Ref. Ares(2021)8010965 - 30/12/2021

D3.1 – Preliminary Safety Systems Definition

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Document info

Document Identifier: e-SHyIPS_D3.1_final.doc (.pdf)

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Deliverable No.:	D3.1
Work Package No.:	3
Date:	22/11/2021
Project No.:	101007226
Classification:	Public
File name:	e-SHyIPS_Deliverable 3.1
Number of pages:	38

Action	By	Date (dd/mm/yyyy)
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Revision History

Date	Revision version	Author	Comments
26/11/2021	00	GHENOVA	First Version
09/12/2021	01	WOIKOSKI	Internal Peer Review
09/12/2021	02	CINECA	Internal Peer Review
16/12/2021	03	GHENOVA	Internal Review
22/12/2021	04	GHENOVA	Final Version
23/12/2021	05	POLIMI	Submitted

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Dissemination level

Public, PU

Disclaimer

Acknowledgements

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 101007226. This JU receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe Research.

The project consortium is composed by: Politecnico di Milano, UNI Ente Italiano Di Normazione, Teknologian Tutkimuskeskus VTT OY, CINECA Consorzio Interuniversitario, ATENA scarl - Distretto Alta Tecnologia Energia Ambiente, Proton Motor Fuel Cell, Levante Ferries Naftiki Etaireia, Ghenova Ingenieria SL, Danaos Shipping Company Limited, OY Woikoski AB, DF - Ingegneria del Fuoco srl, Dimos Andravidas-kyllinis DNV GL Hellas sa, Scheepswerf Damen Gorinchem.

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

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1. Executive Summary

As indicated in D1.1, "Project Concept Functional Scenarios Definition and Initial Safety Plan", the e-SHyIPS project aims to define new guidelines for effective deployment of hydrogen in the 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 of 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.

The aim of this deliverable, entitled "Preliminary Safety Systems Definition", is to present the current Safety Strategy, as the starting point in the Definition of Onboard Safety Systems, to be considered into the Ship Design for each Use Case.

It´s part of the Safety Plan which embraces the whole e-SHyIPS Project, but more focussed on the Systems Design.

The common framework of these uses cases is the deployment of Hydrogen (Compressed H_2 - CH_2 - or Liquefied H_2 – LH_2) from storage to energy conversion onboard through Fuel Cells. Due to the complexity of this task, not all the potential solutions are being considered (Other H_2 based Fuels, Reformer, Internal Combustion Engines…).

Due to the complexity and maturity of new technologies, this Task is being developed in parallel to the definition of Technical Requirements and Preliminary Ship Design for each use case.

The e-SHyIPS Project presents three functional concept scenarios (see D1.1) developed during its first stage: they have been discussed and validated by the Advisory Board experts, to foster the work and research panned for the project and enable practical experiments to be planned.

The Scenarios definition has been set according to the growing market demands for each vessel size. More specifically:

- Scenario S describes inland waterways vessels as widespread means of transport, especially in geographic areas such as Northern Europe;
- Scenario M represents the roll-on-roll-off vessels that are still very recommended due to the global freight and passenger market growth.
- Scenario L addresses a rising target: the luxury cruise ship in the Mediterranean and Baltic-North Sea.

As specific prescriptive rules and regulations are not yet in place for the use of hydrogen as a marine fuel, the initial safety plan, included in D1.1, considered both the "Alternative Design" approach and the reference documents from EU H_2 flagship projects and regulatory and standardisation state of the art. The initial safety plan section highlights the preliminary knowledge about hazards, risks, and possible countermeasures from a global view of the Project.

Furthermore, this safety plan frames a strategy for the generation of safe and robust designs through identification of risks and uncertainties arising from the use of H_2 fuels that could affect the structural strength or the integrity of the ship, systems and/or equipment, safety of onboard for crew and passengers, and the preservation of the environment. The Preliminary Safety Systems Definition will be the result of these studies and procedures applied to the design of the different Hydrogen Systems onboard.

The three scenarios and the safety plan strategies will be deeply studied along the whole project to develop a pre-standard normative plan intended to be applied to as many passenger ferries as possible to maximise the impact of the new knowledge creation.

2. Introduction

2.1 Scope and Objectives

The present deliverable D3.1"Preliminary Safety Systems Definition" is related to Task 3.3, "Safety Systems Definition and Preliminary Design", which is integrated into WP3 "Safety Systems Experiments".

During the development of the Project, Risk Safety Engineering will be performed in strict relation to Safety Plan (or more general Safety Management Strategy Plan). Safety Systems will be finally defined for systems as Ventilation, Gas detection, Fire detection, Fuel Storage, piping and consumers as Fuel Cells and, in general, all the H_2 systems on-board according the design from WP2.

The gathered knowledge in the WP3 will finally contribute to definition of pre-standards about safety systems in WP6.

Regarding Task 3.3 and related D3.1, according to the selected Fuel Cell technology and considering Preliminary Ship Design and experiments (currently under discussion into WP2) as well as Regulation, State of the Art and Theoretical Studies (WP1), as well as Safety Systems Experiments (WP3), the different safety systems related to H_2 installations will be defined.

As this preliminary design won´t be completed until month 24, the present D3.1 will be focused on the procedure to be followed for the Safety Systems Definition as well as main topics related to the Safety Systems associated with the deployment of Hydrogen Systems in the Ship Design for each use case. This approach will be more global at this moment and should be more specified in the next stages, once the Hydrogen Systems and Equipment could have a more accurate definition.

2.2 Connection with other deliverables

The present deliverable is developed within Task 3.3 which will define the Safety Systems Preliminary Design. It will depend on current applicable regulation, the use cases defined in the project and the ongoing preliminary design of each ship corresponding to each use case including potential connections and/or development with CFD´s tasks, among others.

Consequently, this deliverable will have a clear connection with the D1.1 and scenarios definition as well as a state of the art, especially regarding safety regulatory and standardisation framework (D1.3 & D1.4). In table 1, different deliverables with direct connection with D3.1 are shown. Due date of several of them is Month 24, M24 of the Project (current one is M12) which could be a handicap for a proper definition of the safety systems on board, as they will be inputs to be considered.

But, as it will be explained in this deliverable, it is important to introduce a safety perspective from the beginning of the project, to validate the design when feasible and/or to support it as a tool into the "Alternative Design" when the maturity of the technology or regulation could require it.

Deliv. N°	Deliverable Title	WP	Lead Beneficiary	Type	Dissemination Level	Due Date Month
D1.1	Project concept functional scenarios definition and initial safety plan	1	1-POLIMI	Report	Confidential	8
D1.3	State of the art of Safety Standardization Report	1	1-POLIMI	Report	Confidential	24
D1.4	State of the art of safety technical framework and updated risk & safety assessment and plan	1	1-POLIMI	Report	Public	24
D2.1	Functional and Technical Requirements for scenario report	2	1-POLIMI	Report	Confidential	12
D2.2	Description of the LincoSim HPC Simulation platform	2	4 - CINECA	Report	Public	12
D2.4	Preliminary vessel design for each scenario	2	1-POLIMI	Demonstrator	Confidential, only for members of the consortium (including The Commission Services)	24
D2.5	H_2-based fuel propulsion system basic design technical report	2	1-POLIMI	Report	Confidential, only for members of the consortium (including The Commission Services)	24
D5.1	Functional, Technical and Operational Requirements report	5	7- LEVANTE	Report	Public	12

D5.2	Fuel delivery and bunkering solutions for ships - initial results	5	10 - WOIKOSKI	Report	Public	12

Table 1. Connection with other deliverables

Task 3.1 “Guidelines on handling emergency hydrogen discharge or major leak outside the ship. Flow-Paths1” as well as Task 3.2, “Simulation of flammable dispersion on-board and Explosion. Flow-Paths2” will be also significant inputs for the final definition of the safety systems but they won´t contribute yet to this preliminary deliverable.

2.3 *Structure of the document*

The present deliverable will try to be descriptive and self-explanatory along with its structure, which will include as main sections:

- Safety
- Regulation / Standardization
- Preliminary Safety Systems.

The objective is to go from the global view and aspects involved in this project to the specific aim which is the Safety Systems Definition related to the deployment of Hydrogen systems and equipment onboard.

Safety will describe the transversal role of this field along with the whole e-SHyIPS Project, from H_2 particulars to Safety Engineering procedures and Tools.

The second section illustrates the existing regulating framework and its gaps for the deployment of hydrogen-based fuel passenger vessels, as well as the lack of standardization.

The third one will focus on the Safety Systems onboard from a preliminary study of the project scenarios (from the Ship Systems). In the next months with the development of design requirements and the preliminary design itself, it will be possible a deeper study and definition of such systems.

3. Safety

In D1.1 Criterion 4, "Safety engineering strategy information", was introduced, indicating that, compared to the traditional carbon-based fuels, Hydrogen-based propulsion will require different control, monitoring and safety strategies. It will involve a literature review, regulation, ship design and also new studies and experiments to be developed during the project.

From a regulation point of view, IMO IGF Code is a significant input, but it is Natural Gas based on document while there are important differences in safety-related properties between natural gas and hydrogen gas (as well as for LNG and liquefied hydrogen (LH_2).

For instance, the selection of materials to work with Hydrogen technology should consider safety issues including, among others, the potential for embrittlement of materials, hydrogen permeation, extremely low temperature properties, and the possibility of electrostatic build-up and discharge.

In general, the properties of hydrogen should be considered instead of those of Natural Gas, in contrast with what the current IGF Code covers.

3.1 Hydrogen Particulars

Usually, pure hydrogen is obtained from methane (natural gas) or water (e.g., via electrolysis). Among others, Hydrogen main particulars at standard conditions include:

- Non-toxicity.
- Colourless, Tasteless and Odourless.
- Wide flammability range (flammable gas due to its very low activation and ignition energy).
- Low density.
- High energy content per mass compared to other chemical fuels (120.2 MJ/kg).
- Low volumetric energy density.

In the case of a Fuel Cell usage scenario, without fuel reforming, greenhouse gases are not emitted. This is the reason why it is the first option to be considered for the e-SHyIPS Project.

In case of reforming from hydrogen-based fuel, greenhouse emissions should be considered. On the other hand, Hydrogen could be also consumed in Internal Combustion Engines, reducing such emissions (dual fuels) or with zero emission in the case of only pure Hydrogen consumption.

But hydrogen systems deployment in shipping also implies significant challenges and requirements related mainly to:

- Materials (hydrogen Embrittlement).
- Storage (for long routes ships).
- Fuel supply systems.
- Fuel Cell Output Power Ranges.

- Hazards (Ignition, Fire, flame detection, explosions….).
- Ventilation issues.
- Low boiling temperature (LH$_2$).
- Bunkering infrastructure.
- Costs.

3.1.1 3.1.1 Hydrogen as marine fuel

Hydrogen is characterized by having a higher energy content per mass than other marine fuels (120 MJ/kg). Hydrogen fuel can increase the effective efficiency of powertrains. However, on a volumetric basis, due to its lower volumetric energy density, liquid hydrogen may require four times more volume than MGO for an equivalent amount of carried energy or two times more space than LNG.

	UNIT	HYDROGEN	MGO	HEAVY FUEL OIL (HFO)	METHANE (LNG)	ETHANE	PROPANE	BUTANE	DIMETHYL-ETHER (DME)	METHANOL	ETHANOL	AMMONIA
Boiling Point	° C	-253	180-360	180-360	-161	-89	-43	-1	-25	65	78	-33
Density	Kg/m^3	70.8	900	991	430	570	500	600	670	790	790	696
Lower Heating Value	MJ/Kg	120	42.7	40.2	48	47.8	46.3	45.7	28.7	19.9	26.8	22.5
Auto Ignition Temperature	° C	585	250	250	537	515	470	365	350	450	420	630
Flashpoint	° C	-	>60	>60	-188	-135	-104	-60	-41	11	16	132
Energy Density Liquid (H$_2$ Gas at 700 bar)	MJ/L	8.51 (4.8)	38.4	39.8	20.6	27.2	23.2	27.4	19.2	15.7	21.2	15.7
Compared Volume to MGO (H$_2$ Gas at 700 bar)		4.51 (7.98)	1.00	0.96	1.86	1.41	1.66	1.40	2.00	2.45	1.81	2.45

Table 2. Properties of Hydrogen Compared to Other Marine Fuels. *Source: Hydrogen as Marine Fuel. American Bureau of Shipping (ABS). June 2021*

The requirements for the storage of hydrogen in a liquefied or gaseous form need to be considered at the concept stage. It will depend on the ship type and will drive the installation of appropriate high-pressure storage tanks or low-temperature containment arrangements. Liquefied Hydrogen requires very low temperatures, below -253° C, which means new energy consumptions as well as new required volume and weights considering the necessary layers of materials or vacuum insulation for cryogenic storage and other structural arrangements. The following pictures and tables show the main challenges of H2 based fuels.

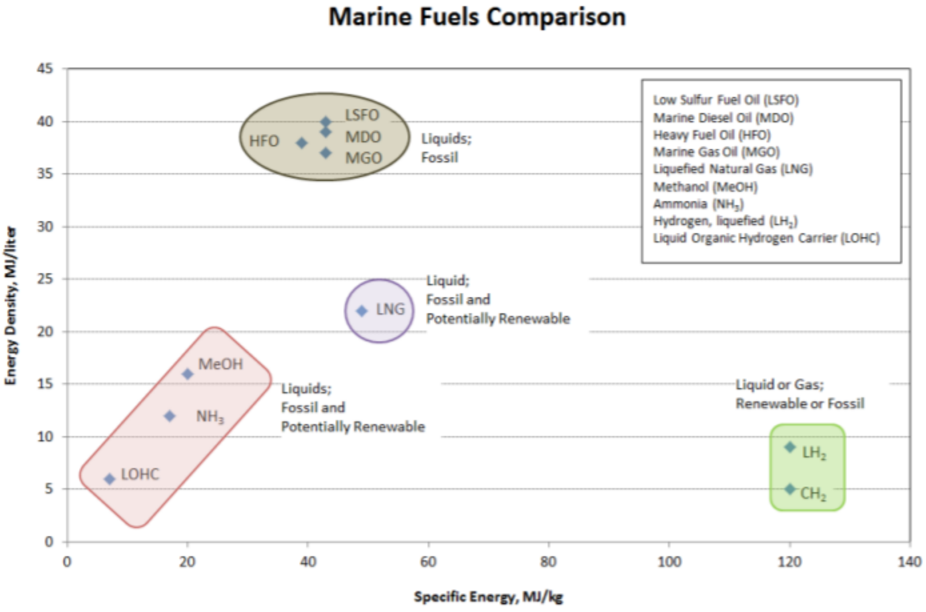

Figure 1. Marine Fuels Comparison

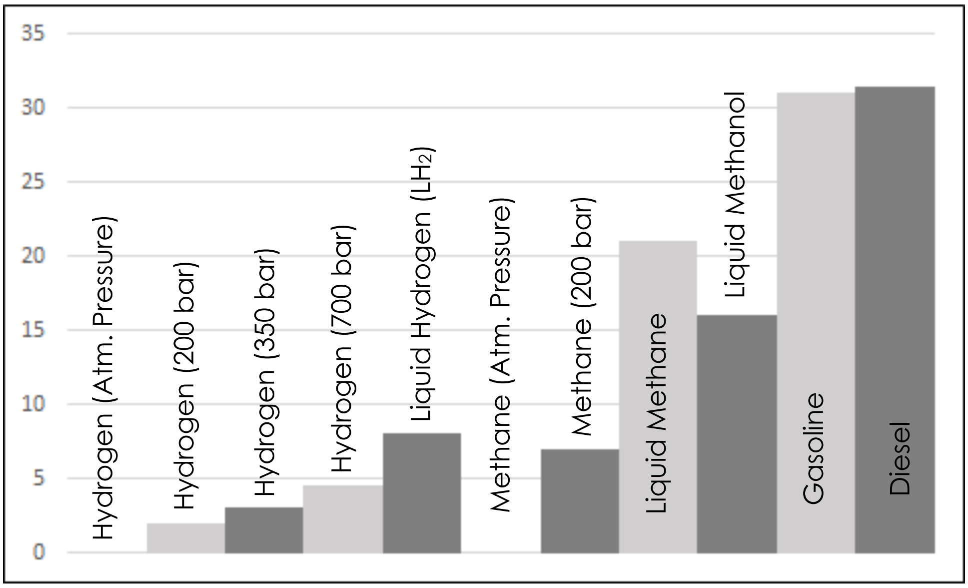

Figure 2. Energy densities

As indicated in 3.1, pure Hydrogen and hydrogen carrier fuels can be consumed in fuel cells generating "zero-emission" electricity. There are several types of fuel cells but in general, they will consume hydrogen and oxygen and they will generate heat, water, and electricity.

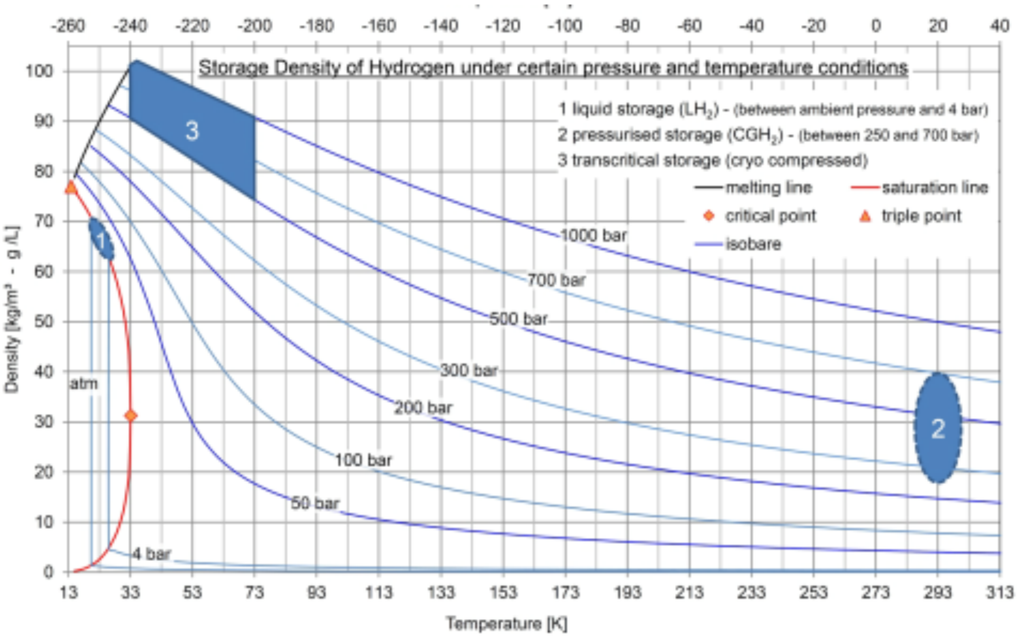

Figure 3. Storage Density of Hydrogen

The following table summarizes some relative benefits and challenges of using hydrogen as marine fuel:

BENEFITS	CHALLENGES
• Carbon and sulphur free. • Can be produced renewably from electrical energy and bio-renewable processes. • Can be stored and transported as a liquid or gas. • Established commercial product on land. • Gaseous, particulate matter and GHG free emissions with fuel cells. • Highly buoyant and disperses If leaked, even at liquid hydrogen temperatures. • Gravimetric Energy density. • Potential Blending in ICEs.	• Lack of marine transport experience. • Possible high fuel cost. • Low availability of renewable produced hydrogen. • Fuel infrastructure and bunkering need investment. • Novel power generation system will require more technology innovation and cost reductions. • High explosion risk in confined spaces. • Low cryogenic temperature challenges (storage, management, leaks, etc.). • Material challenges (permeability, hydrogen embrittlement, etc.). • NOx emissions if burning hydrogen in internal combustion engines (NH3) • Safety Issues • Energy Denisty (Volume). • Volume and weight of storage tanks.

Table 3. Benefits and Challenges of Using Hydrogen as Marine Fuel. (Partially) Source: *Hydrogen as Marine Fuel. American Bureau of Shipping (ABS). June 2021*

3.2 Safety Engineering

As indicated in DNV whitepaper, “Closing the Safety Gap in an era of Transformation”:

“…. we choose to define safety as an emergent property of maritime systems that are robust, resilient, and have a process in place for continuous improvement. Safety as an emergent property means it is greater than the sum of its parts. A system is considered to be a set of human, organizational, and/or technical elements that can achieve things together that each component part cannot accomplish alone….”

Chapter 4 of the IGF Code Part A tries to ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship. It provides details regarding risk assessment and explosion consequences (this will be explained in Section “Risk Assessment”).

To reach this objective of risk management, Safety Engineering will be required. System Safety Engineering is the engineering discipline that will employ specialized knowledge and skills in applying scientific and engineering principles (recognized and accepted ones), criteria, and techniques to identify hazards. Then, through Safety Engineering Studies the hazards will be eliminated, or the associated risks will be mitigated when the hazards cannot be completely eliminated.

It introduces new requirements for design and systems engineering, taking into account the potential risks, verification and validation of effective mitigation, and residual risk acceptance by certification or approval authorities. It identifies and analyses behavioural and interface requirements, the design architecture, and the human interface within the context of both systems and systems of systems (SoS).

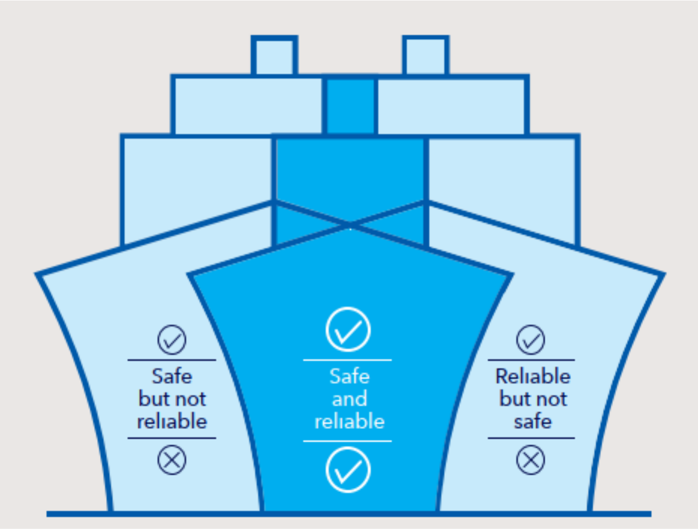

Figure 4. DNV picture Safety & Reliability approach

3.2.1 3.2.1 Hydrogen and Safety

Any project involving hydrogen systems onboard should consider H_2 properties and safety considerations mentioned above. It will have an impact not only on storage, fuel transfer systems, bunkering or powering systems, but also on the structure of the vessel up to the architecture and layout of the ship.

Safetyrelated Hydrogen properties and operation aspects that should require special attention include:

- Low ignition energy (0.0019 mJ).
- Static Electricity Spark (1 mJ).
- Wide flammability range.
- Potentially explosive.
- Hydrogen explosion could be a secondary consequence from a hydrogen leak (and ignition) in an enclosed space, and this scenario might for certain conditions lead to high explosion overpressures.
- Hydrogen gas is a lot lighter than methane. This can be both an advantage and a challenge and it needs to be considered in the design of hydrogen systems because it will be easily leaky and diffusion should be considered.
- Properties of hydrogen need to be considered when selecting materials that will be in contact with hydrogen (e.g. to avoid hydrogen embrittlement and unwanted leaks).
- LH_2 Leakages would produce embrittlement of carbon steel, H_2 vapours denser than the air, freezing of the air or O_2 doped.
- Low Volumetric energy density implies storage solutions at high pressures (up to 700 bar) or very low temperature (LH_2, -253°C)
- Catastrophic rupture of pressurized storage tanks would release huge energy. It will drive the type and location of tanks as well as the structure.

All these aspects should be considered during the design stage (even during preliminary design).

3.3 *Risk Assessment (general).*

Due to the relatively new deployment of associated hydrogen technologies related to Hydrogen powering onboard, as well as Hydrogen properties and peculiarities, risk assessment is required to verify that the system is appropriately safe and can exhibit at least an equivalent level of safety as conventional fuel systems and gas applications. Well-structured risk assessments are important to identify, control and mitigate the potential risks related to hydrogen systems.

As indicated, the primary object of the risk assessment is to identify risks arising from the use of hydrogen affecting the structural strength or the integrity of the ship, safety of crew on board, and preservation of the environment. Consideration should be given to the hazards associated with physical layout, operation and maintenance following any reasonably foreseeable failure.

The methodology used to develop the risk assessment has been based on the IEC 31010 – Risk Management – Risk Assessment Techniques. The following figure shows the risk assessment process, where the process of risk identification, risk analysis and risk evaluation are being included.

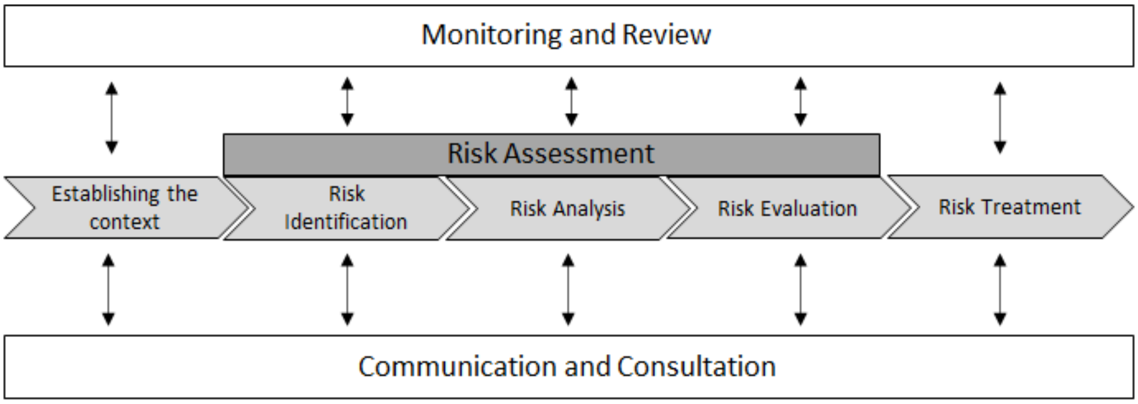

Figure 5. Contribution of risk assessment to the risk management process. *Source: IEC 31010 – Risk Management – Risk Assessment Techniques*

The following paragraphs describe the different steps embedded in the risk management process.

3.4 Risk Identification

Risk identification is the process of finding, recognizing and recording risks.

The purpose of risk identification is to identify what might happen or what situations might exist that might affect the achievement of the objectives of the system or organization. Once a risk is identified, the organization should identify any existing controls such as design features, people, processes and systems.

The risk identification process includes identifying the causes and source of the risk, events, situations or circumstances which could have a material impact upon objectives and the nature of that impact.

3.5 Risk Analysis

Risk analysis consists of determining the consequences and their probabilities for identified risk events, taking into account the presence and the effectiveness of any existing controls.

Methods used in analysing risks can be qualitative, semi-quantitative or quantitative. The degree of detail required will depend upon the particular application, the availability of reliable data and the decision-making needs of the organization.

3.6 Risk Evaluation

Risk evaluation involves comparing estimated levels of risk with risk criteria defined when the context was established, in order to determine the significance of the level and type of risk.

The decision about whether and how to treat the risk may depend on the costs and benefits of taking the risk and the costs and benefits of implementing improved controls. A common approach is to divide risks into three bands as shown in the following figure:

Figure 6. ALARP Triangle. *Source: https://www.ep-consult.co.uk/*

- An upper band where the level of risk is regarded as intolerable whatever benefits the activity may bring, and risk treatment is essential whatever its cost;
- A middle band where costs and benefits, are taken into account and opportunities balanced against potential consequences;
- A lower band where the level of risk is regarded as negligible, or so small that no risk treatment measures are needed.

The ALARP (As Low As Reasonably Practicable) principle used in safety applications follows this approach, where, in the middle band, there is a sliding scale for low risks where costs and benefits can be directly compared, whereas for high risks the potential for harm must be reduced until the cost of further reduction is entirely disproportionate to the safety benefit gained.

3.7 *Safety Distances / Hazardous Areas*

Prescribed criteria for safety distances are normally developed by standardization committees by standards or codes.

A hazardous zone/distance is the research result for a specific design or project.

References are relatively poor yet and non-public regarding Hydrogen Power Ships.

As indicated in DNV "Handbook for Hydrogen Fuelled vessels", within ISO:

- A key purpose of safety distances is to prevent escalation of minor events to major events and prevent direct harm to people".
- Safety distances are therefore not intended to safeguard against catastrophic events"
- Consequently, safety distances are not used or considered applicable as a risk-mitigation measure for low probability, high-consequence events. It may then be reasonable to ask to what degree it is relevant to apply safety

distances for hydrogen applications where explosion events cannot be disregarded".

- Therefore, Hazardous Areas, safety and security zones shall be established and aligned according to the behaviour, dispersion and ignition characteristics /mechanism of hydrogen.
- Hazardous Area is an area in which an explosive gas atmosphere is or may be expected to be present in quantities such as to require special precautions for the construction, installation, and use of equipment.
- The objectives for Hazardous Area implementation are:
    - To allow the definition of adequate measures to mitigate fire and/or explosion risk in areas where a probability frequency for flammability/explosion conditions is known in advance.
    - To develop the necessary safeguards against fire and explosion originated in know flammable atmosphere sources.
    - Elimination of ignition sources in the classified areas.
    - Minimization of the personnel involved in hazardous classified zones to the essential for safe operation.
    - To restrict the use of electrical equipment to certified Ex-proof equipment type. Different equipment will be subject to specific protection types (corresponding to different parts of IEC EN 60079).
    - To allow for safe design even when the presence of flammable/explosive atmosphere cannot be completely eliminated.

It is uncertain to what degree existing gas standards are applicable for hydrogen-fuelled ships, therefore, CFD modelling and gas dispersion analysis (to be proposed into WP3) could be used to determine case by case hazardous zones. Should the quality of the model, the assumptions made, the grid refinement or the convergence study, amongst other aspects relevant to the CFD, be accurate enough, a proposal for a hazardous zone could be supported based on this analysis.

In addition to the hazardous areas, during bunkering operations, safety zones must be established around the bunkering stations prior to hydrogen bunkering operations. The Safety Zone is an area around the bunkering station/facilities to control ignition sources and ensure that only essential personnel and activities are allowed in the area that could be exposed to flammable gas in case of accidental release of or another incident involving hydrogen during bunkering.

Prior to determination of a specific safety zone at a terminal, vapour dispersion data should be calculated for the largest credible leak, based on a risk assessment. The safety zone should never be smaller than the hazardous area distances stated for the receiving vessel, bunker barge, terminal facility or truck.

A Security Zone must be defined and established around the hydrogen bunkering area to monitor and control external activities (e.g., ship movements or vehicles that can lead to incidents that threaten the operation). The security zone may result in limit access for personnel and/or public and it will always be larger than the safety zone.

Prior the operation starts the security zone has to be communicated to all parties it may concern such as adjacent terminals, other vessels and the Port Authority.

4. Regulation / Standardization Framework

The three levels to be considered in this section are:

- International regulations.
- National regulations.
- Class rules.

IMO. The main international actor regarding Regulation / Standardization for Safety in the Maritime Environment is the International Maritime Organization (IMO). Its regulatory framework covers from design to operation.

The preliminary or minimum requirements globally accepted for the construction and operation of the ships are defined by SOLAS, and commercial vessels should comply with this Convention.

Classification Societies. In addition to SOLAS requirements, SOLAS also establish that the design, construction and maintenance of each vessel should fulfil Classification Societies requirements.

IGF Code (IGF Code, 2016). It provides the regulatory framework for the adaptation of low-flashpoint marine fuels (like hydrogen). But it is based on Natural Gas.

As there is a “gap” in the Hydrogen Regulation (lack of prescriptive rules and standards regarding Hydrogen deployment onboard), SOLAS establish the design process based on risk assessment, proving that the design will provide an equivalent safety level.

Alternative Design. The Alternative Design approach as required by the IGF Code for hydrogen-fuelled ships is expected to create a comprehensive, and rather expensive, design and approval process with a high degree of uncertainty. However, the Alternative Design approach opens for solutions not covered by prescriptive rules, and it is developed for new technologies and novel solutions. For such cases, it may be equally efficient, and it offers an assessment process that is more flexible than prescriptive rules.

Alternative Design is a generic process not specific for hydrogen, and has already been applied for new technologies and solutions in the maritime business. Almost all classes of new Cruise ships since 1990 have been developed through Alternative Design Process.

For these vessels, the process commonly includes quantitative fire and evacuation simulations and the use of Computational Fluid Dynamics (CFD). The early applications were based on the provisions in SOLAS Chapter 1, Regulation 5, with the studies typically conducted based on credible fire scenarios based in turn on engineering judgement. The fire sizes were hence not risk-based but rather based on typical fire sizes expected in the relevant areas.

4.1 IGF Code

The Code which is applicable for Hydrogen deployment onboard is the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IGF Code, 1st of January 2017)

The IGF Code contains two main parts:

- Part A: General function-based requirements for low-flashpoint fuel installations
- A-1: Functional and prescriptive requirements for engine installations using natural gas as fuel.

The study of IGF code is in the scope of WP1.

4.2 Gaps

The IMO IGF Code applies to ships to which the International Convention for the Safety of Life at Sea (SOLAS) Part G Chapter II-1 applies and contains only detailed prescriptive requirements for LNG under Part A-1 of the Code. Topics that could be identified in this Code and should be considered during the e-SHyIPS Project, could include, among others:

- Lack of specific Hydrogen Requirements
- Lack of Prescriptive Hydrogen requirements
- That´s why IGF review and update is necessary if other Low-Flashpoint Fuels as Hydrogen should be covered.
- During the ongoing WP1 development of the e-SHyIPS Project, regarding the methodology to run this review of the IGF code to identify potential "gaps", two parallel routes are being put in place:
- Following the current structure and sections of the current IGF Code, Spotting similarities between natural gas and hydrogen, so requirements missing in the IGF code that may be parallel to the one related to natural gas can be identified.
- Focusing on the Hydrogen Properties and Hydrogen technology particulars, to identify missing sections that should be included. (For instance, Fuel cells are not included in the powering systems considered in the current IGF Code and it is the preferred technology in the three scenarios adopted in e-SHyIPS).

4.3 Alternative Design

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

- The equivalence is to be demonstrated by applying the Alternative Design Risk Assessment process and SOLAS novel concepts approval procedure of SOLAS regulation II-1/55, and as required by 2.3 of the IGF Code
- Guidance to perform the Alternative Design Process: "Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-1 and III (MSC.1 / Circ. 1212)".
- The document "Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments" (MSC.1/Circ.1455) is also a key document to understand the approval process required for a hydrogen-fuelled ship.

This last document is applicable for all alternative design processes, describing the details of the Alternative Design process to be followed. This process will require not only the Submitter but Administration implication.

"Novel/new technology or design" (MSC.1/Circ. 1455) which applied to Hydrogen Deployment in Shipping, is defined as:

"New technology is a technology that has no documented track record in a given field of application, i.e., there is no documentation that can provide confidence in the technology from practical operations, with respect to the ability of the technology to meet specified functional requirements. This implies that a new technology either is a:

- *technology that has no track record in a known field*
- *proven technology in a new environment*
- *technology that has no track record in a new environment."*

4.4 Preliminary Risk Assessment for Hydrogen Fuelled Ships.

The objective of the risk assessment developed in this document is to contribute generating safe and robust design through the identification of hazards and uncertainties arising from the use of hydrogen as a marine fuel. The main goals of the safety assessment are to:

- Ensure that hazards associated with the design, operation and maintenance of the system have been identified.
- Ensure an overview of areas where further investigation should be done.
- Ensure that safety requirements identified as a result of the safety assessment have been implemented and/or contribute to the regulations' development. The objective of this task is to identify deviations from existing rules and regulations.

4.4.1 Qualitative Risk Assessment

The primary objective of the risk assessment is to identify risks and uncertainties associated with the hydrogen and its installation on a vessel.

At this stage and taking into account the project maturity, a bow-tie method, included in Annex A, has been selected in order to identify potential hazards that could result in consequences to personnel, the environment, and assets. The core philosophy behind the bow-tie model is to ensure a correlation between the risks related to major accident hazards for a specific site and the ability of the barriers in place to prevent, contain and mitigate the consequential events.

During this phase, the risk assessment has focused on the hazard identification and establishment of preliminary safety requirements.

The risks associated with the concept hydrogen system design have been identified based on available project information and reference documentation (LNG past accidents; identify applicable codes, standards and regulations; etc.).

Risk identification has focused on the following operational modes:

- Normal operation. Normal operation means that the fuel cells are consuming primary fuel and generating electrical power for the total energy supply of the ship.
- Bunkering operation. Bunkering means the loading of primary fuel from a bunker source outside the vessel to the fuel tanks of the vessel.

The main concern relating to the introduction of hydrogen as a ship fuel is the loss of containment of hydrogen causing a leak affecting some areas on the ship. The following table presents the initiating events that are risk drivers for hydrogen operations and identifies common causes for each event:

Initiating Events	Causes
Leakage from pipes, hoses or tanks.	• Corrosion/erosion. • Embrittlement. • Pipe failure (material/welding failure). • Seal failure. • Etc.
Overpressure	• Delivery pressure to high during bunkering operations (supply pump failure). • Pressure increases (tank, pipes, etc.). • External fire.
Transfer/Bunkering System Failure	• Hose failure (equipment fatigue due to extreme temperatures and pressure…). • Excessive movement of the loading arm or transfer system. • Mechanical failure. • Etc.
External Impact	• Cargo or stored object drop onto the hydrogen system (piping, hoses, tanks). • Another vessel collides with the H_2 vessel. • Etc.

Table 4. Hydrogen initiating events and causes.

A hydrogen leak in itself is not a hazard but it forms the basis of all hydrogen hazards since without a leak there is no opportunity for hydrogen to mix with air, and therefore no basis for flammability or asphyxiation hazards. In addition to leaks, the low temperature of liquid hydrogen forms the basis for frostbite hazard.

The main consequences associated with hydrogen hazards and outcomes are shown below. It is noted that the results from the detailed analysis in terms of frequency and consequences have not been assessed at this stage.

- Harmful Gas Concentration

After a hydrogen leak, the gas will be spread by gravity because it is heavier than air. Hydrogen is an asphyxiant that dilutes or displaces the oxygen containing atmosphere, leading to death by asphyxiation where the oxygen level is under 10 per cent in air. Therefore, an asphyxiation outcome is considered credible only if hydrogen leaks into an enclosed area.

Based on the hydrogen characteristics (colourless, odourless and tasteless), its presence cannot be detected by humans, and there are no warning symptoms before unconsciousness results. Hence, hydrogen detectors should be included in all compartments susceptible to hydrogen leakage.

- Contact with Cold Fluids

In scenarios where the hydrogen is stored in liquid form, below - 253° C, the extremely low temperature of liquid hydrogen could result in severe frostbite danger.

The cryogenic nature of hydrogen facilities represents a risk for personnel and equipment. For personnel, a severe frostbite danger occurs whenever skin comes into contact with liquid hydrogen, liquid hydrogen vapours or surfaces directly in contact with liquid hydrogen. Consequently, liquid hydrogen vessels should be completely insulated with specified materials to prevent any contact with the equipment/components.

For equipment, the cryogenic exposure of carbon steel causes embrittlement, possibly resulting in structural failure. Through potential fractures of the hull, following from H_2 spills into unprotected structural steel, it is important to note that hydrogen may penetrate into enclosed adjacent spaces, leading to the potential formation of explosive atmosphere pockets.

- Vapour Cloud Explosion (VCE) and Fire

Once leaked, hydrogen mixes with air and is flammable over a wide range of concentrations. This flammable mixture is very easy to ignite, and, once ignited, burns with great vigour. If hydrogen leaks into an enclosed environment, the risk of combustion and explosion is increased. If hydrogen leaks into an open environment, it rises quickly and is rapidly diffused, reducing the risk of fire.

A vapour cloud explosion (VCE) can occur when a large flammable mass of hydrogen is ignited in an enclosed or partially enclosed environment. Hydrogen clouds can be ignited when the concentration in the air is above the Lower Explosion Limit (LEL) and below the Upper Explosion Limit (UEL) for the given temperature and pressure. The majority of clouds that are ignited do so at their edge as they disperse and meet a strong ignition source (e.g. open flame, internal combustion engine, sparks).

A flash fire is the non-explosive combustion of a flammable vapour cloud resulting from a release of hydrogen into the open air. A pool fire may take place when a hydrogen spill is ignited on a horizontal, solid surface in open areas, within enclosures, or on sea surfaces. If a hydrogen spill is located near an ignition source, the ratio of gas and air is large enough to create a pool fire.

Jet fires occur upon immediate ignition of the hydrogen release. If ignition is delayed, a flash fire will occur.

All foreseeable hazards, their causes, consequences and associated risk control measures have been documented in the bow-ties included in Annex A. The bow-tie for Scenario 1 reflects the risks related to normal operation of the system, and their causes, accidents and controls. The bow-tie for Scenario 2 & 3 reflects the risks related to normal operation and bunkering operations.

4.4.2 Quantitative Risk Assessment. Specific Studies / Experiments

Quantitative analysis involves the use of numerical or quantitative data in the analysis and provides a quantitative result. This approach has the characteristic of being more objective and possibly more accurate, however, the quality of the results to be obtained from a Quantitative Risk Assessment (QRA) to be dependent upon the quality of the input used in the risk assessment.

During the next phases, it will be established the need to carry out simulations or quantitative risk analysis (QRAs) for the scenarios analysed. In order to carry out these simulations, there are several tools, as for example, the e-Laboratory, a virtual laboratory enabling to apprehend the behaviour of hydrogen and fuel cells (HFC) from a physical, an economic or a safety perspective, or the HyRAM toolkit, that integrates state-of-the-art models and data for assessing hydrogen safety.

As a minimum, it is recommended to assess a set of explosion risk scenarios to develop thresholds of needed ventilation rates and other mitigating and preventive measures in rooms where hydrogen can leak. The analysis could be performed with detailed CFD models or simplified predefined models for gas dispersion, ventilation, explosion and load response combined with detailed modelling of leak frequency and ignition probability. CFD models for gas dispersion and explosion are useful to optimize ventilation arrangements, gas detection arrangements or establish hazardous zones during bunkering operations.

5. Safety Systems

The purpose of this section is the definition of the safety requirements (sometimes guidelines more than requirements at this stage) related to Hydrogen deployment onboard and ensure that all identified hazards will have adequate design mitigation coverage. Specific safety requirements or guidelines related to electrical topics associated with Fuel Cell powering function are not considered at this stage.

There are no specific standards for the use of hydrogen as a fuel for ships. However, existing rules and guidelines related to the design and safety requirements for gas-fuelled ships are used as starting points to define the safety requirements for the construction and operation of hydrogen-fuelled ships.

Collectively, safety requirements are designed to prevent accidental releases of hydrogen and mitigate the consequences in case releases do occur. Some safety requirements are established in order to prevent certain initiating events from occurring, others are designed to mitigate certain types of consequences, and some play a role in both prevention and mitigation.

5.1 Storage Systems

For a system with the same capacity, liquid hydrogen (LH_2) has more advantages than compressed hydrogen. This is primarily because leaks are less frequent for liquid systems due to larger tanks, fewer valves, and lower pressure. Leaks from high-pressure tanks can be more severe (larger amounts of gas) and happen more often than for lower-pressure tanks. Liquid hydrogen systems also have unfavourable effects that need to be considered as the possibility of cryogenic consequences due to a leak, evaporator leaks into water pipes, complex bunkering procedures, etc.

Regarding materials used in all components in contact with hydrogen, they should be resistant to hydrogen embrittlement and hydrogen attack. A specific material should not be used unless data is available showing that it is suitable for the planned service conditions. In case of any doubt, the material should be subjected to hydrogen embrittlement susceptibility testing (as per ISO 11114-4) to evaluate material suitability before use.

5.1.1 Compressed Hydrogen Storage (CH_2)

There are no specific standards for the use of onboard compressed hydrogen (CH_2) as fuel for ships, however, existing rules for compressed natural gas (CNG) may be used as a starting point for a more specific hydrogen evaluation.

Storage of high-pressure hydrogen tanks in the open abovedeck can be advantageous since leaks can be dispersed in the open air, reducing cloud size, and the lack of confining walls will reduce the explosion severity, however, there are challenges with storage abovedeck that need to be considered. These can include greater difficulty in detecting gas leaks; reduced ship stability due to increased weights at a higher location in the vessel (design weight distribution could be studied and improved in WP2 thanks to CFD simulations); lack of protection from green sea and weather/ice, leading to a need for weather protection; increased leak frequency due to more corrosion and possible impact from outdoor activities, etc.

For ship applications, the normal approach is to approve pressurized gas tanks on an individual basis. Existing pressure vessel rules may be applicable for pressurized hydrogen-storage vessels to be used on ships, as, for example, European standards used for pressures exceeding 0.5 bar harmonized with the Pressure Equipment Directive (PED).

Pressurized hydrogen tanks and other equipment should be segregated to limit the amount of gas that can leak. The strategy to be followed should be decided for each system among many segregation valves, increasing the frequency of leakage, or increasing the hydrogen cloud, in case of leakage.

5.1.2 Liquid Hydrogen storage

The IGF Code covers the of liquefied gas onboard ships. C-tank rules for storage of liquefied gas will in principle cover hydrogen cooled to liquefied form, however, storage of hydrogen in liquid form (LH_2) involves a temperature as low as -253 °C, colder than any other fuel gases and therefore poses other protection and modelling challenges. The effect caused by condensation of nitrogen and oxygen together with water vapour is special for hydrogen and can be present for larger liquid spills, that may be critical if the spill falls or is sprayed on unprotected steel. The cool temperatures can cause many materials to become brittle and, if they are under stress, they may undergo brittle failure.

For the next phases, safety requirements related to grades of steel and protection to areas will be developed.

5.2 *Ventilation Systems*

In case of a hydrogen leakage into an enclosed volume, ventilation is needed both for hydrogen dilution and extraction purposes. Key objectives of the ventilation in enclosed spaces are to prevent the build-up of flammable gas due to leakage from any piping or other components leading to the units located in the space, or from any unit located in the space.

Ventilation systems required to avoid any vapour accumulation should consist of a mechanical exhaust type, with extraction inlets located to avoid an accumulation of vapour from leaked fuel in the space. The required capacity of the ventilation plant should be based on the total volume of the room and an increase of required ventilation capacity should be taken into account for rooms having a complicated form, as, for example, typical ceiling configurations that include structural beams, cable gates and pipe racks that may contribute to risk of formation of unwanted gas pockets that may be difficult to ventilate efficiently unless specific measures are implemented.

Ventilation of hazardous spaces should be separate from the ventilation used in non-hazardous spaces. Ventilation fans serving spaces where vapour from fuels may be present should not produce an ignition source. Therefore, fans and ventilation ducts should be of non-sparking construction (non-metallic material, non-ferrous material, etc.). In addition, electric ventilation fan motors should not be located in ventilation ducts of hazardous spaces unless the motors are certified for the same hazardous zone as the space served.

Air inlets and air outlets for hazardous enclosed spaces should be taken from areas that, in the absence of the considered inlet, would be non-hazardous. A safety zone, based on the design leak scenario in the room, should be established around the outlets. In addition, air outlets from non-hazardous spaces should be located outside hazardous areas.

For non-hazardous spaces with entries opening to a hazardous area, an airlock should be arranged and the overpressure relative to the external hazardous area should be maintained. Non-hazardous spaces with entry openings to a hazardous enclosed space should be arranged with an airlock and the hazardous space is to be maintained under pressure relative to the non-hazardous space.

Bunkering stations that are not located on the open deck should be suitably ventilated so that any vapour released during bunkering operations should be exhausted outside. If the natural ventilation is not sufficient, the bunkering stations should be subject to special consideration with respect to requirements for mechanical ventilation.

5.3 *Detection / Alarms*

5.3.1 Gas detection system

Gas detection should be provided with point gas detectors that detect gas concentrations and give an alarm or a signal for automatic shutdown at a pre-set gas concentration.

Gas detectors should be fitted in:

- hydrogen tank connection spaces;
- ducts around hydrogen pipes;
- other enclosed spaces containing hydrogen piping or other equipment without ducting;
- machinery spaces containing hydrogen piping, equipment or consumers;
- other enclosed or semi-enclosed spaces where hydrogen vapours may accumulate;
- or at ventilation inlets to accommodation and machinery spaces if required.

The number of detectors in each space should be established taking into account the size, layout and ventilation of the space. Gas detectors should primarily be located in the ceiling and close to possible leak sources if indoor. Outdoor, the gas detectors should be located both at a high level and close to possible leak sources. Buoyancy of hydrogen can cause gas from small leaks to generate a stratified layer of hydrogen at high points in the ceiling. For larger leaks, and if the ventilation is strong, hydrogen can be distributed in the room, therefore, it is also relevant to have gas detectors near the leaking at lower elevations to ensure early detection.

A gas detection system shall be provided with audible and visible alarms located on the navigation bridge or in the continuously manned central control station. The IGF code establishes the activation of the alarm system when the gas vapour concentration is higher than 20% of the lower explosion limit (LEL) in a compartment and 30% of LEL for ventilation ducts around gas pipes in machinery spaces. Possibly, these values should be confirmed in the case of Hydrogen.

In accordance with IGF Code, each ESD-protected machinery space should be provided with a redundant gas detection system.

5.3.2 **Fire detection system**

The fixed fire detection and fire alarm system complying with the FFS Code will be provided for the fuel storage holding spaces and the ventilation trunk for fuel containment system below deck, and for all other rooms of the fuel gas system where a fire cannot be excluded.

Smoke detectors alone are not considered sufficient for the rapid detection of a fire. When it comes to fire detectors for hydrogen, detection by increased temperature may be more appropriate due to the low thermal radiation levels from a small hydrogen fire, whose flames are near invisible and a lower fraction of heat is radiated from the fire than would be the case with natural gas.

Optical sensors for detecting hydrogen fires may be based on ultraviolet (UV) or infrared (IR) and the newer technology such as dual-band systems incorporating logic may deserve further consideration as they claim to feature the capability to trigger quickly on UV, but not activate an alarm unless the appropriate IR bands register. Further investigation of maritime hydrogen fire detection technologies needs to be carried out in the next phases.

5.4 Ignition Control

Sources of ignition in hazardous areas should be minimized to reduce the probability of explosions. This is typically done on electrical and other systems that are not critical to have running during an incident.

Another key factor is to control and minimize the presence of potential ignition sources, and to ensure physical separation between ignition sources and locations with potential for leaks.

Regarding electrical systems, the ship should comply with the requirements of Part D of SOLAS Chapter II-1 and Part 4, Section 8 of the Marine Vessel Rule. Electrical equipment should not be installed in hazardous areas unless essential for operational purposes or safety enhancement, and where they are installed, should be certified in accordance with IEC 60079, or another equivalent standard.

Hoses, transfer arms, piping and fittings provided by the delivering facility used for bunkering are to be electrically continuous, suitably insulated and should provide a level of safety compliant with recognized standards.

Hydrogen can ignite with a weaker ignition source, as little as static electricity. Therefore, the risk of an ignited cloud can be significantly larger for hydrogen considering otherwise equal conditions.

5.5 Isolation

The primary function of the Emergency Shutdown System (ESD) is to stop liquid and vapour transfer and eliminate potential ignition sources in the event of a hazardous scenario in order to regain control of the situation.

ESD should be initiated automatically for hydrogen systems. A manual shutdown can be unreliable and can lead to a large gas cloud before a shutdown is performed.

If limit values determined for the control process e.g., temperature, pressure, etc., are exceeded, may lead to hazardous situations, the fuel cell power system should be automatically shut down and interlocked by an independent protective device. If the fuel supply is shut off due to activation of an automatic valve, the fuel supply should not be opened until the reason for the disconnection is ascertained and the necessary precautions are taken. The following table shows some of the parameters for the safe and effective operation of the control, monitoring and safety system:

Parameter	**Alarm**	**Automatic Shutdown of Tank Valve**	**Automatic Shutdown of Master Fuel Valve**	**Automatic shutdown of Bunkering Valve**
High level fuel tank	x			x
High, high level fuel tank	x			x
Loss of ventilation in the annular space in the bunkering line	x			x
Gas detection in the annular space in the bunkering line	x			x
Loss of ventilation in ventilated areas	x			
Manual shutdown	x			x
Vapour detection in cofferdams surrounding fuel tanks. One detector giving 20% of LEL	x			
Vapour detection in air locks	x			
Vapour detection in cofferdams surrounding fuel tanks. Two detectors giving 40% of LEL	x	x		x
Vapour detection in other area	x			
Vapour detection in ducts around double walled pipes, 20% LEL	x			
Vapour detection in ducts around double walled pipes, 40% LEL	x	x	x	
Liquid leak detection in annular space of double walled pipes	x	x	x	
Liquid leak detection in machinery space	x	x		
Liquid leak detection in pump room	x	x		
Liquid leak detection in protective cofferdams surround fuel tanks	x			
Fire detection in fuel cell space	x			

Manually activated emergency shutdown	x	x	x	x

Table 5. Monitoring of Fuel Cell Power System. Source: Guide for Fuel Cell Power Systems for Marine and Offshore Applications. American Bureau of Shipping (ABS). November 2019

The above description is general for both compressed and liquid hydrogen. However, isolation and shutdown systems for LH_2 should be studied more in detail in the next phases.

For bunkering operations, an emergency Shutdown (ESD) system should be operable from both the ship and the bunker supply facility. This is to allow a rapid and safe shutdown of the bunker supply system without the release of liquid or vapour.

5.6 Vents / Pressure Relief Devices (PRD)

The vent system handles controlled releases of gas, such as blowdown release, that may be initiated either automatically or manually as a result of gas detection or other abnormal process conditions, and the target is that this is done before a leak has caused a fire or an explosion.

Pressure relief devices (PRDs) protect pressure tanks and fuel system from catastrophic failure if the pressure in the system exceeds safe limits. Pressure hydrogen systems should be provided with pressure relief valves mounted downstream of the motive pressure regulator and vents to the atmosphere if the pressure exceeds the safety limits. In tanks, the pressure is released through the Pressure Release Valve (PRV) and liquified gas tanks should be fitted with a minimum of 2 pressure relief valves (PRVs) allowing for disconnection of one PRV in case of malfunction or leakage.

A fire hazard in hydrogen vehicles could cause catastrophic rupture of the hydrogen fuel tanks and fuel system if they are not properly vented. High temperature in a fire could raise the internal pressure of the container and degrade the strength of metal, thermoplastic, and composite container materials, potentially causing rupture. Thermally activated pressure relief devices (TPRDs) are initiated automatically when heated and rapidly blow down or vent the full contents of a hydrogen tank to a safety location to prevent tanks from bursting, and to reduce the duration of the fire.

These two systems (vents and PRVs) should be separate systems with separate piping and masts to create independence of the systems in case of failure.

For the next project phases, the development of a separate assessment is needed in order to develop recommendations for sizing of vents and PRDs for hydrogen systems. Release points on vent/PRV need to be classified with safety distances. Venting to the atmosphere, either resulting from vent/PRV, should be only possible in case of emergency, for safety reasons.

5.7 Firefighting

The main goal of the firefighting system is to prevent escalation of the incident to other parts of the ship or fuel systems that can lead to yet more escalation.

5.7.1 Structural Fire Protection

The space containing fuel containment system should be classified as machinery space of category A, in accordance with SOLAS regulation II-2/9 and it should be separated from other rooms with high fire risks by a cofferdam of at least 900 mm with insulation of A-60 class.

Any boundary of accommodation including navigation bridge windows, service spaces, control stations, machinery spaces, and escape routes facing fuel tanks on open deck should have a fire integrity class of A-60. The A-60 class divisions should extend up to the underside of the deck of the navigation bridge, and any boundaries above that, including navigation bridge windows, shall have A-60 class divisions

The bunkering station is to be separated by A-60 class divisions between Category A machinery spaces, accommodations, control stations and high fire risk spaces except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, and sanitary and similar spaces where the boundary may be reduced to class A.

Special considerations should be taken into account in the next phases for Scenario 2, if fuel pipes are led through ro-ro spaces.

5.7.2 Fire-suppression system

The protocol for fighting a hydrogen fire is to eliminate the fuel source and if this is not an option, allow the fuel to burn itself out under controlled conditions.

Although the hydrogen fire should not be extinguished until the hydrogen flow can be stopped, water sprays shall be used to extinguish any secondary fire and prevent the spread of the fire.

A water spray system should be installed for cooling and fire prevention to cover exposed parts of fuel storage tanks located on open deck and to provide coverage for boundaries of the superstructures, machinery rooms, cargo control rooms, bunkering controls stations, bunkering stations and any other normally occupied decks houses that face the storage tank on open decks unless the tank is located 10 metres or more from the boundaries.

Additionally, a permanently installed dry chemical powder fire-extinguishing system should be installed in the bunkering station area to cover all possible leak points. Dry chemicals make the flames visible.

6. Conclusion

The aim of this deliverable is to present the e-SHyIPS Preliminary Safety Systems Definition after Scenario Definition with 3 different use cases.

While it has been explained that this task is being developed in parallel to the Preliminary Design as well as other tasks related to technology state of the art and regulation and it could be a handicap for the safety systems definition itself, this deliverable could contribute as a new source to the development of requirements and preliminary design in the WP2.

This deliverable shows some contact points between Natural Gas and Hydrogen technology onboard in some aspects. Natural gas as a fuel provides useful insight but needs modification to be applicable for hydrogen deployment.

On the other hand, D3.1 also shows that there are significant properties differences related to safety between natural gas and hydrogen gas, as well as between and liquefied hydrogen (LH_2).

Both aspects must be considered during the next stages of the project.

Finally, the gathered safety guidelines, requirements and ideas, as well as very preliminary hazard studies will be continued in the next stages of this project, contributing to the integration of Safety aspects into the Basic Design along the Alternative Design Approach as requested from regulation Bodies.

Into the WP3 “Safety Systems Experiments”, this deliverable is the first step to the definition of new simulations or experiments that will contribute to improving Hydrogen Knowledge and its Deployment in Shipping.

7. References

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8. Definitions

See e-SHyIPS Project Glossary for complete list of definitions used in this project.

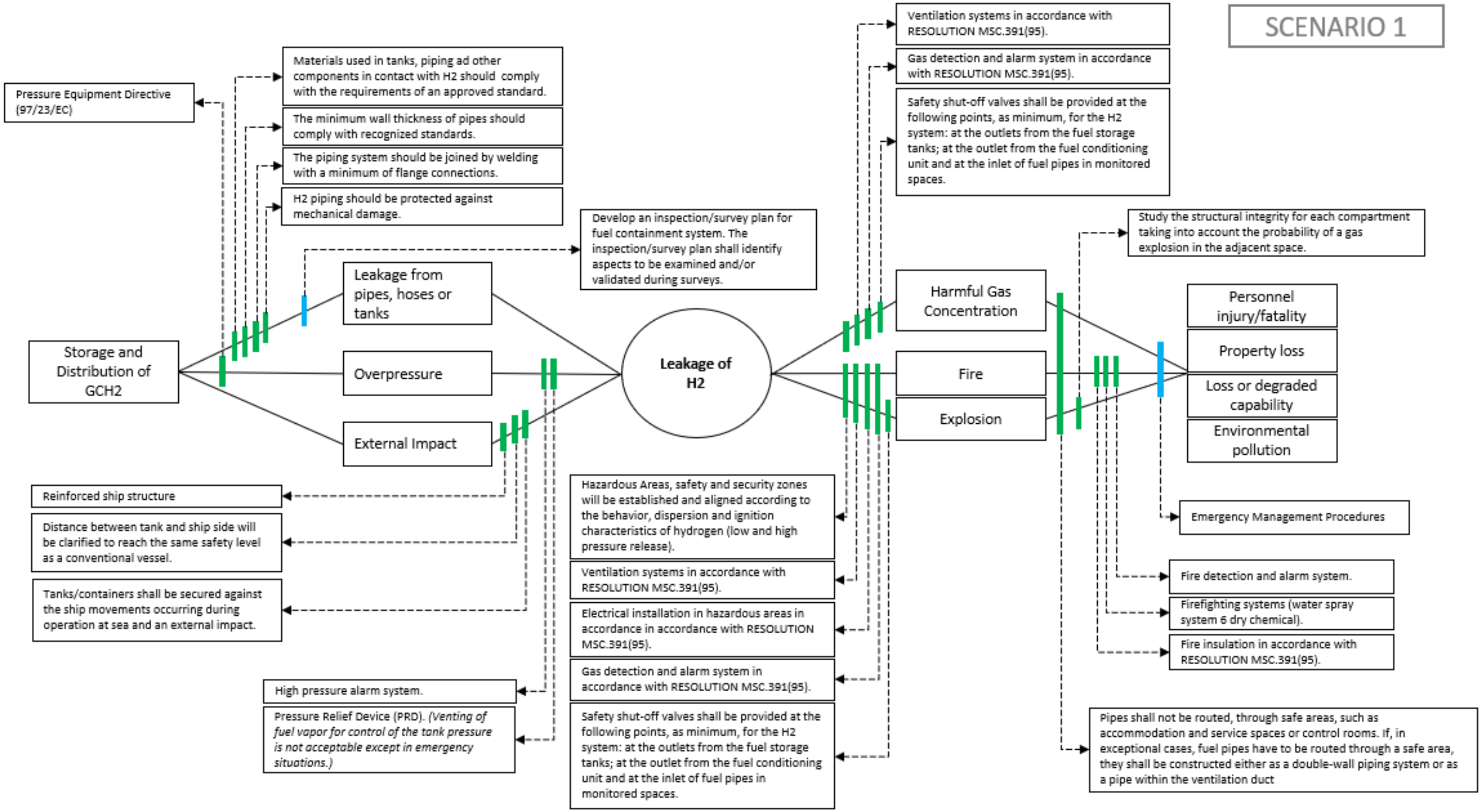
9. Acronyms

ALARP	As Low As Reasonable Practicable
CFD	Computational Fluid Dynamics
GHG	Greenhouse Gas
HyRAM	Hydrogen Risk Assessment Models
MGO	Marine Gas Oil
PRD	Pressure Relief Device
PRV	Pressure Relief Valve
QRA	Quantitative Risk Assessment
VCE	Vapour Cloud Explosion

10.Annexes

[1] Annex A – Bow-Tie Analysis

ANNEX A: Bow-Tie Analysis



Pressure Equipment Directive (97/23/EC)

Materials used in tanks, piping ad other components in contact with H2 should comply with the requirements of an approved standard.

The minimum wall thickness of pipes should comply with recognized standards.

The piping system should be joined by welding with a minimum of flange connections.

H2 piping should be protected against mechanical damage.

Develop an inspection/survey plan for fuel containment system. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys.

Reinforced ship structure

Distance between tank and ship side will be clarified to reach the same safety level as a conventional vessel.

Tanks/containers shall be secured against the ship movements occurring during operation at sea and an external impact.

High pressure alarm system.

Pressure Relief Device (PRD). *(Venting of fuel vapor for control of the tank pressure is not acceptable except in emergency situations.)*

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Safety shut-off valves shall be provided at the following points, as minimum, for the H2 system: at the outlets from the fuel storage tanks; at the outlet from the fuel conditioning unit and at the inlet of fuel pipes in monitored spaces.

Hazardous Areas, safety and security zones will be established and aligned according to the behavior, dispersion and ignition characteristics of hydrogen (low and high pressure release).

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Electrical installation in hazardous areas in accordance in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Safety shut-off valves shall be provided at the following points, as minimum, for the H2 system: at the outlets from the fuel storage tanks; at the outlet from the fuel conditioning unit and at the inlet of fuel pipes in monitored spaces.

Study the structural integrity for each compartment taking into account the probability of a gas explosion in the adjacent space.

Emergency Management Procedures

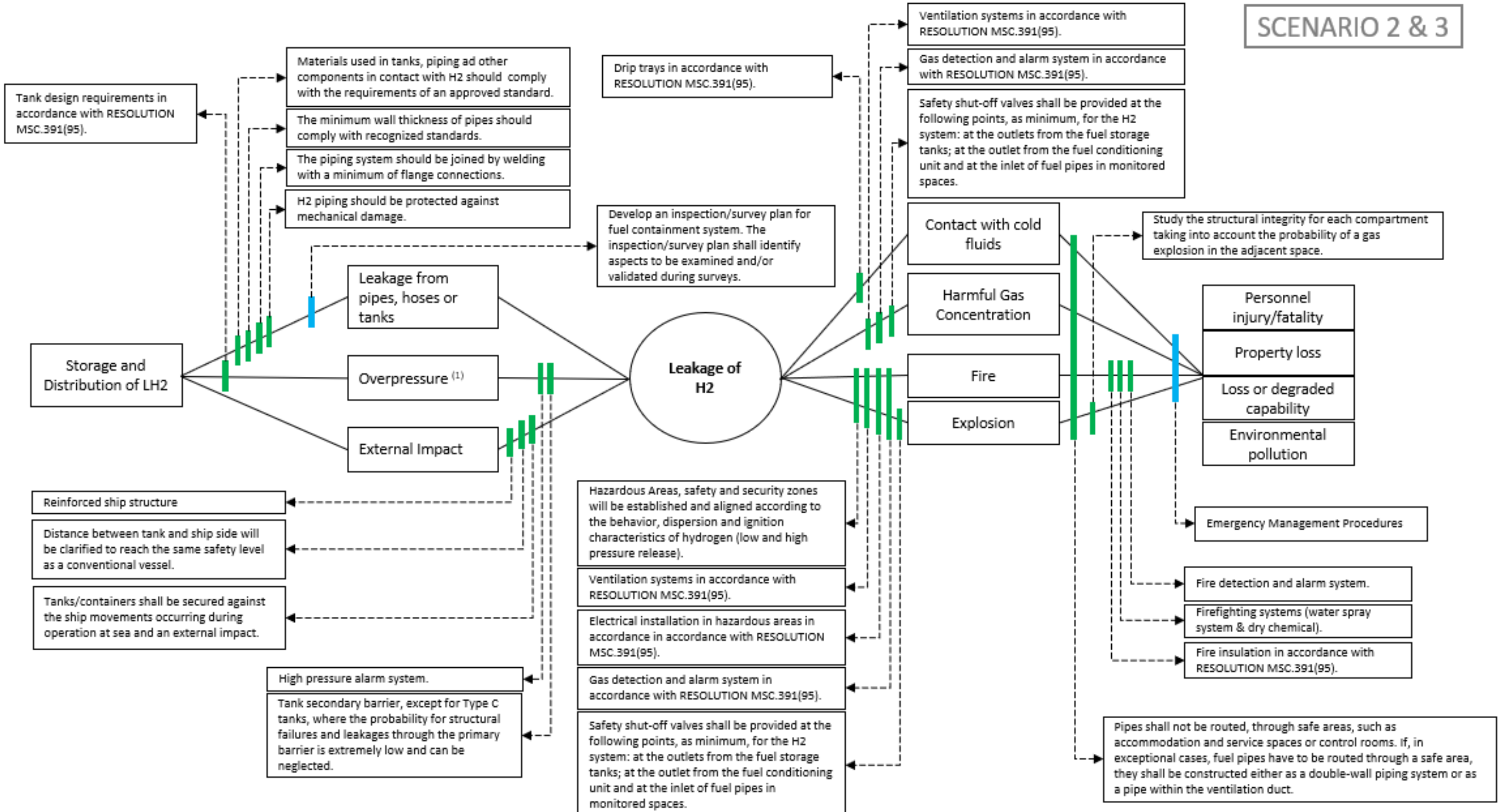
Fire detection and alarm system.

Firefighting systems (water spray system 6 dry chemical).

Fire insulation in accordance with RESOLUTION MSC.391(95).

Pipes shall not be routed, through safe areas, such as accommodation and service spaces or control rooms. If, in exceptional cases, fuel pipes have to be routed through a safe area, they shall be constructed either as a double-wall piping system or as a pipe within the ventilation duct

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



Tank design requirements in accordance with RESOLUTION MSC.391(95).

Materials used in tanks, piping ad other components in contact with H2 should comply with the requirements of an approved standard.

The minimum wall thickness of pipes should comply with recognized standards.

The piping system should be joined by welding with a minimum of flange connections.

H2 piping should be protected against mechanical damage.

Develop an inspection/survey plan for fuel containment system. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys.

Drip trays in accordance with RESOLUTION MSC.391(95).

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Safety shut-off valves shall be provided at the following points, as minimum, for the H2 system: at the outlets from the fuel storage tanks; at the outlet from the fuel conditioning unit and at the inlet of fuel pipes in monitored spaces.

Study the structural integrity for each compartment taking into account the probability of a gas explosion in the adjacent space.

Distance between tank and ship side will be clarified to reach the same safety level as a conventional vessel.

Tanks/containers shall be secured against the ship movements occurring during operation at sea and an external impact.

Tank secondary barrier, except for Type C tanks, where the probability for structural failures and leakages through the primary barrier is extremely low and can be neglected.

Hazardous Areas, safety and security zones will be established and aligned according to the behavior, dispersion and ignition characteristics of hydrogen (low and high pressure release).

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Electrical installation in hazardous areas in accordance in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Safety shut-off valves shall be provided at the following points, as minimum, for the H2 system: at the outlets from the fuel storage tanks; at the outlet from the fuel conditioning unit and at the inlet of fuel pipes in monitored spaces.

Firefighting systems (water spray system & dry chemical).

Fire insulation in accordance with RESOLUTION MSC.391(95).

Pipes shall not be routed, through safe areas, such as accommodation and service spaces or control rooms. If, in exceptional cases, fuel pipes have to be routed through a safe area, they shall be constructed either as a double-wall piping system or as a pipe within the ventilation duct.

(1) It can mainly occur in the case of an accumulation of flammable vapors under the tank roof.

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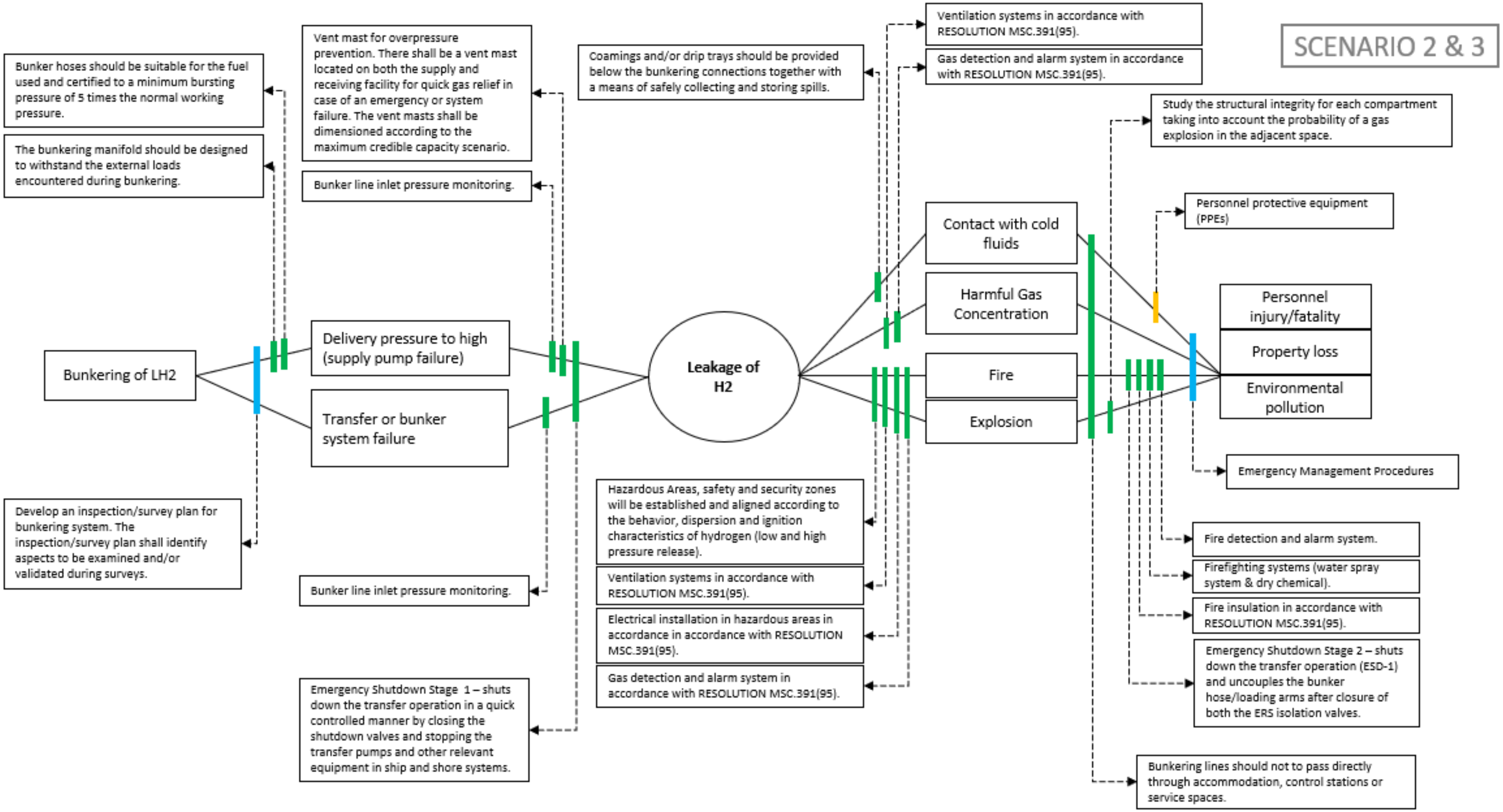

Bunker hoses should be suitable for the fuel used and certified to a minimum bursting pressure of 5 times the normal working pressure.

The bunkering manifold should be designed to withstand the external loads encountered during bunkering.

Develop an inspection/survey plan for bunkering system. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys.

Vent mast for overpressure prevention. There shall be a vent mast located on both the supply and receiving facility for quick gas relief in case of an emergency or system failure. The vent masts shall be dimensioned according to the maximum credible capacity scenario.

Bunker line inlet pressure monitoring.

Bunker line inlet pressure monitoring.

Emergency Shutdown Stage 1 – shuts down the transfer operation in a quick controlled manner by closing the shutdown valves and stopping the transfer pumps and other relevant equipment in ship and shore systems.

Coamings and/or drip trays should be provided below the bunkering connections together with a means of safely collecting and storing spills.

Hazardous Areas, safety and security zones will be established and aligned according to the behavior, dispersion and ignition characteristics of hydrogen (low and high pressure release).

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Electrical installation in hazardous areas in accordance in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Ventilation systems in accordance with RESOLUTION MSC.391(95).

Gas detection and alarm system in accordance with RESOLUTION MSC.391(95).

Study the structural integrity for each compartment taking into account the probability of a gas explosion in the adjacent space.

Personnel protective equipment (PPEs)

Emergency Management Procedures

Fire detection and alarm system.

Firefighting systems (water spray system & dry chemical).

Fire insulation in accordance with RESOLUTION MSC.391(95).

Emergency Shutdown Stage 2 – shuts down the transfer operation (ESD-1) and uncouples the bunker hose/loading arms after closure of both the ERS isolation valves.

Bunkering lines should not to pass directly through accommodation, control stations or service spaces.

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