International regulations and standards for hydrogen in the maritime sector

Challenges and Opportunities from Hydrogen for Cross-Border Maritime Mobility

20th June 2024

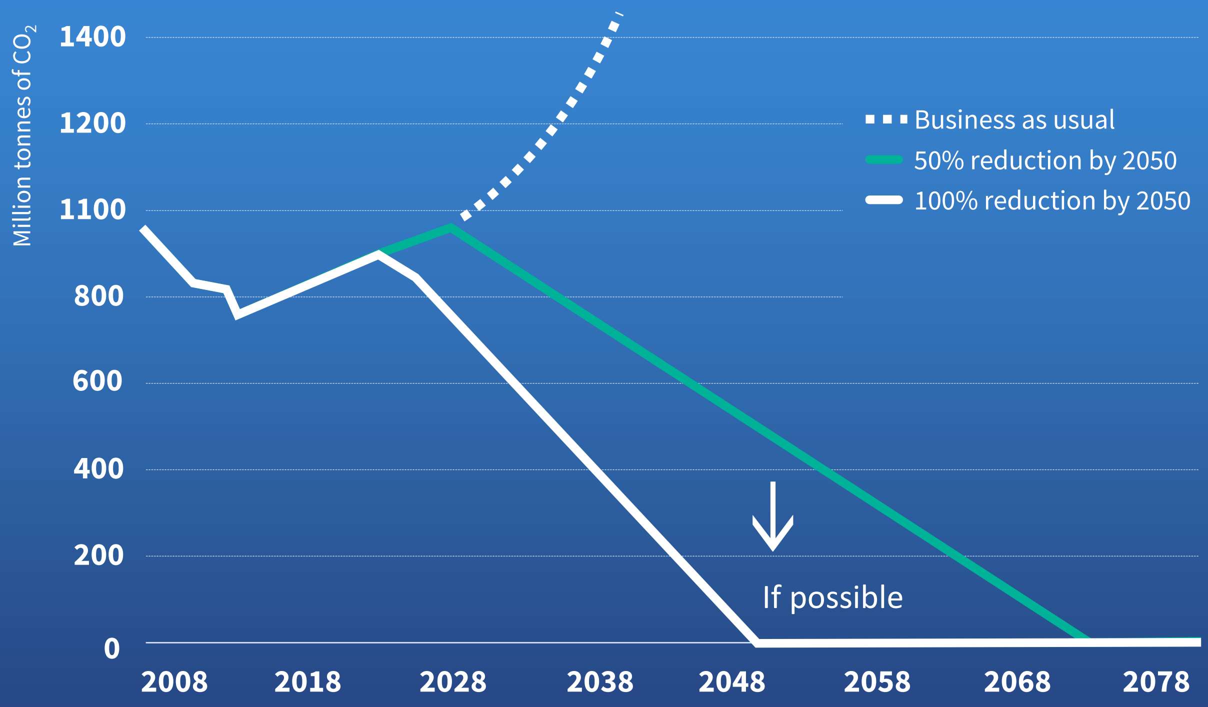
Fabrizio Cadenaro

Lloyd's Register

IMO Goals, strategy and impact on ship design

Entering an era of transition

IMO policy and ambition



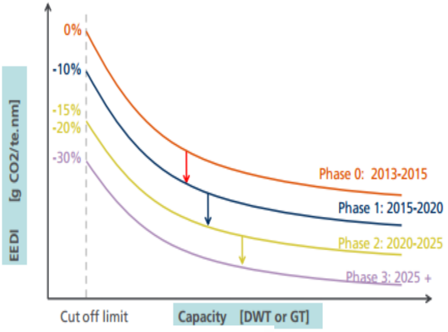
Source: Zero-Emission Vessels: Transition Pathways. 2019

Initial 2018 GHG strategy has been reviewed in 2023 targeting net-zero by 2050

Some regulatory aspects

- A number of regulatory tools have been introduced:
  - EEDI – Energy Efficiency Design Index
  - EEXI – Energy Efficiency eXisting ships Index
  - CII – Carbon Intensity Indicator

$$EEDI = \frac{CO_2\ emission}{Transport\ work}$$



$$CII = \frac{\text{Annual fuel consumption} \bullet CO_2 \text{ factor}}{\text{Annual distance travelled} \bullet \text{Capacity}} \bullet \text{Correction factors}$$

To be developed

- EEDI was adopted in 2013, EEXI and CII in 2021 (MEPC 76 as Marpol Annex VI amendment), entering into force in 2023 (EEXI) and 2024 (CII). EEXI is a “design index” while CII is based on effective voyages and fuel consumption.

- They are, among many other parameters, a function of the carbon content of the fuel

$$EEXI = \frac{\mathrm{CO_2\ emissions}}{\mathrm{transport\ work}} = \frac{\mathrm{Engine\ power} \times \mathrm{SFC} \times c_F}{\mathrm{DWT} \times \mathrm{speed}}$$

Impact on ship design, safety, reliability, dependability

- This would imply a major change in the fuels or broadly the energy sources used in ships, as optimization of existing technology is unlikely to achieve the set goals.
- Some alternative fuels come in the shape of gases or liquids, with relatively low boiling points, flash points and certain peculiar characteristics such as flammability or toxicity.
- They may be suitable for use in fuel cells which may further impact the power generation arrangements of a ship.

What’s the impact of alt-fuels on safety?

Rules and standards should ensure that alternative designs maintain a level of safety, reliability and dependability similar to conventional ships.

	Diesel	LNG	LH2	NH3
Liquid storage temperature [°C]	**Atm**	**-163**	**-253**	**-33**
Storage pressure [bar]	Atm	0 – 10+	0 – 10+	0 – 10+
Liquid density [kg/m³]	840	430+	70	682 with 121 of H
Flash point [°C]	**>60**	**-188**	**<-253**	**n/a**
Flammable limits [%in air]	**.5-5**	**5-15**	**4-75**	**15-28**
Toxic	**Low**	**No**	**No**	**Yes**

- Low flashpoint (less than 60°C required by SOLAS, alternative design as per MSC.1/Circ 1455 likely required)
- Volatile liquids or gases which most likely will have to be strongly compressed or liquefied at sub-zero or cryogenic temperature
- Wide flammability range, toxicity
- Potential large impact on hazardous areas classification, ventilation, fire protection.

A glance at rules and standards

Rule and regulation development for LNG

SOLAS II-2 regulation 4.2.1 limits the flashpoint of oil fuels to 60°C or higher

Current designs must comply with SOLAS, IGF Code and National Administration requirements

SOLAS II-2 regulation 17: Alternative Design and Arrangements

IGC – Safe carriage by sea of bulk liquefied gasses

Resolution MSC 285(86) Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships (2009)

Lloyd's Register Rules for the Carriage of Liquefied Gasses in Bulk

Draft IGF Code

IGF Code

Lloyd's Register Rules for the Classification of Natural Gas Fuelled Ships

(July 2012)

Lloyd's Register Rules and Regulations for the Classification of Ships using Gases or Other Low-flashpoint Fuel (Jul 2016)

IMO

LR & IMO Codes: from LNG to Hydrogen

IMO

IGF Code

Lloyd's Register Rules and Regulations for the Classification of Ships using Gases or Other Low-flashpoint Fuel (Jul 2016)

- IMO MSC.Circ 1647 (fuel cells)
- Interim guidelines for hydrogen as fuel (2024)
- Interim guidelines for ammonia as fuel (2024)

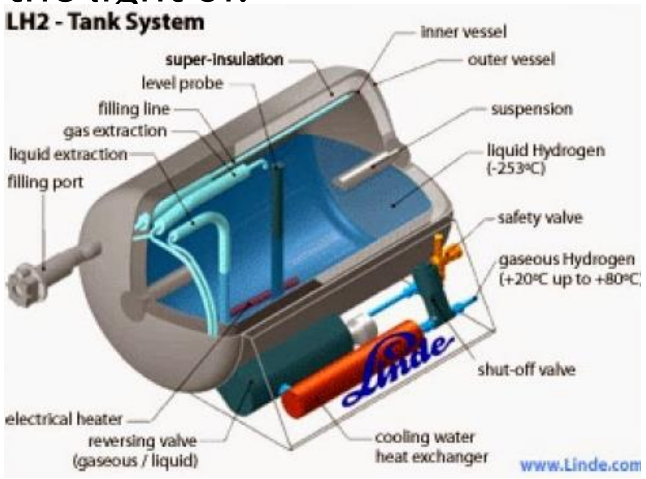
- Appendix LR2 - Ammonia
- Appendix LR3 - Hydrogen
- LR Rules for Ships Pt 5 Ch 26 (fuel cells)
- Guidance Notes on the Installation of Fuel Cells on Ships
- Guidance Notes for Liquid Hydrogen Systems
- LR Type Approval Test Spec 7 (fuel cells)
- Guidance Notes for Fuel System RA, Hazard Identification – Hydrogen and Ammonia

Compressed and Liquid Hydrogen

- IMO has published "Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk" as Resolution MSC.420(97) of 25 November 2016 for transportation as cargo.
- Dedicated guidelines for the use of liquid and compressed hydrogen as fuel are under development at IMO and are expected to be finalized @ CCC10/MSC.108 in late 2024.
- LR Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels, July 2023
  - Appendix LR2 – Requirements for Ships Using Ammonia as Fuel
  - Appendix LR3 – Requirements for Ships Using Hydrogen as Fuel
  - Guidance Notes for Liquid Hydrogen Systems, May 2023

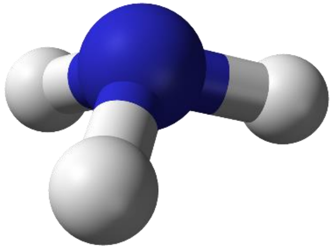
Compressed and Liquid Hydrogen

- Rules cover the same aspects of IGF code for LNG: storage, piping, materials, automation & safety systems, gas detection, fire protection, inertization, ventilation, etc
- Storage of CH2 and LH2, typically in IMO Type C tanks (pressure vessels), is based on experience on LNG and relevant IGF code requirements, plus:
  - LH2 requires vacuum insulation due to extreme temperature
  - Risk assessment work
  - Application of other relevant international standards such as ISO, EN, API, CGA, etc
  - Further consideration on design, technologies and material especially in the light of:
    - The much lower temperature of LH2 (-254°C at ambient pressure)
    - Embrittling effect of hydrogen on materials
    - Higher risk of fire/explosion due to very low ignition energy
    - Higher risk of leakage due to very small molecule size



Chemical storage: Ammonia

- Ammonia is seen as a chemical storage medium for hydrogen, since 18% of its molecular weight is hydrogen, which turns into about 120 kg/m3 of hydrogen for ammonia at boiling point and atmospheric pressure.

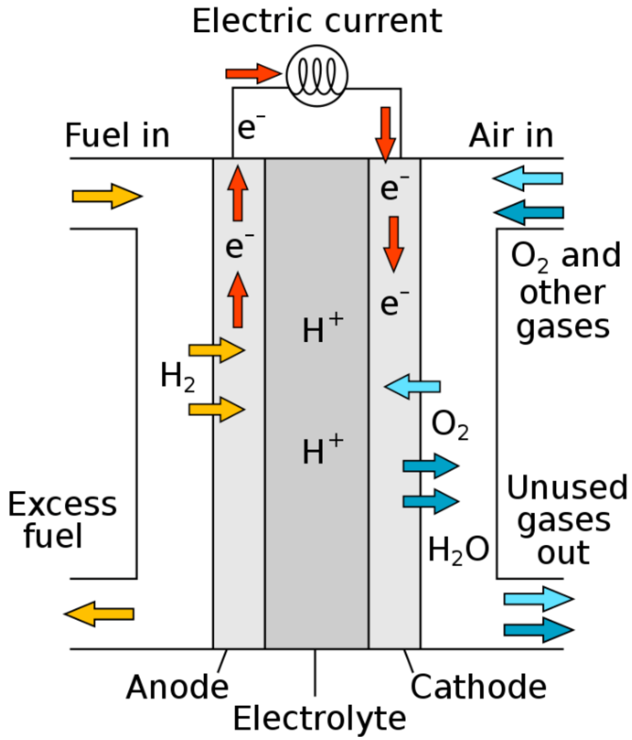


- IMO has begun at MSC.105 (April 2022) to develop guidelines for the use of ammonia as fuel through the CCC sub-committee, aiming to complete them at CCC10/MSC.108 in late 2024.
- LR has pulished rules for ammonia as fuel as Appendix 2 of rules for ships using low flashpoint fuels.

- The main risks is seen as the toxicity.
- Anhydrous (i.e. pure) ammonia however is covered by the IGC code (for gas carriers) both generically as a liquid gas and with some specific requirements on materials. IGC allows for the use of cargoes other than LNG as fuel but toxic cargoes is not permitted, thus ammonia is excluded. (IGC 16.9). Carriage of aqueous ammonia on chemical carriers is covered by the IMO IBC code.

What about fuel cells?

- The goal of the rules is to provide safe and reliable delivery of electrical and/or thermal energy through the use of fuel cell technology. Among the functional objectives one may note:
  - The safety, reliability and dependability of FC systems should be comparable to those of conventional oil fuelled machinery installations.
  - The probability and consequences of fuel-related hazards should be limited to a minimum through arrangement and system design,
  - The design philosophy should ensure that risk reducing measures and safety actions for the fuel cell power installation do not lead to an unacceptable loss of power.
  - A dependability study is required when fuel cells are the main source of power for propulsion



What about fuel cells?

- IMO sub committee on carriage of cargoes and containers (CCC) drafted the Draft Guidelines for fuel cells in the last meeting in September 2021. They have been approved by the IMO Maritime Safety Committee (MSC 105) in April 2022 and published as MSC.1/Circ. 1647 of 15th June 2022.
- Based on MSC Circular 1647, LR Rules for Fuel Cells Power Installation have been published and incorporated as Part 5, Chapter 26 into LR Rules for the Classification of Ships.
- LR Rules for fuel cells are supported by
  - Guidance Notes on the Installation of Fuel Cells on Ships, April 2023
  - LR Type Approval System Test Specification 7, Fuel Cell Modules, January 2023

How to overcome lack or limitations of rules?

- Due to the novel application of hydrogen-as-fuel in the marine sector, rules are still under development and then published as “interim guidelines”.
- This would allow quicker development until they reach a mature stage, when they will likely become parts of the IGF code.
- In the meantime, gaps and missing parts are to be managed, typically with:
  - Risk assessment/Risk Based Certification
  - Adoption of relevant international standards

BS EN ISO 11114-1:2020

INTERNATIONAL STANDARD ISO 11114-1:2020(E)

Gas cylinders — Compatibility of cylinder and valve materials with gas contents —

4. What if there was a hydrogen leak inside the fuel cell room?	1. Broken pipes, mechanical damage to pipes, leaking flanges, broken equipment	1. Potential for asphyxiation (only inside fuel cell container due to relative volume), fire and explosion	C4	1. Mechanical protection	Min	L1	Medium	1. th th w ir S is rc

ARTICLE KD-10
SPECIAL REQUIREMENTS FOR VESSELS IN HYDROGEN SERVICE

KD-1000 SCOPE

(a) The requirements of this Article shall be met for all vessels in hydrogen service, as defined by (b) below. Each

KD-1001 LIMITATIONS

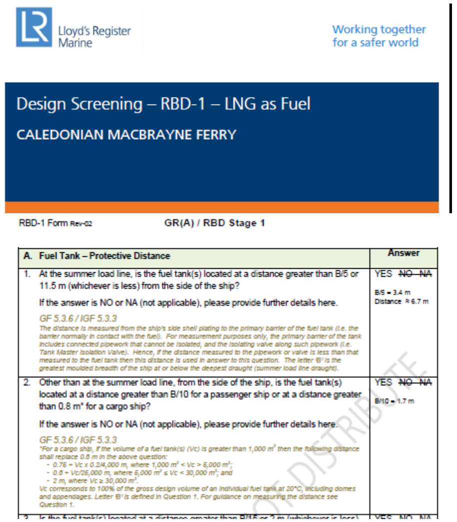
The maximum design temperature shall be limited by the following:

RBC - Risk Based Certification

Class and Statutory Regulations require ‘risk studies’ to identify hazards and to assess and control risks and to show equivalence with SOLAS Alternative Designs and Arrangements.

Risk Based studies are required for novel or complex designs for which prescriptive Rules and Regulations do not currently exist. To undertake consistently these risk studies, RBC process comprises the following stages:

- Stage 1 – Design and Safety statement – may also include a “PAR” – preliminary appraisal of rules questionnaire to identify major issues.
- Stage 2 – Risk Assessment such as an HAZID.
- Stage 3 – Supporting Studies (e.g. Bunker Safety, FMEA).
- Stage 4 –Final Design Assessment such as an HAZOP.
- Stage 5 – Construction and In-Service Assessments (new)


Lloyd's Register Marine

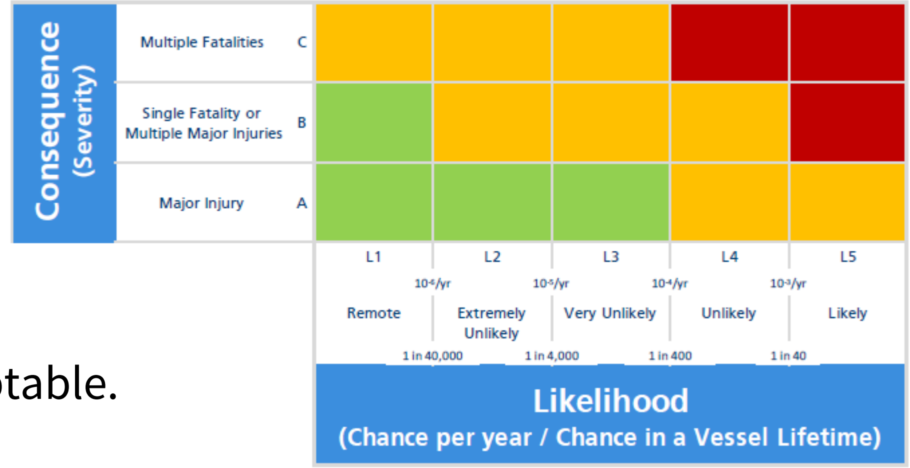
Working together for a safer world

Design Screening – RBD-1 – LNG as Fuel

CALEDONIAN MACBRAYNE FERRY

RBD-1 Form Rev-02 GR(A) / RBD Stage 1

A. Fuel Tank – Protective Distance	Answer
1. At the summer load line, is the fuel tank(s) located at a distance greater than B/5 or 11.5 m (whichever is less) from the side of the ship? If the answer is NO or NA (not applicable), please provide further details here. *GF 5.3.6 / IGF 5.3.3* *The distance is measured from the ship's side shell plating to the primary barrier of the fuel tank (i.e. the barrier normally in contact with the fuel). For measurement purposes only, the primary barrier of the tank includes connected pipework that cannot be isolated, and the isolating valve along such pipework (i.e. Tank Master Isolation Valve). Hence, if the distance measured to the pipework or valve is less than that measured to the fuel tank then this distance is used in answer to this question. The letter 'B' is the greatest moulded breadth of the ship at or below the deepest draught (summer load line draught).*	YES ~~NO NA~~ B/5 = 3.4 m Distance ≈ 6.7 m
2. Other than at the summer load line, from the side of the ship, is the fuel tank(s) located at a distance greater than B/10 for a passenger ship or at a distance greater than 0.8 m* for a cargo ship? If the answer is NO or NA (not applicable), please provide further details here. *GF 5.3.6 / IGF 5.3.3* **For a cargo ship, if the volume of a fuel tank(s) (Vc) is greater than 1,000 m^3 then the following distance shall replace 0.8 m in the above question:* *- 0.76 + Vc x 0.2/4,000 m, where 1,000 m^3 < Vc > 5,000 m^3;* *- 0.8 + Vc/25,000 m, where 5,000 m^3 ≤ Vc < 30,000 m^3; and* *- 2 m, where Vc ≥ 30,000 m^3.* *Vc corresponds to 100% of the gross design volume of an individual fuel tank at 20°C, including domes and appendages. Letter 'B' is defined in Question 1. For guidance on measuring the distance see Question 1.*	YES ~~NO NA~~ B/10 = 1.7 m



The outcome is a list of identified risks, duly ranked and a list of actions required to mitigate those which have been found unacceptable.

The risk assessment process helps to fulfil AD&A requirements from SOLAS/MSC 1455

A quick look at marine regulations timeline

LNG	
2007	LR provisional rules for Methane ships
2009	MSC.285(86) interim guidelines
2012	LR GF rules
2014	LR Risk-Based-Design procedure
2015	IGF code - MSC.391(95) adopted
2017	IGF code entry into force

Hydrogen & Ammonia	
2016	MSC.420(97) interim guidelines for LH2 carriage
2023	LR Rules for gas fuelled ships appendix LR2 & LR3
2024?	IMO interim guidelines for ammonia-as-fuel and LH2/CH2-as-fuel

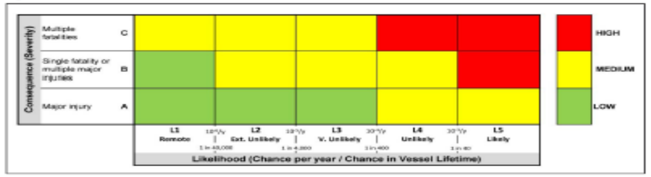
Fuel cells	
2021	IMO MSC.Circ 1647
2022	LR Rules for Fuel Cells Power Installations

Gap with prescriptive rules is covered with dedicated risk assessments

3.4 Risk Rating

Risks identified during the HAZID were rated in accordance with a risk matrix provided by LR Consulting as shown in the Figure below. This matrix is based on LR Consulting's experience in using and developing matrices on behalf of operators in the oil and gas industries. An assessment of risk before and after considering active safeguards was undertaken.

Figure 1: Risk Matrix



It should be noted that the risk ranking is only based on the assessment of risk to personnel and that low severity consequences that could result in minor injury have been excluded from the assessment. This approach helps to ensure that the study team only concentrate on significant risks; which is considered to be an appropriate approach for a HAZID of this type.

Required level of safety – equivalent to "traditional" ships

Some of the works which have been done

There already are a few vessels sailing with hydrogen as fuel

- One hydrogen fuelled vessel – Hydroville – already in class & sailing in Antwerp
- Viking Mars/Fincantieri 6285 – hosts a 100kw CH2/FC generator
- Developing rules for hydrogen storage, fuel cells installation and standards for marine type approval, within IACS, IMO as well as independently. Developing training as well.
- Held and participated to a large number of risk assessment workshops for the development of hydrogen fuelled tugs, ferries and other vessels
- Participating to several privately, EU & UKI founded projects, of which one of the most recent is Shyps, aiming to develop a LH2/FC zero emissions, hydrogen bases, power generation system for ships.

Power & Propulsion Alternatives for Ships, 23rd January 2019, London, UK

Alternative Fuels: The Present and Future of Containment Systems and their impact on the Design and Construction of Ships.

F. Cadenaro, E. Fort, L. Blackmore, Lloyds Register EMEA, UK

SUMMARY

In recent years, driven primarily by SOx emissions regulations, there has been a move towards the adoption of Liquefied Natural Gas (LNG) as a marine fuel. More recent decarbonisation targets, and the emissions regulations that are due to follow, will almost certainly trigger a further move towards other low carbon, carbon neutral and zero carbon fuels. Methanol, ammonia, and hydrogen offer a potential pathway for the decarbonisation of the shipping industry. However, the various physical and thermodynamic properties of such alternative fuels will require new containment systems onboard ships requiring the marine industry to embrace containment technologies used in other industries or, where necessary, develop industry-specific solutions. Shipboard containment systems for diesel fuels are currently physical, based on storage at near ambient temperatures and ambient pressures and for natural gas at high pressure (compressed) or low temperature (cryogenic), or a combination of such. Future containment technologies are likely to also include material and chemical based storage, exploiting chemical processes to hydrogenate or dehydrogenate carriers, in both liquid or solid matrices. This paper provides an overview of alternative fuels and their containment technologies and the implications on ship design and construction.

Questions?

Questions?

Thank you for the attention!

Fabrizio Cadenaro

Lead Specialist, Engineering Systems, Alternative Fuels

LR Global Technical Support Office

T +39 338 6527761 E fabrizio.Cadenaro@lr.org

Lloyd’s Register EMEA

Galleria Protti 1, 34121 Trieste, Italy