization framework; contribute to an update of the IGF Code; contribute to a new standardization deliverable, CWA – CEN Workshop Agreement.

This report is the compendium of task T1.3 activities and results, which all partners of e-SHyIPS project have contributed to, by participating to T1.3 discussions held during the consortium meetings and to the dedicated workshops organized within this task.

GHENOVA, ATENA and UNI wrote the section of this report dedicated to the legislative state of the art.

UNI took care of drafting the section dedicated to the analysis of the standardization state of the art.

POLIMI took care of writing the part dedicated to the scenarios definition and of checking the quality and correctness of the IGF Code results.

DNV technically led a series of gap assessment workshops on the realization of the IGF Code for H_2 as fuel workshops, compiled and reviewed the brainstorming results to form gap categories and, finally led a series of workshops to link gaps to the experiments. All afore mentioned works were completed, apart from the final one, which is due to finish in the beginning of 2023. From the partners in order to rationalize the gaps identified.

All e-SHyIPS partners (and Advisory Board members) have had a crucial role in spotting the IGF Code gaps and in defining the experimental scenarios to close them.

Finally, ATENA, GHENOVA, POLIMI and UNI peer-reviewed this report.

1.3 Structure of the document

The report is organised based on seven sections as follows:

- Section 1 and 2: contain an overview of this document, providing its scope and Structure and the ecosystem of sister projects
- Section 3: contains the analysis of the legislative framework;
- Section 4: contains the analysis of the standardization framework;
- Section 5: contains the IGF Code review;
- Section 6: contains the conclusions and the final remarks.

2. Ecosystem of sister projects

e-SHyIPS project ecosystemic approach intends to exploit the knowledge around hydrogen that is already developed in other industries and aplicable also in the maritime sector, so avoiding "reinventing the wheel" and focusing on spotting further knowledge gaps.

In this perspective, within task 1.3, a mapping of existing hydrogen projects, which could provide relevant information, was also performed.

On March 28th 2022, in Milan, during the e-SHyIPS General Assembly, UNI organized a workshop aimed at gathering partners feedbacks on relevant legisltation and standardization frameworks, but also to spot the most relevant projects and publications[1], in order to eventually capitalize the knowledge already consolidated and validated by other reserachers, and focusing on what was never done before.

A notable number of references, of which 17 projects overall, was identified; mostly, involving EU projects funded under H2020 Framework Programme. For each reference, the following information was identified: the type (EU project vs publication), the scope, the link to the project website, and the possible relevance to e-SHyIPS activities[2].

Table 1 below lists all the projects mapped.

Table 1 – Sister projects: the results of a workshop

Title	Type	Scope	→E-SHyIPS
eGHOST	EU project	The final goal is to provide robust eco-design guidelines for FCH products at different levels of development. The development of guidelines for products at an emerging state will require the adaptation of life cycle thinking tools for considering the time of their future entry.	Fuel cells
H2ports	EU project	The H2Ports project will demonstrate and validate at the Port of Valencia in real port operations two innovative solutions based on	Safety measures

[1] The results of the workshop about the legislative and standardization framework will be deepened in further sections of this deliverable.

[2] For some projects it has also been indicated the mail of a contact person.

		FC technologies and a hydrogen mobile supply station specifically designed for the project.	(port and bunkering)
FLAGSHIPS	EU project	The FLAGSHIPS project will raise the readiness of zero-emission waterborne transport to an entirely new level by deploying two commercially operated hydrogen fuel cell vessels. The demo vessels include a push boat in France (Lyon) and a passenger and car ferry in Norway (Stavanger).	Regulations Review; Fuel Cells
MARHYSAFE	JDP (with DNV)	Objective: build the foundations of non-proprietary heavy duty refueling protocols for large tank systems (larger than 10kg), such as the ones found in heavy duty hydrogen applications.	Handbook on Hydrogen fueled vessels
Prhyde	EU project	PRHYDE is looking at the current and future developments needed for refueling medium and heavy duty hydrogen vehicles, predominantly road vehicles, but also other applications such as rail and maritime. The project aims to investigate refueling protocol requirements, and provide data for compressed (gaseous) hydrogen refueling protocols developed for the 35, 50 and 70 MPa nominal working pressures, that is anticipated to help facilitate the future standardisation of fueling protocols.	Safety and refueling protocol
HySafe	Association	The International Association for Hydrogen Safety has been founded by the EC supported Network of Excellence (NoE) HySafe and facilitates the networking for the further development and dissemination of knowledge and for the coordination of research activities in the field of hydrogen safety. So it supports cost effective hydrogen safety research, enables innovative technologies and engineering, and provides education and training on a professional level. HySafe determines the state-of-the-art in hydrogen safety.	Networking
SH2IPS	National project Norway	Hydrogen efficient and safe implementation will require suitable regulations, codes and standards (RCS). Part A of the IGF Code from the International Maritime Organization (IMO) outlines general goals and functional requirements that apply to hydrogen and other low-flashpoint fuels (LFFs), including §3.2.1. Relevant LFFs for maritime applications include natural gas, hydrogen, ammonia, methanol, ethanol and liquid organic hydrogen carriers (LOHCs). Part A-1 of the IGF Code provides specific requirements for natural gas, including liquefied natural gas (LNG), and IMO has developed interim guidelines for methanol and ethanol. The safety-related properties of hydrogen imply that it is not straightforward to document compliance with the IGF Code through the prescribed alternative design process. To this end, the vision for the SH2IPS project is to contribute to the development of a consistent regulatory framework for the use of hydrogen and hydrogen-based fuels as the primary energy carriers for merchant ships. The project will utilize state-of-the-art experimental facilities at UiB to develop fundamental knowledge and competence on critical ignition and combustion phenomena, as well as novel solutions for explosion protection. SH2IPS also entails a critical evaluation of the strength of knowledge in risk assessments for hydrogen systems. The deliverables include science-based recommendations for relevant RCS and dedicated activities on stakeholder involvement and dissemination.	IGF code review
STASHH	EU project	StasHH will develop an open standard for heavy-duty fuel-cell modules in terms of size, interfaces, control and test protocols, with the objective of kick starting the use of fuel cells and hydrogen in the heavy-duty mobility sector, where electrification with batteries is impractical.	Fuel cells; New standards

HyTunnel-CS	EU project	The project aims at performing pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces.	Explosion and fire prevention
HyMethShip	EU project	The HyMethShip project will undertake risk and safety assessments to ensure that the system fulfills safety requirements for on-board use. It will also take into account the rules and regulations under development for low flashpoint fuels.	Safety and regulations on low flashpoint fuels
HyShip	EU project	The EU-funded HyShip project plans to build a cargo vessel for commercial operation running on liquid hydrogen, establish a viable liquid hydrogen supply chain and a bunkering platform.	Design; bunkering platform; cargo
SH2E	EU project	Besides technological advancements, methodological solutions that allow checking the suitability of FCH systems under sustainability aspects from a life-cycle perspective are needed to sensibly support decision-making. Sound guidelines for Life Cycle Sustainability Assessment (LCSA) of FCH systems are urgently needed. The goal of SH2E is to provide a harmonized (i.e., methodologically consistent) multi-dimensional framework for the LCSA and prospective benchmarking of FCH systems.	Fuel cells (LCA - LCC analysis); New standards; open-source, software
SH2IPDRIVE	National project Netherlands	The project will conduct new research into the development of safely applicable technologies for hydrogen in four different forms: (1) compressed hydrogen gas and (2) liquid hydrogen, and hydrogen bound to carriers such as (3) liquid organic hydrogen carriers and (4) boron hydrides. Another important area of research for the team is research into new fuel cell systems with a higher power density and longer service life, the use of residual heat and the scaling up of fuel cells.	Fuel cells; New standards
HySTRA	International project	With the assistance of NEDO (New Energy and Industrial Technology Development Organization), in the hydrogen energy supply chain pilot project HySTRA is undertaking development of : - brown coal gasification technology - technology of long distance transportation of mass liquefied hydrogen - liquefied hydrogen loading and unloading technologies	IGF Code review
EVERYWH2ERE	EU project	EVERYWH2ERE project will integrate already demonstrated robust PEMFC stacks and low weight intrinsically safe pressurized hydrogen technologies into easy to install, easy to transport FC based transportable gensets. 8 FC contained "plug and play" gensets (4×25 kW + 4×100 kW) to be tested in construction sites, music festivals and urban public events all around Europe.	Fuel cells; Tanks and refueling procedures
CHEK	EU project	The project will develop and demonstrate two bespoke vessel designs – a wind energy optimized bulk carrier and a hydrogen powered cruise ship – equipped with an interdisciplinary combination of innovative technologies working in symbiosis to reduce greenhouse gas emissions by 99% and achieve at least 50% energy savings.	Legislative and standards framework
MARANDA	EU project	In MARANDA project an emission-free hydrogen fueled PEMFC based hybrid powertrain system is developed for marine applications and validated both in test benches and on board the research vessel Aranda, which is one of about 300 research vessels in Europe. Special emphasis is placed on air filtration and development of hydrogen ejector solutions, for both efficiency and durability reasons. In addition, full scale freeze start testing of the system will be conducted. When research vessels are performing measurements, the main engines are turned off to minimize noise, vibration and air pollution causing disturbance in	Fuel Cells; Legislative and standards framework

	the measurements. The 165 kW (2 x 82.5 kW AC) fuel cell powertrain (hybridized with a battery) will provide power to the vessel's electrical equipment as well as the dynamic positioning during measurements, free from vibration, noise and air pollution.	

3. Legislation framework

Maritime transport plays a key role in world trade, with around 35% of European and 77% of foreign trade being carried out by sea. Maritime transport is set to increase in the coming years, so that, considering that ships produce energy through internal combustion engines powered by fossil fuels, greenhouse gas emissions from this sector are also set to increase. The European Environment Agency states that, only in 2018, ships emitted around 140 million tons of CO_2 emissions, accounting for around 18% of global emissions from the maritime sector. To ensure that the goals of the Paris Agreement are not compromised, mitigation measures need to be put in place quickly [1][2].

This section first provides an overview of European legislations with regard to greenhouse gas emissions from the industrial and transport sectors. Secondly, European legislations applied within the maritime sector are discussed in detail. In particular, a series of rules and regulations that influence the use of alternative technologies and fuels on board ships are reported. In addition, what's next in the legislative framework is also mentioned.

3.1 International energy scenario

The 'Kyoto Protocol' was the first international agreement, approved by more than 180 countries in 1997, to mitigate the impacts from the phenomenon of global warming. The 'Kyoto Protocol' requires companies from signatory countries to install greenhouse gas monitoring and absorption systems in their plants in order to reduce CO_2 equivalent emissions by 5.2% compared to 1990 levels.
In addition, several market-based mechanisms are adopted to facilitate the implementation of the Kyoto Protocol. These mechanisms are reported below.

- The Joint Implementation Mechanism (JI), introduced in Art. 6 of the Protocol, allows each signatory country (industrialized country or country with an economy in Transition) to invest in projects to reduce CO_2 equivalent emissions in another signatory country (industrialized country or country with an economy in Transition), benefiting of the ERU (Emission Reduction Units) credits issued by the host country for each ton of CO_2 equivalent avoided.
- The Clean Development Mechanism (CDM), introduced in Art. 12 of the Protocol, allows signatory countries (industrialized countries or countries with economies in Transition) to invest in projects that aim to reduce CO_2 equivalent emissions in developing countries. For each ton of CO_2 equivalent avoided, the relevant

International Authorities (UNFCCC – United Nations Framework Convention on Climate Change) issue CER (Certified Emission Reductions) credits.

- The Mechanism concerning International Emissions Trading (IET), introduced in Art. 17 of the Protocol, allows industrialized signatory countries or countries with economies in Transition collaborating in a common project to trade emission allowances among themselves to cover any emissions that might exceed the Kyoto Protocol's limit.

The main members that benefit from the JI mechanism are European and Western countries, including Canada, Austria, New Zealand and Japan. In contrast, for the CDM mechanism, the main beneficiaries are China, India and Brazil.

In order to contribute to a more effective reduction of greenhouse gas emissions as stipulated in the Kyoto Protocol, EU countries set a new target with Decision 2002/358/EC: to reduce emissions by 8% compared to 1990 levels [3][4].

In this context, with Directive 2003/87/EC, the EU established a EU Emission Trading System (ETS) in order to reduce greenhouse gas emissions in an economically efficient way. The 'Cap and Trade' principle is applied to the ETS, whereby a maximum limit of greenhouse gas emissions must be achieved using emission allowances. Every year, operators of industrial installations must return the number of allowances based on their actual emissions. If the allowances held are greater than those paid out on the market, then companies can sell the remaining allowances. Conversely, if the allowances obtained from the European Commission are not sufficient to cover the emissions emitted, the company can cover its shortfall by purchasing allowances on the market. During the first phase, the EU ETS is activated in 28 EU countries (including the UK) plus the three EFTA countries Iceland, Liechtenstein and Norway. From 2021, with the exit of the United Kingdom from the European Union, the EU ETS is implemented in 27 member states plus Iceland, Liechtenstein and Norway. Specifically, the ETS covers about 11,000 installations across the European Economic Area (EEA) including energy-intensive installations (power plants and industrial plants) and airlines (operating between European countries) covering about 45% of greenhouse gas emissions produced in the EU [5][6][7][8][9].

Since the Kyoto Protocol imposes stricter emission limits for industrialized and not for developing countries, a second agreement was concluded in Paris in 2015, which is based, for the first time, on common principles valid for all countries, thus ending the distinction between industrialized and developing countries. In order to limit global warming, the Paris Agreement aims at a maximum global average temperature increase of 1.5°C compared to the pre-industrial period of 1750. All countries involved must meet every five years to assess progress and must inform the public about their achievements, in order to improve their contributions and ensure maximum transparency and control. The European Union approved the Paris Agreement in 2016, committing to reduce greenhouse gas emissions by at least 40% by 2030 (compared to 1990 levels). Its climate change ambition will increase to stimulate sustainable economic growth, bring health and environmental benefits, create jobs and promote innovation in green technologies.

3.2 European Green Deal

On December 11th 2019, the European Commission, led by President Ursula von der Leyen, proposed an action plan, the 'Green Deal', with policy and legislative proposals to achieve the goal of reduction greenhouse gas emissions from 40% to 55% by 2030 and of climate neutrality by 2050, so that the goals of the Paris Agreement are met.

Thus, the European Green Deal is a package of policy initiatives that aims to set the EU on the path towards a green transition. The first two years are dedicated to the review of existing laws in the areas of energy, climate and transport and introducing new laws on the circular economy, building renovation, agriculture and innovation. In particular, in the Green Deal, the Commission re-examined the following aspects:

- EU ETS extension in maritime transport.
- Revision of Regulation 2018/841 - LULUCF on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry.
- Revision of the Energy Efficiency Directive.
- Promotion of renewable (hydrogen) and low-carbon fuels for hard-to-decarbonize sectors.
- Electrification of energy demand through the use of offshore renewable energy.
- Revision of the Energy Taxation Directive.

On the basis of these proposals, the Commission has proposed two packages: one called 'Fit for 55' (to achieve the target of a 55% CO_2 reduction by 2030) and the other concerning the hydrogen and decarbonized gas market (for climate neutrality by 2050).

Hydrogen is used as an energy carrier or energy storage and is employed in many applications of industry, transport, electricity and construction. This gas is not available on earth in free state, except in marginal quantities. Therefore, it must be produced, like electricity, starting from any energy source, including renewable ones. If hydrogen is produced through the electrolysis of water using an electrolyser supplied from renewable sources, it is green hydrogen. In this case, when green hydrogen is applied, there aren't CO_2 emissions.

On the other hand, if hydrogen is produced by means of processes that use fossil fuels as raw materials, it is fossil-derived hydrogen (or low-carbon hydrogen) with CO_2 emissions.
In order to achieve a complete decarbonization of industrial processes, the Commission proposes green hydrogen as an essential energy carrier to support the EU's commitment to reach carbon neutrality by 2050.

The strategy for the development of renewable hydrogen is based on three steps:

- the first phase (2020 - 2024) consists in the installation of electrolyzers of at least 6GW to produce up to 1 million tons of green hydrogen on site and to serve industrial processes and bus refuelling stations. In addition, the CCUS (carbon capture, utilization and storage) infrastructure is implemented to capture CO_2 emitted from existing plants and therefore to reduce CO_2 emissions in the hard-to-abate sectors and to enable the production of low-carbon hydrogen.
- The second phase (2025 - 2030) aims to increase electrolyzers from 6GW to 40 GW for a production of 10 million tons of green hydrogen and to extend the use of hydrogen in the railway and maritime sectors. During this phase, the objective is to design an infrastructure for hydrogen transport and distribution and a network for H_2 filling stations and for heating residential and commercial buildings.
- Finally, in the third phase (2030 - 2050), the goal is to use renewable hydrogen on a large scale.

In order to exploit the benefits obtained from the production and consumption of this gas, shares of hydrogen for specific sectors are planned.

In the transport sector, hydrogen is considered an excellent alternative solution. Currently, hydrogen refuelling stations fueled by local electrolyzers exist for city buses and trains.

Although hydrogen is a key priority in the European Green Deal as means of a breakthrough for decarbonization, today, hydrogen represents only a few percentage of the global and EU energy mix, produced mainly from fossil fuels and with the release of at least 70 million tons of CO_2 per year. The transition to green hydrogen production and the use of renewable resources for power generation is a hard challenge. The main obstacle is often the high cost of dedicated hydrogen production and utilization (fuel cell) equipment, storage and refuelling plants [10][11][12][13][14].

3.3 Maritime sector: emissions control

Despite the fact that the maritime sector's share of greenhouse gas emissions is lower than that of road transport (71%), its environmental impact is still growing. The sector generates around one billion tons of CO_2 each year, set to rise to 1.6 billion tons by 2050 [16][17].

The International Maritime Organization (IMO) has asserted that, if action isn't taken, greenhouse gas emissions from maritime transport could increase by between 50% and 250% by 2050. The goals of the Paris Agreement and efforts in other areas may be compromised, without law enforcement action. Therefore, in order to reduce pollutant emissions at their source, the IMO aims to adopt regulations on maritime safety, navigation efficiency and the prevention and control of marine pollution from ships.

In August 2009 [19], the IMO proposes the first guidelines to assess the energy efficiency of ships:

- The Energy Efficiency Design Index (EEDI) provides caps on emissions from ships under construction by specifying minimum levels of energy efficiency according to vessel type and size. In this way, shipbuilders and designers can adopt solutions that they consider most convenient for the ship to respect the regulations. For existing ships, the regulatory intervention is more complex: a new energy efficiency index is introduced, the Energy Efficiency Existing Ship Index (EEXI), which is based on carbon dioxide emission intensity.
- The Ship Energy Efficiency Management Plan (SEEMP) sets out how ships must emit less carbon dioxide. While the EEDI indicates how much the ship pollutes independently of the operational measures that can be adopted, the SEEMP shows how much less the ship could pollute over the years by using a number of operational measures such as, for example, reducing the speed of navigation.
- The CII (Carbon Intensity Indicator) measures how efficiently a vessel above 5,000 GT transports goods or passengers and is given in grams of CO2 emitted per cargo-carrying capacity and nautical mile. The first reporting of the CII based on 2023 data is due no later than 31 March 2024. Vessels will receive a rating of A (major superior), B (minor superior), C (moderate), D (minor inferior) or E (inferior performance level). The rating thresholds will become increasingly stringent towards 2030. A vessel rated D for three consecutive years or rated as E, will need to develop a plan of corrective actions [37].

In addition, requirements are imposed on the quality of fuel utilized by ships:

- There is a thresold in the maximum amount of sulphur in marine fuels.
- The different maximum emission levels of nitrogen oxides are determined according to the year of construction of the ship and the characteristics of the engine.

Later, in 2014, with the DAFI Directive (Directive on Alternative Fuels Infrastructure), the IMO implemented infrastructure to increase the use of alternative fuels; It is the 'cold

ironing' technology, which is able to electrify quays in ports to supply electricity required by ships through a power line generally connected to the national grid. This technology reduces the pollutant emissions of vessels during docking in port allowing all loading/unloading operations of the ship and the maintenance of all passenger services.
In 2016, with Directive N. 802, the European Parliament imposed the obligation on ships berthed for more than two hours in EU ports to use fuels with a sulphur content of maximum 0.1% or even to switch off their engines, using cold ironing technology [20].
Furthermore, in line with the Paris Agreement of 2015, with regards to the reduction of greenhouse gas emissions, in April 2018, the IMO aimed to reduce the average carbon intensity of the 40% by 2030 and to reduce total CO_2 emissions of 50% by 2050 (compared to 2008 levels).

In 2020, the Commission decided to increase the target for the reduction of greenhouse gas emissions from 40% to 55% (by 2030). In addition, it aimed to establish a price for CO_2 emissions from this sector through the extension of the EU Emissions Trading Scheme (EU ETS). As part of the 'Fit for 55' package, the FuelEU Maritime initiative has been undertaken: it proposes to increase the share of renewable and low-carbon fuels and the use of advanced propulsion technologies in the maritime sector [18].

3.4 Ships design: an overview of the most relevant legislations

Ships mandatory regulations come from national and international regulations. Flag state is the top level on the regulation framework, enforcing the compliance against international conventions and codes signed and, in addition, some in-house regulations.

Some of these in-house regulations are made to adapt international regulations to other kinds of ships that initially are not affected by these regulations. In other cases these regulations provides interpretations and guidelines on how to apply international regulations. In some cases, additional regulations on specific navigation zones or for specific ship types are provided.

Regarding international regulations, there are mainly two regulation sources in Europe:

- European Union
- International Maritime Organization (IMO)

1.1.1 IMO Regulations

As a specialized agency of the United Nations, IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.

The Organization consists of an Assembly, a Council and five main Committees: the Maritime Safety Committee; the Marine Environment Protection Committee; the Legal Committee; the Technical Cooperation Committee and the Facilitation Committee and a number of Sub-Committees support the work of the main technical committees. In addition to international conventions and codes, the IMO produces guidelines, reccomendations and other guidances notes related to the safety aspects of shipping industry.

There is no present nowadays any specific regulations about the use of Hydrogen on board ships. The IMDG Code (International Maritime Dangerous Goods Code) includes the case of transporting hydrogen, but it is forbidden its use onboard for propulsion. Nevertheless, there are some spceific regulations that intruce the possibility of use hidrogen onboard.

The International Convention for the Safety of Life at Sea (***SOLAS Convention***) is considered the most important of all international agreements concerning the safety of ships. The first version was adopted in 1914 in response to the Titanic disaster and has been modified on numerous occasions. The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships for their safety [22].

On 1 January 2017, the IMO revised the SOLAS Convention by adding a series of measures to improve and strengthen safety in maritime traffic and the protection of those working on board ships.

SOLAS does not indicate specific rules for the use of gaseous fuel on board ships, nor does it indicate special protection features in these cases. The International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) has been developed with this objective. However, the particular amendments required by the SOLAS Convention regarding fire protection and evacuation are made by means of alternative analyses as indicated in chapters SOLAS II-1/55 (Fire) and SOLAS III/38 (Evacuation). These alternative analyses must justify a level of safety equivalent to that prescribed by the standards described in SOLAS in those chapters.

IGF code contains mandatory requirements for the arrangement, installation, control and monitoring of machinery, equipment and systems that use low flashpoint fuel in order to minimize the risk to the ship, its crew and the environment.

The IGF Code applies to:

- Passenger ships.
- Cargo ships over 500 gross tonnages.
- Mobile offshore drilling platforms.
- Related port plants.

IGF code was developed when LNG was the main alternative to traditional fuels. For this reason, the code is focused on this type of fuel, where it is a dedicated section (Part A-1) with specific requirements. There is no such consideration for other gases, although it is planned that in the future it will be extended to cover new fuels such as hydrogen.

Hydrogen is a highly flammable, explosive gas and presents different properties and safety performance with respect to other gases, including natural gas. Therefore, in 2021, the Sub-committee on Carriage of Cargoes and Containers approves with CCC document IEC 60079-10 provisional guidelines for the safety of ships that use on-board fuel cell systems for electric propulsion. The aim is to apply 'an alternative design approach', i.e. to demonstrate that hydrogen can only be used on board the ship if it respects the safety levels as provided for NG [21].

Nonetheless, as of today[3] IGF Code application is still mandatory for hydrogen and, as indicated in the code (Part A-4.2), risk analyses must be carried out to justify the design and safety of the system.

On the other hand, for the EU inland navigation, CESNI issues the ES-TRIN regulation to establish the technical requirements necessary to ensure the safety of inland vessels. In particular, this regulation contains provisions concerning the construction, outfitting and equipping of inland navigation vessels and the use of natural gas as fuel.
Another fundamental aspect is the safety of the storage of liquid gas on board ships.

For a broader application of hydrogen and fuel cells, further regulatory and standardization work is needed to close the gaps found within existing European regulations. The definitive regulations and guidelines will only come into force as a new part of the IGF Code in 2028.

Recently, the focus on the devlopment of the safety framework has increased, due to the increasing pressure to decarbonize the maritime sector. This has led to a revision of the IGF Code roadmap / timeline; interim Guidelines for safety of ships using Fuel Cells finalized in 2021; interim Guidelines for safety of ships using H_2 as a fuel initiated; the work on H_2 and ammonia was taking place in parallel.

[3] December 2022

	CCC6	MSC102	CCC7	MSC105	CCC8	MSC106	CCC9	MSC107	CCC10
	SEP20	NOV20	SEP21	APR22	SEP22	NOV22	SEP23	2023	2024
LNG	Revision Exercise				**Finalize Part A-1 amendments**	**Approve Part A-1 amendments**			
Alcohols	Interim Guidelines finalized	**Interim Guidelines Approved** (MSC.1/Circ.1621)	Interim Guidelines under application				Start discussion of mandatory instruments	Draft mandatory req	
Fuel Cells	Drafting		Finalize Interim Guidelines	**Approve Interim Guidelines**	Interim Guidelines under application				Start discussion of mandatory instruments
LPG	Drafting						Finalize LPG Guidelines	**Approve LPG Guidelines**	
Low-flashpoint Oil Fuels	Discussion		Significant discussion around relevance of this work		How to address safety provisions for low-flashpoint oil fuels? DECISION				
Hydrogen			Initiate development of Interim Guidelines	Drafting					
Ammonia			Initiate development of Interim Guidelines	Drafting					

Figure 1 – IGF Code development roadmap, source: EC Commission, 02.2022

1.1.2 Alternative Design

The International Convention for the Safety of Life at Sea (SOLAS) defines the minimum requirements for the construction, equipment, and operation of ships, while Flag States must ensure that these requirements are met. SOLAS Ch.II-1 Part A-1 Regulation 3-1 states that additional requirements are given by the of a Classification Society which is recognized by the Flag State.

Specific prescriptive rules and regulations are not yet in place for the use of hydrogen as a marine fuel, but SOLAS II-I opens the way for a structured design process based on risk assessments in cases where a ship is deviating from prescribed rules. The purpose is to prove that the chosen solution is providing an equivalent safety level to the one required in SOLAS. This process is commonly referred to as the 'Alternative Design' approach.

The legal basis for the alternative analyses (IMO Regulation) is based on the relevant provisions contained in SOLAS [SOLAS II-1/55 (Fire) and SOLAS III/38 (Evacuation)] and IGF code [Part A-1] as explained above. The objective of the alternative design process is to assess innovative designs against their potential to provide equivalent safety levels to existing designs that compy with rules and regulations.

The approval procedure is defined in "Guidelines for the Approval of Alternatives and Equivalents as provided for in various IMO Instruments (MSC.1/Circ. 1455, 2013)".

This guide shows the steps to follow in the process of carrying out and approving the alternative analyzes by the different parties involved.

The development of an alternative design is described by several Guidelines. The MarHySafe project [38] was the first effort to provide a handbook for hydrogen-fuelled vessels, describing the alternative design process for this application. The Handbook provides the basis for outlining a roadmap to hydrogen safety for the maritime industry based on the current risk-based Alternative Design approval framework.

The Guidelines on alternative design and arrangements for fire safety (MSC/Circ.1002, 2001) define how to:

- establish a design team in continuous communication with the Administration,
- determine the safety margin at the outset of the design process and review and adjust it as necessary during the analysis;
- conduct a preliminary analysis to develop the conceptual design in qualitative terms.
    - Scope: ship, ship system(s), space(s) and/or equipment that represent the alternative design.
    - Identify rules and functional requirements and document them in the preliminary analysis report.
    - Development of fire scenarios.
        - Identification of fire hazards (HAZID).
        - Enumeration of fire hazards.
        - Selection of fire hazards.
        - Specification of design fire scenarios
        - Development of trial alternative designs.
    - Development of preliminary analysis report.
- Quantitative Analysis
    - Quantification of the design fire scenarios: calculating the effects of fire detection, alarm and supression methods, generating time lines of the fire until control and evacuation and estimating consequences in terms of heat, flames heights, smoke and toxic gas generation, etc...
    - Development performance criteria.
        - Analyse SOLAS standards to define quantitative criteria (e.g. A-60 class boundary means that the temperature on the other side of the bulkhead cannot rise above xx degrees in xx time).
        - Types of criteria:
            - Damage to persons.
            - Damage to ship or systems.
            - Damage to the environment.
            - Evaluating of trial alternative designs.

- Document and approve.

The Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III (MSC.1/Circ.1212, 2006) are a version of the previous guidance (MSC/Circ.1002, 2001) where the word "fire" is removed so that the procedure is also valid in evacuation.

On the other hand, the IMO Formal Safety Assessment (MSC-MEPC.2/Circ.12/Rev.2, 2018) guideline is intended to outline the FSA methodology as a tool, which may be used in the IMO rule-making process. It is relevant because it puts numbers in order to carry out the previous alternative analyzes and the risk assessment of the IGF code.

The IACS Rec 146 Risk assessment is a reccomendation of the International Association of Classification Societies (IACS) to set guidelines to perform the risk assesstment required by IGF Code.
This risk assessment is required for the use of hydrogen on board ships. It must eliminate or mitigate any adverse effects to people, the environment or the ship.

It should cover:

- Equipment installed on board to receive, store, condition as necessary and transfer fuel to one or more engines, boilers or other fuel consumers.
- Equipment to control the operation (pressure gauges, temperature regulators, flow meters, signal processors and control panels).
- Equipment to detect, alarm and initiate safety actions.
- Equipment to vent, contain or handle operations outside of that intended (i.e. outside of process norms).
- Fire-fighting appliance and arrregements to protect surfaces from frie, fuel contact and escalation of fire.
- Equipment to purge and inert fuel lines.
- Structures and constructions to house equipment.

Bunkering operations is not covered (it is addressed by ISO/TS 18683 " Guidelines for safety and risk assessment of LNG fuel bunkering operations").

The IGF Code does not require a quantitative analysis to assess the risk for people, ship or environment. A qualitative or semi-quantiative analysis is suitable, although this does not mean that a quantitative approach is unsuitable.

- Risk Assessment Approach
  - Hazard identification
    - Divide the fuel system into discrete parts with respects to equipment function and location.

    - Develop a set of guidewords/phrases and example causes that could result in unwanted events.
    - By reference to design and arrangement information, location plans, process flow diagrams, mitigation measures and planned emergency actions use the prompts to identify potential causes of unwanted events (e.g. fuel releases and loss of power).
    - Record the potential causes of unwanted events and mitigation measures.
  - Consequence analysis
    - For each identified cause, estimate the potential consequences in terms of, for example, major injuries, single and multiple fatalities, adverse environmental impact and damage sufficient to compromise safe operations.
    - Categorise the consequence estimates according to Annex 4. The consequence can be categorised by an expert(s).
  - Likelihood analysis
    - Estimate the annual likelihood of occurrence of 'cause and consequence'
    - Categorise the likelihood estimates according to Annex 4. The frequency can be categorised by an expert(s).
  - Risk analysis
    - Estimate the risk. Risk can be estimated by the SMEs (or a suitably qualified individual) by combining the consequence and likelihood categories to provide a risk rating.
  - Risk assessment
    - Judge if the risk has been 'mitigated as necessary'. The estimated risk can be compared against risk criteria embedded within a risk matrix. This concept is similar to ALARP, it must be justified that any additional or alternative mitigation could not be implemented due to a disproportionate cost/risk reduction ratio.

The team conducting the risk assessment should include subject matter experts (SMEs), who are, collectively, suitably qualified and experienced. The number of SMEs is expected to be four to eight and they have experience in naval engineering.

In addition to the SMEs, the team should be led by a facilitator. The facilitator should be impartial with no vested interests in the fuel system, and experienced in leading such risk assessments.

The risk assessment reporting should provide:

- An overview of the design and arrangement.
- An explanation of the risk assessment process.
  - System/subsystem division.
  - Hazard identification process.

  - Risk assessment criteria.
- Information on the relevant qualifications and expertise of the team.
- The time taken to complete the assessment and whether SMEs were present to provide their expert input.
- Risk results and conclusions.
- Recommendations and actions.

1.1.3 What's next

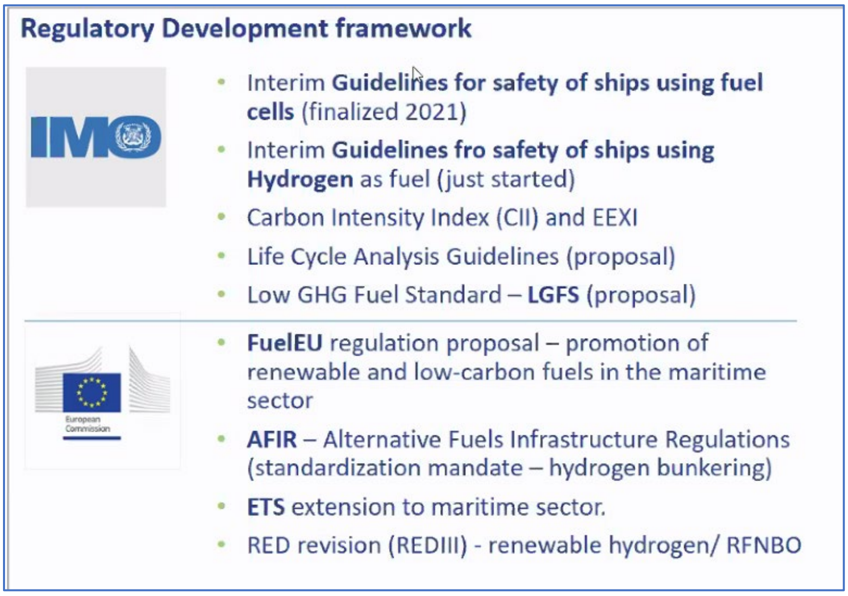


Figure 2 – Regulatory framework: a sum-up, source: EC Commission, 02.2022

The main point is that currently there is no EU legislation that deals with the use of renewable fuels and the application of fuel cells in maritime transport but only proposals waiting to be implemented.

In particular, there exist a draft document on fuel cell installation onboard (2021). This draft, applicable to the installation of fuel cells on ships, is under development with an approval date that was expected by mid-2022 (MSC. 105th session). Sources close to the IMO indicate that it will be goal-based rather than prescriptive, so it will not replace alternative analyses [15].

4. Standards: state of the art

This section contains the results of a mapping of the main standards and technical committees relevant within e-SHyIPS project. In order to let the reader understand the terminology and the content of this mapping, we firstly brief key concepts related to the standardization world[4].

The final aim of this research activity is to understand what is ongoing and eventually what is missing in the standardization world. This in order to actually implement a hydrogen economy in the maritime sector.

4.1 The standardization world

Standardisation has a well-acknowledged role as enabler of (1) a better quality of life, taking into account the protection of the environment for future generations, (2) a more effective and efficient technical-economic system, (3) a more harmonized international trade, (4) a simpler communication based on unified terminology, symbols and codes, (5) a more credible protection of the consumers' needs and interests and (6) health and safety not only in the workplace but also in the use of products, machinery and equipment in private life.

In the last century, standards have more and more covered different aspects of the social and economic life, taking into account the most compelling needs of our societies. In particular, the standardization has undertaken a journey towards the Sustainable Development Goals (SDGs), adopted by the United Nations in 2015. This led to the publication of new standardization deliverables addressing professions, management of the organization, environment, corporate social responsibility, sustainability and, most recently, circular economy, just to make some examples.

Standardization bodies

If we adopt the point of view of European countries, we can divide the Standardization Bodies into three main groups: International Standardization Bodies (ISBs), European Standardization Bodies (ESBs) and National Standardization Bodies (NSBs).

Among the ISBs there are ISO, ITU and IEC. IEC publishes standards within the electronics domain, ITU within the telecommunications sector, and ISO within all the other sectors.

Amidst the ESBs, CENELEC addresses standards in electronics, ETSI publishes standards in telecommunications and CEN covers all the other sectors.

Lastly, the NSBs are many, usually more than one per single country, and normally address macro-topics split in a way that reflects the aforementioned divisions of competences both at European and International level.

The most important aspect is that NSBs have the possibility of participating, within the sector of their competence, both at European and international level, thus having

[4] The content of this introduction on the standardization world is retrieved mainly from a H2020 project deliverable, which was realized by UNI [24].

their own delegations present and voting at technical meetings and providing official comments/positions on the documents under development.

Standardization deliverables

Nowadays the main standardization deliverables can be summarized as follows:

- **Technical Standards:** they are the most significant standardization deliverable, and have a prescriptive nature; they are based on a very well established and consolidated state of the art and are reviewed/withdrawn/confirmed every 5 years.
- **Technical Specification**: they are prescriptive and have a periodic review but are representing a state of the art in progress or not yet consolidated.
- **Technical Report**: they have only informative purposes, they are preparatory for future prescriptive standardization activities and undergo periodic review like all previously mentioned documents.
- "**Light" Standards**: (to make an example, CWA – CEN Workshop Agreement), they are a pre-standard with restricted consensus base; are preparatory for future standardization activities and have a shorter review period.

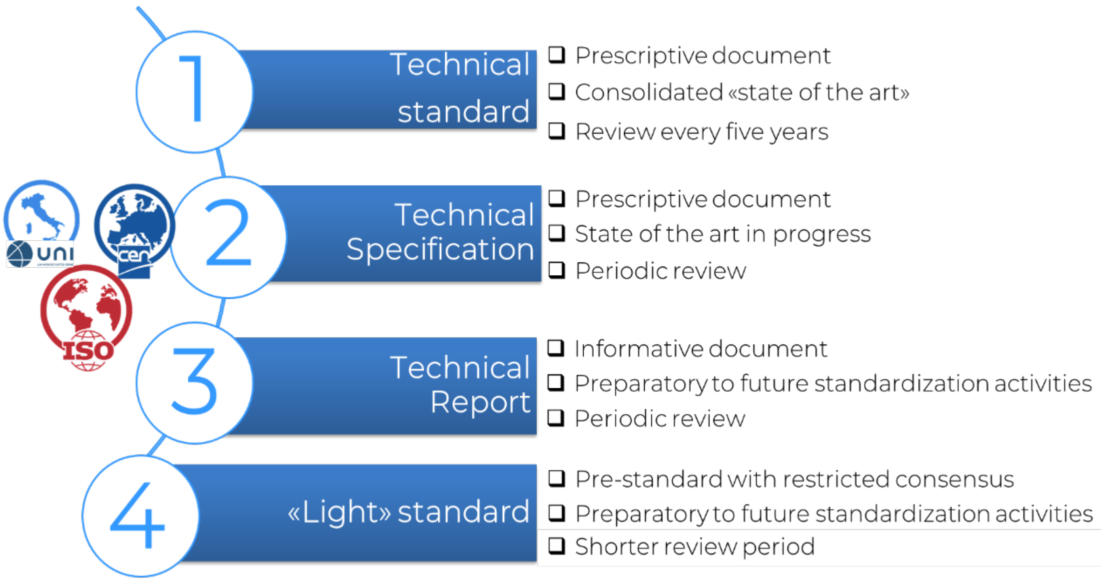


Figure 3 - Standardization deliverables, source: UNI, CEN

A common mistake made by those who do not know the ropes of standardization is to think that a property scheme is a sort of standard.

Standards are characterized by an open and transparent process with public enquiries, a way broader consensus-based approach, a specific legal basis applicable (especially at national and European level), the mitigation of third parties' interests via a multi-stakeholder participative platform and the possibility to be cited in legislative/binding documents.

Property schemes are drafted, published and owned by companies, association or other interest-driven entities, they are the expression of a narrow consensus base, they cannot be cited in legislative/binding documents since they have no legal basis institutionally acknowledged and have no check and balance mechanisms of a single party-based interest in the work.

Standards and Legislation

So far, we have described standardization deliverables as voluntary documents applied on the free choice of the user.

Nonetheless, standardization deliverables, born as non-binding, **can become binding** if cited in national legislations or other national cogent documents. This is the **referral mechanism**. A referral could be *fixed* (or *material*) when the piece of legislation defines that a given standard satisfies the applicable requirement(s) thus becoming an integral part of the mandatory legal requirement (in the IGF Code there are multiple examples). It could also be *mobile* (or *immaterial*) when the piece of legislation requires that a product meets conditions such as "state of the art" or "essential requirements", citing the standard as a possible means to meet these general requirements.

In the first case, the Legislator is declaring the standard(s) *necessary* and the requirement contained in the standard(s) becomes mandatory. In the second case, the Legislator is declaring the standard(s) *sufficient*, which means that they are not the only means of meeting the mandatory requirement.

There is then the **Harmonized Standards Mechanism** under the EU so-called *New Approach*. Harmonized standards are those European standards whose references have been published in the Official Journal of the European Communities with respect to a particular Directive. They can be used to derive a presumption of conformity with the essential requirements of that Directive (ATEX Directive is an example). National authorities are obliged to recognize that **products manufactured in conformity with Harmonized Standards are presumed to conform to the Essential Requirements established by the Directive**. This means that producers have the choice of not manufacturing in conformity with the Harmonized Standards but that in this case they have an obligation to prove that the products conform to the Essential Requirements of the Directive.

Standardization Conformity Assessment (Certification) and Accreditation

Lastly, let us focus on a key aspect related to Standardization: the **Conformity Assessment (or Certification)**. CA refers to any activity that determines whether a product, system, service and sometimes even professionals fulfil the requirements and characteristics described in a standard or other standardization deliverables. Such requirements can include, but are not limited to, efficiency, effectiveness, performance, safety, durability, reliability, environmental impacts such as pollution or noise, knowledge, skills and competences (for people), etc. With the third-party conformity assessment, the application of standards increases the transparency and credibility of organizations and encourages common best practices that can become the "state of the art" of tomorrow, increasing the level of sustainability and circularity.

Verification is generally done through testing or/and inspection. This may or may not include on-going verification. The concrete realization of CA processes is under the responsibility of a Conformity Assessment Body (CAB). Conformity Assessment is overseen and accredited by the Accreditation Bodies operating at national/European/international level.

Accreditation is the declaration by an unbiased body of the competence, independence and impartiality of certification, inspection and verification bodies, and testing and calibration laboratories. The accreditation of CABs gives to certificates of conformity and of calibration, to test and inspection reports issued on the market, a high level of reliability in terms of the quality and safety of verified goods and services and it ensures recognition in the international market place. Accreditation is carried out in compliance with the international standard ISO/IEC 17011. In the EU, Regulation EC 765/2008 requires every member state to nominate a national Accreditation Body and it has granted, for the first time, a legal status to this activity, recognizing it as an expression of public authority.

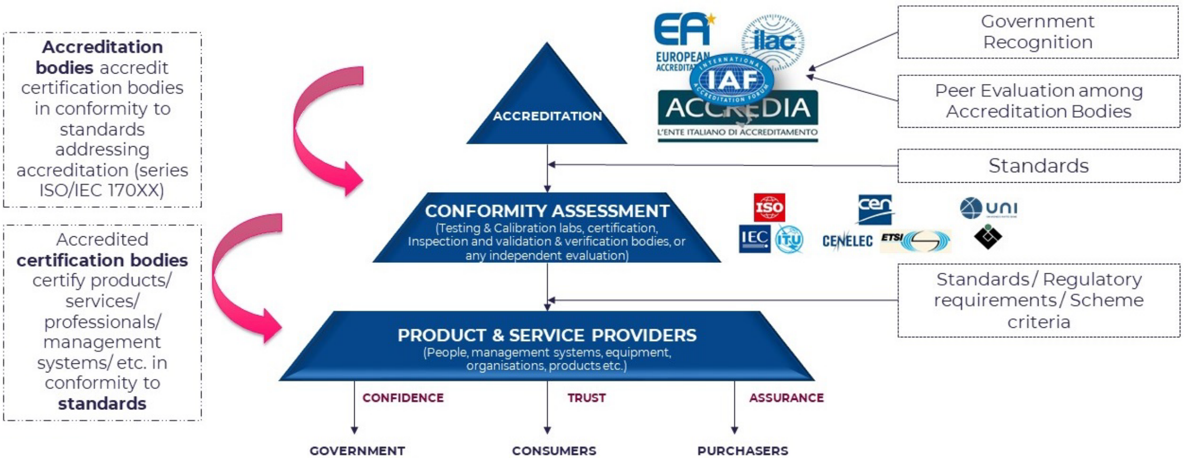


Figure 4 - Standardization, Certification and Accreditation, source: UNI

Safety and standards

Occupational Health and Safety (OH&S) plays an important role in European legislation and is closely linked with standardization in Technical Committees, which develop product standards with OH&S aspects in support of EU directives for products like industrial and domestic machinery, pressure equipment, simple pressure vessels, measuring instruments, sustainable use of pesticides and personal protective equipment.

Equipment and protective systems intended for use in potentially explosive atmospheres (ATEX), covering a range of products, including those used on fixed offshore platforms, petrochemical plants, mines, and flour mills, are regulated by a specific EU Directive, are covered by a wide range of CEN and CENELEC standards.

OH&S is also addressed in risk-oriented standards, for example in the fields of noise, vibration, ergonomics or hazardous substances, and is a horizontal issue in emerging standardization fields such as services, qualification and management systems.

Environment and standards

Since the environment has become part of the priority objectives of governments, there has been a great development of voluntary tools to support all stakeholders in achieving these targets.

Speaking a common language on environmental issues is necessary for the development and implementation of universal policies across Europe. While EU Regulations define general requirements for environmental protection, voluntary Standards specify the technical details, generally accepted, that allow industry and other interested parties to meet these requirements. This co-regulatory approach between legislation and technical standardization, already exemplified by the European New Approach, relieves the regulatory authority and takes advantage of the experience of thousands of experts across Europe who draft the standards according to the updated state of the art of products, processes and systems. The transformation of scientific knowledge into voluntary standards therefore helps to address the challenges of ecological transition and climate change.

Voluntary standards support organizations in satisfying mandatory legislative requirements and maximizing the effectiveness of their actions aimed at reducing environmental impacts. For example, the series EN ISO 14000 provides practical tools for organizations wishing to manage their environmental responsibilities and is recalled in legislation to fulfil environmental requirements. These standards have proven to have a far-reaching impact around the world over the years.

4.2 E-SHyIPS scenarios: a recap

The standards and technical committees mapping has been carried out in coherence with the project scenarios. Below, it is presented an overview of these scenarios to let the reader understand the mapping results.

Based on the scope of e-SHyIPS project, three functional concept scenarios have been built: Deliverable 1.1 [25] includes the three functional concept scenarios developed during the first stage of the project, and then discussed and validated also by the Advisory Board experts, to foster the work and research panned for the project and enable practical experiments to be planned.

More into detail, the scenarios definition has been set according to the growing market demand for each vessel size. The three chosen reference ships are as different as possible in terms of purpose, dimensions, and passengers' capacity. Moreover, to be able to efficiently compare the different features of each vessel scenario, they have been identified according to four criteria: i) **operational profile and vessel typology**; ii) **potential hydrogen technology and systems**; iii) **bunkering strategy**, and iv) **safety engineering strategy**.

Each partner's field of study has set the basis of the involvement in the data gathering activity for each criterion. In relation to the methodology adopted to build the three scenarios, analysis of the market insights, case studies, and literature review were performed, dividing the results into different categories of interest, which then become the main scenarios "theme": **small vessels**, with inland routes; **medium vessels**, with maritime coastal routing with freight and cars on-board; **large vessels**, with more extended routing and wider services offered to the passengers.

Figure 5 – e-SHyIPS scenarios, source: POLIMI

All three categories were deeply analyzed to understand both challenges and potentialities for future on-board hydrogen-based system adoption.

More into details, the Small scenario refers to inland waterways' vessels also know under the name of "water-bus", a widespread means of transport in all the geographical areas, such as norther Europe, where due to the morphology of the territory people and goods are daily moved along canals. The maximum length of this kind of vessel is supposed to be around 30 meters, and the reference ship studied within the project is the waterbus 2407, built from DAMEN shipyard, and currently under operation for many shipping companies.

The Medium scenario is represented by roll-on/roll-off vessels used for freight and passenger transport. This category of vessel refers to the ones typically used by tourists to move among islands with or without cars and also by locals to supply goods to the islands' inhabitants during the year using trucks. The maximum length of this kind of vessel is supposed to be around 100 meters, and the reference ship studied with the project is the Fior di Levante ferry, currently part of the Levante Ferries fleet.

The Large scenario refers to luxury cruise ship: this market share is indeed estimated [26] to grow significantly in 2021-2029, especially in Europe. In terms of shape, dimensions and passengers' capacity, these vessels can be considered as mega-yacht rather than conventional cruise ships. Luxury cruise is designed to meet the needs of a limited number of passengers, which require a high level of comfort and services. The maximum length of this kind of vessel is supposed to be around 150 meters, and the reference ship studied within the project is the Flora Cruise, which is part of the fleet of Celebrity X Cruise company.

Based on the presented scenarios, functional and technical requirements [27] have subsequently been structured to develop and prepare useful requirements that will lead to delivery guidelines and specifications during next tasks of the project.

4.3 Technical committees mapping

The final aim of e-SHyIPS project is to define new guidelines for an effective introduction of hydrogen in maritime passenger transport sector. This includes considerations on what's missing in standards to define and clarify the technical requirements for a safe and effective application of H_2 in the maritime sector.

Considering that H_2 applications in the maritime sector had still not reached a level of maturity such that specific standards have already been defined, e-SHyIPS partners performed a standardization landscape scan of existing hydrogen standards in non-maritime applications. This as an input to identify initial standardization gaps which will be addressed during the last two years of the project (2023 and 2024).

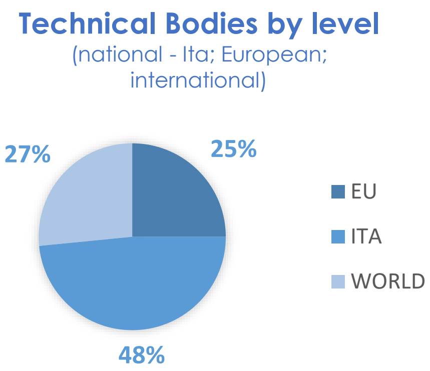
Results

In order to have a complete framework, UNI started mapping the technical committees which possibly are in charge to develop standards relevant within e-SHyIPS vision. This mapping is not a pure research activity for its own sake, but is needed to understand with are the relevant stakeholders we should interact with and in supporting future standardization developments.

UNI has considered the scenarios defined in the project, analyzing the four criteria used to define them, so to spot key topics. These topics have been used to spot keywords and consequently identify the national (Italian), European and International technical committees developing standards on those themes.

More than 20 years of expertise in standards development of the UNI technical project manager carrying out most of the work, let to identify all possible themes linked to e-SHyIPS scenarios: from vessels design, to bunkering, from explosion prevention, to materials, components and valves.

The result is a mapping of 128 technical bodies (TBs). For each TB it has been indicated whether it's a national, European or International body, the link to retrieve more details, the criteria of the scenario it may be matched with. Below, the figures illustrate some statistics, while the table includes the complete list of the TBs mapped.



	N° of Technical Bodies by scenarios' criteria
OPERATIONAL PROFILE AND VESSEL TYPOLOGY	15
H2 TECHNOLOGY AND SYSTEMS	21
PORT AND BUNKERING	68
SAFETY ENGINEERING STRATEGY	77
ENVIRONMENT	3

Figure 6 – Technical Bodies mapping: statistics, source: UNI

Table 2 - Technical Bodies mapping: results, source: UNI

TECHNICAL BODY	LEVEL	SCENARIO BLOCK
UNI/CT 004 Environment	ITA	ENVIRONMENT
UNI/CT 004/GL 16 Environmental impact assessment	ITA	ENVIRONMENT
UNI/CT 011 Fire behaviour	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 92 Fire safety	WORLD	SAFETY ENGINEERING STRATEGY
UNI/CT 011/GL 01 Reaction to fire	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 92/SC 1 Fire initiation and growth	WORLD	SAFETY ENGINEERING STRATEGY
UNI/CT 011/GL 02 Fire resistance	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 92/SC 2 Fire containment	WORLD	SAFETY ENGINEERING STRATEGY
UNI/CT 011/GL 07 Fire safety engineering	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 92/SC 4 Fire safety engineering	WORLD	SAFETY ENGINEERING STRATEGY
CEN/TC 127 WG 8 Fire Safety Engineering	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 056 Hydrogen	ITA	H2 TECHNOLOGY AND SYSTEMS
CEN/CLC/JTC 6 Hydrogen in energy systems	EU	H2 TECHNOLOGY AND SYSTEMS
ISO/TC 197 Hydrogen technologies	WORLD	H2 TECHNOLOGY AND SYSTEMS
UNI/CT 025 Maintenance	ITA	PORT AND BUNKERING
CEN/TC 319 Maintenance	EU	PORT AND BUNKERING
CEN/TC 348 Facility Management	EU	PORT AND BUNKERING
ISO/TC 267 Facility management	WORLD	PORT AND BUNKERING
UNI/CT 025/SC 04 Maintenance in the transport sector	ITA	PORT AND BUNKERING

UNI/CT 026 Non-ferrous metals	ITA	PORT AND BUNKERING
UNI/CT 055 Metrology of flow, pressure, temperature	ITA	H2 TECHNOLOGY AND SYSTEMS SAFETY ENGINEERING STRATEGY
UNI/CT 055/GL 01 Flow	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
ISO/TC 30 Measurement of fluid flow in closed conduits	WORLD	H2 TECHNOLOGY AND SYSTEMS SAFETY ENGINEERING STRATEGY
UNI/CT 055/GL 03 Pressure and temperature	ITA	H2 TECHNOLOGY AND SYSTEMS SAFETY ENGINEERING STRATEGY
CEN/TC 423 Means of measuring and/or recording temperature in the cold chain	EU	H2 TECHNOLOGY AND SYSTEMS SAFETY ENGINEERING STRATEGY
UNI/CT 030 Ships, crafts and marine technology	ITA	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 8 Ships and marine technology	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
CEN/TC 15 Inland navigation vessels	EU	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 030/SC 01 Naval installations, safety and fire protection and rescue equipment	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 8/SC 1 Maritime safety	WORLD	SAFETY ENGINEERING STRATEGY
ISO/TC 8/SC 4 Outfitting and deck machinery	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 8/SC 3 Piping and machinery	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 8/SC 2 Marine environment protection	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY ENVIRONMENT
UNI/CT 030/SC 04 Small crafts	ITA	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
CEN/SS T01 Shipbuilding and maritime structures	EU	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 030/SC 05 Recreational craft	ITA	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 8/SC 12 Ships and marine technology - Large yachts	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 188 Small craft	WORLD	OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 034 Fire fighting	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 21 Equipment for fire protection and fire fighting	WORLD	SAFETY ENGINEERING STRATEGY
CEN/TC 191 Fixed firefighting systems	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 034/GL 06 Firefighting and rescue equipments	ITA	SAFETY ENGINEERING STRATEGY
CEN/TC 192 Fire and Rescue Service Equipment	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 034/GL 04 Automatic fire detection systems	ITA	SAFETY ENGINEERING STRATEGY
CEN/TC 72 Fire detection and fire alarm systems	EU	SAFETY ENGINEERING STRATEGY
ISO/TC 21/SC 3 Fire detection and alarm systems	WORLD	SAFETY ENGINEERING STRATEGY
UNI/CT 034/GL 09 Smoke and heat control systems	ITA	SAFETY ENGINEERING STRATEGY
UNI/CT 037 Fixed and transportable vessels for compressed, dissolved or liquefied gases	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 23 Transportable gas cylinders	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 58 Gas cylinders	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 037/GL 01 Cryogenic vessels	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 220 Cryogenic vessels	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING

CEN/TC 268 Cryogenic vessels	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 037/GL 03 Tanks for the transport of the compressed, dissolved or liquefied gas (joint working group with CUNA)	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 296 Tanks for the transport of dangerous goods	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 037/GL 05 Vessels for the transport of gas (Excluding LPG and cryogenic) - Designe	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 58/SC 3 Cylinder design	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 037/GL 06 Vessels for the transport of gas (Excluding LPG and cryogenic) - Accessories	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 58/SC 2 Cylinder fittings	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 037/GL 07 Vessels for the transport of gas (Excluding LPG and cryogenic) - Operational requirements	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 58/SC 4 Operational requirements for gas cylinders	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 039 Welding	ITA	PORT AND BUNKERING
ISO/TC 44 Welding and allied processes	WORLD	PORT AND BUNKERING
IIW International Institute of Welding	WORLD	PORT AND BUNKERING
CEN/TC 121 Welding and allied processes	EU	PORT AND BUNKERING
UNI/CT 042 Safety	ITA	SAFETY ENGINEERING STRATEGY
UNI/CT 042/GL 50 Potentially explosive atmospheres	ITA	SAFETY ENGINEERING STRATEGY
CEN/TC 305 Potentially explosive atmospheres - Explosion prevention and protection	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 053 Industrial valves	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 100 CIG	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 101 CIG - Gas quality	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 193 Natural gas	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/SS N21 Gaseous fuels and combustible gas	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 234/WG 11 Gas Quality	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 193/SC 1 Analysis of natural gas	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 158 Analysis of gases	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 238 Test gases, test pressures, appliance categories and gas appliance types	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 102 CIG - Measuring Transmission	ITA	SAFETY ENGINEERING STRATEGY
CEN/TC 234/WG 5 Gas measuring	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 105 CIG - Distribution	ITA	SAFETY ENGINEERING STRATEGY
CEN/TC 234 Gas infrastructure	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/SS B25 Building and construction - Gas distribution installation and related equipment	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 113 CIG - Natural gas transportation system	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 234/WG 7 Gas compression	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING

CEN/TC 234/WG 8 Industrial piping	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 234/WG 3 Gas Transportation	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 114 CIG - Plant components and equipment	ITA	SAFETY ENGINEERING STRATEGY
ISO/TC 161 Controls and protective devices for gas and/or oil	WORLD	SAFETY ENGINEERING STRATEGY
CEN/TC 235 Gas pressure regulators and associated safety devices for use in gas transmission and distribution	EU	SAFETY ENGINEERING STRATEGY
CEN/TC 58 Safety and control devices for burners and appliances burning gaseous or liquid fuels	EU	SAFETY ENGINEERING STRATEGY
UNI/CT 116 CIG - Metering Distribution	ITA	PORT AND BUNKERING
CEN/TC 237 Gas meters	EU	PORT AND BUNKERING
UNI/CT 121 CIG - Natural Gas Storage in transmission systems	ITA	PORT AND BUNKERING
UNI/CT 122 CIG - Gas veichles refuelling	ITA	PORT AND BUNKERING
UNI/CT 200 CTI	ITA	PORT AND BUNKERING
UNI/CT 215 CTI - Energy audits in transport - National activity	ITA	PORT AND BUNKERING
UNI/CT 222 CTI - Structural integrity of pressure systems and equipment	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 223 CTI - Operation and safety devices of pressure systems and equipment	ITA	SAFETY ENGINEERING STRATEGY
UNI/CT 234 CTI - Engines - Joint Committee CTI-CUNA	ITA	PORT AND BUNKERING
CEN/TC 270 Internal combustion engines	EU	SAFETY ENGINEERING STRATEGY OPERATIONAL PROFILE AND VESSEL TYPOLOGY
ISO/TC 70 Internal combustion engines	WORLD	SAFETY ENGINEERING STRATEGY OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 266 CTI - Safety in major-accident hazard establishments	ITA	SAFETY ENGINEERING STRATEGY
UNI/CT 286 CTI - Hydrogen	ITA	H2 TECHNOLOGY AND SYSTEMS
ISO/TC 197 Hydrogen technologies	WORLD	SAFETY ENGINEERING STRATEGY
UNI/CT 286/GL 01 CTI - Tanks for hydrogen in land vehicles	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 286/GL 02 CTI - Hydrogen from water electrolysis and from fuels	ITA	H2 TECHNOLOGY AND SYSTEMS
UNI/CT 286/GL 03 CTI - Components for the transport of hydrogen gas - metal hydrides	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 286/GL 04 CTI - Refuelling stations with hydrogen gas and hydrogen mixtures	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 286/GL 05 CTI - Specifications for hydrogen as fuel	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 300 CUNA - Technical Commission for Vehicle Standardisation	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 310 CUNA - Automotive Engines	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
UNI/CT 310/GL 05 Gaseous fuel engines and related systems and services	ITA	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING
ISO/TC 22/SC 41/JWG 5 Joint ISO/TC 22/SC 41 - ISO/TC 197 WG: Fuel system components and refuelling connector for vehicles propelled by blends of natural gas and hydrogen	WORLD	H2 TECHNOLOGY AND SYSTEMS PORT AND BUNKERING

UNI/CT 319 CUNA - Hybrid, Fuel Cell and Electric Propelled Vehicles	ITA	H2 TECHNOLOGY AND SYSTEMS OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 319/GL 01 Hydrogen-powered vehicles	ITA	H2 TECHNOLOGY AND SYSTEMS OPERATIONAL PROFILE AND VESSEL TYPOLOGY
UNI/CT 700 UNSIDER - Italian Body for the Standardisation of the Iron and Steel Industry	ITA	PORT AND BUNKERING
UNI/CT 700/SC 27 Steels for pressure purposes	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 459/SC 7 Steels for pressure purposes	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 17/SC 10 Steel for pressure purposes	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 700/SC 30/GL 01 Pipes for pressure purposes	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ECISS/TC 110/WG 1 Tubes for pressure purposes	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 17/SC 19 Technical delivery conditions for steel tubes for pressure purposes	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
UNI/CT 700/SC 30/GL 15 Industrial pipes	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
CEN/TC 267 Industrial piping and pipelines	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
IEC/TC 105 Fuel cell technologies	WORLD	H2 TECHNOLOGY AND SYSTEMS
UNI/CT 700/SC 34/GL 01 Pipes and fittings for pipelines and transport of oil and gas	ITA	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ECISS/TC 110/WG 2 Line pipe	EU	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING
ISO/TC 67/SC 2 Pipeline transportation systems	WORLD	SAFETY ENGINEERING STRATEGY PORT AND BUNKERING

Among these 128 technical bodies, UNI has identified 4 technical committees (at European and International level) which are the key standardization stakeholders the e-SHyIPS should interact with.

e-SHyIPS is already in touch with three of them, CEN JTC 6, CEN TC 305 and ISO TC 197 (while CEN JTC 6 and CEN TC 305 have also agreed to enter the project Advisory Board). For the remaining technical committee, IEC TC 105, there is a planning within the consortium to reach them out throughout the 2023.

Below, a focus for each TC to deepen their relevance for e-SHyIPS project and the development of new standards for H_2 applications in the maritime sector.

1.1.4 Focus A) ISO/TC 197 "Hydrogen technologies"

This international technical committee (TC) was created in 1990 and its scope covers the standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen.

As of December 2022, the TC has a structure that do not take into account sectors different from the automotive one, but discussions are ongoing to keep the pace with the development of H_2 technologies applications also to other sector (e.g. maritime and aviation) [30].

The table below illustrates the structure of the technical committee.

Table 3 – ISO TC 197 structure, source: ISO

Reference	Title
SC 1	Hydrogen at scale and horizontal energy systems
AHG 1	Permanent editing committee
JWG 30	Joint ISO/TC 197 - ISO/TC 22/SC 41 WG: Gaseous hydrogen land vehicle fuel system components
TAB 1	Technical Advisory Board
WG 5	Gaseous hydrogen land vehicle refueling connection devices
WG 15	Cylinders and tubes for stationary storage
WG 18	Gaseous hydrogen land vehicle fuel tanks and TPRDs
WG 19	Gaseous hydrogen fueling station dispensers
WG 21	Gaseous hydrogen fueling station compressors
WG 22	Gaseous hydrogen fueling station hoses
WG 23	Gaseous hydrogen fueling station fittings
WG 24	Gaseous hydrogen – Fuelling protocols for hydrogen-fueled vehicles
WG 27	Hydrogen fuel quality
WG 28	Hydrogen quality control
WG 29	Basic considerations for the safety of hydrogen systems
WG 31	O-rings
WG 32	Hydrogen generators using water electrolysis
WG 33	Sampling for fuel quality analysis
WG 34	Hydrogen generators using water electrolysis test protocols and safety requirements

The TC counts 30 participating members (in blue in the figure below) and 14 observing members (in orange in the figure below).

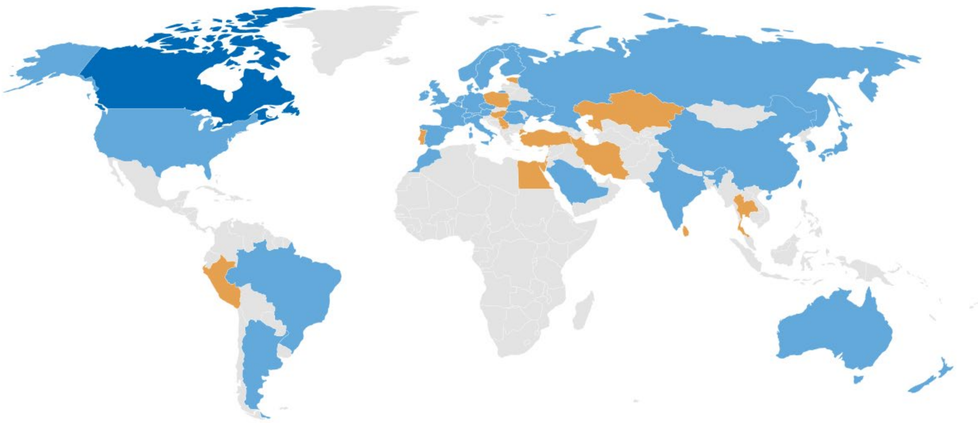


Figure 7 – ISO TC 197 Members, source: ISO

As of December 21st, 2022, the TC has published (including updates) 18 ISO standards; while 21 (including updates) are under development.

Considering the relevance of this TC, on December 2022, during its plenary meeting, UNI shared a presentation of E-SHyIPS project to inform them about the ongoing activities, with a focus on the IGF Code review (see section 5).

1.1.5 Focus B) CEN/CLC/JTC 6"Hydrogen in energy systems"[5]

CEN CENELEC Joint Technical Committee 6 "Hydrogen in energy systems" has been created in 2016 in order to prepare standards in the field of systems, devices and connections for the production, storage, transport and distribution, measurement and use of hydrogen from renewable energy sources and other sources, in the context of the European strategy for the development and acceptance of the hydrogen market.

The scope of JTC 6 includes cross cutting items such as: terminology, Guarantee of Origin, interfaces, operational management, relevant hydrogen safety issues, training and education [29].

In the business plan of the JTC, the identified and prioritized standardisation needs were:

- Terms and definitions for the field of work;
- Guarantee of Origin for hydrogen produced from renewable and/or low carbon primary energy;
- Cross-cutting items (non-technical):
  - Societal acceptance;
  - Legal aspect;
  - Training and education
- Cross-cutting items (technical);
  - Certification;
  - Competence of personnel.
  - Safety related standards. The safety aspects regard general safety, leakage, explosion, gas detection, materials compatibility, global safety issues for hydrogen and systems, etc. safety aspects related to hydrogen and the pure hydrogen related aspects for the mixture of hydrogen with natural gas (the liaison with CEN/TC 234 is of importance).
  - Technical issues such as monitoring, testing and metering,
- Specification of new electrolyser key performance indicators (KPIs) related with new operating conditions related to the coupling with renewable energy sources;
- The actions at the interfaces with the related connected grids (electricity, natural gas and hydrogen infrastructure), Liaisons with, amongst others, CEN/TC 234, CEN-

[5] Data as of November, 2nd 2022

CENELECETSI Smart Meters Coordination Group (SM-CG) and CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG), is of importance in this field;
- multigrid interaction related issues (electricity-gas-heating and cooling);
- aspects related to the use of hydrogen for applications;
- The adoption of relevant ISO and IEC standards as European standards. The TC will discuss and decide for what Standards under ISO/TC 197 or IEC/TC 105 and falling under the scope of the CEN-CENELEC/TC 6 this applies (this excludes the standards related to the Standardisation Request M/533).

It is excluded: storage and transport of liquid hydrogen (which is covered in the scope of CEN/TC 268 "Cryogenic vessels and specific hydrogen technologies applications"); storage and transport of compressed hydrogen (which is covered in the scope of CEN/TC 23 "Transportable gas cylinders"); vehicle refueling stations and associated equipment and procedures as related to the standardization Request M/533; the injection of hydrogen and the mixture of hydrogen with natural gas (H_2NG) in the gas infrastructure (which is covered in the scope of CEN/TC 234 "Gas infrastructure"); the use of mixtures of natural gas with hydrogen (H_2NG) [28].

The table below illustrated the structure of the JTC.

Table 4 – CEN CENELEC JTC 6 structure, source: CEN

Reference	**Title**
WG 1	Terms and definitions
WG 2	Guarantees of Origins
WG 3	Hydrogen safety

The Secretariat of the JTC 6 is led by the NEN (Royal Netherlands Standardization Institute) and counts the following liaison and partner organizations: AIB, ECOS, ENTSOG, FARECOGAZ, GERG, Hydrogen Europe, Hydrogen TCP.

The following table show the current work program of the JTC 6.

Table 5 – CEN CENELEC JTC 6 work program, source: CEN

Project	**Title**	**Status**	**Forecasted voting date**
prEN ISO 24078 (WI=JT006001)	Hydrogen in energy systems - vocabulary	Under Drafting	2023-07-26
(WI=JT006002)	Safe use of hydrogen in built constructions	Under Drafting	

1.1.6 Focus C) CEN/TC 305 "Potentially explosive atmospheres - Explosion prevention and protection"

In Europe, equipment and protective systems intended for use in potentially explosive atmospheres (ATEX) are regulated by the ATEX Directive (2014/34/EU).

There are two main CEN and CENELEC Technical Committees developing standards in support of the ATEX Directive, i.e. CEN/TC 305 'Potentially explosive atmospheres - Explosion prevention and protection' and CLC/TC 31 'Electrical apparatus for potentially explosive atmospheres'.

Standards developed for meeting the ATEX Directive requirements, are harmonized standards, cited in the Official Journal of the European Union [31][33].

CEN/TC 305 was established in 1993, with the purpose to elaborate standards on explosion prevention and protection for any application in explosive atmospheres with the exception of explosions expected from explosives or unstable substances.

As of December 2022, the scope of this TC covers:

- test methods for determining the flammability characteristics (ignition, propagation, explosion effects, etc.) of substances;
- equipment and protective systems for use in potentially explosive atmospheres and equipment and systems for explosion prevention and protection [32].

The table below illustrated the structure of the TC 305.

Table 6 – CEN TC 305 structure, source: CEN

Reference	**Title**
WG 1	Test methods for determining the flammability characteristics of substances
WG 2	Equipment for use in potentially explosive atmospheres
WG 3	Devices and systems for explosion prevention and protection
WG 4	Terminology and Methodology
WG 5	Equipment and components in underground mines and reciprocating internal combustion engines for potential explosive atmospheres
WG 6	Flame arresters

The following table show the current work program of the TC 305.

Table 7 – CEN TC 305 work program, source: CEN

Project	Title	Status	Forecasted voting date
EN 1127-1:2019/prA1(WI=00305174)	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology	Under Drafting	2024-09-23

prEN 13237(WI=00305163)	Potentially explosive atmospheres - Terms and definitions for equipment and protective systems intended for use in potentially explosive atmospheres	Under Approval	2024-01-05
prEN 14460 rev(WI=00305172)	Explosion resistant equipment	Preliminary	2024-10-14
prEN 14983(WI=00305162)	Explosion prevention and protection in underground mines - Equipment and protective systems for firedamp drainage	Under Approval	2023-02-06
prEN 14986(WI=00305169)	Design of fans working in potentially explosive atmospheres	Under Enquiry	2023-07-03
prEN 15198 rev(WI=00305173)	Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres	Preliminary	2025-05-12
prEN 16447 rev(WI=00305167)	Explosion isolation flap valves	Preliminary	
prEN ISO 80079-41(WI=00305159)	Explosive atmospheres - Part 41: Reciprocating internal combustion engines	Under Drafting	2021-03-22
prEN ISO/IEC 80079-49(WI=00305168)	Explosive atmospheres - Part 49: Flame arresters - Performance requirements, test methods and limits for use (ISO/IEC/DIS 80079-49:2022)	Under Approval	2023-07-25
prEN ISO/IEC 80079-50(WI=00305171)	Explosion venting devices	Under Drafting	2024-04-02
(WI=00305165)	Generation of flammable dust clouds for testing of explosion protective systems and devices	Preliminary	
(WI=00305166)	Explosion absorbing systems	Preliminary	

1.1.7 Focus D) IEC/TC 105 "Fuel cell technologies"

The IEC TC 105, which holds a liaison with ISO/TC 197, aims at preparing international standards regarding fuel cell (FC) technologies for all FC types and various associated applications such as stationary FC power systems for distributed power generators and combined heat and power systems, FCs for transportation such as propulsion systems[6], range extenders, auxiliary power units, portable FC power systems, micro FC power systems, reverse operating FC power systems, and general electrochemical flow systems and processes [34].

The TC counts 20 participating countries and 11 observing members, while the secretariat is held by IEC National Committee of Germany, DKE German Commission for Electrical, Electronic & Information Technologies of DIN and VDE.

The table below illustrated the structure of the TC 105.

Table 8 – IEC TC 305 structure, source: IEC

Reference	**Title**
WG 105	General safety standard for fuel cell power systems

[6] Projects with applications in the field of road vehicles will be coordinated with ISO/TC 22 and its relevant SCs using the cooperation modes defined in the ISO/IEC Directives.

WG 106	Calculation of rated power and power density of a stack/module
WG 211	Energy storage systems using fuel cell modules in reverse mode – Performance of power-to methane energy systems
WG 212	Stationary fuel cell power systems - Performance of small systems with/without supplementary heat generators for multiple units operation by an energy management system
WG 303	Fuel cell power systems for excavators – Performance
WG 304	Fuel cell power systems for unmanned aircraft systems – Performance
WG 402	Micro fuel cell power systems - Safety
WG 406	Power, data interchangeability and performance test methods for Fuel Cell Power Systems for laptop computers
	Maintenance Teams
MT 101	Terminology
MT 102	Fuel cell modules - Safety
MT 103	Single cell test methods for PEFC
MT 104	Single cell/stack test methods for SOFC
MT 201	Stationary fuel cell power systems - Safety
MT 202	Fuel cell power systems - Performances
MT 203	Stationary fuel cell power systems – Performance of small fuel cell power systems
MT 204	Stationary fuel cell power systems - Installation
MT 205	Stationary fuel cell power systems – Small systems with combined heat and power output
MT 206	Energy storage systems using fuel cell modules in reverse mode - Solid oxide single cells and stacks
MT 207	Energy storage systems using fuel cell modules in reverse mode - Single cells and stacks with proton exchange membrane
MT 208	Energy storage systems using fuel cell modules in reverse mode - Performance of power-to-power systems
MT 209	Life cycle assessment - Streamlined life-cycle
MT 210	Life cycle assessment - Product category rules
MT 301	Fuel cell power systems for electrically powered industrial trucks – Safety
MT 302	Fuel cell power systems for electrically powered industrial trucks - Performance
MT 401	Portable fuel cell power systems - Safety
MT 403	Micro fuel cell power systems - Performance
MT 404	Micro fuel cell power systems - Fuel cartridge interchangeability
MT 405	Micro fuel cell power systems - Power and data interchangeability
	Joint Working Groups
JWG 16	Cogeneration Combined Heat and Power (CHP) Managed by TC 5
JWG 51	Fuel cell systems for railway applications Managed by TC 9
JWG 7	Flow Battery Systems for Stationary applications Managed by TC 21
	Advisory Groups
AG 1	Cross-cutting
AG 2	Stationary
AG 3	Transports
AG 4	Portable
AG 12	Chair's Advisory Group (CAG)
	Ad-Hoc Groups
ahG 4	Monitoring the smart grid
ahG 9	Questionnaire implementing TC 105 documents
ahG 11	Accelerated stress testing

As of November 2022, the TC has published 29 standards (see table 9), while it counts 15 standards under development (see table 10).

Table 9 – IEC TC 305 standards published, source: IEC

REFERENCE	DATE	TITLE
IEC 62282-2-100:2020	2020-05-07	Fuel cell technologies - Part 2-100: Fuel cell modules - Safety
IEC 62282-3-100:2019 RLV	2019-02-12	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety
IEC 62282-3-100:2019	2019-02-12	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety
IEC 62282-3-200:2015	2015-11-19	Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods
IEC 62282-3-201:2017+AMD1:2022 CSV	2022-02-03	Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems
IEC 62282-3-201:2017	2017-08-10	Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems
IEC 62282-3-201:2017/AMD1:2022	2022-02-03	Amendment 1 - Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems
IEC 62282-3-300:2012	2012-06-14	Fuel cell technologies - Part 3-300: Stationary fuel cell power systems - Installation
IEC 62282-3-400:2016	2016-11-16	Fuel cell technologies - Part 3-400: Stationary fuel cell power systems - Small stationary fuel cell power system with combined heat and power output
IEC 62282-4-101:2022 RLV	2022-08-11	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety
IEC 62282-4-101:2022	2022-08-11	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety
IEC 62282-4-102:2017	2017-04-10	Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods
IEC 62282-4-600:2022	2022-08-12	Fuel cell technologies - Part 4-600: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) - Fuel cell/battery hybrid systems performance test methods for excavators
IEC 62282-5-100:2018	2018-04-12	Fuel cell technologies - Part 5-100: Portable fuel cell power systems - Safety
IEC 62282-6-100:2010+AMD1:2012 CSV	2012-10-14	Fuel cell technologies - Part 6-100: Micro fuel cell power systems - Safety
IEC 62282-6-100:2010	2010-03-03	Fuel cell technologies - Part 6-100: Micro fuel cell power systems - Safety
IEC 62282-6-100:2010/COR1:2011	2011-12-16	Corrigendum 1 - Fuel cell technologies - Part 6-100: Micro fuel cell power systems - Safety

IEC 62282-6-100:2010/AMD1:2012	2012-10-12	Amendment 1 - Fuel cell technologies - Part 6-100: Micro fuel cell power systems - Safety
IEC PAS 62282-6-150:2011	2011-04-21	Fuel cell technologies - Part 6-150: Micro fuel cell power systems - Safety - Water reactive (UN Devision 4.3) compounds in indirect PEM fuel cells
IEC 62282-6-200:2016	2016-09-22	Fuel cell technologies - Part 6-200: Micro fuel cell power systems - Performance test methods
IEC 62282-6-300:2012	2012-12-13	Fuel cell technologies - Part 6-300: Micro fuel cell power systems - Fuel cartridge interchangeability
IEC 62282-6-400:2019	2019-05-22	Fuel cell technologies - Part 6-400: Micro fuel cell power systems - Power and data interchangeability
IEC TS 62282-7-1:2017	2017-01-27	Fuel cell technologies - Part 7-1: Test methods - Single cell performance tests for polymer electrolyte fuel cells (PEFC)
IEC 62282-7-2:2021	2021-05-21	Fuel cell technologies - Part 7-2: Test methods - Single cell and stack performance tests for solid oxide fuel cells (SOFCs)
IEC 62282-8-101:2020	2020-02-18	Fuel cell technologies - Part 8-101: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation
IEC 62282-8-102:2019	2019-12-13	Fuel cell technologies - Part 8-102: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation
IEC 62282-8-201:2020	2020-01-10	Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems
IEC TS 62282-9-101:2020	2020-10-27	Fuel cell technologies - Part 9-101: Evaluation methodology for the environmental performance of fuel cell power systems based on life cycle thinking - Streamlined life-cycle considered environmental performance characterization of stationary fuel cell combined heat and power systems for residential applications
IEC TS 62282-9-102:2021	2021-01-14	Fuel cell technologies - Part 9-102: Evaluation methodology for the environmental performance of fuel cell power systems based on life cycle thinking - Product category rules for environmental product declarations of stationary fuel cell power systems and alternative systems for residential applications

Table 10 – IEC TC 305 work program, source: IEC

PROJECT REFERENCE	TITLE	WG	FCST. PUBL. DATE
PWI 105-1	General safety standard		
IEC 62282-2-400 ED1	Fuel cell technologies - Part 2-400: Fuel cell modules - Calculation of Rated Power and Power Density of a PEM stack and PEM module	WG 106	2024-02
IEC 62282-3-100 ED3	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety	MT 201	2025-10

IEC 62282-3-200 ED3	Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods	MT 202	2025-06
IEC 62282-3-201 ED3	Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems	MT 203	2025-06
IEC 62282-3-202 ED1	Fuel cell technologies - Part 3-202: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems that can be complemented with a supplementary heat generator for multiple units operation by an energy management system	WG 212	2024-07
IEC 62282-4-102 ED2	Fuel cell technologies - Part 4-102: Fuel cell power systems for electrically powered industrial trucks - Performance test methods	MT 302	2023-01
IEC 62282-4-202 ED1	Fuel cell technologies - Part 4-202: Fuel cell power system for unmanned aircrafts - Performance test methods	WG 304	2023-12
IEC 62282-6-101 ED1	Fuel cell technologies - Part 6-101: Micro fuel cell power systems - Safety - General requirements	WG 402	2023-11
IEC 62282-6-106 ED1	Fuel cell technologies – Part 6-106: Micro fuel cell power systems – Safety – Indirect Class 8 (corrosive) compounds	WG 402	2023-11
IEC 62282-6-107 ED1	Fuel cell technologies - Part 6-107: Micro fuel cell power systems – Safety – Indirect water-reactive (Division 4.3) compounds	WG 402	2023-11
IEC 62282-6-401 ED1	Fuel cell technologies - Part 6-401: Micro fuel cell power systems - Power and data interchangeability - Performance test methods for laptop computers	WG 406	2023-06
IEC 62282-8-201 ED2	Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems	MT 208	2023-11
IEC 62282-8-301 ED1	Fuel cell technologies - Part 8-301: Energy storage systems using fuel cell modules in reverse mode - Power to methane energy systems based on solid oxide cells including reversible operation - Performance test methods	WG 211	2023-09
IEC 63341-3 ED1	Railway applications - Rolling stock - Part 3: Fuel cell systems for propulsion - Performance requirements and test methods	WG 19	2023-12

4.4 Standards mapping

Considering that H_2 applications in the maritime sector have not reached a maturity level such that specific standards have been developed, e-SHyIPS project has started its mapping of technical references looking at non-maritime applications. This is perfectly in line with CEN CENELEC position, to use the words of the CEN /CLC JTC 6 Chairman (PhD Bernard Gindroz) "it is extremely important to align inland standards to maritime applications"[7].

The rationale behind is that for some general aspects and transversal topics, also other sectors technical requirements and solutions may suggest a pathway to answer to some questions (like for example linked to safety procedures).

[7] SFEM Workshop 03.02.2022

UNI with the support of all the partners has mapped standards related to H_2 (in non-maritime applications), natural gas and cryogenic vessels which could be relevant for the project activities.

The result is a list of 15 standards under development (from ISO TC 197) and 39 current standards.

For each standard it has been listed the reference, the title, a summary of the content and also some keywords to facilitate the search for technical references.

The table below includes all the results.

Table 11 – Standards mapping: results, data as of December 22nd 2022

REFERENCE	TITLE	SCOPE	KEYWORDS	STATUS
UNI ISO/TR 15916:2018	Basic considerations for the safety of hydrogen systems	ISO/TR 15916:2015 provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards.	Hydrogen storage Properties of Hydrogen relevant for Safety	Current (update in progress)
UNI ISO 14687:2020	Hydrogen fuel quality -- Product specification	This document specifies the minimum quality characteristics of hydrogen fuel as distributed for utilization in vehicular and stationary applications. It is applicable to hydrogen fueling applications, which are listed in Table 1.	Quality characteristics PEM fuel cell Vehicular and stationary applications	Current
UNI ISO 19880-1:2020	Gaseous hydrogen -- Fuelling stations - Part 1: General requirements	This document 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 fueling stations that dispense gaseous hydrogen to light duty road vehicles (e.g. fuel cell electric vehicles).	Fuelling stations GH2 Road vehicles	Current
UNI ISO 19880-3:2022	Gaseous hydrogen — Fuelling stations — Part 3: Valves	This document provides the requirements and test methods for the safety performance of high pressure gas valves that are used in gaseous hydrogen stations of up to the H70 designation. This document covers the following gas valves: check valve; excess flow valve; flow control valve; hose breakaway device; manual valve; pressure safety valve; shut-off valve.	Valves Hydrogen stations	Current
UNI ISO 19880-5:2022	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies	This document specifies the requirements for wire or textile reinforced hoses and hose assemblies suitable for dispensing hydrogen up to 70 MPa nominal working pressure, in the operating temperature range of −40 °C to 65 °C. This document contains safety requirements for material, design, manufacture and testing of gaseous hydrogen hose and hose assemblies for hydrogen fueling stations. Hoses and hose assemblies excluded from the scope of this document are the following: 1) those used as part of a vehicle high pressure on-board fuel storage system, 2) those used as part of a vehicle low pressure fuel delivery system, and 3) flexible metal hoses. NOTE 1 This document was developed primarily for hoses and hose assemblies for dispensing high pressure hydrogen from refueling dispensers to hydrogen vehicles. Requirements for hoses used to deliver hydrogen from a transportable vessel (e.g. trailer) into a buffer storage of a station are addressed in ISO 16964. NOTE 2 Hose assemblies include the hose with connectors on each end (see Figure 1). Each connector has two basic functional elements that	Fueling station hoses Wire or textile reinforced hoses	Current (update in progress)

		are addressed as described below: 1) Coupling to hose. This function is defined by requirements and verified (along with the hose itself) by performance-based tests in this document. 2) Fitting for transition and connection to the piping system or equipment. This function is addressed by reference to appropriate hydrogen equipment standards and piping codes.		
UNI ISO 19880-8:2022	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control	This document specifies the protocol for ensuring the quality of the gaseous hydrogen at hydrogen distribution facilities and hydrogen fuelling stations for proton exchange membrane (PEM) fuel cells for road vehicles.	Road vehicles Fuelling stations Quality characteristics	Current (AMD 2021)
UNI ISO 26142:2022	Hydrogen detection apparatus -- Stationary applications	ISO 26142:2010 defines the performance requirements and test methods of hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations in stationary applications. The provisions in ISO 26142:2010 cover the hydrogen detection apparatus used to achieve the single and/or multilevel safety operations, such as nitrogen purging or ventilation and/or system shut-off corresponding to the hydrogen concentration. The requirements applicable to the overall safety system, as well as the installation requirements of such apparatus, are excluded. ISO 26142:2010 sets out only the requirements applicable to a product standard for hydrogen detection apparatus, such as precision, response time, stability, measuring range, selectivity and poisoning. ISO 26142:2010 is intended to be used for certification purposes.	Stationary applications Requirements and Test Methods Hydrogen concentration	Current
ISO 22734:2019	Hydrogen generators using water electrolysis -- Industrial, commercial, and residential applications	This document defines the construction, safety, and performance requirements of modular or factory-matched hydrogen gas generation appliances, herein referred to as hydrogen generators, using electrochemical reactions to electrolyze water to produce hydrogen. This document is applicable to hydrogen generators that use the following types of ion transport medium: group of aqueous bases; group of aqueous acids; solid polymeric materials with acidic function group additions, such as acid proton exchange membrane (PEM); solid polymeric materials with basic function group additions, such as anion exchange membrane (AEM). This document is applicable to hydrogen generators intended for industrial and commercial uses, and indoor and outdoor residential use in sheltered areas, such as car-ports, garages, utility rooms and similar areas of a residence. Hydrogen generators that can also be used to generate electricity, such as reversible fuel cells, are excluded from the scope of this document. Residential hydrogen generators that also supply oxygen as a product are excluded from the scope of this document.	Hydrogen generators Requirements Industrial use Commercial use Residential use	Current
UNI ISO/TS 19883:2022	Safety of pressure swing adsorption systems for hydrogen separation and purification	ISO/TS 19883:2017 identifies safety measures and applicable design features that are used in the design, commissioning, and operation of pressure swing adsorption systems for hydrogen separation and purification. It applies to hydrogen pressure swing adsorption systems that process all kinds of impure hydrogen streams as feed, including both stationary and skid-mounted pressure swing adsorption systems for hydrogen separation and purification in commercial or industrial use. This document also applies to small-scale PSA hydrogen system installed within containers, where allowed by local regulations.	Hydrogen pressure swing adsorption systems	Current
UNI ISO 19882:2022	Gaseous hydrogen -- Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	This document establishes minimum requirements for pressure relief devices intended for use on hydrogen fueled vehicle fuel containers that comply with ISO 19881, IEC 62282-4-101, ANSI HGV 2, CSA B51 Part 2, EC79/EU406, SAE J2579, or the UN GTR No. 13. The scope of this document is limited to thermally activated pressure relief devices installed on fuel containers used with fuel cell grade hydrogen according to SAE J2719 or ISO 14687 for fuel cell land vehicles, and Grade	Vehicles fuel container Pressure relief devises	Current (update in progress)

		A or better hydrogen according to ISO 14687 for internal combustion engine land vehicles. This document also contains requirements for thermally activated pressure relief devices acceptable for use on-board light duty vehicles, heavy duty vehicles and industrial powered trucks such as forklifts and other material handling vehicles, as it pertains to UN GTR No. 13. Pressure relief devices designed to comply with this document are intended to be used with high quality hydrogen fuel such as fuel complying with SAE J2719 or ISO 14687 Type 1 Grade D. Pressure relief devices can be of any design or manufacturing method that meets the requirements of this document. This document does not apply to reseating, resealing, or pressure activated devices. Documents which apply to hydrogen fuel vehicles and hydrogen fuel subsystems include IEC 62282- 4- 101, SAE J2578 and SAE J2579.		
UNI ISO 19881:2022	Gaseous hydrogen — Land vehicle fuel containers[8]	This document contains requirements for the material, design, manufacture, marking and testing of serially produced, refillable containers intended only for the storage of compressed hydrogen gas for land vehicle operation. These containers a) are permanently attached to the vehicle, b) have a capacity of up to 1 000 l water capacity, and c) have a nominal working pressure that does not exceed 70 MPa. The scope of this document is limited to fuel containers containing fuel cell grade hydrogen according to ISO 14687 for fuel cell land vehicles and Grade A or better hydrogen as per ISO 14687 for internal combustion engine land vehicles. This document also contains requirements for hydrogen fuel containers acceptable for use on-board light duty vehicles, heavy duty vehicles and industrial powered trucks such as forklifts and other material handling vehicles.	Storage of compressed hydrogen Land vehicle operation	Current (update in progress)
UNI EN ISO 17268:2020	Gaseous hydrogen land vehicle refuelling connection devices	This document defines the design, safety and operation characteristics of gaseous hydrogen land vehicle (GHLV) refuelling connectors. GHLV refuelling connectors consist of the following components, as applicable: receptacle and protective cap (mounted on vehicle); nozzle; communication hardware. This document is applicable to refuelling connectors which have nominal working pressures or hydrogen service levels up to 70 MPa. This document is not applicable to refuelling connectors dispensing blends of hydrogen with natural gas.	Land vehicles Refuelling connectors	Current (update in progress)
UNI ISO 16111:2022	Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride	This document defines the requirements applicable to the material, design, construction, and testing of transportable hydrogen gas storage systems, referred to as "metal hydride assemblies" (MH assemblies) which utilize shells not exceeding 150 l internal volume and having a maximum developed pressure (MDP) not exceeding 25 MPa. This document is applicable to refillable storage MH assemblies where hydrogen is the only transferred media. It is not applicable to storage MH assemblies intended to be used as fixed fuel-storage onboard hydrogen fuelled vehicles.	Hydrogen storage Metal hydride assemblies	Current
UNI ISO 16110-1:2022	Hydrogen generators using fuel processing technologies — Part 1: Safety	ISO 16110-1:2007 applies to packaged, self-contained or factory matched hydrogen generation systems with a capacity of less than 400 m3/h at 0 °C and 101,325 kPa, herein referred to as hydrogen generators, that convert an input fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device using the hydrogen (e.g. a fuel cell power system or a hydrogen compression, storage and delivery system). It applies to hydrogen	Hydrogen generators Safety	Current

[8] This document specifies details on cylinder design for onboard applications and for stationary applications. Annex C gives an overview of low-temperature effects of hydrogen on materials, and the document also suggests suitable material-selection criteria, including how to consider hydrogen embrittlement.

		generators using one or a combination of the following input fuels: — natural gas and other methane-rich gases derived from renewable (biomass) or fossil fuel sources, e.g. landfill gas, digester gas, coal mine gas; — fuels derived from oil refining, e.g. diesel, gasoline, kerosene, liquefied petroleum gases such as propane and butane; — alcohols, esters, ethers, aldehydes, ketones, Fischer-Tropsch liquids and other suitable hydrogen-rich organic compounds derived from renewable (biomass) or fossil fuel sources, e.g. methanol, ethanol, di-methyl ether, biodiesel; — gaseous mixtures containing hydrogen gas, e.g. synthesis gas, town gas. ISO 16110-1:2007 is applicable to stationary hydrogen generators intended for indoor and outdoor commercial, industrial, light industrial and residential use. It aims to cover all significant hazards, hazardous situations and events relevant to hydrogen generators, with the exception of those associated with environmental compatibility (installation conditions), when they are used as intended and under the conditions foreseen by the manufacturer.		
UNI ISO 16110-2:2022	Hydrogen generators using fuel processing technologies — Part 2: Test methods for performance	ISO 16110-2:2010 provides test procedures for determining the performance of packaged, self-contained or factory matched hydrogen generation systems with a capacity less than 400 m3/h at 0 °C and 101,325 kPa, referred to as hydrogen generators, that convert a fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device using the hydrogen (e.g. a fuel cell power system, or a hydrogen compression, storage and delivery system).	Hydrogen generators Test methods	Current
ISO 13985:2006	Liquid hydrogen -- Land vehicle fuel tanks	This International Standard specifies the construction requirements for refillable fuel tanks for liquid hydrogen used in land vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided. This International Standard is applicable to fuel tanks intended to be permanently attached to land vehicles.	Land vehicles Hydrogen storage	Current
ISO 13984:1999	Liquid hydrogen — Land vehicle fuelling system interface	This International Standard specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refuelling procedure and thus to provide a reasonable level of protection from loss of life and property. This International Standard is applicable to the design and installation of liquid hydrogen (LH2) fuelling and dispensing systems. It describes the system intended for the dispensing of liquid hydrogen to a vehicle, including that portion of the system that handles cold gaseous hydrogen coming from the vehicle tank, that is, the system located between the land vehicle and the storage tank.	Land vehicles Hydrogen storage	Current
UNI EN 13645:2006	Installations and equipment for liquefied natural gas - Design of onshore installations with a storage capacity between 5 t and 200 t	This European Standard specifies requirements for the design and construction of onshore stationary liquefied natural gas (LNG) installations with a total storage capacity between 5 and 200 t	Design Construction	Current
UNI EN 12838:2003	Installations and equipment for liquefied natural gas - Suitability testing of LNG sampling systems	This standard specifies the tests to be carried out in order to assess the suitability of LNG sampling systems designed, in combination with an analytical device such as a chromatograph, to determine the composition of Liquefied Natural Gas.	Design Test methods	Current
UNI EN 1474-2:2020	Installation and equipment for liquefied natural gas - Design and testing of marine transfer systems - Part 2: Design and testing of transfer hoses	This European Standard gives general guidelines for the design, material selection, qualification, certification, and testing details for Liquefied Natural Gas (LNG) transfer hoses for offshore transfer or on coastal weather-exposed facilities for aerial, floating and submerged configurations or a combination of these. Whilst this European Standard is applicable to all LNG hoses, it is acknowledged that there may be further specific requirements for floating and submerged hoses.	Design Construction	Current

UNI EN ISO 20257-1:2020	Installation and equipment for liquefied natural gas - Design of floating LNG installations - Part 1: General requirements	This document provides requirements and guidance for the design and operation of floating liquefied natural gas (LNG) installations, including installations for the liquefaction, storage, vaporization, transfer and handling of LNG, in order to have a safe and environmentally acceptable design and operation of floating LNG installations. This document is applicable to: — floating LNG liquefaction installations (plant) — FLNG; — floating LNG regasification installations (plant) — FSRU; — floating storage units — FSU. This document is applicable to offshore, near-shore or docked floating LNG installations. This document includes any jetty in the scope in case of docked floating LNG installations with regards to the mooring. This document briefly describes floating LNG mooring concepts. This document is applicable to both new built and converted floating LNG installations, and addresses specific requirements. This document is not applicable to: — onshore LNG storage, liquefaction and/or regasification installations/plants, except for docked FSRU and/or FLNG installations; — offshore LNG plants based on non-floating structure (such as gravity based structure [GBS] principle); and — support onshore based facilities (such as support vessels, tugs, etc.). This document is not intended for design floating power generation facilities though relevant parts of this document can be used.	Liquefied NG installation Design Construction	Current
UNI EN ISO 21593:2020	Ship and marine technology - Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas	This document specifies the design, minimum safety, functional and marking requirements, as well as the interface types and dimensions and testing procedures for dry-disconnect/connect couplings for LNG hose bunkering systems intended for use on LNG bunkering ships, tank trucks and shore-based facilities and other bunkering infrastructures. It is not applicable to hydraulically operated quick connect/disconnect couplers (QCDC) used for hard loading arms, which is covered in ISO 16904. Based on the technology used in industrial manufacturing at the time of development of this document, it is applicable to sizes of couplings ranging from DN 25 to DN 200.	Ship and marine technology	Current
UNI EN ISO 20519:2022	Ships and marine technology - Specification for bunkering of liquefied natural gas fuelled vessels	This document specifies requirements for LNG bunkering transfer systems and equipment used to bunker LNG fuelled vessels, which are not covered by the IGC Code. This document is applicable to vessels involved in international and domestic service regardless of size, and addresses the following five elements: a) hardware: liquid and vapor transfer systems; b) operational procedures; c) requirement for the LNG provider to provide an LNG bunker delivery note; d) training and qualifications of personnel involved; e) requirements for LNG facilities to meet applicable ISO standards and local codes.	Bunkering Ship and marine technology	Current
UNI EN ISO 16904:2016	Petroleum and natural gas industries - Design and testing of LNG marine transfer arms for conventional onshore terminals	This European Standard specifies the design, minimum safety requirements and inspection and testing procedures for liquefied natural gas (LNG) transfer arms intended for use on conventional onshore (LNG) terminals 1). It also covers the minimum requirements for safe LNG transfer between ship and shore. Although the requirements for remote control power systems are covered, the standard does not include all the details for the design and fabrication of standard parts and fittings associated with transfer arms. The content of this European Standard is supplementary to local or national standards and regulations and is additional to the requirements of EN 1532 and EN 1473.	Design Test methods	Current
UNI EN ISO 16903:2015	Petroleum and natural gas industries - Characteristics of LNG, influencing the design, and material selection	This International Standard gives guidance on the characteristics of liquefied natural gas (LNG) and the cryogenic materials used in the LNG industry. It also gives guidance on health and safety matters. It is intended to act as a reference document for the implementation of other standards in the liquefied natural gas field. It is intended as a	Characteristics of LNG Design	Current

		reference for use by persons who design or operate LNG facilities.		
UNI EN ISO 28460:2011	Petroleum and natural gas industries - Installation and equipment for liquefied natural gas - Ship-to-shore interface and port operations	The international Standard specifies what is required by ship, terminal and port service providers to ensure the safe transit of the LNG carrier through the port area and the safe and efficient transfer of its cargo. It is applicable to: - pilotage and Vessel Traffic Services (VTS); - tug operators; - terminal operators; - ship operators; - suppliers of bunkers, lubricants and stores and other providers of services whilst the LNG carrier is moored alongside the terminal.	Safety Port	Current
UNI EN 1474-3:2009	Installation and equipment for liquefied natural gas - Design and testing of marine transfer systems - Part 3: Offshore transfer systems	This European Standard gives general guidelines for the design of liquefied natural gas (LNG) transfer systems intended for use on offshore transfer facilities or on coastal weather exposed transfer facilities. The transfer facilities considered may be between floating units, or between floating and fixed units. The specific component details of the LNG transfer systems are not covered by the European Standard.	Transfer system Design Construction	Current
UNI EN ISO 16923:2018	Natural gas fuelling stations - CNG stations for fuelling vehicles	This document covers the design, construction, operation, inspection and maintenance of stations for fuelling compressed natural gas (CNG) to vehicles, including equipment, safety and control devices. This document also applies to portions of a fuelling station where natural gas is in a gaseous state and dispensing CNG derived from liquefied natural gas (LCNG) according to ISO 16924.	Fuelling stations Vehicles Design	Current
UNI EN ISO 16924:2018	Natural gas fuelling stations - LNG stations for fuelling vehicles	This document specifies the design, construction, operation, maintenance and inspection of stations for fuelling liquefied natural gas (LNG) to vehicles, including equipment, safety and control devices. This document also specifies the design, construction, operation, maintenance and inspection of fuelling stations for using LNG as an onsite source for fuelling CNG to vehicles (LCNG fuelling stations), including safety and control devices of the station and specific LCNG fuelling station equipment.	Fuelling stations Vehicles Design	Current
UNI EN 13423:2021	Natural gas vehicles - Requirements for NGV workshops and the management of compressed natural gas (CNG) vehicles	This document provides requirements for operation of vehicles that use compressed natural gas (CNG) as a fuel for propulsion, covering various aspects of NGV workshops including activities, risk management, planning, personnel, layout, systems and operations. It provides requirements regarding the management of NGVs including use, parking, fuelling for commissioning, inspection, installation, repair and maintenance, disposal, transportation and documentation. This document is applicable to the management of CNG vehicles with a fuel system pressure of 20 MPa (200 bar) at 15 °C. This document can also be applied to vehicles with higher fuel system pressures, taking into account additional safety aspects. This document also applies to servicing, repair and maintenance of NGVs when work is not performed on the gas fuel system.	Guidelines for users Parking areas Filling stations Equipped workshops	Current
UNI EN ISO 21028-1:2016	Cryogenic vessels - Toughness requirements for materials at cryogenic temperature - Part 1: Temperatures below -80 °C	ISO 21028-1:2016 specifies the toughness requirements of metallic materials for use at a temperature below -80 °C to ensure their suitability for cryogenic vessels. ISO 21028-1:2016 is not applicable to unalloyed steels and cast materials.	Cryogenic vessels Metallic materials	Current
UNI EN 1797:2003	Cryogenic vessels - Gas/material compatibility	This European Standard specifies requirements for gas/materials compatibility for cryogenic vessels (such as chemical resistance) but it does not cover mechanical properties (e.g. for low temperature application). It gives guidance for compatibility with gases other than oxygen and it gives detailed requirements for oxygen and oxygen enriched atmosphere compatibility and defines the testing methods for establishing oxygen compatibility of materials (metallic and non-metallic) to be used for cryogenic vessels and associated equipment. It mainly deals with materials that are normally or could be in contact with liquid/gaseous	Material compatibility	Current

		oxygen e.g., materials for cryogenic vessels used for the storage and/or transport of liquid oxygen. It also deals with the materials which can be in contact with oxygen enriched environment e.g. insulating materials used for nitrogen, neon, hydrogen and helium cryogenic vessels in case of air condensation.		
UNI EN 13648-1:2009	Cryogenic vessels - Safety devices for protection against excessive pressure - Part 1: Safety valves for cryogenic service	This European Standard specifies the requirements for the design, manufacture and testing of safety valves for cryogenic service, that is to say for operation with cryogenic fluids (as defined in EN 1251-1) below - 10 °C in addition to operation at ambient temperature. It is a requirement of this European Standard that the valves comply with EN ISO 4126 1 or EN ISO 4126-4. In the event of different requirements, the requirements for cryogenic service shall be applied. NOTE 1 A cryogenic fluid (refrigerated liquefied gas) is a gas which is partially liquid because of its low temperature (including totally evaporated liquids and supercritical fluids). This European Standard is restricted to valves not exceeding a size of DN 100 for category B. The valves of category A are limited to DN 25 and set pressures up to 40 bars. Both categories are designed to relieve single phase vapours or gases. A valve can be specified, constructed and tested such that it is suitable for use with more than one gas or with mixtures of gases. NOTE 2 All safety valves covered in this European Standard correspond to category IV of PED (Directive 97/23/EC) and category 3 of TPED (Directive 99/36/EC). NOTE 3 This European Standard does not provide methods for determining the capacity of relief valve(s) for a particular cryogenic vessel. Such methods are provided in EN 13648 3.	Valves	Current
UNI EN 13648-2:2004	Cryogenic vessels - Safety devices for protection against excessive pressure - Bursting disc safety devices for cryogenic service	This European Standard specifies the requirements for the design, manufacture and testing of bursting disc safety devices for cryogenic service, i.e. for operation with cryogenic fluids below - 10 °C in addition to operation at ambient temperature. It is a requirement of this standard that the bursting disc safety device(s) comply with prEN ISO 4126-2. In the event of different requirements, this standard takes precedence over that standard. This standard is restricted to bursting disc safety devices not exceeding a size of DN 100 designed to relieve single phase vapors or gases. A bursting disc assembly can be specified, constructed and tested such that it is suitable for use with more than one gas or with mixtures of gases. NOTE This standard does not provide methods for determining the capacity of bursting disc safety devices for a particular cryogenic vessel. Such methods are provided in prEN 13648-3.	Design safety devices	Current
ISO/AWI TR 22734-2	Hydrogen generators using water electrolysis — Part 2: Testing guidance for performing electricity grid service	-	Electricity grid service	Work in progress
ISO/WD 19887	Gaseous Hydrogen — Fuel system components for hydrogen fuelled vehicles	-	Vehicles	Work in progress
ISO/CD 19885-1	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 1: Design and development process for fuelling protocols	-	Fuelling protocols	Work in progress
ISO/AWI 19885-2	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 2: Definition of communications between	-	Communication b/w vehicle and dispenser control	Work in progress

	the vehicle and dispenser control systems			
ISO/AWI 19885-3	Gaseous hydrogen — Fuelling protocols for hydrogen-fuelled vehicles — Part 3: High flow hydrogen fuelling protocols for heavy duty road vehicles	-	Fuelling protocols Road vehicles	Work in progress
ISO/CD 19880-6	Gaseous hydrogen — Fueling stations — Part 6: Fittings	-	Fuelling stations	Work in progress
ISO/AWI 19884-1	Gaseous hydrogen — Cylinders and tubes for stationary storage — Part 1: General Requirements	-	Hydrogen storage	Work in progress
ISO/PWI 24078	Hydrogen in energy systems — Vocabulary	-	Vocabulary	Work in progress
ISO/WD 19880-7	Gaseous hydrogen — Fuelling stations — Part 7: O-rings	-	O-rings	Work in progress
ISO/AWI 19880-9	Gaseous hydrogen — Fuelling stations — Part 9: Sampling for fuel quality analysis	-	Sampling Fuel quality	Work in progress
ISO/CD 14687	Hydrogen fuel - Product specification	-	Fuel	Work in progress
PD ISO/TR 16113	Applications for hydrogen absorbed in reversible metal hybrids not covered in ISO 16111	-	Reversible metal hybrids	Work in progress
ISO/CD 19880-2	Gaseous hydrogen - Fuelling stations: Part 2: dispensers	This document describes the safety requirements and test methods for the components and systems that enable the transfer of compressed hydrogen to a hydrogen vehicle as addressed in ISO 19880-1 by a hydrogen dispenser with dispensing pressures up to the H70 pressure class.	Fuelling stations Safety	Work in progress

Further standards considered relevant in the framework of e-SHyIPS scenarios, emerged during the project activities. Among those, particularly relevant proved to be:

- UNI EN ISO 11114-4:2017 "Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement" which specifies the test methods to select metallic material resistant to hydrogen embrittlement.
- UNI ISO 11119-1:2017 "Gas cylinders - Refillable composite gas cylinders and tubes - Design, construction and testing - Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l" which specifies details on cylinder design for transportable applications.
- ISO 21013-1:2021 "Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves", for the requirements related to reclosable pressure-relief valves.
- ISO 21013—2:2007 "Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices, for the requirements related to reclosable pressure-relief devices.

- UNI EN ISO 21013-3:2016 "Cryogenic vessels - Pressure-relief accessories for cryogenic service - Part 3: Sizing and capacity determination"

Of course this list of standards is not comprehensive of all relevant technical references in the scope of e-SHyIPS project, nonetheless it has provided an important starting point for the IGF Code gap analysis (see section 5).

1.1.8 Standardization gaps: a European perspective

At European level there are some discussions ongoing to identify the standardization needs related to the maritime applications for hydrogen fuel on board, deep sea and short sea shipping as well as inland waterways, and what kind of (pre-normative) research is still needed as input for standardization.

This has been the focus of an important workshop organized by CEN CENELEC JTC 6 in February 2022[9] and which e-SHyIPS project has participated to as one of the main EU projects on this topic.

In this section we highlight, per theme, some main gaps and needs emerged during this workshop and follow-up discussions.

- **Metrology**
  It is important to settle a metrology system (especially for billing) and that this is also regulated by law. Automotive sector can provide an example.
  It would be also important to developing a network for metrology (energy gases) and some projects related to metrology and H_2, composition, material science etc.
- **Powertrain**
  Fuel cells and deep sea shipping: power density limitations restrict the level of applicability of fuel cells on ocean going ships. This needs to be explored (especially in terms of safety implications) before being taken in by standardization bodies.
- **Bunkering**
  Liability: in case of integrity issues on tanks systems, the Flags do not always are aware of who owns the movable asset.
  On board storage: it is needed to speed up the regulations in terms of use of hydrogen on board and acceptance of vessels. It is expected to have IMO rules within 3 years for inland navigation, but it is expected to have them in a shorter time. It may be useful to have a draft standard (taking into account IMO regulations and LGN experience) to speed up the process, which instead of focusing on all storage options, makes a note on priorities (e.g. swapping on deck).

[9] SFEM/WG Hydrogen. In 2020 the SFEM/WG hydrogen formulated four priority topics: aviation, maritime transport, trains, and the horizontal topic of liquefied hydrogen. After a discussion with several stakeholders from Hydrogen Europe, Fuel Cells Joint Undertaking and JRC it has decided to change priorities and to also work towards a gap analysis on the roll-out of hydrogen in the heavy-duty sector. So in 2022 it has organized three workshops to gather inputs from relevant market stakeholders.

Not just vessels: it is important to not focus just on vessels but to take into consideration also on shore. For LNG there exist a Netherlands reference (PGS 33-2), but for H_2 a harmonized on shore based bunkering standard is missing.

- **Synergies**

  Automotive: take into account the possibility to apply road standards also to gaseous H_2 small ships, but revisions may be needed and further research should be carried out on this.

  LNG: LNG guidelines (like SGMF Guide) could be an inspiration for the maritime sector and hydrogen applications, but differences in terms of properties and technologies implemented need to be carefully taken into account.

  Explosion hazards: CEN TC 305 has a big package of standards for explosion protection and prevention, starting with EN 1127-1:2019 which include Hazard assessment for electrical and mechanical components; moreover, CENELEC TC 31[10] has published standards EN IEC 60079-10-1:2021 and EN IEC 60079-14 for the installation, EN IEC 60079-29 series for gas detection, IEC 60079-13 for pressure-ventilated room.

  All these standards are linked to the Directive 2014/34/EU ATEX which is used on land base, but their application may be suitable also on board[11].

Finally, it is quite clear the importance to avoid "standardizing too early": still many safety issues (e.g. LH_2 transfer shore ↔ ships) need to be addressed and pre-normative research is key in filling these knowledge gaps.
On top, the standards developed need to be aligned with IMO regulations and capitalize on projects results.
Based on these considerations, e-SHyIPS has carried a review of the IGF Code (see next section).

5. IGF CODE review

5.1 Overview

IGF Code is a mandatory code for ships using gases or other low-flashpoint fuels, aimed to minimize the risk to ships, their crews and the environment, given the nature of the fuels involved. It includes also training requirements for seafarers working on those ships.

IGF Code considers other low-flashpoint fuels may be used as marine fuels on ships, provided they meet the intent of the goals and functional requirements of the IGF Code, so providing an equivalent level of safety.

Nonetheless, as mentioned in section 3.4.1 there is still no specific reference to hydrogen. For this reason, and given the considerations emerged from the European

[10] CLC/TC 31 - Electrical apparatus for explosive atmospheres
[11] Comment from CEN TC 305 Chairman

market (see section 4.4.1) e-SHYIPS has carried out a review of the IGF Code to spot existing gaps in its requirements for an effective use of H_2 as an alternative fuel on board.

The Gap analysis has followed 2 steps as summarized in the figure below.

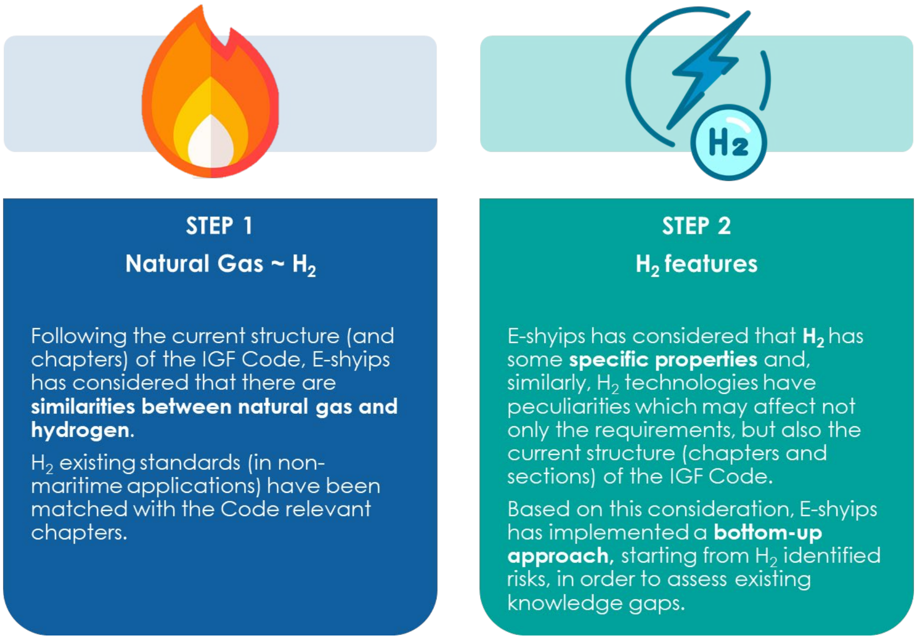


Figure 8 – IGF Code review: the methodology, source: UNI

The gap assessment of the IGF code was led by DNV with participation of all e-SHyIPS partners. The process was conducted in a series of workshops, organized by UNI, were the following bottom-up approach was implemented:

- The existing IGF code structure as basis for the review.
- Existing hydrogen standards were used as references to juxtapose hydrogen's properties and intrinsic specificities against LNG/NG, (among the current standards listed in Table 11 – Standards mapping: results, data as of December 22nd 2022).
- The partners commented on the potential applicability of each set of code specifications to Hydrogen, specifying capabilities, bottlenecks and knowledge gaps.

This analysis was carried out through 8 workshops (2 hours each), organized by UNI and led by DNV, involving all consortium partners and members of the Advisory Board of the project which could give deeper information on specific topics (e.g. bunkering). According to a member of the AB of the project participating to IMO committees, this bottom-up approach is different from the one adopted by IMO.

Therefore, eSHyIPS can arrive to pre-normative requirements form two different ways: (a) exploiting the work conducted in this gap assessment effort and (b) addressing the top-bottom findings from other eSHyIPS WPs or IMO works.

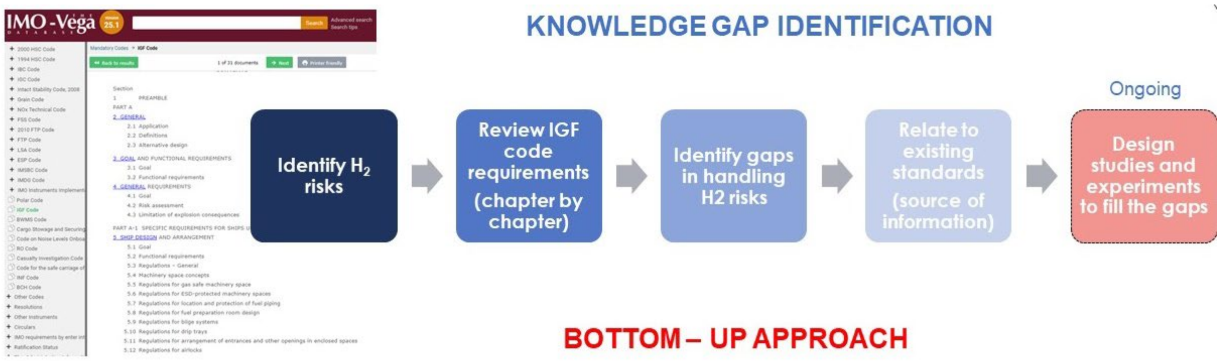


Figure 9 – IGF Code review: the bottom-up approach, source: UNI

Table 12 – IGF Code structure, source: DNV

		Category of system specifications
1	**GENERAL**	
2	**GENERAL REQUIREMENT**	
3	**SHIP DESIGN AND ARRANGEMENT**	Arrangements
	Machinery space concepts	
	Gas safe machinery space	
	ESD-protected machinery spaces	
	Location and protection of fuel piping	
	Fuel preparation room design	
	Bilge systems	
	Drip trays	
	Arrangement of entrances and other openings in enclosed spaces	
	Airlocks	
4	**FUEL CONTAINMENT SYSTEM**	Fuel storage system
	Liquefied gas fuel containment	
	Portable liquefied gas fuel tanks	
	CNG fuel containment	
	Pressure relief system	
	Loading limit for liquefied gas fuel tanks	
	Maintaining of fuel storage condition	
	Atmospheric control within the fuel containment system	
	Atmosphere control within fuel storage hold spaces (Fuel containment systems other than type C independent tanks)	
	Environmental control of spaces surrounding type C independent tanks	

	Inerting	
	Inert gas production and storage on board	
5	**MATERIAL AND GENERAL PIPE DESIGN**	Materials
	General pipe design	
	Materials	
6	**BUNKERING**	Bunkering process
	Bunkering station	
	Manifold	
	Bunkering system	
7	**FUEL SUPPLY TO CONSUMERS**	Fuel supply
	Redundancy of fuel supply	
	Safety functions of gas supply system	
	Fuel distribution outside of machinery space	
	Fuel supply to consumers in gas-safe machinery spaces	
	Gas fuel supply to consumers in ESD-protected machinery spaces	
	Design of ventilated duct, outer pipe against inner pipe gas leakage	
	Compressors and pumps	
8	**POWER GENERATION INCLUDING PROPULSION AND OTHER GAS CONSUMERS**	Primary energy conversion machinery
	Internal combustion engines of piston type	
	Main and auxiliary boilers	
	Gas turbines	
9	**FIRE SAFETY**	Safety systems / Fire protection
	Fire protection	
	Fire main	
	Water spray system	
	Dry chemical powder fire-extinguishing system	
	Fire detection and alarm system	
10	**EXPLOSION PREVENTION**	Safety systems / Explosion prevention
	Area classification	
	Hazardous area zones	
11	**VENTILATION**	Safety systems / Ventilation
	Tank connection space	
	Machinery spaces	
	Fuel preparation room	
	Bunkering station	
	Ducts and double pipes	
12	**ELECTRICAL INSTALLATIONS**	Electric installations and power transmission
	General	
13	**CONTROL, MONITORING AND SAFETY SYSTEMS**	

	Bunkering and liquefied gas fuel tank monitoring	Control, monitoring and safety systems
	Bunkering control	
	Gas compressor monitoring	
	Gas engine monitoring	
	Gas detection	
	Fire detection	
	Ventilation	
	Safety functions of fuel supply systems	
14	**MANUFACTURE, WORKMANSHIP AND TESTING**	
	General test regulations and specifications	
	Welding of metallic materials and non-destructive testing for the fuel containment system	
	Other construction in metallic materials	
	Testing	
	Welding, post-weld heat treatment and non-destructive testing	
	Testing regulations	
15	**DRILLS AND EMERGENCY EXERCISES**	
16	**OPERATION**	
	Maintenance	
	Bunkering operations	
	Enclosed space entry	
	Inerting and purging of fuel systems	
	Hot work on or near fuel systems	
17	**TRAINING**	

The following sections highlight the results of this gap analysis and the experimental scenarios that e-SHyIPS consortium is planning to close the relevant gaps identified.

5.2 Land-based standards as input to IGF Code update: e-SHyIPS results

In the first step of the gap analysis, the consortium matched the list of standards analysed in section 4 with the relevant chapters of the IGF Code (and whenever possible, with the specific sections). This in order to check which requirements listed in the IGF Code may be traced back to the requirements contained in the standards.

The table below illustrates the results of this first step: for each chapter of the IGF Code it has been reported the technical references that the consortium has matched, indicating in brackets also the specific section, which the standard was matched to, and the topic, which that standard in that section may address. Some requirements are repeated in several chapters and the technical reference is applicable as well as; in this case, they are listed just once. For example when it comes to H_2, welded joints are preferred since leaks are not acceptable; the UNI ISO/TR 15916:2018 and UNI EN 13648-1:2009 are relevant technical references on this point, and they are listed in the table just in the "material and general pipe design", although this topic is faced also in other chapters of the IGF Code, like "fuel supply to consumers".

Table 13 – IGF Code review: step 1 results, source: e-SHyIPS consortium

IGF CODE CHAPTER	**STANDARDS** (IGF Code requirement → topic)
SHIP DESIGN AND ARRANGEMENT	**UNI ISO/TR 15916:2018** (*Gas safe machinery space* → assessment of the conditions)
	IEC 62282-2 and series IEC 62282-3 (*Gas safe machinery space* → fuel cells and venting insulation)
	UNI ISO/TR 15916:2018 (*Fuel preparation room design* → requirements for location)
	UNI ISO/TR 15916:2018 (missing: requirements for risk assessment, HAZID)
	UNI ISO/TR 15916:2018 (missing: requirements for storage tanks location)
	UNI ISO 19880-1:2020 (missing: requirements for labelling of hazardous areas)
FUEL CONTAINMENT	**UNI ISO/TR 15916:2018** (*General* → gap in design conditions + on board storage capacity requirements)
	UNI ISO/TR 15916:2018 (*Pressure and temperature maintenance* → missing methods to maintain pressure and temperature in H_2 tanks + failures)
	UNI ISO/TR 15916:2018 (*Pressure and temperature maintenance* → valves[12])
	UNI EN ISO 21028-1:2016 (*Strength requirements* → ultimate design conditions)
	UNI EN 1797:2003 (*Pressure relief considerations*)
MATERIAL AND GENERAL PIPE DESIGN	**UNI ISO 19880-1:2020** (*General pipe design*→ explosion risk mitigation + equipment and components)
	UNI ISO/TR 15916:2018 + UNI EN ISO 21028-1:2016 (*Materials* → type of materials, Design conditions, strength requirements)
	UNI ISO/TR 15916:2018 + UNI EN 13648-1:2009 (*Piping* → joints, preferable for welded joints)
BUNKERING[13]	**UNI ISO 19880-1:2020** (*Bunkering station* → hoses and manifolds, max pressure and acceptable – TBE - leakage rate)
	UNI ISO 19880-3:2022 (*missing:* H_2 bunkering)

[12] Although new standards are currently under development on this topic. UNI EN ISO 16923:2018 may be also a relevant reference.

[13] Equipment on board the vessel

FUEL SUPPLY TO CONSUMERS	**UNI ISO 19880-1:2020** (*Safety functions* → mitigation of risks related to formation of flammable mixtures, potential of ignition, fire/explosion, effects of external fires/events)
	UNI ISO/TR 15916:2018 *(Safety functions → H_2 dispersion behaviour to be taken into account)*
POWER GENERATION INCLUDING PROPULSION AND OTHER GAS CONSUMERS	**UNI ISO 19880-1:2020** (*missing: isolation of H_2* containment systems → mitigation of risks related to formation of flammable mixtures)
	UNI ISO/TS 19883:2022 (*missing: reformers*[14])
	UNI ISO 14687:2020 (*missing: fuel cell* → H_2 fuel quality requirements for PEM fuel cells)
FIRE SAFETY	**UNI ISO/TR 15916:2018** *(Fire main + Fire detection and alarm system → general remarks about safety requirements)*
EXPLOSION PREVENTION	**UNI ISO/TR 15916:2018** *(General → remarks about safety requirements)*
CONTROL, MONITORING AND SAFETY SYSTEMS	**UNI ISO/TR 15916:2018 + UNI ISO 26142:2022** *(Gas detection → use of alarms and warning devices + H_2 detection apparatus)*
	UNI ISO/TR 15916:2018 *(Fire detection → procedures for hazards mitigation)*
VENTILATION	**UNI ISO/TR 15916:2018** *(Ventilation rates / safety limits → thresholds to be updated + adding prevention of hydrogen/oxidizer mixtures from accumulating in confined spaces)*
ELECTRICAL INSTALLATIONS	**Directive 2014/34/EU (ATEX) harmonized standards[15] + UNI ISO 19880-1:2020 + UNI ISO/TR 15916:2018** (Requirements for electric installations (incl. lighting), missing: explosion-proof certification → equipment used in explosive atmospheres)
MANUFACTURE, WORKMANSHIP AND TESTING	**UNI ISO 19880-1:2020** (*General test regulations and specifications* → testing[16], training, technical documentation, inspection, etc.)

[14] Reformers are not in the e-SHyIPS scope as the project is related to 100% pure H_2.

[15] See section 4.3.3.

[16] Also UNI ISO 19881:2022 may be relevant (when it comes to containers).

DRILLS AND EMERGENCY EXERCISES	**UNI ISO 19880-1:2020 + UNI ISO/TR 15916:2018** (Emergency shutdown + extreme events examples)
OPERATION	**UNI ISO/TR 15916:2018** (Maintenance → long term planning)
	UNI ISO/TR 15916:2018 (Operational requirements → HAZID)
	UNI ISO 19880-1:2020 (*Bunkering operations*)
	UNI ISO 19880-1:2020 + UNI ISO/TR 15916:2018 (*Exposure of personnel, PPE* → protection measures + PPE)
	UNI ISO 14687:2020 **UNI EN ISO 16924:2018** **UNI EN ISO 16923:2018** **UNI EN ISO 28460:2011** **UNI EN ISO 20519:2022** **UNI ISO 26142:2022** **ISO 22734:2019** **UNI ISO/TS 19883:2022** **UNI EN ISO 21593:2020** **UNI ISO 16110-1:2022** **UNI ISO 16110-2:2022** **UNI EN 13648-1:2009** **UNI EN 13648-2:2004**
TRAINING	**UNI ISO/TR 15916:2018** **UNI ISO 19880-1:2020** **UNI ISO/TS 19883:2022** **UNI EN ISO 21593:2020** **UNI ISO 16110-1:2022** **UNI EN 13648-1:2009** **UNI EN 13648-2:2004**

It is pretty evident that among the standards matched, the UNI ISO/TR 15916:2018 ("Basic considerations for the safety of hydrogen systems") is the most important technical reference, given the relevance it has in basically all chapters of the IGF Code. This is because it provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety (see Annex [1] for the Table of content of this standard). This standard was developed by ISO in 2015 (replacing the 2004 version) and it was adopted by UNI, at Italian level, in 2018. Currently[17], the standard is under review and the new version is expected to be published soon.

5.3 E-SHyIPS contribution to closing identified gaps

The second step of the IGF Code review, the gap analysis, has focused on H_2 specific features and its technologies. First of all, it has been clarified which may be the possible risks related to H_2. The figure below shows them.

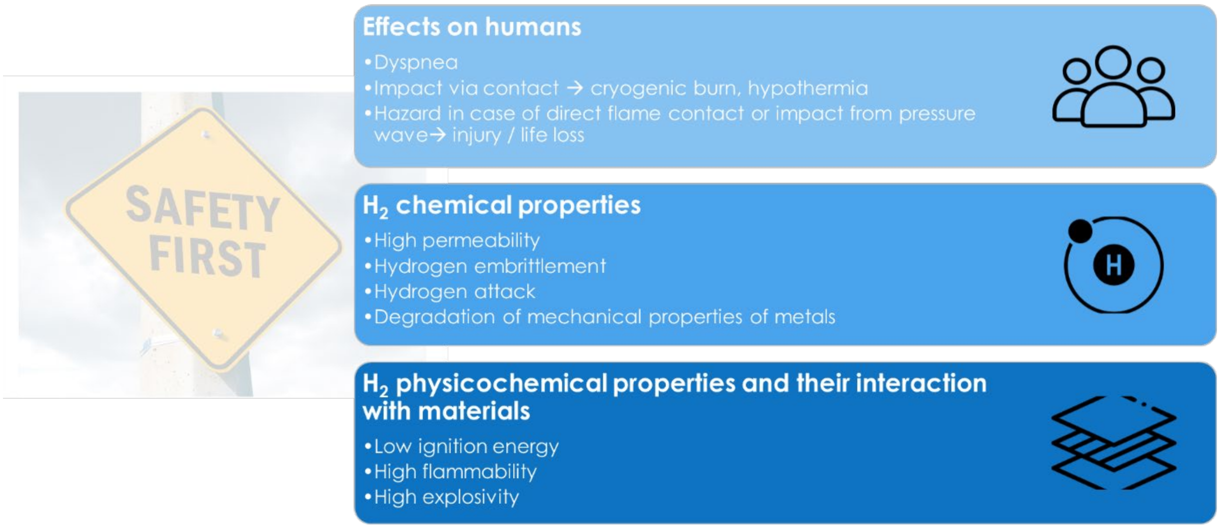


Figure 10 – IGF Code review: H_2 risks, source: DNV

The common causes (like the development of flammable and/or explosive mixture generation, without these being avoided or traced) and consequences (inhibition of propagation of events, e.g. from lack of protective barriers; fires and explosions; mechanical damage; material defects; impact via contact) were also considered.

Keeping in mind these risks, the e-SHyIPS consortium has reviewed the IGF Code chapter by chapter, asking itself, for every requirement, if there exist a gap related to H_2 risks.

This exercise has resulted in about 100 gaps, review by DNV and classified according IGF subcategory. The following tables present the gaps directly connected with project contributions by experimentation and ecosystem knowledge review.

Furthermore, it is important to point out that the target of this entire gap analysis has always been to suggest project partners' experimental plans and simulations for risk analysis, so that the experimental results could be translated into concrete suggestions for IGF Code updates (to be developed in WP6). For this reason, the gap analysis exercise has been completed with three workshops (2.5 hours each) in which the partners discussed about how and which Work Package (WP) could address those gaps. Also proposal for new sections / chapters of the Code have been included.

[17] As of December 29th, 2022.

The table below summarizes the results of this second step.

Table 14 – IGF Code review: step 2 results, source: e-SHyIPS consortium

Category	Sub-Category	Gaps and proposed actions	e-SHyIPS contribution
Arrangements and location	Safety barriers	Assess safe limits in case of grounding collision for all systems that involve H_2, including tank-fuel cell connection.	Qualitative comparative assessment based on literature review, SOLAS requisites, variant scales (WP2).
	Impact of stresses	Assess safe conditions for onboard storage, fuel handling, piping and tank-fuel cell connection under extreme weather conditions and ship motions (winter/snow, summer/extreme heat ingress), including requirements for insulation of double pipes. Assess propagation of strengths of tank supports to the tank and potential mechanical or thermodynamic impact.	Extreme weather conditions: assessment of heat ingress in pipes, tanks for various insulations (WP5). To be addressed also whether this item falls into scope of WP4. Ship motions: Case M - acceleration at different points of the ship/H_2 structure and the center of gravity in different point of the ship, at different sea states (WP2). Literature review on standards related to trucks, max shock estimation (TBC).
	Integrity loss	Assess requirements for fuel containment, handling and piping systems related to ignition and explosion avoidance (increased criticality compared to LNG).	To be assessed if it can be planned an experiment in WP3.
	Dispersion of fumes	Perform dispersion calculations and assess safety barriers needed in the case of open deck storage (gas and liquid). Avoid, if possible, fuel pipes in spaces where trailers/cars are present.	To be assessed if it can be planned an experiment in WP3. Fuel pipes at cargo spaces: suggested to include this item in the risk assessment (WP3).
Equipment and components	Containment technologies	Review of the relevance of different tank types to H_2. Review ISO 13985:2006 "Liquid hydrogen — Land vehicle fuel tanks" that could fit in the IGF code content. Assess the lifespan of maritime hydrogen containment systems and piping.	Review of the relevance of different tank types to H_2. Justification of the selection of specific tanks for the case studies (WP2). Describe a min level of analyses that are required to complete a fuel containment system risk assessment for hydrogen (WP3). Lifespan of H_2 containment: input can be taken from component manufacturers. In WP4, indirect assessment of contaminations over performance (WP3 input needed here).

Electrical equipment	Include explosion-proof certification and ATEX requirements for electrical components in H_2 systems. Electrical installations specifications should ensure no ignition sources in positions where H2 is present. Standard that provides requirements for equipment at explosive atmospheres are linked to Directive 2014/34/EU (ATEX). Revise electrical requirements to account for designs that a single fault would not result into a wider spectrum of failing conditions, not restricted only to the pressure maintenance of the tank, but listing all possible potential consequences. According to the IGF code, electric installations should be designed such that a single fault will not result in the loss of ability to maintain fuel tank pressures and hull structure temperature within normal operating limits. The IGF code requirement is related to liquid fuels, so is relevant to LH_2. However, for CGH_2, the requirement is not directly relevant, but shut-off valves have to be capable to operate, in case of power loss (either independent power source or special valves).	ATEX requirements review (WP6). Design of electrical systems and single fault allowance (WP3 for safety systems design – TBC).
Energy converted types and their auxiliaries	Include requirements for fuel cells and their auxiliary systems in the IGF code.	Inclusion of requirements for FCs and their auxiliary systems: to be addressed in WP6.
Fuel pumps	Assess whether a submerged fuel pump can be used in liquefied H_2 tanks.	Submerged pumps: to explore this gap and address through review (WP2 and WP5).
Hoses	Include protection against overpressure at the design of ship's fuel hoses.	To be addressed in WP5 system design.
Manifolds	Assess an acceptable level of leakage rate in case of no dry-disconnect of bunkering manifold connections.	TBE in WP5 and WP3.

	Pipelines	Assess the minimum acceptable pipeline diameter and operational pressure to satisfy technological requirements to mass flow rate. Assess safety barriers to mitigate risks related to formation of flammable mixtures, potential of ignition, fire/explosion, effects of external fires/events in piping systems.	Simulations with COSSMOS to evaluate flow rates during operations and bunkering (WP2, WP5). Comparative assessment against land-based standards. Safety barriers for formation of flammable mixture in WP3
	Valves	Assess preventive measures needed in the design of LH_2 and CGH_2 valves (risk-based approach). Ensure automatic operation, with the capacity to be operated manually in case of emergency. Assess the requirements for stresses on valves / max limits and Ultimate Design conditions. Check loads from ISO standards and assess any potential gaps (UNI EN ISO 21028-1:2016)	Preventive measures in design of LH_2 and CGH_2 (WP6 and WP3, TBE). Not necessarily an experiment, but a proposal to IGF code update. Information from land-based standards.
Fuel	Fuel quality	Assess hydrogen fuel quality requirements (that would apply e.g. for PEM fuel cells).	ISO standard on Fuel Quality: no need for simulations (WP6).
Goals and risk-based design	Goal	Include as functional goals of the fire safety systems the mitigation of events (that could trigger fire), the ignition control, and the maintenance of structural integrity.	Simulations in different conditions of ventilation / diffusion of vapors, as preventive control measure to avoid explosion (WP3). How results of the simulations could reach out to functional goals differences: current status, leakages not permissible; possible solution, use of CFD simulations (TBE). Review requirements related to class 2.1 package for the H_2 tanks in the S case scenario.
	Power and fuel redundancy	Develop a new concept for machinery, special for H_2 that includes requirements from both concepts, including redundancy of systems in case of blackout (hot/cold reserve). Assess redundancy in fuel supply and how this is handled in the case of LNG.	Machinery simulation in COSSMOS: assessment of reliability of different machinery configurations/accounting failures. Ultimate goal: deliver prescriptive requirements for machinery configuration, hybridization as a preventive measure (to assess), HAZID workshop results (WP3).

		Assess min required hydrogen capacity to perform operations and ensure safety onboard.	
	Risk-based design	Assess a list of hazards that an H_2 safe design should account for to ensure that all risks are met and mitigated.	Set-up of all HAZIDZ and RA during WP3 can help design that list. In WP6 refer to that list in the IGF code goals.
Materials and manufacture	Joints and testing	Land-based standards that could offer input for the IGF code update: UNI ISO 19880-1:2020 contains requirements for: testing, systems inspection and tests, pressure, leak, electrical, safety performance testing, e-training, technical documentation, inspection and maintenance planning. UNI ISO/TR 15916:2018: welded joints are preferred where leaks cannot be tolerated. Testing [14.5.1.1] all liquefied gas fuel tanks and process pressure vessels shall be subjected to hydrostatic or hydro-pneumatic pressure testing in accordance with 16.5.2 to 16.5.5, as applicable for the tank type.	In WP6 it may be proposed the development of a dedicated chapter with requirements related to Materials and manufacture for H_2 use and separated from piping systems. WP4 will test materials for fuel/FC sides, results may be used to enhance the above proposal: effects over lifetime.
	Material testing against fire protection	Materials used in onboard H_2 systems, (e.g. for insulation), need testing for fire protection sufficient for the case of H_2.	
Safety systems	Drainage	Assess material requirements to avoid cracking caused by contact with condensed air (no bituminus surfaces).	(WP6) To assess this gap based on knowledge gained from outside the consortium, reference to external sources.
	Emergency shut down	Assess the need of emergency shut down systems as a means to restrict fire propagation. Assess the avoidance of spurious shutdown (IGF code: 15.2.5) and how to recognize failures in instrumentation over the true fails e.g. in case of blackout. In this regard, a gap is identified on regarding the resilient design towards internal failures. H_2 safety systems follow a fail-proof design so they should either fulfil safety	(WP3) HAZID: to assess emergency shut down system as control measure to restrict fire propagation. (WP3) To assess whether this can be included as a prescriptive requirement for resilient instrumentation and control design. The case of spurious shutdown may happen in 2 cases. 1) an instrument failure. In this case, the solution could be similar to the one used with the interlock between the fire detectors and the firefighting systems, that at least two detectors

	requirements or allow safe shutdown.	detect a leak or a fire to activate the shutdown system. This is acceptable in the case discussed above, but there is still an open question whether this is acceptable with hydrogen (TBE if faceable in WP3). 2) A total system failure. In the case of a blackout, it is not clear whether the hydrogen transfer system should stop or if it is going to have an emergency power supply. If the system does not stop, the instrumentation may be powered from the same emergency system as the transfer system (TBE).
Explosion prevention	Update H_2 system design philosophy to accept a min level of risk that ensures, in case of a failure, that the effects are contained (e.g. avoid the progress of deflagration to detonation). Assess the explosion prevention design to account for design for min risk level and containment of effects, ignition prevention and mitigation of events' propagation.	(WP6) + (results of WP3): update H_2 system design philosophy to accept a min level of risk. Assess during HAZID whether different control measures are necessary or not, according to this approach. (WP6) + (results of WP3): consequence study providing with relation between risks vs measures (e.g. leaks vs ventilation). Consequence calculation to be prerequisite. Check this gap and proposed solutions with CEN TC 305 Chairman (member of e-SHyIPS AB).
Fire and gas detection and alarm system	Assess the need and features of hydrogen detectors and their instrumentation / control system (e.g., intervention time). Review the Interim guidelines for Fuel Cells regarding fire detection mechanism. UNI ISO/TR 15916:2018 defines requirements for safety systems per hazard and suggests measures/ways to minimize consequences, such that could support the development of procedures for hazards mitigation. Gap in the definition of fire detection, to extend to fire and gas detection.	(WP3) TBE if possible to use the CFD scenarios to assess behavior of a detection system (intervention time). Give input to design of detection systems. Moreover, as mentioned in "Handbook for Hydrogen-fuelled Vessels" by DNV, more research is needed on hydrogen fire detection technologies because currently there are many uncertainties, for example, with the UV optical sensors. TBE if it may be possible to consult external sources, like a detector manufacturer which has already done some testing. (WP6): change the definition of fire detection, to extend to fire and gas detection.

Fire main	Update goals of fire safety systems: (a) fighting of a fire not caused by H_2; and (b) fighting of a fire caused in a system where H_2 is leaking. Update IGF code with regards to fire safety systems. UNI ISO/TR 15916:2018 provides general remarks on safety characteristics, incl. flammability and detonation limits, H_2 properties, dispersion behavior, flammability and detonation limits.	(WP6) + (WP3) assess in WP3 HAZID whether the same preventive measures and controlling measures can mitigate risks. Assess whether a suggestion to update goals of fire safety systems is relevant: (a) fighting of a fire not caused by H_2; and (b) fighting of a fire caused in a system where H_2 is leaking. In WP6, reconsider this statement according to experiment results and propose an update of the IGF code with regards to fire safety systems.

Further gaps identified which will be deepened in WP6, in order to define experimental plans to address them, are summarized in the table below.

Table 15 – IGF Code review: step 2 further results, source: e-SHyIPS consortium

Category	**Sub-Category**	**Gaps and proposed actions**
Safety systems	Fire propagation avoidance	Assess safety measures for risk mitigation related to formation of flammable mixtures, potential of ignition, fire/explosion, effects of external fires/events. Assess the requirements for space separation, to avoid cross contamination and fire propagation: H_2 fire occurs at higher temperature compared to LNG. Standard flame tests of A-60 materials may not cover temperatures related to H2 flames. In case of jet flames, A-60 boundaries may not be sufficient. Concentration of flame in certain points may cause these boundaries to loose integrity. Higher capacity boundaries need to be assessed. Assess the need of supportive measures in case of non-visible flame and the ignition control. Assess the need of fire boards and segregation systems.
	Fire-extinguishing system	Assess suitability of different firefighting materials, attention may be needed to the material-sensitive requirements. This depending on the level of the phenomenon (deflagration/detonation/etc.).

Hazardous area zones, area classification and distances	Assess requirements for crew and passenger areas, including safe distances from H_2 systems and safety barriers, proper engine room and storage tanks location. Assess requirements for separations between compartments - not necessarily a single bulkhead. Assess requirements and safety barriers that would allow tank location below deck. Assess the area definition and distances of hazardous zones, as protective measures for handling H_2 risks during bunkering. Prescriptive requirements on zones and distances are given in IEC standard / IEC 60079-10-1:2020 version. Assess levels of isolation from oxidizers, hazardous materials, and other equipment. Check the definition of zones and compare with the scope of the FC interim guideline. Assess the conditions to maintain gas safe machinery space (get info from UNI ISO/TR 15916:2018, consider gastight external enclosure for fuel cells, flat surface on the top to avoid fumes accumulation).
Labelling	Assess requirements for labelling, Warning signs, equipment marking.
Leakage of gas	Requirements regarding the GHG potential of methane, e.g. gas leakage treatment, are irrelevant to H_2.
Leakage of gas	Assess safety measures for risk mitigation related to formation of flammable mixtures, potential of ignition, fire/explosion, effects of external fires/events. Assess H_2 dispersion behavior (UNI ISO/TR 15916:2018). Assess systems for protection from condensation of air from fuel leakage. Assess measures to avoid the formation of pockets of liquid in the pipes, e.g. through purging of the pipes. Assess requirements in IGF code chapter 15 regarding bunkering and liquefied gas fuel tank monitoring and control.
Pressure relief systems	Assess the insulation features for storage vessels and piping. Assess the fire resistance systems at the area of the storage vessel and piping. Assess the boil-off treatment system. Assess means of protection against over pressurization with a pressure-relief system.

		Assess requirements for fuel pressure management, including effect of ship motions, and shock vibrations. Assess passive or active measures to control acceleration. Assess acceptable methods for the marine environment to maintain pressure and temperature in H2 tanks and piping systems (UNI ISO/TR 15916:2018) and boil-off management systems, including relief valve types. Assess requirements for cryogenic systems (UNI ISO/TR 15916:2018).
	Safety systems arrangement	Follow-up on requirements for safety functions arrangements and independency (IGF code: 15.2.4), based on criticality. The definition of independency is probably loose, so there is a need to investigate whether this covers: component separation, control/ monitoring/ power systems separation.
	Ventilation	Assess detection and ventilation requirements to avoid unburnt fuel environment generation. Review the Interim Guidelines for FCs. Assess requirements for ventilation depending on purpose of a particular space / compartment (e.g. machinery use, etc.). Update requirements about ventilation rates and safety limits. Enforce ventilation requirement for all spaces involving H2 gas, e.g. fuel storage, preparation, ducts, pipes, etc.
Safety systems, Operating procedures	Inerting / purging / Gas freeing / Explosion venting / Venting processes	Assess H_2 purging and inerting systems/materials/process specifications, including the design and the procedural steps. Assess the necessary level of pressurization of pipes to avoid risks of contamination. Assess the need of separate venting for all gas consumers, in conjunction with the IMO interim guidelines for FCs. Make considerations for variant cases, e.g. that of distributed fuel cells at different ship positions. Assessment of explosion venting design to avoid jet-fire development and detonation. Assess requirements about venting insulation and mast dimensions and properties. Assess design specifications to avoid deflagration (ignition could produce deflagration, subsonic propagating flame) and especially the progress towards detonation in congested geometries. Design for detonation is an extreme condition, whereas a design for control of any range

		between deflagration conditions is expected, with primary focus on proper venting. Assess the inclusion of H_2 gas concentration detectors.
Other	Events, functionalities, training	Land-based standards that could offer input for the IGF code update: UNI ISO/TR 15916:2018: examples of extreme events. PPE and training staff. UNI ISO 19880-1:2020: emergency shutdown functionalities, emergency response plans, training, technical documentation, inspection and maintenance planning, PPE and training staff.

The following section addresses the open questions and presents the next steps of e-SHyIPS IGF Code review.

5.4 IGF Code review: open questions and next steps

The gap analysis carried out by e-SHyIPS project made it clear that some current requirements of IGF Code are not suitable for H_2 and the structure itself needs to be reviewed to account for this fuel specific features and technologies.

Many land-based standards may be a good starting point for a bottom-up approach (and in line with CEN CENELEC attitude), but further pre-normative research is required, even to cope with the most recent technological developments that some standards have still not embedded. Indeed, it is not easy to transfer directly their technical requirements to the maritime sector since the key process for installation of hydrogen on board is the identification of hazards (as part of the risk assessment) and this have to be ship-specific. IMO should define the framework but, as on IGF Code, the assessment must be done ship by ship considering type, range, autonomy, human elements and everything that make application on board unique from all other means of transport (starting from the size and volume of hydrogen to be used).

Moreover, about the technology, it is clear that there are many open questions regarding safety of ships using fuel cells. Some of these open questions have been included in Tables 14 and 15, when it comes to fire detection, explosive atmosphere, fire extinguishing and structural fire protection.

Starting in 2023, e-SHYIPS consortium will follow-up this analysis, concretizing as much as possible the contributions it would like to give to close the gaps identified and exploring which further contributions it may give to deepen also the safety systems gaps.

The results will be gathered in a strategic roadmap (developed within WP6) that would represent the advice of the hydrogen and maritime experts to the sector with the scope of supporting the update of the IGF Code, with a particular attention to safety.

E-SHyIPS will try to reach IMO (through a Flag administration) to make its contribution effective.

6. Conclusions

Finally, here a recap[18] of what's ongoing and what we should expect in the next future of hydrogen applications to the maritime sector.

- **Standards and Regulations:** existing LH_2 standards are mainly based on knowledge developed in the 1970's.
    - Available documents are mostly based on NFPA 55 "Compressed Gases and Cryogenic Fluids Code", which is aimed at facilitating protection from physiological, over-pressurization, explosive, and flammability hazards associated with compressed gases and cryogenic fluids.
    - Several activities are underway now in:
        - **IMO**:
            - Interim Guidelines for safety of ships using fuel cells (finalized 2021);
            - Interim Guidelines for safety of ships using Hydrogen as fuel (initiated in 2022);
            - Carbon Intensity Index (CII) and EEXI;
            - Life Cycle Analysis Guidelines (proposal)
            - Low GHG Fuel Standard – LGFS (proposal)
        - **EU:**
            - FuelEU regulation proposal – promotion of renewable and low-carbon fuels in the maritime sector including: 1) reduction Targets for GHG intensity of energy used onboard; 2) mandate for zero-emissions at berth; 3) pooling Mechanism – reward for "over-achievers".
            - AFIR – Alternative Fuels Infrastructure Regulations (standardization mandate – hydrogen bunkering).
            - ETS extension to maritime sector.
            - RED revision (RED III) - renewable hydrogen/ RFNBO.

    - **Laws and New Initiatives**
        - March 2020, first EU Climate law. Aimed to transform into law the goals set out in the European Green Deal.

[18] Main considerations from SFEM Workshop 03.02.2022.

E-SHyIPS is a project funded by the European Union Framework Programme for Research and Innovation Horizon 2020 under GA n. 101007226

- 2030 Climate Target Plan: the Commission aims at cutting EU GHG emissions by at least 55% in 2030 and to become climate neutral in 2050[19].
- Recently, the Commission proposed the Fit 55 package implement the targets.

- **Further initiatives**:
  - **US**: (Sandia National Laboratory) revision of NFPA 55 [35], new separation distances.
  - **EU**: European Commission has a mandate in preparation to require CEN developing standards on LH_2 interoperability.

H_2 represents certainly a valid ally to reach the zero-carbon target in the maritime sector. It can leverage on renewable electricity storage for long-term energy use; technology transfer; good potential for multi-modal synergies – and cross sector applications; and good "state-of-the-art" technology with new innovative business case developments. Nonetheless it needs to cope with several challenges when it comes to the maritime sector: it is important to be aware that a Life Cycle Assessment for zero-emissions will be required; there are still many knowledge gaps related to ship design and integration, risk assessment and storage on board (among others). These challenges are paired with relevant threats that hamper H_2 implementation in the maritime sector, above all, the proliferation of "tailor-made" solutions and the lack of standardization initiatives with a low industry involvement. The way the market will face these threats will determine the competitiveness of H_2 above other fuels. Still, the international market is offering interesting opportunities (FuelEU, AFIR and green corridors, IMO GHG reduction strategy) that make clear and unavoidable the path the market is expected to take. [36]

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8. Annexes

[1] Table of Content ISO/TR 15916:2015 Basic considerations for the safety of hydrogen systems – source: ISO

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