Development of a proposal for technical regulations on the use of hydrogen as fuel in inland navigation

On behalf of

Deutsches Maritimes Zentrum e.V.

Lloyd's Register

Deutsches Maritimes Zentrum

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1. Foreword

Founded in 2017, the Deutsche Maritime Zentrum e. V. (DMZ) is an independent, publicly funded, cross-industry think tank based in Hamburg. It focuses on future topics such as non-fossil fuels, emission-free propulsion systems, modern safety systems and autonomous shipping. The core is formed by questions of the design and implementation of research, development and innovation in the maritime sector. They serve to increase knowledge, to further develop the state of the art and to strengthen the international competitiveness of Germany as an industry location.

Lloyd's Register (LR) is a global engineering, technical and business services company wholly owned by the Lloyd's Register Foundation, a charity dedicated to research and technology. Founded in 1760 as a marine classification society, LR now operates across industries and employs around 8,500 people in 78 countries. LR has a long-standing reputation for integrity, impartiality and technical excellence. The compliance, risk and technical advisory service gives LR's clients confidence that their company's assets are safe, sustainable and reliable. Through its global technology centers and research network, LR is at the forefront of understanding the application of emerging technologies and technologies to future-proof our customers' businesses.

In the summer of 2021, the German Maritime Center commissioned the company Lloyds Register EMEA to “develop a proposal for technical regulations on the use of hydrogen as a fuel in inland navigation”.

2. Background / Initial Situation

The transition from conventional to renewable fuels is a highly topical issue in the entire transport sector. This also applies to the maritime industry in sea shipping as well as to traffic on inland waterways. Already today, January 2022, there are pilot projects in which inland vessels are powered by hydrogen and fuel cells. These ships receive special permits because the use of hydrogen as a fuel in European inland shipping is still strictly prohibited.

The Paris Agreement of December 2015 aims to slow down climate change by reducing CO2 emissions. The comprehensive reduction of greenhouse gas and pollutant emissions in inland navigation must be promoted. In the Mannheim Declaration signed on October 17, 2018, the transport ministers of the member states of the Central Commission for the Navigation of the Rhine (CCNR – Belgium, Germany, France, the Netherlands and Switzerland) reaffirmed furthermore the goal of largely eleminating emissions of greenhouse gases and other pollutants by 2050.

The declaration emphasized the need for up-to-date, practicable and harmonized environmental and safety regulations in Rhine and inland navigation. The CCNR was commissioned to develop a roadmap to further improve the environmental sustainability of inland navigation in order to reduce emissions from

- greenhouse gases by 35% by 2035 compared to 2015,
- pollutants by at least 35% by 2035 compared to 2015,
- eliminate greenhouse gases and other pollutants as far as possible by 2050.

It can be assumed that clear legislation on the use of alternative fuels will motivate the industry to implement innovations. This presupposes that the use of hydrogen is fundamentally possible and that appropriate safety regulations are in place.

Various hydrogen projects in inland waterway transport are being funded for the implementation of potential innovations. The project "Rhine Hydrogen Integration Network of Excellence" (RH2INE) aims to develop market-ready solutions for an infrastructure for using hydrogen in the inland transport chain, e.g. inland waterway transport, road and rail freight transport. In phase 1 of the project 12 barges are to be implemented [1].

The inland waterway vessel projects ELEKTRA, HADAG and MSC Maas are currently under construction or in the planning stage. Gaseous compressed hydrogen is used as fuel for all three projects. Refillable gas cylinders are used to store the hydrogen on board. These are grouped together in bundles. There are several interchangeable bundles on board each ship.

These barges should be equipped with the following hydrogen storage capacity:

- ELEKTRA, 6 bundle, each 125kg H2
- MSC Maas, 2 bundle, each 500kg H2
- HADAG Ferry, 2 bundle, each 125-150kg H2

3. Regulations for inland shipping

The same technical regulations apply to all inland waterways in the European Union. The basis for this harmonization is EU Directive 2016/1629 laying down technical regulations for inland waterway vessels, amending Directive 2009/100/EC and repealing Directive 2006/87/EC. The uniform technical regulations contained in the European standard of technical regulations for inland navigation vessels (ES-TRIN) ensure the safety of inland vessels in Europe. The standard includes the harmonized technical regulations for Rhine and European inland navigation to which the Directive (EU) 2016/1629 laying down technical regulations for inland vessels and the Rhine Ship Inspection Regulations (RheinSchUO) refer.

The European Committee for Drawing Up Standards in the Field of Inland Navigation (CESNI) is responsible for the development of technical standards in the field of inland navigation. The aim of this body is to facilitate the harmonization of technical standards in the inland navigation sector across Europe. Ongoing updates are intended to ensure that scientific and technical progress can be taken into account and that a high level of safety and efficiency in inland navigation is guaranteed.

In the leaflet published by CESNI on deliberation on derogations and equivalences of technical requirements of the ES-TRIN, it is reported that in the past, the technical regulations for ships navigating the Rhine were drawn up by the Central Commission for the Navigation of the Rhine (CCNR). This body thus has extensive knowledge in relation to the development and updating of the technical regulations for inland waterway vessels. Participation in the CCNR is open to experts from all Member States and the leadership of the CCNR ensures that the accumulated expertise can continue to be fully used for the benefit of inland waterways in the Union.

Vehicles that operate on the Rhine and on waterways in the EU must have a Rhine Vessel Inspection Certificate or a Union Certificate for Inland Navigation Vessels. Both certificates are issued by the national competent authority and confirm the full compliance of the vehicle with the technical requirements of the ES-TRIN. The aim of these regulations is to ensure a high level of safety in inland navigation and to protect the environment and people on board.

„The CCNR and EU legal frameworks allow derogations to the technical requirements of the ES-TRIN in justified cases:

- to encourage innovation and the use of new technologies in inland navigation;
- when the technical requirements are technically difficult to apply or where their application might entail disproportionate costs (hardship clause).

In both cases, the ship owner must initiate the derogation request from the provisions of the technical standard ES-TRIN at the national competent authority. The competent authority examines the application and decides, together with the shipowner, whether the vessel should receive a Rhine certificate or Union certificate. Depending on this decision, the relevant member state applies to the CCNR or CESNI Committee for approval to derogate from the ES-TRIN.

The derogation is approved for a single craft by the inspection body based

- either on an implementing act by the European Commission (EC) subsequent to the CESNI Committee's opinion or
- on the CCNR's recommendation.

For series of vessels with the same derogations from the ES-TRIN, each vessel will need its own application for approval for derogation. Following the approval by the CCNR or EC the specific derogations are entered in the Rhine certificate or Union certificate by the competent national authority upon issue. Moreover, a register of approved derogations granted by the CCNR since 1996 is available on its website. The approval of a derogation by the CCNR is sometimes referred to as "recommendation". [2]

4. Hydrogen storage on board of ships

Hydrogen storage methods are presented in Table 1 below. The storage of hydrogen in pressure vessels and tanks in compressed form and in cryogenic liquefied form is considered as relevant for this study. In the study 'Hydrogen containment Systems' [3], the storage of compressed hydrogen and cryogenic liquefied hydrogen under pressure is considered to be the most advanced storage technology. Material-based storage methods still need an estimated 5-10 years of development before this technology can be available on a large scale.

Storage method	Containment system	Pressure	Temperature	State of aggregation
Physical-based				
Pressurized	Fixed: Pressure cylinders/tubes (type I,II,III & IV) Swappable: type I-IV cylinders/tubes in cylinder racks, or 20/40 ft ISO tube- or cylindercontainers.	200-500 bar	Ambient	Gas
Liquid	Fixed: Super insulated tanks (IMO type C) Swappable (possibly[1]): Super insulated ISO tank-containers	Atmospheric to 5 barg[2]	-245 to -250 °C	Liquid
Material-based				
Sodium borohydride ($NaBH_4$)	Crystal: Storage similar to salt (plastic containers) Liquid: Plastic containers, IBC tanks, storage for corrosive liquids	Atmospheric	Ambient	Solid (crystal) Liquid (dissolved in water)
Ammonia	1. Insulated tanks	1. Atmospheric	1. -34°C	1. Liquid
	2. Insulated pressure tanks	2. 10-30 bar	2. Ambient	2. Gas
LOHC	Tanks similar to diesel tanks; ISO tank-containers, large (tailored) tanks	Atmospheric	Ambient	Liquid
Methanol	1. Tanks similar to diesel tanks; ISO tank-containers, fixed carbon steel tanks	1. Atmospheric	1. Ambient	1. Liquid
	2. CO_2 tanks	2. 12-25 bar	2. -35 °C to -15 °C	2. Liquid

Table 1 Overview of hydrogen storage methods, containment systems and physical parameters for use in IWT [3]

(1) Swappable liquid hydrogen tank-containers will most likely not be applied in shipping due the safety risks associated with hoisting. This is further discussed in Sub-Activity report 1.1b

(2) The pressure in liquid hydrogen fuel tanks will increase due to the generation of boil-off gas caused by heat inleak. The pressure will increase even more when there is no continuous gas consumption by the engine. This pressure can normally increase up to values of 7-10 bar, depending on the opening pressure of the pressure safety valve. 5 barg is a typical pressure that you would expect to see for fuel tanks for inland vessels (based on expert judgement and in comparison with LNG fuel tanks).

Hydrogen has specific properties that need to be considered for safe onboard storage and use as a fuel. Compared to other low flash point fuels such as methane, hydrogen has a low density and boiling point. The minimum ignition energy of hydrogen is very low and is given as 0.017 megajoules (mJ), with the entire ignitable range being extremely pronounced with a lower ignition limit of 3% by volume and an upper limit of 75% by volume. With regard to the detailed properties of hydrogen, reference is made to the specific technical literature and standards [4].

Due to these specific properties, the resulting risks and hazards in the use and operation of ships with hydrogen as fuel must be taken into account. A bow-tie diagram is presented in Figure 1 below, listing specific events that may lead to a potential release of hydrogen. The potential consequnces are set against the events. Protective measures are necessary or may be necessary to prevent unacceptable consequences.

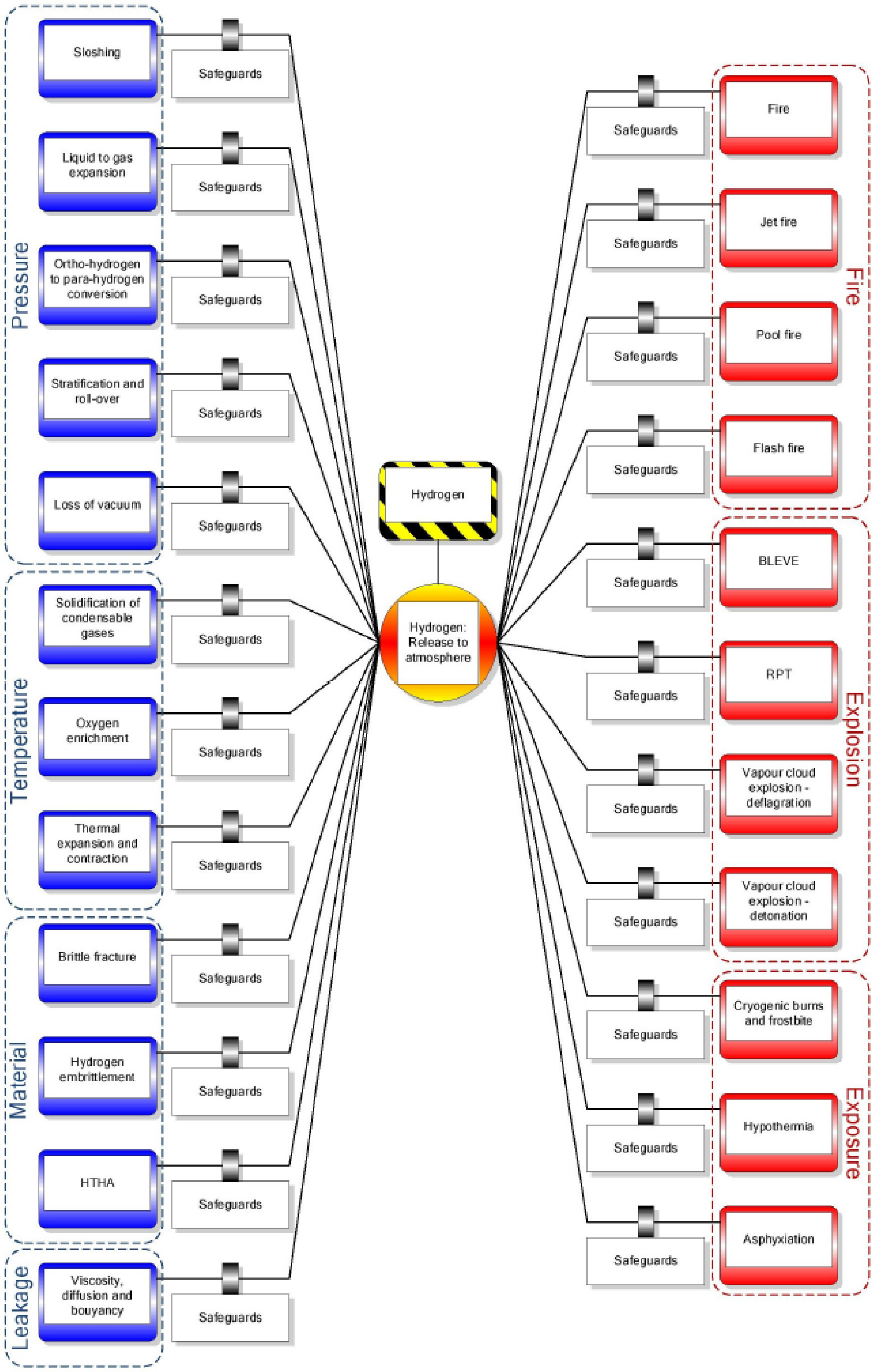

Figure 1 Hydrogen release to atmosphere – initiating hazardous events and potential consequences requiring additional consideration [5]

5. Goal-based approach

Rules and regulations can follow a goal-based approach, a prescriptive approach, or a combination of both approaches. With a comparison of prescriptive regulations and goal-based regulations the differences can be qualitatively highlighted.

Prescriptive regulations:	**Goal-based regulations:**
Specific rules defining technical solutions	Regulators define specific objective
Reactive, driven by accident history	Nature of the technical solution is left to the operator
Regulators actively involved in drafting	Risk assessment fits well into this structure
	Potential for cost-benefit decision making

Table 2 Comparison of prescriptive and goal-based regulations

According to the IMO 'Generic Guidelines for Developing IMO Goal-Based Standards' [6] goal-oriented regulations are superordinate standards and procedures that must be fulfilled in the maritime sector for ships for example through the application of regulations, rules and standards. Goal-based standards consist of at least one goal, the functional requirements associated with the goal, and verification that the regulations, rules and standards meet the functional requirements and the goals. The International Code for the Safety of Ships Using Gases or Other Low-Flash Point Fuels (IGF Code) is an international standard for ships using low-flash point fuels. The basic philosophy of the IGF Code [7] takes into account the goal-based approach according to MSC.1/Circular 1394 'Generic Guidelines for Developing IMO Goal-Based Standards' [6].

The goal of the IGF Code is for example to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.

The functional requirements provide the criteria that must be met to achieve these goals. Rules and regulations provide detailed requirements that must be met to achive the functional requirements and their objectives. Where appropriate industry standards, guidelines and best practices may be referenced by the rules and regulations. The structure of the goal-oriented approach of the International Maritime Organization (IMO) is taken from MSC.1/Circular 1394 'Generic Guidelines for Developing IMO Goal-Based Standards' [6] and is shown in Figure 2 below. Regulations should not only follow the prescriptive or goal-oriented approach, but both approaches should be used in a complementary manner.

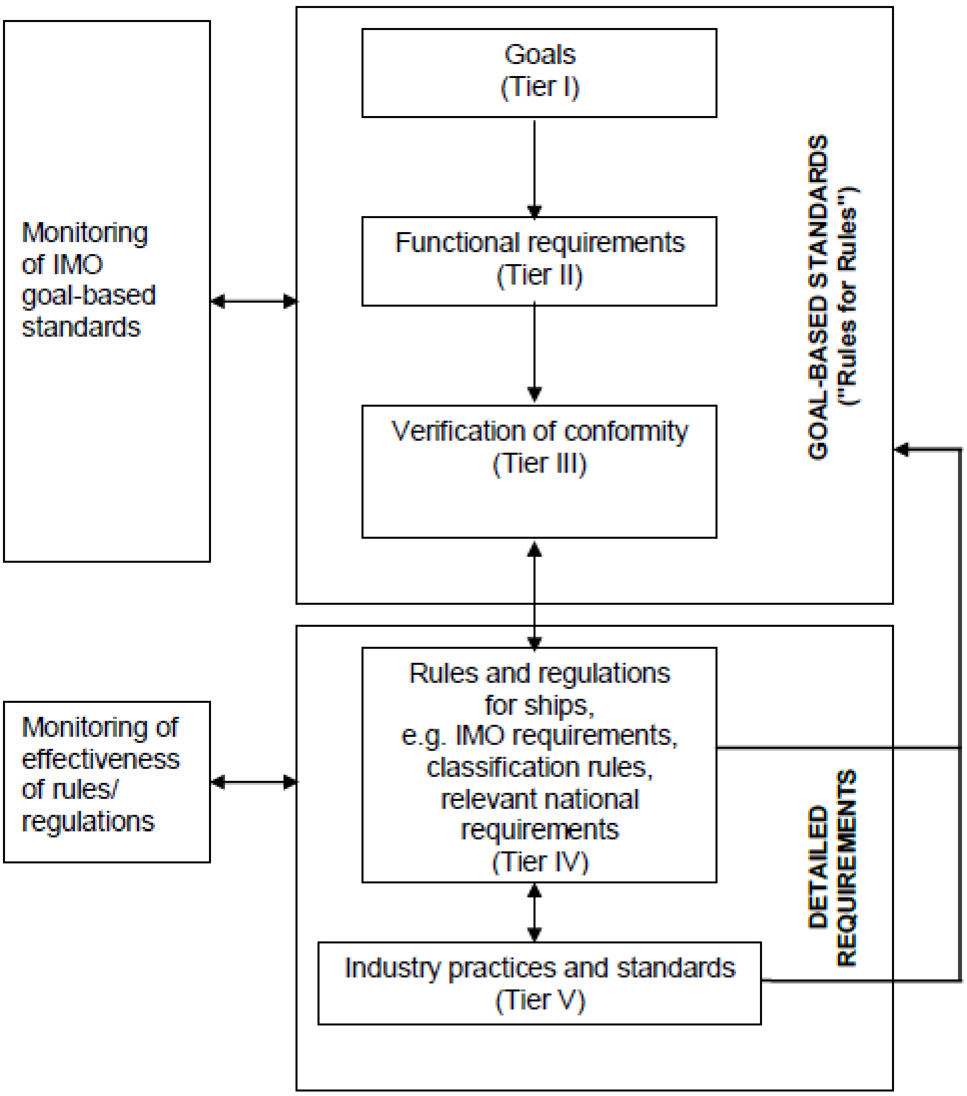

Figure 2 Goal-based standards framework [6]

6. Work package 1, Presentation of the regulatory situation

6.1. Task

Work package 1 analyzes how the European standard of technical regulations for inland navigation vessels (ES-TRIN) must be supplemented so that compressed or cryogenic hydrogen can be used on inland vessels. For this purpose, relevant standards and other regulations as well as the recommendations according to §2.20 RheinSchUO, which were issued within the framework of pilot applications for the use of hydrogen as a fuel in inland navigation, are evaluated.

For the regulation ES-TRIN Annex 8, Section II Fuel Storage, Part 2 Hydrogen a provisional structure is being developed and presented to the client. In the following chapter relevant standards and regulations for inland navigation vessels and for compressed or cryogenic hydrogen are listed.

6.2. Relevant standards and regulation

In the following standards, rules and regulations are listed and described for their potential relevance to hydrogen as a fuel for inland navigation vessels. Their relevance is assessed with regard to a possible addition to ES-TRIN Annex 8 and the result is presented qualitatively.

6.2.1. European Committee for Drawing up Standards in the Field of Inland Navigation (CESNI), European Standard laying down Technical Requirements for Inland Navigation Vessels (ES-TRIN), Edition 2021/1

Chapter 30 of the technical regulations for inland vessels [8] considers fuels with a flash point of 55°C or below. Propulsion and auxiliary systems may be installed that use fuels with a flash point of 55 °C or below, provided that the requirements specified for these fuels in Chapter 30 and Appendix 8 have been complied with. The only fuel listed in the ES-TRIN edition 2021/1 Annex 8 is currently liquefied natural gas. Regulations for fuel cells and methanol, as well as a restructuring of Chapter 30 and Appendix 8, are in preparation. And it is to be expected that these changes will be reflected in the coming editions of ES-TRIN. Specific requirements for hydrogen as a fuel beyond the general requirements in Article 30 ´Special provisions for vehicles on which propulsion or auxiliary systems are installed that are operated with fuels with a flash point of 55°C or below´ do not exist. Annex 8 Section I LNG currently addresses the following content:

- Chapter 1 General

  1.1 Application

  1.2 Definitions

  1.3 Risk assessment

  1.4 General requirements

  1.5 Knowledge of the technical service

  1.6 Marking

- Chapter 2 Vessel arrangements and system design

  2.1 LNG containment system

  2.2 Engine rooms

  2.3 Liquefied Natural Gas (LNG) and Natural Gas piping systems

  2.4 Drainage systems

  2.5 Drip trays

  2.6 Arrangement of entrances and other openings

  2.7 Ventilation systems

  2.8 LNG bunkering system

  2.9 Filling limits of LNG fuel tanks

  2.10 Gas supply system

  2.11 Exhaust system and gas supply shut down

- Chapter 3 Fire Safety

  3.1 General

  3.2 Fire alarm system

  3.3 Fire protection

  3.4 Fire prevention and cooling

  3.5 Fire extinguishing

- Chapter 4 Electrical Systems
- Chapter 5 Control, Monitoring and Safety Systems

  5.1 General

  5.2 LNG bunkering system and LNG containment system monitoring

  5.3 Engine operation monitoring

  5.4 Gas warning equipment

  5.5 Safety functions of gas supply system

Article 30 ´Special provisions applicable to craft equipped with propulsion or auxiliary systems operating on fuels with a flash point equal to or lower than 55°C´ requires in Article 30.01 (5) (a) the submission of a risk assessment according to Annex 8. The basic concept of the LNG risk assessment requirements can be traced back to:

- When to carry out a risk assessment.
- What is the objective of the risk assessment.

- Which methodology should be used.
- What is at least to be considered in this risk assessment.
- What else should be documented.

The specific requirements for a risk assessment according to Annex 8 Chapter 1.3 [8] are as follows:

- A risk assessment shall be conducted on all concepts and configurations which are new or have been significantly modified. The risks arising from the use of liquefied natural gas (LNG) affecting people on board including passengers, the environment, the structural strength and the integrity of the craft shall be addressed.
- Reasonable consideration shall be given to the hazards associated with physical layout, operation, and maintenance, following a failure.
- The risks are to be determined and assessed using a risk analysis technique recognised by the inspection body, such as International Standards ISO 31000 : 2018 and ISO 31010 : 2019.
- Loss of function, component damage, fire, explosion, tank room flooding, vessel sinking and electric overvoltage shall as a minimum be considered.
- The analysis must help to ensure that risks are eliminated wherever possible.
- Risks which cannot be eliminated entirely are to be mitigated to an acceptable level.
- The major scenarios and measures for eliminating or mitigating risks shall be described.

From the regulatory concept of the technical regulations for inland vessels using fuels with a flash point of 55°C or below and taking into account the in Annex 8 specified goal-oriented criteria, it is derived that in addition to the prescriptive requirements in Annex 8 a risk assessment according to Article 30 must be carried out in order to ensure sufficient safety.

A reference to a required equivalence with regard to the safety of ships fueled with conventional fuels, such as required by the Lloyd's Register, Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels [12], the IMO MSC.391(95) – Adoption of the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) [14] and the IGF Code, International Code for the Safety of Ships Using Gases or Other Low-Flashpoint Fuels [7] could not be identified.

6.2.2. Central Commission for the Navigation of the Rhine, Recommendations to the Ship Inspection Commission according to § 2.19/§ 2.20 of the Rhine Ship Inspection Regulations for Rhine Navigation

According to the Rhine Ship Inspection Regulations (RheinSchUO) [16], the inspection commission can permit deviations from the ES-TRIN [8] if they are recognized as equivalent based on recommendations from the Central Commission for Rhine Navigation. See also §2.20 of the Rhine ship inspection regulations [16]. With reference to the recommendations to the ship inspection commission according to §2.19/§2.20 of the Rhine ship inspection regulations [9], two recommendations were identified which relate to the use of hydrogen.

- Recommendation No. 11/2012 of 11. December 2012, VINOTRA 10
- Recommendation No. 8/2012 of 13. Junie 2012, BORNEO

Both ships refer to hydrogen as a gaseous additive to fossil fuel for generators and as an additive to diesel fuel for the main propulsion engine with a water electrolysis system. For this report, it is assumed that hydrogen is used as an additive to diesel as a fuel for engines with the aim of reducing emissions and consumption. Specific requirements are defined in the recommendations, for example for hydrogen generation, storage, transfer, design and monitoring.

Due to the in the recommendation not presented technical details it can be qualitatively stated hereinafter that the conditions for the recommendation in principle reflect the safety requirements for fuels with a low flash point, as listed for example in the regulatory requirements for liquefied natural gas. See for example LR Rules for Gas-fuelled Ships [12] and ES-TRIN, Appendix 8 [8]. The following is mentioned as conditions for adequate safety when adding hydrogen:

- Appropriate ventilation
- Appropriate equipment
- Tested equipment
- Appropriate design pressures
- Appropriate operating pressures
- Limitation of the amount of hydrogen
- Limitation of tank volumes

6.2.3. Deviation and equivalence with regard to the technical regulations of the ES-TRIN [8] for certain vehicles according to Directive (EU) 2016/1629 [22]

The legal framework of the European Union allows derogations from the technical regulations of the ES-TRIN [8] in justified cases in order to promote innovation and the use of new technologies. The inland push boat "Elektra" and the container ship "MSC Maas" were subjected to this approval process as described in the leaflet on deliberation on derogations and equivalences of technical requirements of the ES-TRIN for specific craft [2].

The propulsion system of the Elektra is based on a system of fuel cells and accumulators with hydrogen as fuel. The fuel storage system consists of several interchangeable cylinder bundles. The concept of the Elektra is described in the technical reports [20] and [21] as well as in the publication ´Nachweis der Realisierbarkeit eines innovativen Antriebskonzeptes für Binnenschiffe in Bezug auf die Gefährdungspotentiale mittels des risikobasierten Entwurfes am Beispiel des Schubbootes ELEKTRA´ [28]. The safety-relevant concepts were described for the hydrogen system as follows:

- The hydrogen tanks, the fuel regulation system and the fuel cells are installed on the open deck. The minimal amounts of hydrogen escaping from the quick-release couplings when the tank is replaced dillute immediately in the fresh air.
- Safety valves are connected to a vent line on the ship so that in the event of overpressure, the hydrogen is vented in a controlled manner at a location where neither man nor machine is endangered.
- The dispersion at the vent opening was examined in strong winds and it could be shown that there is no danger.

- All hydrogen lines are technically permanently gastight.
- The system is redundant. In the event of a defect, the supply of the fuel cells is secured.
- Hydrogen detectors immediately identify unusual conditions. A safety routine is then automatically initiated.

Six cylinder bundles, each with 20 gas cylinders made of composite materials, were provided for the fuel supply of the "Elektra". The gas cylinders comply with the standard ISO 11119-3 [23] Type IV with a pressure of 500 bar and a volume of 211 litres. A bundle of cylinders contains 125 kg of hydrogen. For the "MSC Maas" two standard 40 ft containers each with 7 gas cylinders made of composite materials were provided. The gas cylinders comply with the ISO 11515 [24] Type II standard with a pressure of 300 bar. A container contains 500 kg of hydrogen.

6.2.4. Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels

The 'Lloyd's Register, Rules and Regulations for the Classification of Ships' [18] contain the applicable provisions for the classification of ships. Ships built in accordance with Lloyd's Register Group Limited rules and regulations or equivalent requirements are given a class in what is known as the register book. The Class will be maintained as long as compliance with the applicable rules is demonstrated during the mandatory surveys. The IGF Code [14] has been adopted into the rules for gas-fueleld ships by classification societies such as Lloyd's Register. The 'Lloyd's Register, Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels' [12] define requirements for propulsion systems and auxiliary machinery systems that use methane as a fuel. The aim of these regulations is to achieve a level of safety and reliability that corresponds to that of propulsion systems using conventional fuels. The classification rules 'LR Rules and Regulations for the Classification of Ships' [18] are to be applied in addition to the 'LR Rules for Gas Fueled Ships' [12].

Essentially the IGF Code [14] and the Lloyd's Register classification regulations for gas-powered ships [12] include the following content:

- Goal and functional requirements, general requirements
- Specific requirements for ships using natural gas as fuel
- Ship design and arrangement
- Fuel containment system
- Material and general pipe design
- Power generation including propulsion and other gas consumer
- Explosion prevention
- Ventilation
- Electrical installation
- Control, monitoring and safety systems
- Manufacture, workmanship and testing
- Drills and emergency exercises

The basic philosophy of the IGF Code [14] and the 'LR Rules for Gas Fueled Ships' [12] is a goal-based approach. Goals to be met and functional requirements are set out for each section in the code to minimize the risk to the ship, crew and environment taking into account the properties of the fuel. This forms the basis for the design, construction and operation.

The "Lloyd's Register, Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels" [12] are divided into Parts A to D. Generic requirements for all fuels with low flashpoints are listed in Parts A and D and in parts A-1, B-1 and C-1 requirements for methane fuel are included. Parts A-2, etc. have yet to be developed for other low flash point fuels.

Chapter reference	Chapter title	Notes
1:	PREAMBLE	Applicable to to all gaseous and low flashpoint fuels (unless otherwise stated)
Part A:	General, GOAL AND FUNCTIONAL REQUIREMENTS, General Requirements	Applicable to to all gaseous and low flashpoint fuels (unless otherwise stated)
Part A-1:	Specific Requirement for Ships Using Natural Gas as Fuel	Not applicable to hydrogen: Parts A-1, B-1 and C-1 cover specific requirements for ships using natural gas as fuel
Part B-1:	Manufacture, Workmanship and Testing	
Part C-1:	Drills and Emergency Exercises, Operation, Annex	
Part D:	Training	Applicable to to all gaseous and low flashpoint fuels (unless otherwise stated)

Table 3 Structure of the IGF Codes and the Lloyd's Register, Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels

As long as requirements for other fuels have not yet found their way into the regulations, they must comply with the requirements of "Alternative Design and Arrangements" (AD&A). Reference is made to 'Lloyd's Register, Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels' [12], Part A, 2.3 'Alternative Design' and to the publications of the International Maritime Organization:

- IMO SOLAS Chapter II-1, Part F, Regulation 55 ´Alternative Design and Arrangements´
- IMO MSC.1/Circular.1455 ´Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments´
- IMO MSC.1/Circular.1212 ´Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-1 and III´

6.2.5. ShipRight – Design and Construction – Additional Design Procedures – Risk Based Designs (RBD)

As already mentioned, the basic philosophy of the IGF Code [14] is a goal-based approach. A risk assessment should be carried out to ensure that all risks to the ship, crew and environment are addressed considering the properties of the fuel. The LR RBD [13] process supports and provides additional guidance to meet these requirements.

6.2.6. European Agreement from 26. May 2000 concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN)

The Convention contains provisions for dangerous substances and objects, their carriage in packages or in bulk on board inland waterway vessels or tankers and provisions for the construction and operation of such vessels. It also includes regulations and procedures for the examination, the issuance of the approval certificates, the recognition of the classification societies, deviations, controls as well as the training and testing of experts [10]. Part 9 of the regulation concerns construction requirements for dry cargo vessels, certain seagoing vessels and various types of tankers. For Type G[1] tankers construction requirements are specified in Chapter 9.3, which address the following content:

- Materials of construction
- Classification
- Protection against the penetration of dangerous gases and the spreading of dangerous liquids
- Hold spaces and cargo tanks
- Ventilation
- Stability
- Engine rooms
- Accommodation and service spaces
- Inerting facilities

[1] Ein Tank vessel, intended for the carriage of gases under pressure or in a refrigerated state.

- Cofferdam
- Safety and control installations
- Cargo tank openings
- Pressure test
- Regulation of cargo pressure and temperature
- Residual tank and container
- Pumps and piping
- Refrigeration system
- Water-spray system
- Engines
- Oil fuel tanks
- Exhaust pipes
- Bilge pumping and ballasting arrangements
- Fire-extinguishing arrangements
- Fire and naked light
- Cargo heating system
- Surface temperature of installations and equipment
- Type and location of electrical installations and equipment
- Type and location of electrical and non-electrical installations and equipment intended to be used in explosion hazardous areas
- Earthing
- Special equipment
- Valve for degassing to reception facilities
- Admittance on board
- Prohibition of smoking, fire or naked light
- Emergency exit

ADN [10] defines comprehensive and very specific packaging requirements for the transport of dangerous goods. For tankers, these requirements imply that it is a ship that is conceptually suitable for the transport of substances as listed in ADN [10], Part 3, Table C and that the structural arrangement, e.g. wheelhouse and cargo area, meets these requirements. A typical arrangement of a tanker is shown in Figure 3 below using the example of zone division.

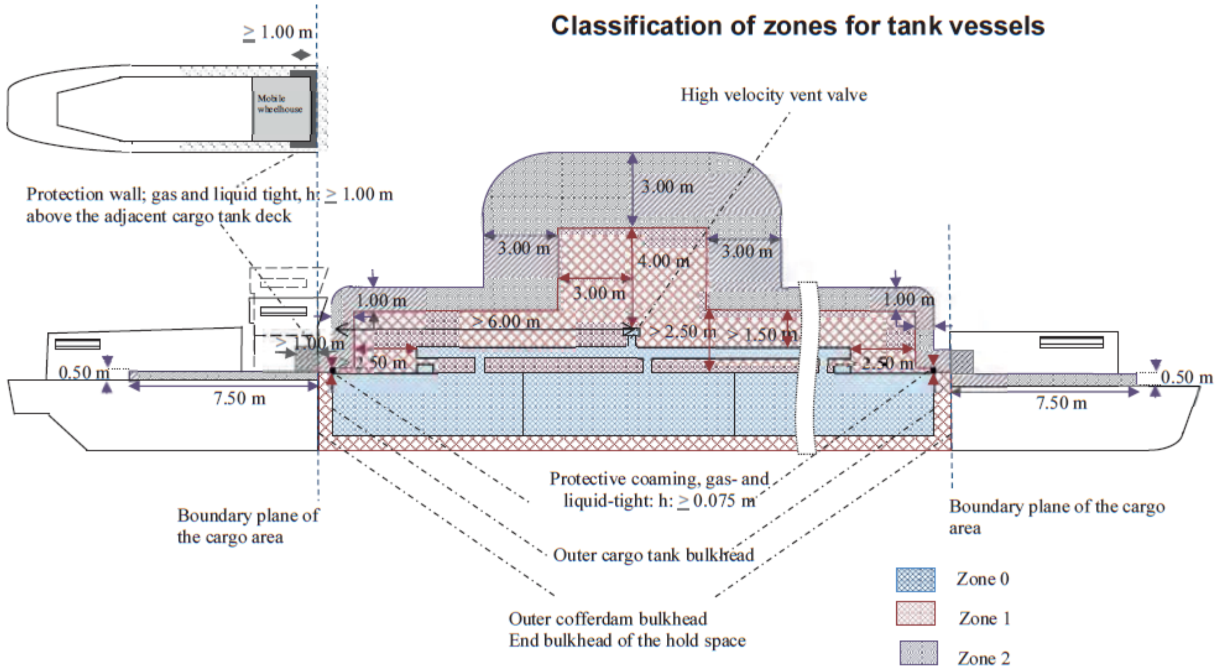

Figure 3 Classification of zones for tank vessels [10]

The specified safety-related requirements take into account the operational profile, cargo transport and cargo transfer of an inland tanker. The ship's technical spaces are separated with regard to their risk, ventilation is controlled and potentially explosive areas are identified. In addition, the individual properties of the cargo are taken into account in the requirements and individual requirements are made, such as a required inerting, the addition of stabilizers or a limitation of the maximum or minimum temperature during transport, tank types, etc.

For pressure vessels, 9.3.1.23.1 of ADN [10] stipulates for example that the loading and unloading lines comply with the regulations for pressure vessels issued by the competent authority or a recognized classification society for the substances to be transported.

Hydrogen with substance identification No. 1966 as refrigerated and liquid cargo or with substance identification No. 1049 as compressed cargo is currently not listed in Table C of the list of dangerous goods permitted for carriage in tankers. For this reason, the suitability of the regulatory requirements for hydrogen cannot be assumed.

Regulatory requirements can be derived from ADN [10] in the following form:

- Ship's equipment, operation and system design
- Fire protection
- Electrical systems
- Control-, monitoring- and safety systems

6.2.7. Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR), Vol. I+II, Status 1.1.2021

The Convention contains provisions for the international carriage of dangerous goods by road. This convention provides general rules and defines scope and applicability. Furthermore, the following content is addressed:

- Classification
- Dangerous goods list, special provisions and excemptions related to limited and excepted quantities
- Packing and tank provisions
- Consignment procedure
- Requirements for the construction and testing of packings, intermediate bulk container (IBCs), large packings, tanks and bulk containers
- Provisions concerning the conditions of carriage, loading, unloading and handling
- Provisions concerning transport equipment and transport operations
- Requirement for vehicle crews, equipment, operation and documentation

The register of dangerous goods lists hydrogen compressed, UN No. 1049, and hydrogen refrigerated and liquid, UN No. 1966. Specifications for packaging and portable tanks can be found in Table A 'List of Dangerous Goods' in Chapter 3.2. For the packaging as well as for the portable tanks the referenced chapters in Part 6 'Requirements for the construction and testing of packings, intermediate bulk container (IBCs), large packings, tanks and bulk containers' contain requirements. Part 6 of the ADR [19] 'Requirements for the construction and testing of packings, intermediate bulk container (IBCs), large packings, tanks and bulk containers' includes requirements relating to:

- Construction and testing of packings
- Construction and testing of pressure receptacles, aerosol dispenser, small receptacles containing gas (gas cartridges) and fuel cell cartridges containing liquefied flammable gas
- Construction and testing of packings for Class 6.2 infectious substances of Category A
- Construction, testing and approval of packages for radioaktive material and for approval of such material
- Construction and testing of intermediate bulk containers (IBCs)

- Construction and testing of large packings
- Design, construction, inspection and testing of portable tanks and UN multiple-element gas containers (MEGCs)
- Construction, equipment, type approval, inspection and tests, and marking of fixed tanks (tank-vehicles), demountable tanks and tank-containers and tank swap bodies, with shells made of metallic material, and battery-vehicles and multiple element gas containers (MEGCs)
- Design, construction, equipment, type approval, testing and marking of fibre-reinforced plastics (FRP) fixed tanks (tank-vehicles), demountable tanks, tank-containers and tank swap bodies
- Construction, equipment, type approval, inspection and marking of vacuum-operated waste tanks
- Design, construction, inspection and testing of bulk containers
- Construction, equipment, type approval, inspection and tests and marking of tanks, bulk containers and special compartments for explosives of mobile explosives manufacturing units (MEMUs)

6.2.8. PD ISO/TR 15916:2015 Basic consideration for the safety of hydrogen systems

The technical report PD ISO/TR 15916 ´Basic considerations for the safety of hydrogen systems´ [4] provides the basics on the safety aspects for gaseous and liquid hydrogen. Safety-relevant properties of hydrogen, associated risks and hazards are described. Hydrogen systems are presented and measures to contain and control hazards and risks are addressed.

6.2.9. MSC.420(97) Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk

Ships for the transport of liquefied gases must comply with the IGC Code [17] if they fall within its scope. Minimum requirements are provided for various specific gases, although there are no specific requirements for hydrogen. The 'MSC.420(97) Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk' [15] provides recommendations for the exclusive transport of liquid hydrogen, describes the properties and minimum hazards of hydrogen that must be considered. The recommendations relate to the following hydrogen hazards:

- Low temperature
- Hydrogen embrittlement
- Hydrogen permeability
- Hydrogen fire
- Flammability
- Pressure, expansion
- Ignitability
- Density and diffusivity

6.2.10. Standards for cryogenic vessels and gas cylinders

Standards exist for gas cylinders and cryogenic vessels. These standards define requirements for the materials used, design, manufacture and testing. Examples of standards for gas cylinders and cryogenic vessels are listed in Table 4 'Standards for cryogenic vessels and gas cylinders'. Depending on the design and integration of the tank storage system on crafts the hydrogen storage could be installed permanently or as an exchangeable (swappable) tank bundle. The suitability of the tank systems for storing hydrogen on inland waterway vessels must be verified by means of a risk assessment.

Standard	Title
ISO TS 17519	Gas cylinders — Refillable permanently mounted composite tubes for transportation
EN ISO 9809 Serie	Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes
DIN EN ISO 11120	Gas cylinders — Refillable seamless steel tubes of water capacity between 150 l and 3000 l — Design, construction and testing
ISO 11515	Gas cylinders — Refillable composite reinforced tubes of water capacity between 450 L and 3000 L — Design, construction and testing
EN 12245	Transportable gas cylinders — Fully wrapped composite cylinders
EN 17339	Transportable gas cylinders — Fully wrapped carbon composite cylinders and tubes for hydrogen
EN 13530 Serie	Cryogenic vessels — Large transportable vacuum insulated vessels
EN 13458 Serie	Cryogenic vessels — Static vacuum insulated vessels
ISO 20421 Serie	Cryogenic vessels — Large transportable vacuuminsulated vessels
ISO 21009 Serie	Cryogenic vessels — Static vacuum insulated vessels

Table 4 Standards for cryogenic vessels and gas cylinders

6.3. GAP Analysis

Relevant standards and regulations for the definition of regulatory requirements for hydrogen as a fuel on inland waterway vessels were listed and described in chapter 6.2. Due to the respective area of application of the standards and regulations a different picture emerges in the possible suitability as a basis for a regulatory proposal or supplement for hydrogen as a fuel. In the following Table 5 the scope of the regulations is presented qualitatively with reference to 'low-flashpoint fuels', 'properties of hydrogen', 'hydrogen as a fuel' and 'hydrogen-fuel containment system'.

Regulations	Scope of application	Low-flashpoint fuel	Properties of hydrogen	Hydrogen as fuel	Hydrogen-fuel containment system
ES-TRIN Edition 2021/1	Inland water vessel	+	-	-	-
Recommendations according RheinSchUO	Inland water vessel	+	-	+/-	+/-
Deviations according directive EU 2016/1629	Inland water vessel	+	-	+	+
ADN (relating Tankers)	Inland water vessel	-	-	-	-
ADR	Road	+	-	-	+
LR/IGF Code, IMO Circulars, RBD Process	Ocean going vessels	+	-	-	-
MSC.420(97) H2 Carrier	Hydrogen- Ocean going vessels	-	+	-	+/-
PD ISO/TR 15916	General H2	-	+	-	+/-

Table 5 Qualitative representation of the scope of application

6.4. Conclusion / Recommendation

Regulatory requirements for low flash point fuels already exist for inland watercrafts and seagoing vessels. They are included in the ES-TRIN and in the regulatory requirements of the IGF Code. Methane is currently the only fuel listed. Regulatory requirements for methanol are currently being developed within CESNI or for example have already been published by the IMO as preliminary guidelines. Irrespective of this the various classification societies have published further recommendations.

Regardless of the fuel used it can be assumed that essential safety aspects and in particular the areas to be regulated are applicable to all fuels with a low flash point as can be found and are reflected in e.g. the requirements for methane from the ES-TRIN or the IGF Code.

Due to the novelty of low-flashpoint fuels the underlying philosophy of the IGF Code [14] and the 'LR Rules for Gas Fueled Ships' [12] is a goal-based approach. A risk analysis must be carried out and the result documented. The requirements for the risk assessment can be found in the respective regulations. The IGF Code [14] requires that the level of safety and reliability to be achieved shall be equivalent to that of conventional oil-fuelled machinery.

The requirements for the construction and the equipment for the storage of hydrogen are not yet taken into account or only to a limited extent in the ES-TRIN or the regulatory requirements of the IMO. Special properties of hydrogen and the basics of safety aspects, hazards, preventive measures and detection can be found in PD ISO/TR 15916 [4].

Lloyd's Register, Guidance Notes for Fuel System Risk Assessments, Hazard Identification - Hydrogen and Ammonia [5] supports the risk assessment and the identification of hydrogen-specific hazards. Events and consequences that pose a comparable or additional risk compared to LNG are listed in Tables 6 and 7 below. The properties of hydrogen compared to methane and typical ignition sources are shown in Tables 8 and 9.

For supplementing the European standard of technical regulations for inland navigation vessels it is recommended that based on the existing structure for low-flashpoint fuels the requirements for hydrogen are added. A basis for the supplement can be for example the PD ISO/TR 15916 [4], the Lloyd's Register Guidance Notes for Fuel System Risk Assessments, Hazard Identification - Hydrogen and Ammonia [5] and the Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk [15]. The supplement can be based on prescriptive regulatory requirements, a goal-oriented approach, or a combination of both.

Initiating hazardous events	
Pressure related	Sloshing
	Liquid to gas expansion
	Ortho-hydrogen to para-hydrogen conversion
	Stratification and roll-over
	Loss of vacuum
Temperature related	Solidification of condensable gases
	Oxygen enrichment
	Thermal expansion and contraction
Material related	Brittle fracture
	Hydrogen embrittlement
	High Temperature Hydrogen Attack
Leakage related	Viscosity, diffusion and buoyancy

Table 6 Hydrogen release to atmosphere – initiating hazardous events requiring additional consideration [5]

Consequences	
Fire related	Fire
	Jet fire
	Pool fire
	Flash fire
Explosion related	Boiling Liquid Expanding Vapour Explosion
	Rapid Phase Transition
	Vapour cloud explosion – deflagration
	Vapour cloud explosion – detonation
Exposure related	Cryogenic burns and frostbite
	Hypothermia
	Asphyxiation

Table 7 Hydrogen release to atmosphere – potential consequences requiring additional consideration [5]

Property	Units	Hydrogen	Methane
Molecular Mass	g/mol	2	16
Equivalent volume of gas at NTP to liquid at NBP	-	845	640
Boiling temperature at NBP[1]	°C (K)	–252,85 (20,3)	–161,55 (111,6)
Liquid density at NBP[1]	kg/m^3	70,8	422,5
Gas density at NBP[1]	kg/m^3	1,34	1,82
Gas density at NTP[2]	kg/m^3	0,09	0,65
Viscosity[2]	$g/cm.s \times 10^5$	0,083	0,651
Diffusion coefficient in air[2]	cm^2/s	0,61	0,16
Specific Heat at constant pressure[2]	J/g.K	14,89	2,22
Minimum ignition energy in air[2]	mJ	0,02	0,29
Minimum auto-ignition temperature[3]	°C	585	540
Ignition limits in air[2]	Vol %	4,0–75,0	5,3–15,0
Detonability limits in air[2]	Vol %	13–65	6–13,5
Stoichiometric combustion in air[3]	Vol %	29,5	9,5
Flame temperature in air[2]	°C	2045	1875
Laminar burning velocity[3]	m/s	2,37	0,42
Quenching gap[3]	mm	0,6	2,0
Thermal energy radiated from flame to surroundings[2]	%	5–10	10–33

Table 8 Comparison of properties of hydrogen and methane [5]

Ignition sources		
Electrical	Mechanical	Thermal
Static discharge	Mechanical impact	Open flames
Electrical arc	Friction, galling, fretting (e.g. ship contact)	Hot surfaces
Charge accumulation and discharge	Metal fracture	Welding
Short circuits, sparks and arcs	Tensile rupture	Exhaust from thermal IC engine
Static electricity – two phase flow	Mechanical vibration	Explosive charges
Static electricity – flow with solids (snow)		High velocity jet heating
Lightning / charged atmosphere		Shock waves created by a rupture
Electrical charge generated by equipment operation		Fragments from burst disc or vessel

Table 9 Hydrogen ignition sources [5]

6.5. Proposed structure

ANNEX 8
SUPPLEMENTARY PROVISIONS APPLICABLE TO CRAFT OPERATING ON FUELS WITH A FLASHPOINT EQUAL TO OR LOWER THAN 55 °C

Section II
Fuel Storage

Part 2
Hydrogen

Chapter 1 General

1.1 Application
1.2 Definitions
1.3 Risk assessement
1.4 General Requirements
1.5 Knowledge of technical service
1.6 Marking

Chapter 2 Vessel Arrangements and System Design

2.1 Hydrogen containment system (tank and cylinder)
2.2 Hydrogen piping systems
2.3 Drainage systems
2.4 Drip trays
2.5 Arrangement of entrances and other openings
2.6 Ventilation systems
2.7 Hydrogen bunkering system
2.8 Filling limits of hydrogen fuel tanks
2.9 Fuel supply system
2.20 Exhaust system and fuel supply shut down

Chapter 3 Fire Safety

3.1 General
3.2 Fire alarm system
3.3 Fire protection
3.4 Fire prevention and cooling
3.5 Fire extinguishing

Chapter 4 Electrical Systems

Chapter 5 Control, Monitoring and Safety Systems

5.1 General
5.2 Hydrogen bunkering system and hydrogen system monitoring
5.3 Gas warning equipment
5.4 Safety functions of gas supply systems

7. Work package 2, Draft technical regulations for inland vessels

7.1. Task

The objective of this task is to develop a proposal for technical regulations or technical requirements for inland waterway vessels that are operated with hydrogen as an energy source. This proposal is intended to complement the European standard of technical regulations for inland navigation vessels and to be compatible with the existing regulations for other fuels. This draft of the regulations for inland navigation vessels might be included and published in the ESTRIN as Annex 8 "Supplementary provisions applicable to craft operating on fuels with a flashpoint equal or lower than 55 °C", Section I - "Definitions", Section II "Fuel storage", Part 2 – “Hydrogen”.

7.2. Regulatory proposal

The regulatory proposal for inland vessels using hydrogen as an energy carrier was presented at the working session of the temporary working group CESNI/PT/FC. Currently, Chapter 30 ´Special provisions applicable to craft equipped with propulsion or auxiliary systems operating on fuels with a flashpoint equal to or lower than 55 °C´ and Annex 8 ´Supplementary provisions applicable to craft operating on fuels with a flashpoint equal or lower than 55 °C´ of the European standard laying down technical requirements for inland navigation vessels Edition 2021/1 will be revised. Requirements for both fuel cells and methanol as a fuel are currently being discussed. The structure of the regulatory proposal for "hydrogen" is based on the ES-TRIN edition 2021/1.

The draft of the regulations will be circulated within the associations recognized by CESNI which actively participate in the work of the committee and the working groups. The recognized associations may provide information and further suggestions to the Committee through the Secretariat. In addition to this commenting process other industrial companies such as tank manufacturers are also invited to comment on the technical content.

The draft of the CESNI working document Annex 8, Section I – "Definitions of terms", Section II "Fuel storage", Part 2 - "Hydrogen" can be requested from the German associations recognized by CESNI. This includes the Bundesverband der Deutschen Binnenschifffahrt e.V., der Verband für Schiffbau und Meerestechnik e.V. und der Verein für europäische Binnenschifffahrt und Wasserstraßen e.V.:

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	Rule proposal	ES-TRIN 2021	Location based on restructured proposal CESNI/PT/FC (20) 11 rev.3 CESNIptfc20_11en_rev3_160721 gp.docx
	Annex 8 ***Supplementary provisions applicable to craft operating on fuels with a flashpoint equal to or lower than 55 °C*** **Section [ ]** ***Hydrogen (H2)*** **Chapter 1** **General**	***Annex 8*** ***Supplementary provisions applicable to craft operating on fuels with a flashpoint equal to or lower than 55 °C*** **Section I** ***Liquefied Natural Gas (LNG)*** **Chapter 1** **General**	
1.1	**Application**	**Application**	*Article 30.01*
1.1.1	The provisions of Section I apply to craft equipped with propulsion or auxiliary systems operating on hydrogen (H2) according to ([ ] and 1.2.1) and address all areas that need special consideration for the usage of hydrogen (H2) as fuel. [Naming and abbreviation examples used for hydrogen: • ADR: 1049 hydrogen, compressed; 1966 hydrogen, refrigerated liquid • PD ISO/TR 15916: hydrogen (H2), gaseous hydrogen (GH2), liquid hydrogen (LH2) • ASME B31.12-2019: gaseous hydrogen (GH2), liquid hydrogen (LH2) • (EU) No 406/2010: liquid hydrogen, cryogenic hydrogen, gaseous hydrogen, pressurised hydrogen, hydrogen gas]	The provisions of Section I apply to craft equipped with propulsion or auxiliary systems operating on liquefied natural gas (LNG) according to (1.2.1) and address all areas that need special consideration for the usage of liquefied natural gas (LNG) as fuel.	*Article 30.01 (1)*

Table 10 Preview regulatory proposal

8. Work package 4, Transfer to regulation development for sea-going ships

8.1. Task

In work package 4 the regulatory proposal from work package 2 for Annex 8 ES-TRIN - hydrogen - is examined in relation to international maritime shipping or coastal ships and presented in the report on the study. So far no regulations on bunkering and storage of hydrogen have been passed by the International Maritime Organization (IMO). The results and experiences from work package 2 and work package 3 are processed with a view on transferring the safety concepts to the forthcoming development of regulations for seagoing vessels in the IMO.

8.2. Transfer of safety concepts

The regulatory proposal for fuels with a low flash point in work package 2 is based on the existing structure of ES-TRIN [8] in edition 2021/1. The European standard for inland vessels is currently being revised to include regulatory requirements for fuel cells and methanol as a fuel.

A restructured and revised proposal regarding Chapter 30 ´Special provisions applicable to craft equipped with propulsion or auxiliary systems operating on fuels with a flashpoint equal to or lower than 55 °C´ and regarding Appendix 8 ´Supplementary provisions applicable to craft operating on fuels with a flashpoint equal or lower than 55 °C´ is currently being discussed within the ´European Committee for drawing up Standards in the Field of Inland Navigation' (CESNI).

To demonstrate the transferability of safety concepts reference is made below to the goals and functional requirements of IMO MSC.391(95) ´Adoption of the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)´ [14] and of the technical regulations for inland crafts [8]. Furthermore the specific requirements from MSC 420(97) 'Interim recommendations for Carriage of Liquefied Hydrogen in Bulk' [15] are compared with the requirements of the regulatory proposal from work package 2. In contrast to inland navigation ocean-going ships can operate at great distances from the coastal catchment area and in far less favourable weather conditions, wave heights and ship acceleration. Furthermore depending on the type of ship and the operating profile a larger quantity of fuel to be stored is to be expected. This can result in increased safety requirements.

8.2.1. IGF Code and ES-TRIN

The IGF Code [14] for the safety of ships using gases or other fuels with a low flash point incorporated by the classification societies implies a goal-based approach. Goals to be met and functional requirements are set out for each section in the code to minimize the risk to the ship, crew and environment, taking into account the properties of the fuel. General requirements, objectives and functional requirements for all low flash point fuels are listed in Part A and Part D. Specific requirements, objectives and functional requirements limited to natural gas as a fuel can be found in part A-1 'Specific requirements for ships using natural gas as fuel', B-1 'Manufacture, workmanship and testing' and C-1 'Drills and emergency exercises. A risk assessment is required with a necessary limitation of explosion consequences in Part A, Section 4. Lloyd's Register incorporated the IGF Code [14] into the 'Rules and Regulations for the Classification of Ships using Gases or other Low-Flashpoint Fuels' [12].

In its 2021/1 edition the European Standard for Inland navigation Vessels [8] considers in Chapter 30 ´Special provisions applicable to craft equipped with propulsion or auxiliary systems operating on fuels with a flashpoint equal to or lower than 55 °C´. ´Supplementary provisions applicable to craft operating on fuels with a flashpoint equal or lower than 55 °C´ can be found in Appendix 8 for LNG. Specific requirements, goals and functional requirements limited to natural gas as a fuel can be found in Annex 8 Section I Chapter 1.4 with a required risk assessment according to Chapter 1.3.

Both the IGF Code [14] and the ES-TRIN [8] specify goals to be met, functional requirements and a limitation of the consequences of explosions. The requirements in the IGF Code [14] currently go beyond the requirements specified in ES-TRIN [8]. The goals and functional requirements of the IGF Code [14] for all low flash point fuels are presented in Table 11 below. The corresponding goals and functional requirements of the ES-TRIN [8] are compared to those of the IGF Code [14].

IGF-Code	ES-TRIN
3.1 Goal The goal of this Code is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.	Annex 8, Section I, 1.4.2 The LNG system shall be designed, constructed, installed, maintained and protected to ensure safe and reliable operation.
3.2 Functional requirements	
3.2.1 The safety, reliability and dependability of the systems shall be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.	
3.2.2 The probability and consequences of fuel-related hazards shall be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of gas leakage or failure of the risk reducing measures, necessary safety actions shall be initiated.	
3.2.3 The design philosophy shall ensure that risk reducing measures and safety actions for the gas fuel installation do not lead to an unacceptable loss of power.	Chapter 30, Article 30.06 In the event of an automatic shutdown of the propulsion system or parts of the propulsion system, the craft shall be able to make steerageway under its own power.

IGF-Code	ES-TRIN
3.2.5 Equipment installed in hazardous areas shall be minimized to that required for operational purposes and shall be suitably and appropriately certified.	Annex 8, Section I, 1.4.6 Equipment installed in hazardous areas shall be minimized to that required for operational purposes and shall be suitably and appropriately certified.
3.2.6 Unintended accumulation of explosive, flammable or toxic gas concentrations shall be prevented.	Annex 8, Section I, 1.4.7 Unintended accumulation of explosive or flammable gas concentrations shall be prevented.
3.2.7 System components shall be protected against external damages.	Annex 8, Section I, 1.4.3 Components of the LNG system shall be protected against external damages.
3.2.8 Sources of ignition in hazardous areas shall be minimized to reduce the probability of explosions.	Annex 8, Section I, 1.4.8 Sources of ignition in hazardous areas shall be excluded to reduce the probability of explosions.
3.2.9 It shall be arranged for safe and suitable fuel supply, storage and bunkering arrangements capable of receiving and containing the fuel in the required state without leakage. Other than when necessary for safety reasons, the system shall be designed to prevent venting under all normal operating conditions including idle periods.	
3.2.10 Piping systems, containment and over-pressure relief arrangements that are of suitable design, construction and installation for their intended application shall be provided.	
3.2.11 Machinery, systems and components shall be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.	
3.2.12 Fuel containment system and machinery spaces containing source that might release gas into the space shall be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable.	Annex 8, Section I, 1.4.10 A fire or explosion caused by released gas in LNG containment systems and engine rooms shall not render the essential machinery or equipment in other compartments inoperable.

IGF-Code	ES-TRIN
3.2.13 Suitable control, alarm, monitoring and shutdown systems shall be provided to ensure safe and reliable operation.	
3.2.14 Fixed gas detection suitable for all spaces and areas concerned shall be arranged.	
3.2.15 Fire detection, protection and extinction measures appropriate to the hazards concerned shall be provided.	
3.2.16 Commissioning, trials and maintenance of fuel systems and gas utilization machinery shall satisfy the goal in terms of safety, availability and reliability.	
3.2.17 The technical documentation shall permit an assessment of the compliance of the system and its components with the applicable rules, guidelines, design standards used and the principles related to safety, availability, maintainability and reliability.	Chapter 30, Article 30.01 (3) Propulsion and auxiliary systems according to (2) shall be constructed and installed under the supervision of the inspection body. Chapter 30, Article 30.01 (4) For the purpose of discharging tasks pursuant to this chapter, the inspection body may employ a technical service in accordance with Article 30.07. Chapter 30, Article 30.01 (5) Before commissioning of a propulsion or auxiliary system according to (2), the following documents shall be submitted to the inspection body: a) a risk assessment according to Annex 8, b) a description of the propulsion or auxiliary system, c) drawings of the propulsion or auxiliary system, d) a diagram of the pressure and temperature within the system, e) an operating manual containing all applicable procedures, intended for practical use of the system, f) a safety rota according to Article 30.03,

IGF-Code	ES-TRIN
	g) a copy of the inspection certificate referred to in Article 30.02(4).
3.2.18 A single failure in a technical system or component shall not lead to an unsafe or unreliable situation.	Annex 8, Section I, 1.4.1 A single failure in the LNG system shall not lead to an unsafe situation.
19.1 Goal The goal of this chapter is to ensure that seafarers on board ships to which this Code applies are adequately qualified, trained and experienced.	
19.2 Functional requirements Companies shall ensure that seafarers on board ships using gases or other low-flashpoint fuels shall have completed training to attain the abilities that are appropriate to the capacity to be filled and duties and responsibilities to be taken up, taking into account the provisions givenin the STCW Convention and Code, as amended.	

Table 11 Objective and functional requirements of the IGF Code and the ES-TRIN

The objective of the IGF Code [14] is to provide a safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel. With this goal and the functional and general requirements the basic criteria for the inherent safety concept are defined. A presentation of the future goals, functional requirements and limitations of the consequences of an explosion in the ES-TRIN [8] and a comparison with those of the IGF Code [14] is recommended in order to assess whether the safety concept can be further transferred.

8.2.2. MSC 420(97) Interim recommendations for Carriage of Liquefied Hydrogen in Bulk

The interim recommendations MSC 420(97) ´Interim recommendations for Carriage of Liquefied Hydrogen in Bulk´ [15] for the carriage of liquefied hydrogen in bulk were developed on the basis of similar cargoes, e.g. liquefied natural gas, as described in Chapter 19 of the IGC codes [17]. Tables 1 and 2 of the preliminary recommendation MSC 420(97) [15] list general and specific requirements for the carriage of liquefied hydrogen. The regulatory proposal from work package 2 will be examined and qualitatively assessed for compliance with the specific requirements of this recommendation. The result is shown in Table 12 below.

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
1	Requirements for materials whose design temperature is lower than -165°C should be agreed with the Administration, paying attention to appropriate standards. Where minimum design temperature is lower than -196°C, property testing for insulation materials should be carried out with the appropriate medium, over a range of temperatures expected in service.	2.1.4	The LH2 fuel tank shall be an independent tank designed in accordance with the European Standards EN 13530 : 2002, EN 13458-2 : 2002 in combination with dynamic loads, or the IGC-Code (type C tank) [ISO 20421-1, ISO 21009-1]. [Acceptable standards for storage of GH2, including type 1, 2, 3, 4 and 5, to be discussed, e.g. EN ISO 9809, EN ISO 11120, ISO 11119, ISO 11515, ISO TS 17519] The inspection body can accept other equivalent standards of one of the Rhine riparian States and Belgium.	partially met
2	Materials of construction and ancillary equipment such as insulation should be resistant to the effects of high oxygen concentrations caused by condensation and enrichment at the low temperatures attained in parts of the cargo system (refer to the requirement for nitrogen).			open

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
3	For cargo pipes containing liquid hydrogen and cold hydrogen vapour, measures should be taken to prevent the exposed surfaces from reaching -183°C. For places where preventive measures against low temperature are not sufficiently effective, such as cargo manifolds, other appropriate measures such as ventilation which avoids the formation of highly enriched oxygen and the installation of trays recovering liquid air may be permitted in lieu of the preventive measures. Insulation on liquid hydrogen piping systems exposing to air should be of non-combustible material and should be designed to have a seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation.	2.1.15 2.3.5	It shall be possible to purge gas and vent hydrogen fuel tanks (after LH2 is fully evaporated to gas and same where LH2 is used in pipes (gas temp should > -210˚C)) including gas piping systems. It shall be possible to perform inerting with an inert gas (e.g. nitrogen or argon) prior to venting with dry air, to exclude an explosion hazardous atmosphere in hydrogen fuel tanks and gas piping. Low temperature piping shall be thermally isolated from the adjacent hull structure, where necessary. Protection against accidental contact shall be provided.	partially met
4	Appropriate means, e.g. filtering, should be provided in cargo piping systems to remove impure substances condensed at low temperature.			open
5	Pressure relief systems should be suitably designed and constructed to prevent blockage due to formation of water or ice.	2.1.10	If condensation and icing due to cold surfaces of hydrogen fuel tanks may lead to safety or functional problems, appropriate preventive or remedial measures shall be taken. The space to which the hydrogen leaks should vent	partially met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
			directly to the outside (to avoid under pressure).	
		2.1.16	Hydrogen containment system's pressure and temperature shall be maintained at all times within their design range.	
6	At places where contact with hydrogen is anticipated, suitable materials should be used to prevent any deterioration owing to hydrogen embrittlement, as necessary.	2.1.4	The LH2 fuel tank shall be an independent tank designed in accordance with the European Standards EN 13530 : 2002, EN 13458-2 : 2002 in combination with dynamic loads, or the IGC-Code (type C tank) [ISO 20421-1, ISO 21009-1]. [Acceptable standards for storage of GH2, including type 1, 2, 3, 4 and 5, to be discussed, e.g. EN ISO 9809, EN ISO 11120, ISO 11119, ISO 11515, ISO TS 17519] The inspection body can accept other equivalent standards of one of the Rhine riparian States and Belgium.	partially met
		2.1.6 (b)	If tank connections are below the highest liquid level of the LH2 fuel tanks, drip trays shall be placed below the tanks that meet the following requirements: the material of the drip tray shall be suitable stainless steel.	
		2.1.8	If the secondary barrier of the hydrogen containment system is part of the hull structure it may be a boundary of the tank room subject to necessary precautions against leakage of cryogenic liquid.	
7	All welded joints of the shells of cargo tanks should be of the in-plane butt weld full penetration type. For dome-			open

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
	to-shell connections only, tee welds of the full penetration type may be used depending on the results of the tests carried out at the approval of the welding procedure.			
8	Double tube structures ensuring no leakage, or fixed hydrogen detectors being capable of detecting a hydrogen leak, should be provided for places where leakage of hydrogen may occur, such as cargo valves, flanges, and seals.	2.3.1 5.4.1 5.4.2 (a)-(h)	Hydrogen (H2) piping through other engine rooms or non-hazardous enclosed areas of the craft shall be enclosed in double wall piping or ventilated ducting. Gas warning equipment shall be designed, installed and tested in accordance with a recognized Standard, such as European Standard EN 60079-29-1 : 2016. Permanently installed gas detectors (parts per million (PPM) type) shall be fitted in: tank connection areas including fuel tanks, pipe connections and first valves, ducts around gas piping, engine rooms containing gas piping, gas equipment or gas consuming equipment, the room containing the gas preparation system, other enclosed rooms containing gas piping or other gas equipment without ducting, other enclosed or semi-enclosed rooms where gas vapours may accumulate including interbarrier spaces and tank rooms of independent hydrogen fuel tanks other than type C, air locks, and	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
			ventilation outlets to rooms in which gas vapours may accumulate.	
9	Helium or a mixture of 5% hydrogen and 95% nitrogen should be used as the tightness test medium for cargo tank and cargo piping.			open
10	The amount of carbon dioxide carried for a carbon dioxide fire-extinguishing system should be sufficient to provide a quantity of free gas equal to 75% or more of the gross volume of the cargo compressor and pump rooms in all cases.			open
11	When deterioration of insulation capability by single damage is possible, appropriate safety measures should be adopted taking into account the deterioration.			open
12	When vacuum insulation is used for a cargo containment system, the insulation performance should be evaluated to the satisfaction of the Administration based on experiments, as necessary.	2.1.16 2.1.17	Hydrogen containment system's pressure and temperature shall be maintained at all times within their design range. If the hydrogen system is switched off, the pressure in the LH2 fuel tank, shall be maintained below the maximum working pressure of the LH2 fuel tank for a period of 15 days. It shall be assumed that LH2 fuel tank was filled at filling limits according to 2.9 and that the craft remains in idle condition.	partially met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
13	Appropriate measures should be provided to prevent vents becoming blocked by accumulations of ice formed from moisture in the air.			open
14	Due consideration should be given to means for handling boil-off gas.	2.1.16	Hydrogen containment system's pressure and temperature shall be maintained at all times within their design range.	met
		2.1.17	If the hydrogen system is switched off, the pressure in the LH2 fuel tank, shall be maintained below the maximum working pressure of the LH2 fuel tank for a period of 15 days. It shall be assumed that LH2 fuel tank was filled at filling limits according to 2.9 and that the craft remains in idle condition.	
15	Due consideration should be given to static electricity associated with rotating or reciprocating machinery including the installation of conductive machinery belts and precautionary measures incorporated in operating and maintenance procedures. Anti-static clothing and footwear, and a portable hydrogen detector should be provided for each crew member working in the cargo area.			open

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
16	An operation manual for a liquefied hydrogen carrier should include limitations of various operations in relation to environmental conditions.	1.4.9	A detailed operating manual of the hydrogen system shall be provided on board craft using hydrogen as fuel and which as minimum: contains practical explanations about hydrogen bunkering system, hydrogen containment system, hydrogen piping system, Gas supply system, engine room, ventilation system, leakage prevention and control, monitoring and safety system, describes the bunkering operations, especially valves operation, purging, inerting and gas freeing. This may also include the exchange of hydrogen containment system, e.g. tanks or containers/racks with hydrogen tanks. describes the relevant method of electrical insulation during bunkering operations, describes the details of risks identified in the risk assessment as referred to in (1.3) and the means by which they are mitigated.	met
17	An appropriate procedure should be established for warm-up, inert gas purge, gas-free, hydrogen purge and pre-cooling. The procedure should include: .1 selection of inert gas in relation to temperature limit; .2 measurement of gas concentration; .3 measurement of temperature; .4 rates of supply of gases;	1.4.9	A detailed operating manual of the hydrogen system shall be provided on board craft using hydrogen as fuel and which as minimum: contains practical explanations about hydrogen bunkering system, hydrogen containment system, hydrogen piping system, Gas supply system, engine room, ventilation system, leakage prevention and control, monitoring and safety system, describes the bunkering operations, especially valves operation, purging, inerting and	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
	.5 conditions for commencement, suspension, resuming and termination of each operation; .6 treatment of return gases; and .7 discharge of gases.		gas freeing. This may also include the exchange of hydrogen containment system, e.g. tanks or containers/racks with hydrogen tanks. describes the relevant method of electrical insulation during bunkering operations, describes the details of risks identified in the risk assessment as referred to in (1.3) and the means by which they are mitigated.	
18	Only almost pure para-hydrogen (i.e. more than 95%) should be loaded in order to avoid excessive heating by ortho- to para-hydrogen conversion.			open
19	Fire detectors for detecting hydrogen fire should be selected after due deliberation, taking into account the features of hydrogen fire, to the satisfaction of the Administration.	3.	Fire safety	met
20	At the design stage, dispersion of hydrogen from vent outlets should be analysed in order to minimize risk of ingress of flammable gas into accommodation spaces, service spaces, machinery spaces and control stations. Extension of hazardous areas should be considered based on the results of the analysis.	1.4.4 1.4.5	Hazardous areas shall be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the craft, people on board, environment and equipment. In particular, hazardous areas are parts of the vessel not intended for passengers as referred to in Article 19.06(11). Appropriate measures shall be taken to keep passengers away from hazardous areas.	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
		1.4.7	Unintended accumulation of explosive or flammable gas concentrations shall be prevented.	
		2.1.13	The exhaust outlets of the pressure relief valves shall be located not less than 2,00 m above the deck at a distance of not less than 1,50 m [and according safety distance calculation 1.6 kW/m2 limit or 4.7 kW/m2 with protective clothing for passing only] of any escape route, door opening, window (unless window are A30 equivalent), from the accommodation, passenger areas and work stations, which are located outside the hold or the cargo area.	
		2.7	Ventilation systems	
21	Due consideration should be given to appropriate safety measures to prevent formation of explosive mixture in the case of a leakage of hydrogen, including: .1 installation of hydrogen detectors in order to detect a possible ground-level travel of low temperature hydrogen gas, and at high points in spaces where warm hydrogen gas can be trapped; and .2 application of "best practice" for land-based liquid hydrogen storage	3.	Fire safety	partially met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
	taking into account appropriate guidance such as "Cryogenics Safety Manual – Fourth Edition (1998)".			
22	In the case that fusible elements are used as a means of fire detection required by paragraph 18.10.3.2 of the Code, flame detectors suitable for hydrogen flames should be provided in addition at the same locations. Appropriate means should be adopted to prevent the activation of ESD system owing to false alarm of flame detectors, e.g. avoiding activation of ESD system by single sensor (voting method).	3.2	Fire alarm system	met
23	Consideration should be given to enhance the ventilation capacity of the enclosed spaces subject to liquefied hydrogen leakage, taking into account the latent heat of vaporization, specific heat and the volume of hydrogen gas in relation to temperature and heat capacity of adjacent spaces.	2.7	Ventilation systems	met
24	Liquid and gas hydrogen pipes should not pass through enclosed spaces other than those referred to in paragraph 5.2.2.1.2 of the Code, unless:	2.3.1	Hydrogen (H2) piping through other engine rooms or non-hazardous enclosed areas of the craft shall be enclosed in double wall piping or ventilated ducting.	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
	.1.1 the spaces are equipped with gas detection systems which activate the alarm at not more than 30% LFL and shut down the isolation valves, as appropriate, at not more than 60% LFL (see sections 16.4.2 and 16.4.8 of the Code); and .1.2 the spaces are adequately ventilated; or .2 the spaces are maintained in an inert condition. This requirement is not applicable to spaces constituting a part of a cargo containment system using vacuum insulation where the degree of vacuum is monitored.	2.3.7 2.2	Hydrogen (H2) piping through other engine rooms or non-hazardous enclosed areas of the craft shall be enclosed in double wall piping or ventilated ducting. Engine rooms	
25	A risk assessment should be conducted to ensure that risks arising from liquefied hydrogen cargo affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed. Consideration should be given to the hazards associated with properties of liquefied hydrogen and hydrogen gas, physical layout, operation and maintenance, following any reasonably foreseeable	1.3.1	A risk assessment shall be conducted on all concepts and configurations which are new or have been significantly modified. The risks arising from the use hydrogen affecting people on board including passengers, the environment, the structural strength and the integrity of the craft shall be addressed. Reasonable consideration shall be given to the hazards associated with physical layout, operation, and maintenance, following a failure.	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
	failure. For the risk assessment, appropriate methods, e.g. HAZID, HAZOP, FMEA/FMECA, what-if analysis, etc., should be adopted taking into account IEC/ISO 31010:2009 "Risk management – Risk assessment techniques"7) and SAE ARP 5580-2001 "Recommended failure modes and effects analysis (FMEA) practices for non-automobile applications".	1.3.2	The risks are to be determined and assessed using a risk analysis technique recognised by the inspection body, such as International Standards ISO 31000: 2018 and ISO 31010: 2019. Loss of function, component damage, fire, explosion, tank room flooding, vessel sinking and electric overvoltage shall as a minimum be considered. The analysis must help to ensure that risks are eliminated wherever possible. Risks which cannot be eliminated entirely are to be mitigated to an acceptable level. The major scenarios and measures for eliminating or mitigating risks shall be described.	
26	Relief valve sizing should be undertaken for the most onerous scenario. Whether this scenario is brought into existence due to fire or by loss of vacuum from the overall insulation system should be assessed and the resulting magnitude of the heat flux on the containment system considered in each case.	2.1.11 [ ] [ ]	Each LH2 fuel tank is to be fitted with at least two pressure relief valves that can prevent an overpressure if one of the valves is closed off due to malfunctioning, leakage or maintenance. Each GH2 fuel tank is to be fitted with at least one pressure relief valve and one TPRD that can prevent an overpressure if one of the valves is closed off due to malfunctioning, leakage or maintenance. For each GH2 containment system an additional TPRD is to be provided that covers a fire exposure of the whole containment system. Containment systems too large to be protected by an additional TPRD, evidence is to be provided by testing for A60 fire that the GH2	met

No.	MSC.420(97), Special Requirements	Rule proposal Hydrogen (AP2)		Comment
			containment system will be safely vented and not rupture. The inspection body can accept other equivalent standards for fire testing. [Application of land based bonfire testing procedures e.g.: FMVSS 304, SAE TIR J2579, EC 79/2009 and EU 406/2010, (AE J2579 covers whole H2 system), Global Technical Resolution (GTR-No. 13) with remark to H2 test gas to be discussed]	
27	A filling limit exceeding 98% at reference temperature should not be permitted.	2.9	Filling limits of LH2 fuel tanks	met
28	Bolted flange connections of hydrogen piping should be avoided where welded connections are feasible.			open
29	Due consideration should be given to the invisible nature of hydrogen fire.	3.2.2	Smoke detectors alone are not sufficient for rapid detection of a fire. There shall also be suitable UV and or IR flame detectors to rapid detect hydrogen fires for all rooms of the hydrogen system and on open decks where hydrogen fires cannot be excluded.	met

Table 12 Requirements in MSC.420(97) and regulatory proposal for hydrogen

8.3. Conclusion / Recommendation

A transfer of the safety concept as used in the ES-TRIN [8] would be possible to a limited extent and only with special consideration of the individual risk minimization measures in connection with the defined goals. Chapter 9.2.1 of this report points out the differences between the IGF Code [14] and ES-TRIN [8] in terms of the objective and the functional requirements. While the IGF Code [14] in its objective requires that a single failure in a technical system or component must not lead to an unsafe or unreliable situation, under the current ES-TRIN [8] for liquefied natural gas and for hydrogen in the regulatory proposal this is only the failure of a system. While the IGF Code [14] requires equivalent safety, reliability and system stability comparable to conventional oil-fuelled main and auxiliary machinery, such a requirement does not exist in the current ES-TRIN [8]. For this reason unrestricted transferability of the overall concept cannot be assumed.

However, specific measures to achieve the functional goals within the ES-TRIN [8] can be considered suitable for a transfer. This must be done by taking the required safety level into account which is based on the respective maritime application and will be proven in a risk assessment. A comparison of the special requirement of MSC 420(97) 'Interim recommendations for Carriage of Liquefied Hydrogen in Bulk' [15] with the given requirements in the regulatory proposal was carried out in Chapter 9.2.2. From this comparison it can be seen that there is agreement across the board with regard to the respective special requirements. However, as shown in Table 13 below it can also be stated that certain specific requirements from the interim recommendation for tankers for the transport of liquid hydrogen have not yet been addressed in the regulatory proposal for hydrogen for inland navigation vessels.

Requirements for	No.	Relation	Draft supplementary ES-TRIN provisions for hydrogen
Cargo tank type and construction	1	Construction and testing	2.1.4
Hydrogen enrichment	2, 3	Low temperature	2.1.5
Filters in cargo line	4	Low temperature	
Blocked safety valve	5	Low temperature	2.1.10, 2.1.16
Tank welds	7	Construction and testing	
Leak testing	9	Construction and testing	
CO2 extinguishing agent	10	Fire	
Insulation	11, 12	Low temperature	2.1.6, 2.1.17
Ventilation	13	Low temperature	
Electrostatic charge	15	Fire	
Hydrogen quality	18	Pressure	
Hydrogen detection	21	Fire	3.
Flanged connection	28	Construction and testing	

Table 13 Comparison of the requirements for tankers according to MSC.420(97) and the draft for supplementary ES-TRIN provisions for hydrogen

Specific requirements in the regulatory proposal are significantly unsuitable or only partially suitable for a transfer:

- tank arrangement and distances to the ship’s hull,
- design, construction and testing of the hydrogen tanks,
- distances to the ventilation openings and safety valve outlet,
- distances of fuel piping to the ship’s hull.

A reassessment of these requirements with regard to the risks to be expected, e.g. with regard to collision or leakage scenarios and the associated consequences for ocean-going ships, is necessary.

9. Management Summary

With this study a proposal for technical regulations for inland vessels that are operated with hydrogen as an energy carrier was developed. This proposal is intended to complement the European standard laying down technical requirements for inland navigation vessels (ES-TRIN) and be compatible with the existing regulations for other fuels. The international working body responsible for these regulations is the European Committee for drawing up Standards in the field of Inland Navigation. At present the current regulations for inland navigation vessels using fuels with a flash point of 55°C or below deal only with LNG. This study analyses how technical regulations for inland navigation vessels would need to be supplemented so that compressed or cryogenic (low-temperature) hydrogen could be used as a fuel. In addition it is examined how the technical principles of this draft regulation can potentially be transferred to seagoing vessels.

An important goal of the European Union is to shift more inland waterway freight traffic to rivers and canals in the EU and there to emission-free ships. This transfer should take place at the same time as the reduction of greenhouse gases and other pollutants by 2050.

The energy transition is a complex and time-consuming process for inland shipping which can be understood as an existential challenge. Only when inland navigation makes the transition to climate-neutral propulsion political support will be given to the development of this sector. In order to be able to use regenerative or alternative fuels including hydrogen on inland vessels across Europe without special permits in individual cases the European standard laying down technical requirements for inland navigation vessels must be supplemented accordingly.

Regulations for liquefied natural gas as a fuel have already been developed for the European Committee for the Development of Standards in the Field of Inland Navigation[2] and published with the European Standard of Technical Regulations for Inland Waterways. Regulations for fuel cells and methanol are currently still being discussed within the European Committee and are to be published shortly. So far neither the European Committee nor the International Maritime Organization (IMO) have developed regulations for hydrogen as a fuel. The updated legal framework aims to enable the regular use of alternative fuels on board inland waterway vessels. There are already a number of projects in which the use of liquid, cryogenic and compressed gaseous hydrogen as a fuel for ships has been tested or is being tested. Numerous project results and documents have been published that consider the particular dangers of hydrogen.

This study analyses how the European standard for inland waterway vessels needs to be supplemented to allow compressed or cryogenic hydrogen to be used on inland waterway vessels. Standards and other regulations for the transport and use of hydrogen and recommendations within the framework of pilot applications that use hydrogen as a fuel in inland navigation were examined for their relevance. The result is presented qualitatively in a gap analysis. A structure was drawn up for the new regulations to be developed which includes the definition of the ship-side technical requirements for the bunkering and storage of cryogenic and pressurized hydrogen and proposals for regulatory implementation. The regulatory requirements for cryogenic or compressed hydrogen on inland waterway vessels were examined with regard to a transfer of technical principles regardless of the vessel type.

In addition to the ES-TRIN, the recommendations of the Central Commission for Navigation on the Rhine (CCNR), the regulations of the classification society Lloyd's Register, the European Agreement concerning the International Carriage of Dangerous Goods on Inland Waterways, standards regarding hydrogen and recommendations of the International Maritime Organization have been evaluated to develop the new text of the rules. The result is shown graphically in a qualitative gap analysis. The regulations under consideration

[2] European Standard laying down Technical Requirements for Inland Navigation Vessels (ES-TRIN), Edition 2021/1

provide to a varying extent the basics on the properties of hydrogen, storage of hydrogen and hydrogen as a fuel.

This draft of the rule text describes the scope of application and lists the necessary definitions. General requirements are presented such as requirements for the arrangement on the ship and for the system design, for fire protection and for the electrical systems, as well as for the control, for the monitoring and for the safety systems. Requirements for the energy converters are not included in this proposal. The regulatory proposal forms the basis for further discussion for the temporary CESNI working group `CESNI/PT/FC`.

Furthermore the transferability of the concept to seagoing vessels was examined, the objectives and functional requirements of the IGF Code[3] were described and compared with the ES-TRIN. Specific requirements for the carriage of hydrogen based on the Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk[4] are compared with the specific requirements of the regulatory proposal and are qualitatively assessed.

The study comes to the conclusion that the European standard of technical regulations for inland waterway vessels (based on the existing structure for fuels with a low flash point and taking into account the specific properties and hazards) can be supplemented by hydrogen and recommends its implementation.

The supplements could be implemented based on prescriptive requirements or goal-oriented requirements or a combination of both.

Based on the ES-TRIN a structure is suggested. This follows the current structure of the supplementary requirements for fuels with a low flash point of the ES-TRIN and can be considered as constructive. Due to the safety concept of the IGF Code and the concept of the ES-TRIN a transfer of these supplementary technical regulations to international maritime shipping or coastal shipping is only conceivable to a limited extent and can only take place with special consideration of the individual risk minimization measures. An individual assessment of the regulatory proposals with regard to the overarching goal(s), the functional requirements and their fulfilment is recommended. Additional specific measures beyond the outlined regulatory proposal are presented. Finally specific requirements that are not or only partially suitable are presented in the regulatory proposal for a transfer.

The proposed draft of supplementary technical regulations for inland navigation craft - using hydrogen as a fuel with a low flash point - will support and accelerate the transition to further climate-neutral propulsion systems in inland navigation. The use of hydrogen in inland navigation can contribute to achieving the goals agreed in the Paris Agreement and the Mannheim Declaration.

The study came to the conclusion that the draft of the rule text should be presented to the relevant expert groups of the European committee for the development of standards in the field of inland navigation followed by a further discussion of the content and detailed definition of the requirements.

[3] IMO MSC.391(95) – Adoption of the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code), Adopted on 11 June 2015

[4] IMO MSC.420(97) – INTERIM RECOMMENDATIONS FOR CARRIAGE OF LIQUEFIED HYDROGEN IN BULK, Adopted on 25 November 2016

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12. Abbrevations

ADN	European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
AD&A	Alternative Design and Arrangement
AP	Work Package
BLEVE	Boiling Liquid Expanding Vapour Explosion

CCNR	Central Comission fort he Navigation of the Rhine
CESNI	European Committee for Drawing Up Standards in the Field of Inland Navigation
DMZ	Deutsches Maritime Zentrum e. V.
EC	European Commission
EMEA	Europe Middle East Africa
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation Vessels
EU	European Union
GH2	Gaseous Hydrogen
HDE	Hydrogen Diesel Enrichment
HTHA	High Temperature Hydrogen Attack
H2	Hydrogen
IBC	Intermediate Bulk Container, large packings, rigid or flexible portable packing according to ADR
IGC Code	International Code for the Construction and Equipment of Ships carrying Liquefied Gases in Bulk
IGF Code	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
IMO	International Maritime Organisation
ISO	International Organisation for Standardization
IWT	Inland Water Transport
LH2	Liquid hydrogen
LNG	Liquefied Natural Gas
LR	Lloyd’s Register
MSC	Maritime Safety Committee
RBD	Risk Based Design
RheinSchUO	Rheinschiffsuntersuchungsordnung
RPT	Rapid Phase Transition
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
ZKR	Zentralkommission der Rheinschifffahrt

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[32] ISO 21009-1 Cryogenic vessels - Static vacuuminsulated vessels Part 1: Design, fabrication, inspection and tests

[33] DIN EN ISO 9809 Gasflaschen - Auslegung, Herstellung und Prüfung von wiederbefüllbaren nahtlosen Gasflaschen aus Stahl

[34] DIN EN ISO 11120 Gasflaschen - Wiederbefüllbare nahtlose Großflaschen aus Stahl mit einem Fassungsraum zwischen 150 l und 3 000 l - Auslegung, Bau und Prüfung

[35] ISO 11119 Gas cylinders - Design, construction and testing of refillable composite gas cylinders and tubes

[36] ISO 11515 Gas cylinders - Refillable composite reinforced tubes of water capacity between 450 L and 3000 L - Design, construction and testing

[37] ISO TS 17519 Gas cylinders – Refillable permanently mounted composite tubes for transportation

[38] DIN EN 60079-29-1 Explosionsfähige Atmosphäre - Teil 29-1: Gasmessgeräte - Anforderungen an das Betriebsverhalten von Geräten für die Messung brennbarer Gase

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