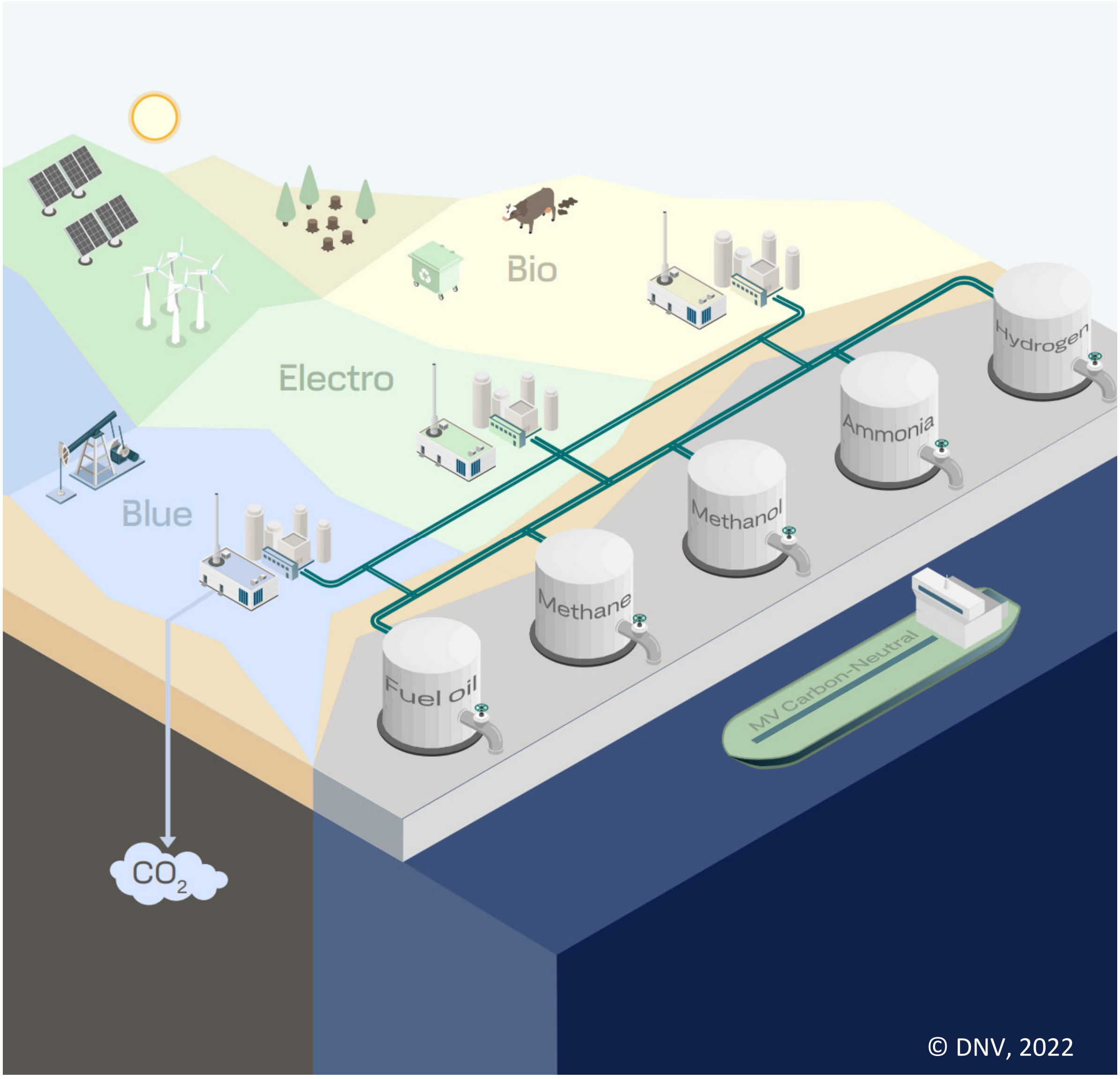
Nordic Roadmap

Future Fuels for Shipping



Nordic Roadmap Publication No. 1-B/1/2022

By: Linda Sigrid Hammer, Marius Leisner, Hans-Christian Wintervoll, Øyvind Endresen, Olav Tveit and Magnus S. Eide.

Foreword

DNV and partners Chalmers, IVL Swedish Environmental Research Institute, MAN Energy Solutions, Menon, and Litehauz have been tasked by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers to develop a Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping. The overall aim of the project is “to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping”.

To support this overall aim, DNV is responsible for task 1-B Technical and regulatory analysis and has prepared this report. MAN Energy Solutions has contributed with valuable input.

28th November 2022

Linda Sigrid Hammer
Principal Consultant, DNV

NORDIC ROADMAP FOR THE INTRODUCTION OF SUSTAINABLE ZERO-CARBON FUELS IN SHIPPING

State of play – status on regulatory development for zero-carbon fuels

The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers

Report No.: 2022-1161, Rev. 2.0
Document No.: 1-B/1/2022
Date: 2022-11-28

Project name:	Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping	DNV Maritime Environment Advisory Veritasveien 1 1363 Høvik Norway
Report title:	State of play – status on regulatory development for zero-carbon fuels	
Customer:	The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers, Kongensgate 20, 0153 Oslo, Norway	
Customer contact:	Sveinung Oftedal	
Date of issue:	2022-11-28	
Project No.:	10284686	
Organisation unit:	Environment Advisory	
Report No.:	2022-1161, Rev. 2.0	
Document No.:	1-B/1/2022	

Applicable contract(s) governing the provision of this Report:

Objective: This report establishes the status quo of the regulatory situation for the safe onboard use of natural gas, methanol, ammonia and hydrogen and research efforts to further rule developments.

Prepared by:	Verified by:	Approved by:
Linda Sigrid Hammer Principal Consultant	Olav Tveit Vice President	Terje Sverud Head of Section
Marius Leisner Senior Principal Consultant	Magnus S. Eide Principal Consultant	

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Keywords:
Alternative fuels safety
Ammonia fuel
Hydrogen fuel
Methanol fuel
IGF Code

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
1.0	2022-11-14	First issue	LSHAM/MALE	OTV/MASTE	TSV
2.0	2022-11-28	Final version	LSHAM/MALE	OTV/MASTE	TSV

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EXECUTIVE SUMMARY

This report is developed as a part of the project "Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping" [1,2]. The overall aim of the project is to "to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping". Lack of international safety regulations is identified as a key barrier against implementation of zero-carbon fuels.

To reduce this barrier, one objective of the project is to provide stakeholders in the Nordic countries with a technical knowledge base for selected zero-carbon fuels to facilitate submissions to IMO with proposals for regulations on the use of ammonia and hydrogen as ship fuels. Hydrogen, ammonia (both pre-selected by the customer) and methanol (selected based on the screening in Task 1-A) are subject to further analysis in Task 1-B Technical and regulatory analyses.

What we did:

This report establishes the status quo of the regulatory situation and research efforts to further rule developments for the selected potential zero-carbon fuels. We have made a review of IMO regulations and guidelines, IMO-submissions, class rules and guidelines, and other sources to establish an overview of existing regulatory development initiatives, pilot projects, and other research activities involving methanol, ammonia, hydrogen, and natural gas.

We find that:

For ammonia and hydrogen, the two zero-carbon fuels that were pre-selected by the customer to be addressed in this study, detailed and prescriptive statutory regulations have yet to be developed by IMO.

The IMO has provided an international mandatory regulatory framework for alternative fuels through the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) which puts internationally recognized safety barriers in place to ensure safe use of natural gas as a fuel. However, neither methanol, ammonia nor hydrogen are currently covered by detailed technical requirements in the Code. The lack of design guidance is complicating the building process for everyone involved. A shipbuilder will have to demonstrate through extensive risk evaluations that the chosen fuel system design solution meets the intent of the goal and functional requirements of the IGF Code and provides the same level of safety as having a new and conventional fuel oil system for propulsion and power generation. This is not a design process that most shipbuilders and designers are used to work with, it requires more time and resources, and is creating uncertainty and an additional business risk for the project since acceptance of design premises are not necessarily a given outcome. This is a significant barrier to the widespread uptake of ammonia or hydrogen as fuel in shipping.

From a regulatory point of view methanol gained an advantage over ammonia and hydrogen when IMO in December 2020 approved the "Interim Guideline for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel", and by that provided an international standard for methanol as fuel. If agreed by the Flag Administration, these Guidelines can be used lieu of the risk-based alternative design process for methanol fuelled ships. Additionally, class rules have been in place for methanol as fuel since 2013. Hence, a lack of rules and regulations is not regarded as a significant barrier against the implementation of methanol as fuel.

Currently there are no international statutory standards beyond the IGF Code for implementing ammonia or hydrogen fuel systems on ships, but the development of guidelines for these fuels is included on the already extensive work plan related to alternative fuels in IMO. This work can draw on experience from marine transport of ammonia and the of use of ammonia as refrigerant onboard. Also, classification societies have issued initial class rules for the use of ammonia

[1] The term sustainable zero-carbon fuels is used to indicate fuels with potential zero climate impact throughout their lifecycle.

[2] https://futurefuelsnordic.com/

as fuel. Hydrogen does not have the same history in maritime applications, and there are currently no existing class rules for hydrogen as fuel. There are knowledge gaps related to hydrogen safety that needs to be closed.

Through this project, the consortium provides the Nordic countries with knowledge on safety characteristics of the selected potential zero-carbon fuels and corresponding suitable safety barriers to contain the safety risks. This knowledge base can be used to develop common understanding and strengthen the cooperation between the Nordic countries in this field. In co-operation with Nordic Maritime Administrations and other Nordic stakeholders it can also be used to develop submissions to IMO to further international development of regulations for alternative fuels. Many classification societies have issued a first version of class rules covering the installation and use of ammonia as fuel. This can be taken as an indication that class societies consider the integration of an ammonia fuel system feasible from a safety perspective. It must be noted that there have been no newbuild projects putting these rules to the test yet. However, research projects, e.g., AEngine[3], contributes to verifying the rules. Further ammonia regulatory development in IMO requires initiatives from member states, developing and submitting documents to the Sub-Committee on Carriage of Cargoes and Containers (CCC).

Hydrogen as fuel has not seen the same initiatives for rule development from classification societies as ammonia. Further work on hydrogen rule development could focus on developing prescriptive regulations when safe solutions are identified for specific safety challenges. When a technical standard is in place for parts of the system it would simplify the risk based alternative design process by reducing the scope to the remaining parts of the system. Additionally, one could put effort into making the alternative design process more efficient, with the aim of reducing uncertainties in the approval process.

This report focuses on onboard regulations for ships using potential zero carbon fuels, i.e., international IMO regulations and class rules. It should however be noted that different onshore safety regulations and criteria may apply in the Nordic countries. This will be further considered in other project tasks.

[3] https://www.dnv.com/expert-story/maritime-impact/Harnessing-ammonia-as-ship-fuel.html

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1 INTRODUCTION

DNV, together with partners Chalmers, IVL, MAN Energy Solutions, Menon, and Litehauz, have been assigned the Nordic Roadmap project by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers. The project has an overall aim “to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping”. Hydrogen, ammonia[4] (pre-selected by the customer) and methanol (selected based on the screening in Task 1-A) are subject to further analysis in Task 1-B Technical and regulatory analyses.

Most potential zero-carbon fuels have properties posing different safety challenges from those of conventional fuel oils. This requires the development of regulations and technical rules for safe design and use onboard ships in parallel with the technological progress needed for their uptake.

Alternative fuel technologies have reached different levels of technical and regulatory maturity. Figure 1-1 shows that the current maturity level of methanol fuel technologies is higher than those of ammonia and hydrogen. For ammonia, we see a development of 2-stroke and 4-stroke engine technologies on parallel paths enabling uptake in deep-sea and regional short-sea shipping. For hydrogen, the timeline reflects that short-sea shipping is expected to be instrumental in maturing the technology. Consequently, the development of fuel cells and 4-stroke engines are ahead of other hydrogen energy converters. The new fuels have reached different level of regulatory maturity – with methanol regulations for onboard use being the most mature and hydrogen the least mature of the three fuels assessed. For ammonia and hydrogen detailed and prescriptive statutory regulations have yet to be developed by IMO. This is a significant barrier to their widespread uptake as fuel in shipping.

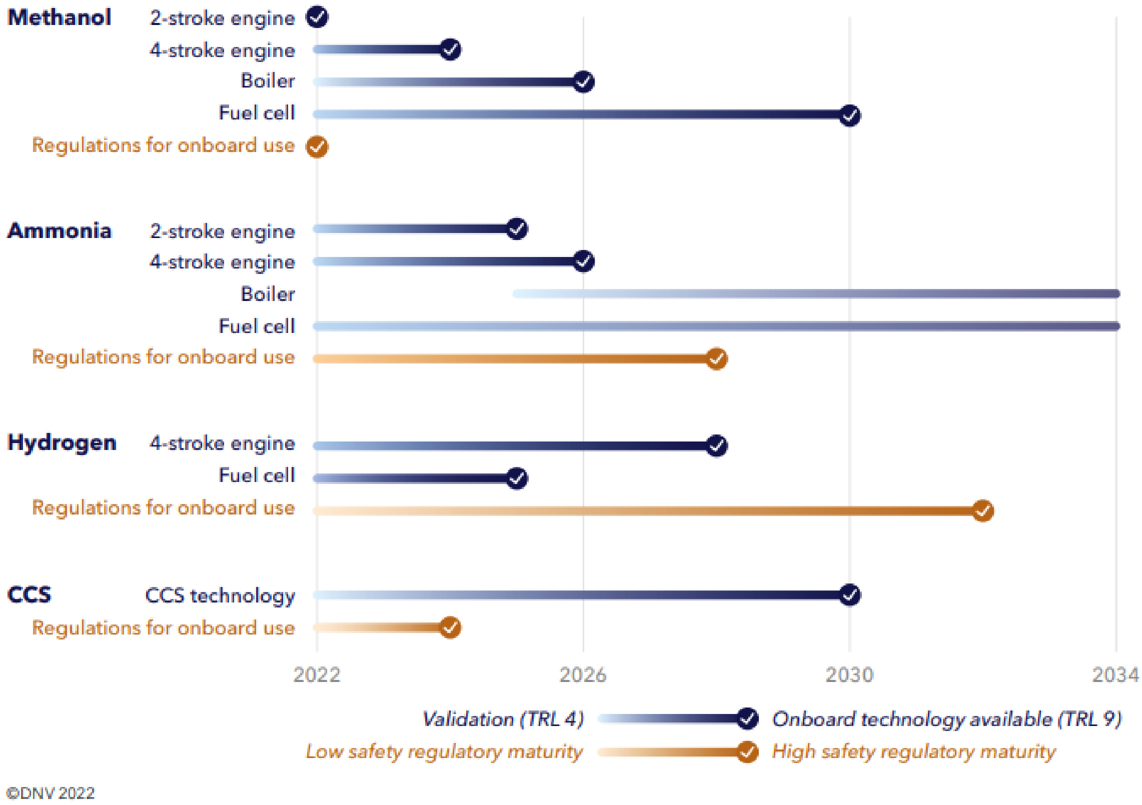

Figure 1-1 Estimated maturation timelines for energy converters, onboard CCS[5] technologies, and corresponding regulations for onboard use (DNV, 2022).

[4] Ammonia when used as fuel is anhydrous ammonia (less than 0.2% water).

[5] CCS; carbon capture and storage

Through this project, the consortium will provide the Nordic countries with knowledge on safety characteristics of the selected fuels and corresponding suitable safety barriers to contain the safety risks. In co-operation with Nordic Maritime Administrations and other Nordic stakeholders this knowledge base can be used to develop submissions to IMO to further international development of safety regulations for alternative fuels.

This report is the result of a high-level review of IMO-submissions, class rules and guidelines and other sources to establish and overview of existing regulatory development initiatives, pilot projects, and other research activities. The intention is to establish the status of the regulatory development for ammonia, hydrogen, methanol, and natural gas as marine fuels as per November 2022 as a starting point to advance the development within this project and beyond.

This report has the following structure:

- Chapter 2: Status of fuel transition
- Chapter 3: Safety – a prerequisite for the successful and timely introduction of alternative fuels
- Chapter 4: Regulatory framework
- Chapter 5: Regulatory status per fuel
- Chapter 6: How to advance regulatory framework

2 STATUS OF FUEL TRANSITION

Decarbonizing shipping will predominantly require new fuels, but also higher energy efficiency and improved logistics. Irrespective of efficiency improvements implemented, a change to carbon-neutral fuels will be required to meet ambiguous decarbonisation goals. Unfortunately, the new fuels are not available today in sufficient quantities, are lacking a global and Nordic bunkering infrastructure, are usually more space demanding onboard and much more expensive.

The severity of barriers against implementation will vary between fuel types. Safety is also a primary concern, with the absence of prescriptive rules and regulations complicating the implementation of required technology onboard. The technical applicability and commercial viability of alternative fuels will vary greatly for different ship types and trades.

Policy developments and stakeholders' engagement over the next decades will drive shipowners to identify, evaluate, and use technologies, fuels, and solutions that help decarbonize ships, cut energy consumption, and meet other environmental requirements.

Figure 2-1 shows the status for the uptake of alternative fuels in the fleet – as well as in the order book as of June 2022. In gross tonnage (GT) terms 5.5% of the ships in operation and 33% of those on order can operate on alternative fuels (including LNG carriers). The equivalent percentages when considering number of ships are 1.2 % and 21% respectively. In other words, 1046 out of 4967 ships are ordered with alternative fuel capability.

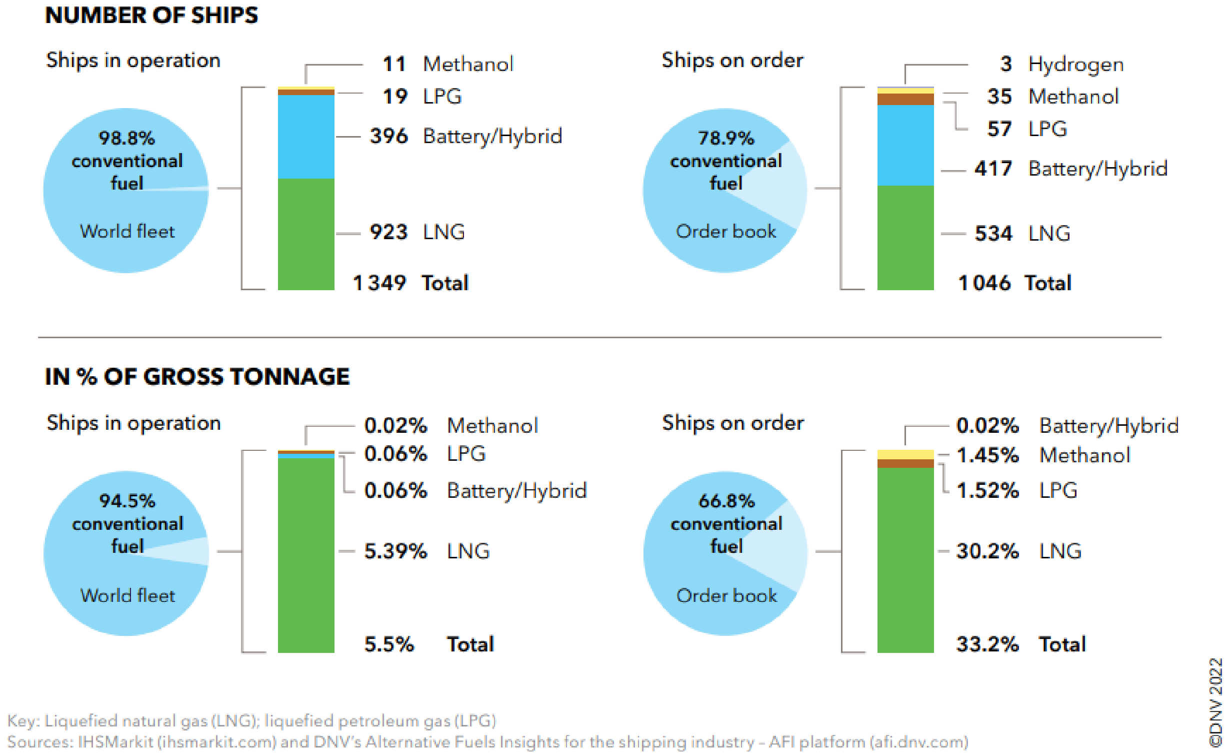

Figure 2-1 Alternative fuel uptake in the world fleet in number of ships and gross tonnage (DNV, 2022).

In number of ships, the uptake is dominated by battery/hybrid ships together with liquefied natural gas (LNG) fuel. However, in gross tonnage LNG fuel dominates reflecting that battery/hybrid solutions are applied mostly on smaller vessels. Of the 923 ships in operation with LNG fuel, there are 630 LNG carriers and 293 LNG fuelled ships of other types. The uptake of methanol and LPG is starting to show in the statistics together with the first hydrogen fuelled newbuilds. In addition, numerous potential newbuilds with various alternative fuels are being projected (DNV, 2022).

The trend of larger ships being ordered with alternative fuel propulsion is continuing, with LNG as the dominant fuel. LNG is a popular fuel choice in the car carrier and container ship segments and a significant uptake is also seen for tankers and bulk carriers. Of the 1046 ships on order with alternative fuels, 167 are LNG fuelled LNG carriers, 367 are LNG fuelled ships of other types, while 417 are using battery/hybrid propulsion. In the short-sea segment, being the first LNG fuel mover already years ago, the clear trend towards electrification for ferries is continuing, with some looking towards hydrogen and fuel cell technology to increase range.

Methanol had previously been a choice exclusively for tankers in the methanol trade with 11 ships in operation and 14 new tankers on order. This year we see an uptake also in the container segment with 21 ships on order with methanol as fuel. 76 LPG carriers using LPG as fuel are either in operation or on order.

It should be noted that the majority of ships using alternative fuels can also burn conventional fuel oils.

The strong interest in ammonia as fuel reflected in concepts and pilot studies is currently restricted by immature converter technologies. This is expected to change when the technology becomes available.

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3 SAFETY – A PREREQUISITE FOR THE SUCCESSFUL AND TIMELY INTRODUCTION OF ALTERNATIVE FUELS

Decarbonization involves alternative fuels and operations with new safety-related risks (DNV GL, 2020). A successful uptake of alternative fuels depends on the ability to maintain a safety culture where all stakeholders take the responsibility to handle the new challenges introduced with the new fuels. With the introduction of new marine fuels, the toxicity of methanol and ammonia, and the extreme flammability of hydrogen brings along new sets of safety challenges originating from the physical properties of each fuel.

Their successful implementation requires development of international regulations to ensure a safe integration of onboard fuel installations. This must be done in parallel with maturation of fuel technologies related to storage, distribution and energy conversion through pilot projects and adoption by first movers.

The gradual introduction of LNG as a fuel, examples set by first movers, and the experience of decades of carriage and consumption of boil-off on gas carriers has been important for the wider uptake for deep-sea shipping we see today. The entry into force of the IGF Code 17 years after the launch of the Norwegian LNG fuelled ferry “Glutra” provided an international regulatory framework to handle gases and other low flashpoint fuels, and is a result of 20 years of learnings and experiences of designers, shipowners, manufacturers, yards, flag states and classification societies in how to safely integrate LNG fuel systems onboard ships. Based on these experiences and the carriage onboard gas carriers, DNV has also developed rules for the other relevant hydrocarbon gas LPG applying the same safety principles.

To a lesser degree, similar experiences have been gained for methanol through carriage and use as fuel on chemical carriers and as a common cargo on Offshore Supply Vessels. An IMO Interim Guideline for Methyl/Ethyl alcohols as fuel is in place, providing guidance and support for the integration of the fuel system onboard.

For ammonia the picture is different. The maritime industry has experience with carriage of ammonia in gas carriers and refrigerant in refrigeration plants, but not as a fuel. Due to its toxicity, the introduction of ammonia as fuel creates new challenges related to safe bunkering, storage, supply and consumption. Considering that commercially available energy converters are some years into the future and that regulatory developments in IMO are barely initiated yet, major deployment of ammonia as fuel may happen in a much shorter time span than for LNG, LPG and methanol and with much less experience to base safety decisions on.

The rules and regulations for natural gas, LPG, methanol and ammonia used the rules for carriage of the same substances as cargo on gas carriers and chemical tankers as a starting point. However, adaptations were made taking into account that the substances were stored and used outside a defined cargo area and by crew that had a limited experience and training in handling the substances as cargo. The adaptations typically involved implementing a number of additional safety barriers above and beyond the rules applied when carrying the substances as cargo. Major accidents related to the use of e.g., LNG, LPG and methanol as fuel have been avoided, and the significance of that cannot be underestimated.

Apart from a pilot project in Japan[6], hydrogen is not transported as a marine cargo, and the experiences as a marine fuel is currently limited to small scale R&D projects. The safety implications of storing and distributing hydrogen on board ships are not clear. The general understanding of hazards and risk associated with hydrogen, and particularly liquid hydrogen (LH2), is limited. Several R&D initiatives are currently ongoing to improve the understanding of LH2 and associated hazards. For hydrogen the potential explosion risk related to the low ignition energy and the wide flammability range requires special attention. The very low boiling temperature for hydrogen makes it more challenging to store in its liquefied form (DNV, 2021).

An accident involving a new alternative ship fuel would, in addition to the risk to persons directly involved, be a serious set-back for the use of this fuel for the whole industry. Further, it is critical that the new industry standards maintain the

[6] The SUISO FRONTIER commences its maiden voyage to Australia, marking the start of the World's First Demonstration of International Transportation of Large Volume Liquefied Hydrogen - https://www.hystra.or.jp/en/gallery/article.html#news06

same safety level as for conventional oil-fuelled ships. This cannot be achieved through development of regulations alone but depends on how ships are designed, built, and operated on this basis. An increased focus on safety will be required for all stakeholders in the maritime industry going forward with the implementation of new fuels (DNV, 2022).

4 REGULATORY FRAMEWORK

4.1 International Regulations, Class Rules and Industry Standards

Maritime rules and regulations in general exist on three levels: international regulations, national/regional regulations, and class rules (Figure 4-1). Additionally, standardisation organisations and industry associations provide standards and guidelines relevant for alternative fuels. Rules and regulations sometimes refer to accepted industry standards for e.g., materials, electrical equipment, and area classification.

The international regulations are enforced by the Flag State, which has incorporated the IMO Conventions (e.g., SOLAS[7], MARPOL[8], STCW[9]) into domestic law – referred to as statutory regulations. Class Rules are followed up by Classification Societies, which often also act on behalf of Flag States towards verifying compliance with Statutory Regulations (as Recognized Organisations). Port State Control (PSC) is the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is manned and operated in compliance with these rules.

Vetting inspection is a grading system of a ship, enabling a potential charterer or insurer to compare between similar ships and choose the best for his needs, to maximize efficiency. Note that chartering vetting regimes may be based on charterers standards, which contain requirements that are more stringent than the minimum standard set by IMO and Classification Societies. An example in so respect is the OCIMF SIRE regime which is applied for tankers.

The maritime rules and regulations applicable for conventional ships are to a large extent prescriptive[10] and proven through decades of designing, building and operating oil-fuelled ships. Hence, approval of conventional oil-fuelled ships is a well-known and predictable process in the maritime industry. The more demanding risk-based approval process referred to as the "alternative design approach" applicable for ships using new fuels not covered by prescriptive regulations is described in 4.2. It should be noted that the scope of the maritime rules and regulations for ships using gases and low flashpoint fuels are generally limited to the fuel installation onboard the ship, i.e., it stops at the bunkering connection of the ship. The bunker facilities (shore side bunker installation or bunker barge/ship) pertain to different regulatory regimes. Hence, there will be an interface between the receiving ship and the bunker facility and corresponding regulations.

[7] SOLAS – The International Convention for the Safety of Life at Sea

[8] MARPOL – The International Convention for the Prevention of Pollution from Ships

[9] STCW – The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers

[10] Prescriptive requirements explicitly states both «what to do» and «how to do it».

Figure 4-1 The maritime regulatory framework includes international regulations from IMO, national regulations from Flag States, rules from classification societies, port state control, and charterer and insurer vetting (Source: maritimeinfo.org).

Statutory regulations

The IMO has developed the International Code of Safety for Ships Using Gases and Other Low-Flashpoint Fuels (IGF Code, 'the Code'), providing an international regulatory framework. The IGF Code applies to ships to which Part G of International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS) Chapter II-1 applies. The purpose of the IGF Code is to provide an international standard for ships other than gas carriers, which are covered by the IGC Code[11], operating with gas or low-flashpoint liquids as fuel.

This is implemented at national level in the Nordics through national law. Norway and Denmark have developed specific regulations addressing ships using fuels with a low flashpoint:

For Norwegian flagged ships using gases or other low flashpoint fuels, the Norwegian Regulation of 27 December 2016 No 1883 on ships using fuel with a flashpoint of less than 60°C applies. This regulation makes the IGF Code mandatory for all Norwegian flagged ships (also ships not required to hold international safety certificates). Further, it requires that the ship shall satisfy a recognized Classification Society's rules for ships using fuel with a flashpoint of less than 60°C (FOR-2016-12-27-1883, 2017).

The Danish Maritime Authorities (DMA), requires, through Bek. nr. 1154 (19.12.2019) that ships using fuels with low flashpoint shall fulfil the requirements stated in the IGF Code (DMA Bek. nr. 1154, 2019). Further, DMA has issued a circular (DMA RO Circular no. 030, 12.05.2021) "to enlighten the approval process of alternative or equivalent energy sources on board Danish ships where there is no or minor guidelines and regulations for the design (…)". This Circular

[11] IGC Code – The International Code of the Construction of Equipment of Ships Carrying Liquefied Gases in Bulk

makes the IMO's MSC.1/Circ. 1455 – Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments mandatory.

Class Rules

DNV and other Class Societies have issued class rules for the use of methanol, ethanol, ammonia and LPG as fuel in addition to natural gas.

A Classification Society is a non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures (Class Rules). Classification societies certify that the construction of a vessel comply with relevant standards and carry out regular surveys in service to ensure continuing compliance with the standards. A Classification Certificate issued by a Classification Society recognised by the proposed ship register is required for a ship's owner to be able to register the ship and to obtain marine insurance on the ship. Classification Societies tend to have a faster rule development cycle than IMO. When a Classification Society has developed a set of rules covering the use of a fuel where specific design requirements are not included in the IGF Code, a Flag Administration may accept the application of this rule set to ease the alternative design approach (see chapter 4.2). A set of class rules may also form basis for development of international regulations in IMO.

The International Association of Classification Societies (IACS) is an interest organization dedicated to act as a means for collaboration among classification societies to contribute to maritime safety and regulation. The IACS members contribute as technical advisers to the International Maritime Organization (IMO) through IACS - which has consultative status in IMO. IACS has developed Unified Interpretations of the IGF Code (UI GF) for Part-A1 (LNG). IACS has recently launched a new "Safe decarbonisation Panel" to support the implementation of new fuels and technologies with initial focus on ammonia, hydrogen, carbon capture & storage and batteries.[12]

4.2 The IGF Code – a goal-based standard

Goal-based standards (GBS) are high-level standards and procedures that are to be met through regulations, rules and standards for ships. GBS are comprised of at least one goal, functional requirement(s) associated with that goal, and verification of conformity that rules/regulations meet the functional requirements including goals. In order to meet the goals and functional requirements, classification societies acting as recognized organizations (ROs) and/or national Administrations will develop rules and regulations accordingly. These detailed requirements become a part of a GBS framework when they have been verified, by independent auditors and/or appropriate IMO organs, as conforming to the GBS.

The basic principles of IMO goal-based standards/regulations are[13]:

- Broad, over-arching safety, environmental and/or security standards that ships are required to meet during their lifecycle.
- The required level to be achieved by the requirements applied by class societies and other recognized organizations, Administrations, and IMO.
- Clear, demonstrable, verifiable, long standing, implementable and achievable, irrespective of ship design and technology. Specific enough in order not to be open to differing interpretations.

The basic philosophy of the IGF Code considers the goal based approach (MSC.1/Circ.1394). Therefore, goals and functional requirements are specified for each section forming the basis for the design, construction and operation.

The current version of the Code includes prescriptive regulations to meet the functional requirements for natural gas as fuel (IGF Code Part A-1). Regulations for other gases or low-flashpoint liquids as fuel will be added to the Code as, and when, they are developed by the IMO. In the meantime, for other gases and low-flashpoint liquids, compliance with the

[12] IACS Council launches new 'Safe Decarbonisation Panel' to support the implementation of new fuels and technologies: https://iacs.org.uk/news/iacs-council-launches-new-safe-decarbonisation-panel-to-support-the-implementation-of-new-fuels-and-technologies/

[13] IMO Goal Based Standards: https://www.imo.org/fr/OurWork/Safety/Pages/Goal-BasedStandards.aspx

goal and functional requirements of the Code must be demonstrated through a risk-based approval process referred to as the “alternative design approach” (Figure 4-2). This means that a shipbuilder will have to demonstrate through extensive risk evaluations that the chosen fuel system design solution meets the intent of the goal and functional requirements of the IGF Code and provides the same safety level as a new and conventional oil-fuelled ship. This is not a process that most shipbuilders and designers are used to work with, it requires more time and resources, and is creating uncertainty and an additional business risk for the project since acceptance of design premises are not necessarily a given outcome.

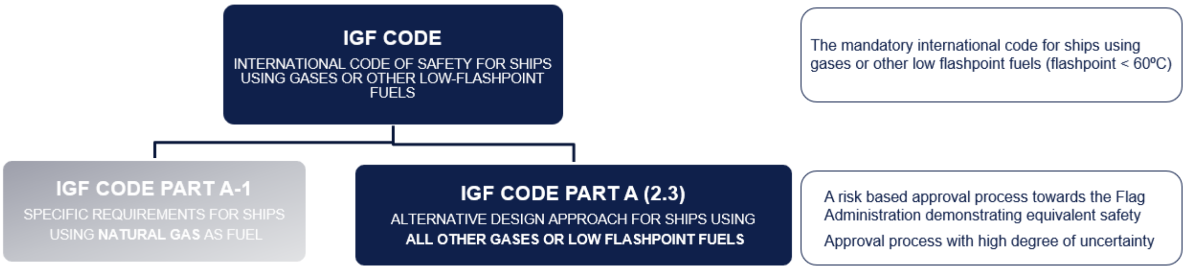

Figure 4-2 The IGF Code is the mandatory international regulatory framework.

The IMO provides the methodology for the Alternative Design process in the document ’Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments’ (MSC.1/Circ 1455, 2013). The process for approval of preliminary design is illustrated in Figure 4-3, and the process for final design in Figure 4-4. These figures show clearly that close interaction is required between the Submitter (the Project Owner) and the Administration throughout the approval process, and that the Submitter needs to approach the Flag Administration very early in the process. The exact requirements may vary on a case-by-case basis, depending on the Flag Administration and factors relating to the design and its maturity. When applying the Alternative Design approval process, several iterations may be needed to build confidence towards the approval body (Flag Administration) and prove equivalent safety.

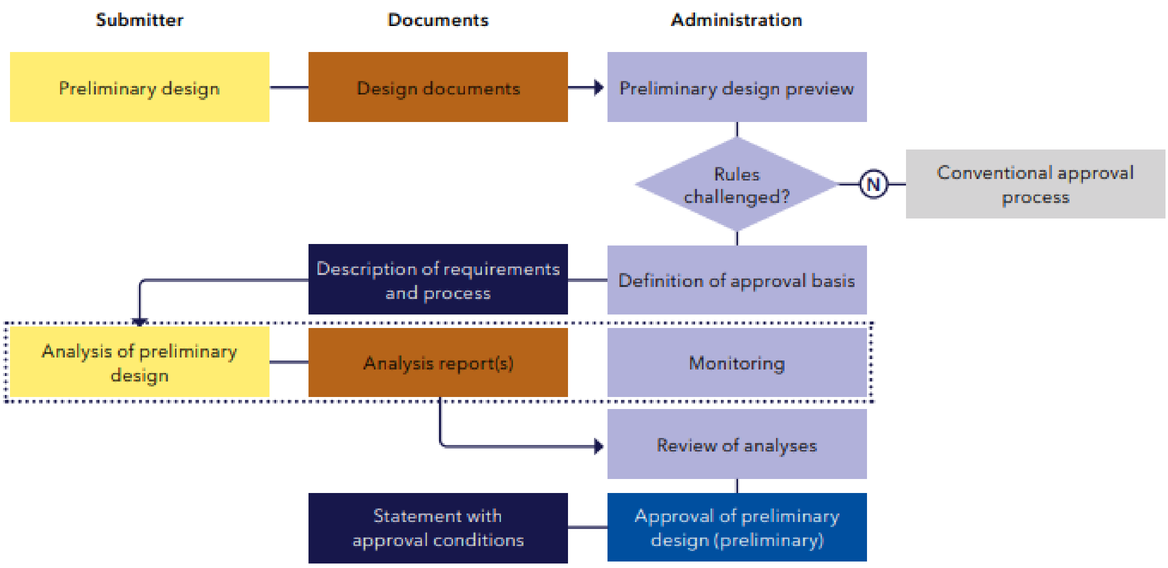

Figure 4-3 Overview of the approval procedure for preliminary design required according to the Alternative Design approach (ref. MSC.1/Circ.1455, 2013), describing the roles of the Administration (Flag State) and the Submitter (Project Owner) (MarHySafe, 2021).

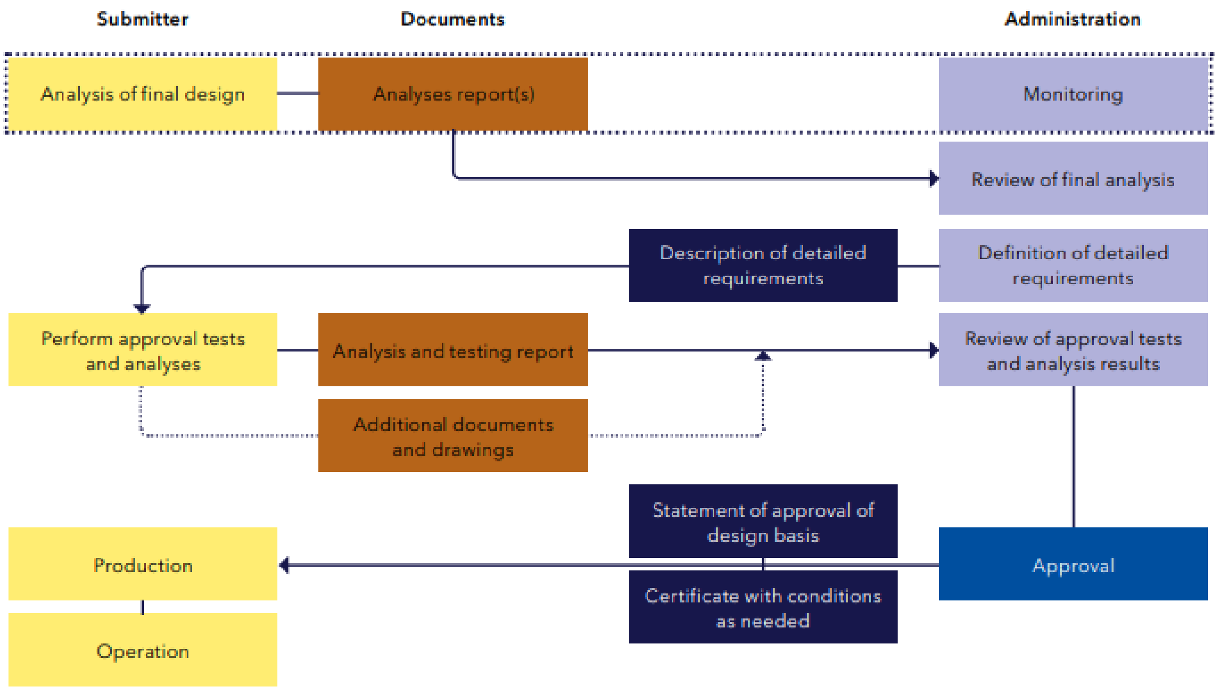

Figure 4-4 Overview of the approval procedure for final design required according to the Alternative Design approach (ref. MSC.1/Circ.1455, 2013), describing the roles of the Administration (Flag State) and the Submitter (Project Owner) (MarHySafe, 2021).

4.3 IMO process and work plan

The amendments of the IGF Code and development of guidelines for gases and low-flashpoint fuels lies with the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC). CCC meets in September each year and has a working group on the IGF Code. Further development work and discussions is done in correspondence groups. Deadline for submissions to CCC (more than 6 pages) is typically in mid-June (bulky documents 13 weeks deadline).

The work plan for the development of provisions for new low-flashpoint fuels under the IGF Code includes ongoing and planned development of safety for several alternative fuels: LPG, low-flashpoint oil fuels, hydrogen, ammonia, and methanol/ethanol. As can be seen from Figure 4-5, drafting and agreeing new regulations in IMO takes time. The development starts when it is agreed as a *work item*, i.e., put on the agenda in the IGF Code working group. Provisions for new fuels are initially developed as non-mandatory interim *guidelines* with the aim to gain experience with the new fuel before they are included as *mandatory regulations* by amendment of the IGF Code. Provisions agreed in the CCC sub-committee are sent to MSC for *approval*. There is a four-year cycle of *entry into force* (when the requirements start to be enforced*)* of amendments to the IGF Code (2024, 2028 etc). Amendments adopted less than 18 months before the end of a four-year cycle of entry into force enters into force at the end of the next four-year cycle. IMO usually tries to act on a consensus basis. This is because it is important that measures adopted by the Organization, which can have a major impact on shipping, achieve as much support as possible. Class societies have a leaner rule development and hearing process and can develop class rules more quickly (see more regarding use of class rules in 4.1).

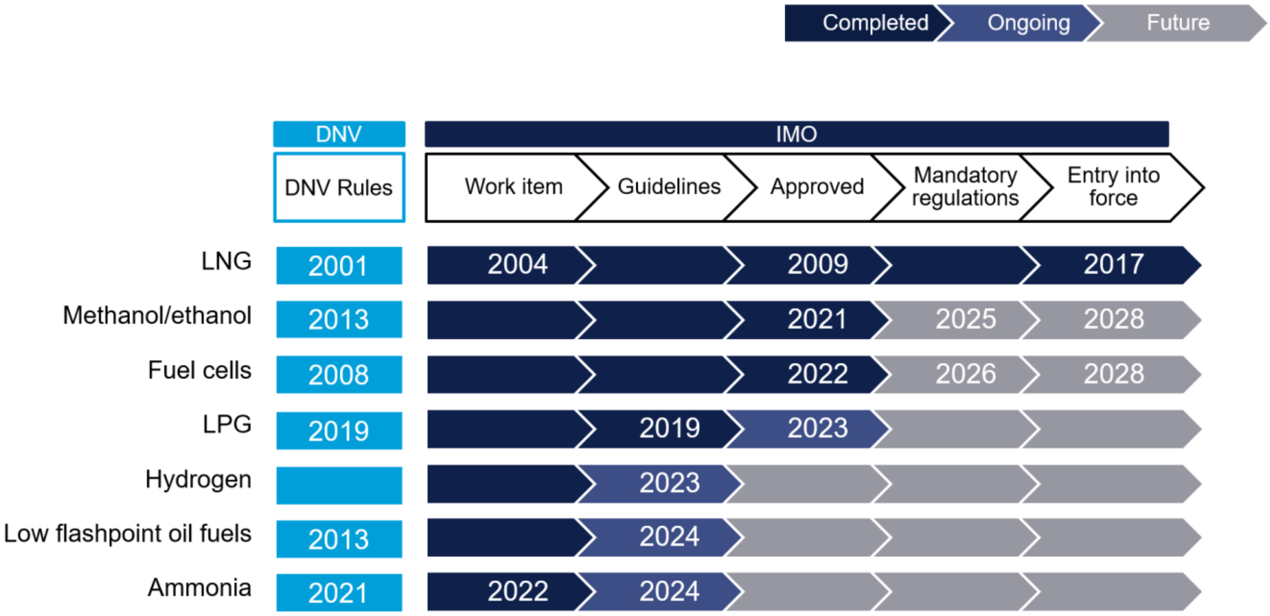

Figure 4-5 Status on development of safety requirements for alternative fuels compared to first issue of DNV class rules.[14]

[14] Source: Work plan for the next phase of the development of the IGF Code, CCC 8/WP.3, Annex 4, various IMO documents and DNV estimates. Future dates are indicative.

5 REGULATORY STATUS

Table 5-1 and Figure 5-1 provide an overview of the regulatory status and current experience for natural gas, methanol, ammonia, and hydrogen as maritime fuels as per October 2022. The status is further elaborated on in the following subchapters.

Table 5-1 Regulatory status and current experience per fuel.

	IMO	Class	Current experience
Natural gas	IGF Code Part A-1 provides prescriptive requirements	Class rules in place	Ships in operation since 2000 Transported as cargo on gas carriers
Methanol	IGF Code Alternative design approach IMO interim guidelines provide an international standard	Class rules in place	Ships in operation since 2013 Transported as cargo on chemical tankers and offshore supply vessels
Ammonia	IGF Code Alternative design approach	Class rules in place	No ships in operation Transported as cargo on gas carriers
Hydrogen	IGF Code Alternative design approach	No class rules in place	No ships in operation

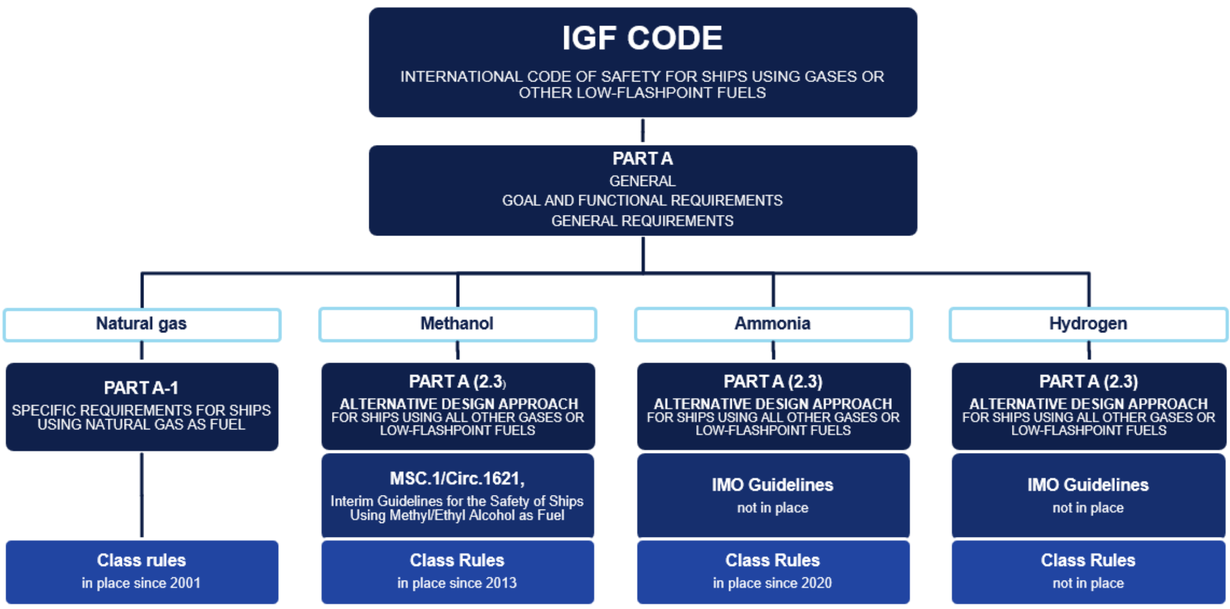

Figure 5-1 Regulatory status per fuel

5.1 Natural gas

Natural gas is usually liquefied by cooling for ease of storage and referred to as liquefied natural gas – LNG, when used as fuel.

5.1.1 IMO Status

The IGF Code entered into force on January 1st, 2017 and provides specific requirements for ships using natural gas as fuel. For gas carriers using LNG as fuel, the prescriptive requirements in the IGC Code Ch.16 *Use of cargo as fuel* applies.

5.1.2 Class Status

For natural gas, class rules have been in place since 2001, and has been further developed in parallel with the technological development in the maritime industry. The International Association of Classification Societies (IACS) has developed Unified Interpretations of the IGF Code.

5.1.3 Current experience

The maritime industry has experience with LNG through decades of carriage and consumption of boil-off gas on gas carriers, and through the gradual introduction of LNG as fuel on other ship types since 2000. As per June 2022, there are 923 LNG fuelled ships in operation (630 LNG carriers and 293 LNG fuelled ships of other types) and 534 LNG fuelled ships on order (167 LNG carriers and 367 LNG fuelled ships of other types).[15]

5.2 Methanol

Methyl alcohol is a chemical within the formula CH_3OH, also known as methanol. Ethyl alcohol is a chemical within the formula C_2H_5OH, also known as ethanol.

5.2.1 IMO status

In 2020, IMO provided an international standard through the non-mandatory interim guidelines for methyl/ethyl alcohols (methanol/ethanol) which can be used in lieu of the Alternative Design Approach mandated by the IGF Code if agreed by the Flag Administration.

In the work plan for the IGF Code working group, start to discuss the development of mandatory instruments (i.e., to include methanol requirements in the IGF Code) regarding methyl/ethyl alcohols (methanol/ethanol) is scheduled for CCC 9 in 2023, if time permits.

5.2.2 Class status

For methanol, class rules have been in place since 2013.

5.2.3 Current experience

The maritime industry has experience with methanol through carriage and use as fuel on chemical carriers and as a common cargo on offshore supply vessels.

Methanol as fuel has previously been a choice exclusively for tankers in the methanol trade with 11 ships in operation and 14 new tankers on order as per June 2022. Stena converted one existing 4-stroke engine to methanol fuel on one of their RoPax vessels in 2015. This year we see an uptake also in the container segment with 21 ships on order with methanol as fuel.[16]

[15] The statistics are taken from DNV's Alternative Fuels Insight platform, launched in 2018 as the industry go-to source for information on uptake of alternative fuels and technologies in shipping, and on bunkering infrastructure for alternative fuels (afi.dnv.com).

[16] The statistics are taken from DNV's Alternative Fuels Insight platform, launched in 2018 as the industry go-to source for information on uptake of alternative fuels and technologies in shipping, and on bunkering infrastructure for alternative fuels (afi.dnv.com).

5.3 Ammonia

Ammonia, NH_3, is a gas at ambient conditions, which is usually liquefied by cooling or pressurization for ease of storage.

5.3.1 IMO Status

Ammonia, being a gas at atmospheric conditions is regulated through the IGF Code. No prescriptive requirements are yet in place; hence the alternative design approval process is required.

The IGC Code chapter 16 applicable for gas carriers prohibits the use of ammonia as fuel due to its toxicity.

It should be noted that it has been argued in IMO that the safety of ships using ammonia as fuel might not fall under the scope of the IGF Code, and that the flashpoint for ammonia as a marine fuel need to be further clarified (CCC7/15).

A correspondence group has collected information on the safe use of ammonia as fuel and submitted their report to CCC8 meeting in September 2022 (CCC 8/13 and CCC 8/INF.10). Development of guidelines for the safety of ships using ammonia as fuel was agreed as a new work item by MSC105 in April 2022 and is included on the agenda for CCC8 in September 2022. The report of the working group at CCC8 (CCC8/WP.3) regarding development of such guidelines is briefly summarized in Table 5-2. The correspondence group was re-established and instructed to develop interim guidelines for the safety of ships using ammonia as fuel and submit a written report to CCC 9 (scheduled September 2023) (CCC8/18).

The IMO documents related to development of technical provisions for the safety of ships using ammonia as fuel are listed in Table 5-2.

Table 5-2 IMO documents on ammonia as maritime fuel

Source	Title	Content
CCC 8/18	REPORT TO THE MARITIME SAFETY COMMITTEE AND THE MARINE ENVIRONMENT PROTECTION COMMITTEE	This document provides the report from CCC8 to MSC and MEPC. The Sub-Committee agreed to re-establish the Correspondence Group on Development of Technical Provisions for Safety of Ships using Alternative Fuels, under the coordination of Germany, 1 and instructed it to develop interim guidelines for the safety of ships using ammonia as fuel, taking into account documents CCC 8/13, CCC 8/13/1, CCC 8/13/2 and annex 3 to document CCC 8/WP.3; and submit a written report to CCC 9.
CCC8/WP.3	DEVELOPMENT OF GUIDELINES FOR THE SAFETY OF SHIPS USING AMMONIA AS FUEL Report of the Working Group	This document provides the report of the working group on Development of Technical Provisions for Safety of Ships Using Alternative Fuels at CCC8. Main outcome regarding development of guidelines for the safety of ships using ammonia as fuel: - The structure to be followed should be that of the IGF Code. - The use of ammonia constitutes a different risk profile compared to LNG, the latter which is regulated in IGF Code part A-1. - Toxicity and corrosivity most important issues to be addressed differently than in the IGF Code. - The environmental effects of ammonia will need to be addressed. - The use of ammonia as fuel is in conflict with existing mandatory instruments, i.e., MARPOL regulation VI/18 and IGC Code chapter 16 that both prohibit the use of toxic or harmful fuels. Legal implications should be discussed at Committee level once these Interim Guidelines were finalized.

		- It will be necessary to consider that the use of ammonia would require setting permissible limits of exposure (short/long-term) to humans. - CCC 8/13/2 to be taken into account when developing the draft Interim Guidelines and forwarded to MEPC once the Interim Guidelines are more mature and the input needed from MEPC and other IMO bodies more concrete. - Any issues requiring input from any other body with a particular expertise should be identified by CCC 9. - Annex 3 (based on the annex to document CCC 8/13/1) was prepared to provide further guidance to the Correspondence Group.
CCC 8/13	DEVELOPMENT OF GUIDELINES FOR THE SAFETY OF SHIPS USING AMMONIA AS FUEL Report of the Correspondence Group (safety information for the use of ammonia) Submitted by Japan	This document provides the report of Correspondence Group on Development of Technical Provisions for the Safety of Ships using Low-flashpoint Fuels, regarding collection of the safety information for the use of ammonia.
CCC 8/INF.10	DEVELOPMENT OF GUIDELINES FOR THE SAFETY OF SHIPS USING AMMONIA AS FUEL Summary of comments provided to the Correspondence Group (safety information for the use of ammonia) Submitted by Japan	This document provides a summary of comments provided to the Correspondence Group on Development of Technical Provisions for the Safety of Ships using Low-flashpoint Fuels, regarding collection of the safety information for the use of ammonia.
CCC 8/13/1	Issues to be considered and possible way forward for the development of guidelines for the safety of ships using ammonia as fuel Submitted by Japan, Singapore, ICS and INTERCARGO	This report provides information on possible issues to be considered for developing guidelines for the safety of ships using ammonia as fuel and proposes the way forward. While, as mentioned above, differences between natural gas and ammonia, especially in toxicity and risk for fire and explosion, should be carefully considered, the co-sponsors believe that the content of the IGF Code is a good starting point to consider the draft guidelines of ammonia-fuelled ships under these urgent circumstances, since the IGF Code is the one instrument to be applied for gas-fuelled ships in general and there is nearly a decade of implementation experience. The co-sponsors propose that the Sub-Committee firstly analyses the requirements which should be amended, added or removed from those of the IGF Code and then identify prioritized issues, such as ventilation capacity, the

		measures to treat ammonia gas or bilge containing ammonia. In doing so, the annex to this document would be helpful. Due to the toxicity of ammonia, there are many provisions which will need in-depth consideration, and consequently the applicability of the IGF Code as a base document may need to be reassessed. The co-sponsors therefore propose to establish a correspondence group to prepare the draft guidelines for the safety of ships using ammonia as fuel with subsequent finalization at CCC 9.
CCC 8/13/2	Comments on document CCC 8/13 Submitted by the Republic of Korea	This document appreciates the hard work of the Correspondence Group and proposes a review of the environmental effect which will be considered in future discussions. If ammonia is discharged or vented at sea, there is a concern over not only the ship's stability and safety issues but also environmental pollution. As ammonia is discharged to the sea or the atmosphere, it can cause pollution to the marine environment due to chemical reactions or toxicity at sea. Therefore, appropriate actions are needed to consider the environmental impacts. Some of the Member States in the discussion of the Correspondence Group commented that some of the 26 items for consideration regarding the development of ammonia safety regulation need to be considered with MARPOL, which are also included in document CCC 8/INF.10. In particular, it is believed that effective and meaningful discussions can be conducted only when the safety standards of ammonia and marine pollution standards are reviewed at the same time, and appropriate measures are needed for the development of TOR so that the environmental impact of ammonia can be reviewed.
MSC 105/20	REPORT OF THE MARITIME SAFETY COMMITTEE ON ITS 105TH SESSION	Following discussion, the Committee agreed to include in the biennial agenda of the CCC Sub-Committee for 2022-2023 and the provisional agenda for CCC 8 an output on "Development of guidelines for the safety of ships using ammonia as fuel", with a target completion year of 2023.
MSC 104/15/9	Hazard Identification of ships using ammonia as fuel by Japan, Singapore, ICS and INTERCARGO	This document proposes a new output to develop non-mandatory guidelines for safety of newly built ships using ammonia as fuel.
MSC 104/15/10	Hazard Identification of ships using ammonia as fuel by Japan	This document provides the results of hazard Identification of ships using ammonia as fuel.
MSC 104/15/30	Necessity of deliberations on operational safety measures and fire safety measures Submitted by Japan	This document points out the necessity of careful deliberations on operational safety measures and fire safety measures for ammonia fuelled ships

CCC 7/15	REPORT TO THE MARITIME SAFETY COMMITTEE AND THE MARINE ENVIRONMENT PROTECTION COMMITTEE	The development of guidelines for ships using ammonia as fuel was included in brackets in the updated work plan for the next phase of the development of the IGF Code. Depending on the outcome of MSC 104 (Annex 2). In the meantime, The Re-established Correspondence Group is instructed to collect information on the safe use of ammonia as fuel.
CCC 7/3/9	Comments on CCC 7/3/Rev.1 Report from the Correspondence Group and proposal for developing guidelines for the use of ammonia and hydrogen as a fuel Submitted by Austria, et. al.[17]	This document comments on progress made in the report from the Correspondence Group on Development of Technical Provisions for the Safety of Ships using Low-flashpoint Fuels and proposes to include the development of two separate guidelines for the safety of ships using ammonia and hydrogen as fuel, in the work plan of the CCC Sub- Committee.
CCC 7/INF.8	Forecasting the alternative marine fuel: ammonia Submitted by the Republic of Korea	This document introduces the outline of the outlook of ammonia as green ship fuel by the Republic of Korea.

5.3.2 Class status

For ammonia as fuel, class rules and guidelines from various classification societies have existed since 2021 to accommodate owners, shipyards, and designers considering ammonia as fuel (Table 5-3). It should however be noted that the class rules have various detail level and remain to be proven as no ammonia fuelled ship is realized yet.

Table 5-3 Class rules and guidelines for ammonia as fuel

Source	Title
DNV (2021)	DNV Rules for Classification of Ships Pt.6 Ch.2 Sec.14 Gas fuelled ammonia
ABS (2021)	ABS Guide for Ammonia Fuelled Vessels
NK (2021)	Guidelines for Ships Using Alternative Fuels (Edition1.1)
RINA (2021)	RINA Rules for the Classification of Ships
BV (2021)	BV Ammonia-fuelled Ships – Tentative Rules Rule Note NR 671 DT R00 E
KR (2021)	KR Guidelines for Ships Using Ammonia as Fuels

5.3.3 Current experience

The maritime industry has experience with carriage of ammonia in gas carriers and as a refrigerant in refrigeration plants, but not as a fuel. Due to its toxicity, the introduction of ammonia as fuel creates new challenges related to safe bunkering, storage, supply, and consumption.

[17] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and European Commission

The strong interest in ammonia as fuel reflected in concepts and pilot studies is currently restricted by immature converter technologies. This is expected to change when the technology becomes available.

In an ongoing EU project, demonstration of a 2MW ammonia driven SOFC system is planned during 2024, retrofitting an existing supply vessel, the Viking Energy. Such demonstration and pilot projects are expected to significantly improve the speed of maturing the technology.[18,19]

In June 2022, it was announced that Enova supports two ammonia-powered tankers and two car carriers for Færder Tankers. [20,21]

5.3.4 Relevant standards

Ammonia is a widely used chemical, supporting the production of fertilizers, pharmaceuticals, and many other chemical applications. CCC 8/13 (Japan) includes a comprehensive list of information on safety for ammonia as a fuel including standards for land use. In the Nordic Roadmap project, we will focus on the selected standards listed in Table 5-4 in our efforts to advance the regulatory framework for ammonia as fuel.

Table 5-4 Relevant standards for ammonia

Source	Title	Content
EPA (2016)	EPA Acute Exposure Guideline Levels Ammonia 7664-41-7	Environmental Protection Agency Acute exposure guideline levels for airborne chemicals.
IEC	IEC 60079-10-1; 2008 E	Explosive atmospheres - Part 10-1: Classification of areas
IEC	IEC 60079-17	Explosive Atmospheres - Part 17: Electrical installations inspection and maintenance
IEC	IEC 60092-502; 1999	Electrical installations in ships - Tankers - Special features for tankers
Karabeyoglu A, Brian E. (2012)	Fuel conditioning system for ammonia fired power plants. NH_3 Fuel Association.	Exposure guidance.

18 https://www.offshore-energy.biz/worlds-1st-ammonia-powered-fuel-cell-to-be-installed-on-a-vessel/
19 https://shipandbunker.com/news/world/977374-eidesvik-aker-bp-seek-to-retrofit-offshore-support-vessels-with-ammonia-fuel-cells
20 https://presse.enova.no/pressreleases/enova-supports-hydrogen-projects-in-the-maritime-sector-with-nok-1-dot-12-billion-3190919
21 https://www.nrk.no/trondelag/gir-1_1-milliard-til-hydrogenproduksjon-1.16013944

5.3.5 R&D projects and reports

Selected R&D projects and reports with relevant information for safe use of ammonia as a marine fuel are summarized in Table 5-5.

Table 5-5 R&D projects and reports on ammonia

Source	Title	Content
ABS (2020)	Sustainability Whitepaper Ammonia as a Marine Fuel	This whitepaper provides information for the consideration of ammonia as a marine fuel option in both the near-term and long-term. Ammonia has greater prescriptive requirements for containment and equipment than most of the other alternative fuels under consideration, is a globally traded commodity and there currently exist many smaller gas carriers that may be suitable as bunkering vessels. However, for ammonia to become a commercially viable long-term fuel option, comprehensive supply-side infrastructure would need to be built and stringent new safety regulations be developed and implemented.
ALFA LAVAL, HAFNIA, HALDOR TOPSOE, VESTAS, SIEMENS GAMESA (2020)	Ammonfuel - An industrial view of ammonia as marine fuel	The marine industry report on major issue related to the use of ammonia as marine fuel. It covers all aspects of the process including conventional and future green ammonia production, experience regarding safety of ammonia from other areas, the logistics of providing ammonia where it is needed, and the application on board vessels. The focus is on cost, availability, safety, technical readiness, emissions and the elimination of risks related to future environmental and climate related regulations and requirements. The conclusion is that ammonia is an attractive and low risk choice of marine fuel, both in the transition phase towards a more sustainable shipping industry and as a long-term solution.
Cheliotis, M. et al. (2021)	Review on the Safe Use of Ammonia Fuel Cells in the Maritime Industry *Energies* 2021, *14*(11), 3023; https://doi.org/10.3390/en14113023	Based on the potential of NH_3 fuel for future widespread use, especially in marine applications, there is a need for knowledge development. In detail, there is a clear need for the identification of the hazards and consequences of NH_3 release through various dispersion studies. To that end, physical release experiments and simulation-based studies are required. Finally, and as also discussed in the paper, regulations and guidelines must be developed in parallel with the knowledge development.
DNV (2020)	Ammonia as a marine fuel DNV Group technology & Research, White Paper 2020	This paper examines the current use of ammonia in shipping and other industries and considers what it would take for ammonia to be adopted at scale as a maritime fuel. We think that there are significant but not insurmountable technical and safety challenges associated with ammonia as a marine fuel.
EMSA (2022)	Potential of Ammonia as Fuel in Shipping By ABS, CE-DELFT & ARCSILEA	To provide regulators and stakeholders with the information required to make informed regulatory and investment decisions, this study provides information on the properties, production, suitability and sustainability of using ammonia as a marine fuel. Furthermore, an examination of the current regulatory instruments is presented, as are a techno-economic assessment and a series of detailed risk-based case studies that examine the commercial and safety implications of using ammonia as a marine fuel. There are still barriers which the industry, engine manufacturers, producers, and other industry segments, as well as policy makers and regulators, need to address in a collaborative manner. Despite the extensive experience in its handling, there is

		little knowledge on using ammonia as a fuel. Given that it is toxic and corrosive, there are some concerns related to the safety of using ammonia as fuel onboard ships and their engines. Therefore, further work on understanding these risks and their possible mitigation is needed. Additional guidelines and regulations are needed, bearing in mind the increased number of operations (such as bunkering) and human interaction, when the uptake of ammonia takes place. The report includes a high-level summary of 23 important recommendations based on HAZID-studies which require further study and research.
GSP (2021a)	Ammonia bunkering of passenger vessel – concept quantitative risk assessment.	The Green Shipping Programme (GSP) have several pilots on ammonia as fuel. The first pilot was Ammonia as a fuel for passenger ships (Colorline): As part of this pilot a high-level quantitative risk assessment (QRA) was performed of defined conceptual bunkering operations of liquid ammonia both at pressurized and refrigerated conditions in the Port of Oslo. The passenger ship sailing between Oslo and Kiel was used as representative for the ammonia receiving ship.
GSP (2021b)	Ammonia as a Marine Fuel Safety Handbook	The handbook gives a high-level overview of the safety related properties of ammonia and comparison with the properties of methane to evaluate whether the safety barriers developed for natural gas is relevant for ammonia. On this background, it is discussed how the ship arrangement is affected by the ammonia fuel installation.
LR (2020)	Hydrogen and Ammonia Infrastructure. Safety and Risk Information Guidance. Report for: Ocean Hyway Cluster	This report discusses risk aspects related to infrastructure (production, transport, storage and bunkering) for hydrogen and (anhydrous) ammonia related to use as a maritime fuel. An overview of relevant historical accidents for the different fuels is given; for hydrogen and natural gas this is primarily explosion accidents, while for ammonia toxic exposure of people is the main concern. There is a potential for major accidents for all three fuels. For most properties, hydrogen is very different from other gases. Traditional mitigation methods like room ventilation, explosion panels, water deluge and inert gases will normally not work for a reactive hydrogen mixture. A completely different mitigation philosophy may be required with main focus on prevention of flammable atmospheres. The risk will generally tend to increase with the degree of confinement, i.e. any release and accumulation of flammable or toxic gases will be much more critical to people present inside a building where a release would happen. Similarly, many incident scenarios which outdoors could be dramatic, but not life-threatening, could have disaster potential inside a long tunnel or enclosed deck on a ferry. Both for hydrogen and natural gas, there have been an extensive experimental activity in recent decades to understand the explosion behaviour. Some of these experiments are discussed in the report. As ammonia is much less reactive than natural gas, and at the same time toxic, the main focus of ammonia experiments has been to study toxic hazard distances from pressurized, flashing releases. Some consequence assessment examples are performed for releases of refrigerated ammonia, pressurized ambient ammonia, liquid hydrogen,

		compressed hydrogen and LNG. Large, medium and small releases were simulated for a small storage facility in moderate winds. The conclusion from this assessment is that the compressed hydrogen facility and the refrigerated ammonia facility seem to be the safer solutions. For the LNG and LH_2 scenarios, the most severe events gave non-tolerable consequences, with fatality risk 200m or more away, with some fatality risk beyond the fence for the medium release scenarios. It is foreseen that bunkering for LH_2 and LNG will require somewhat larger safety distances, and a potential need to move the bunkering site away from the operations. For the pressurized ammonia scenarios more severe consequences were predicted. It is expected that pressurized ammonia will require a separate, well protected, bunkering location. Due to the severe consequences predicted, even for the medium release rate, it is proposed to aim for using refrigerated ammonia rather than pressurized ammonia during transport, storage and bunkering processes. Conclusions from this assessment are in line with conclusion from two previous ammonia safety studies, considering the use of ammonia as fuel for cars.
MAN ES (2020)	MAN B&W two stroke engine operating on ammonia	This paper presents MAN Energy Solutions's current knowledge about ammonia as a potential long-term fuel for two-stroke marine engines. The Innovation Fund Denmark supports the AEngine project with the aim to design and demonstrate an ammonia-based propulsion system. MAN ES is the AEngine project coordinator and part of the cross-functional project team together with Eltronic FuelTech (fuel supply systems), Technical University of Denmark and the classification society DNV GL.
MTF (2022)	Preliminary Discussion Report on the Use of Ammonia as Fuel for Ships	The Maritime Technology Forum (MTF)[22] investigates possible ways forward on the development of an international safety regulatory framework with regard to the use of ammonia as an alternative fuel for ships. Exchange of views, no common position at this point. 1. *General discussion on the regulatory framework necessary for the use of low-flashpoint fuel and ammonia as fuel:* • IGF Code applicable to "ships other than gas carriers using low-flashpoint fuels" and IGC Code applicable to "gas carriers using low-flashpoint fuels" in principle. • Whether the IGF Code (instead of the IGC Code) would be applicable to gas carriers using low-flashpoint gaseous fuels other than that being carried as their own cargo (e.g. LPG carriers using LNG as fuel). •Whether ammonia falls under the category low-flashpoint fuels and thereby the IGF Code. •16.9.2 of the IGC Code stipulates that the use of cargoes identified as toxic products shall not be permitted and that ammonia is specifically listed as a toxic product in Chapter 19 of the IGC Code. If applied, it would need to be revised. •Whether it would be allowed to release ammonia into the sea or atmosphere only in cases of emergency or also during normal operations. There needs to be specific regulations controlling the releasing and discharging of ammonia to a

[22] The founding members of the MTF include Flag State administrations and Classification Societies. The Flag State administrations include Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan; the Norwegian Maritime Authority; and the Maritime and Coastguard Agency, United Kingdom. The Classification Society members are American Bureau of Shipping, DNV, Lloyd's Register and Nippon Kaiji Kyokai.

		certain degree, while it remains uncertain whether such regulation would be sufficient to be solely under MARPOL or whether the additional revision of SOLAS or the IGF Code would be necessary. 2. *Assessing the basic properties of ammonia:* • Toxicity the primary critical hazard. Explosivity and flammability may require less stringent regulations in the IGF Code, especially considering the risk of fire associated with ammonia in comparison to natural gas. 3. *Basic concepts for safety measures in accordance with the basic properties of ammonia:* • Arrangements of spaces with respect to possible ammonia leakages would need to be duly considered more in terms of the risk from toxicity than that from fire or explosion. • Need for the introduction of a conceptualized toxic hazard zone • Vent mast arrangement; prescriptive requirement of requirement for dispersion analysis, • Need for appropriate means to reduce the ammonia in the gases being released from vent outlets • Consideration of operational safety measures to protect the crew and others in charge of operations involving ammonia; • Designing ammonia fuel containment and fuel supply systems which do not release certain concentrations of ammonia into the atmosphere (not greater than 30 ppm for instance) except in some situations like in the case of a fire; and, • the containment of ammonia itself together with associated processes and hazards.
Nordic Innovation (2021)	NoGAPS: Nordic Green Ammonia Powered Ship	The NoGAPS project brings together key players in the value chain for a Nordic-based ammonia-powered vessel. Together this consortium has elaborated a concept for an ammonia-powered gas carrier, transporting ammonia as a cargo in Northern Europe and using zero-emission ammonia as a fuel. The report includes some high-level considerations related to safe design and handling of ammonia and regulatory framework. A phase 2 of the project is initiated.
NTU (2022)	Ammonia as a Marine Fuel – Bunkering, Safety and Release Simulations By the Maritime Energy & Sustainable Development (MESD) Centre of Excellence	The study led by MESD, together with ASTI, ABS and industry partners, aims to provide a timely report to the marine community that includes ammonia production and supply, hypothetical ammonia bunkering process, and impact analysis of ammonia release from various scenarios. The study started in September 2020 and concluded in September 2021, aiming at audiences ranging from port operators, bunker suppliers, ship owners and port authorities to other relevant stakeholders considering ammonia as the next generation low carbon fuel
PHE (2015)	Ammonia - Toxicological Overview PHE publications gateway number: 2014790	Public Health England paper providing information on toxicological effects of ammonia for necessary safety considerations. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/455704/Ammonia_TO_PHE_240815.pdf
Together in Safety (2022)	Future fuels risk assessment	'Together in Safety' has carried out a series of hazard identification workshops with the purpose of identify and prioritising recommendations to the industry to ensure the safe deployment of future fuels. The fuels considered were LNG, Methanol,

		Ammonia and Hydrogen with the assumption that these are likely fuels to be used. The workshops were based on a tanker design using LNG as a fuel. The working group consisted of representatives from the following companies: APM Terminals, Carnival Corporation, Chevron, Euronav, Lloyd's Register, Mærsk, MSC Ship Management, OCIMF and Shell. If one assumes that the higher the risk rankings are correlated to the effort required for implementing the fuel compared to the HFO baseline, then it follows that methanol would require the least effort with regards to additional safety measures, followed by LNG, hydrogen and ammonia being the most demanding, but with all requiring inherently safer designs for implementation. Conclusions: As the shipping industry migrates through the energy transition there shall be inherent risks that need to be mitigated. Out of the fuels reviewed, methanol poses the least risk, followed by LNG, hydrogen and ammonia risk ratings increasing. A number of risks for ammonia as a fuel are classified as High (Intolerable), and as such the hazards should be eliminated, substituted or sufficient controls put in place to significantly reduce the risk to with medium or a low risk rating. Across all the fuels there are a number of medium risk rating, whilst these may be accepted tolerable, every effort must be demonstrated that the risks have been reduced to be As Low As Reasonably Practicable (ALARP). The recommendations can be defined in areas of responsibility between design, operator, regulators and ports. This report is produced to enable those stakeholders to ensure the risks raised and identified are dealt with in further projects, and further risk fed back to 'Together in Safety' to incorporate into future updates. Regardless of the vessels fuel, there are scenarios where vessels shall come across another vessel operating on a different fuel, and thereby having potentially a different and unknown risk category. This could be through port operations, collision, rescue or grounding. It is the intention of 'Together in Safety' to work collectively within the industry to address this challenge.
de Vries (2019)	Safe and effective application of ammonia as a marine fuel.	Available online: https://repository.tudelft.nl/islandora/object/uuid:be8cbe0a-28ec-4bd9-8ad0-648de04649b8?collection=education

5.4 Hydrogen

5.4.1 IMO status

Hydrogen, being a gas at atmospheric conditions is regulated through the IGF Code. No prescriptive requirements are yet in place; hence the alternative design approval process is required.

Development of guidelines for ships using hydrogen as fuel was included on the updated work plan for the IGF Code working group at CCC7 in September 2021. A correspondence group prepared a first draft set of guidelines as basis for further consideration by the Sub-Committee and submitted their report to CCC 8 meeting in September 2022 (refer to

CCC 8/3 Annex 9). The report of the working group at CCC8 (CCC8/WP.3) regarding development of such guidelines is briefly summarized in Table 5-2. The correspondence group was re-established and instructed to further develop interim guidelines for the safety of ships using hydrogen as fuel and submit a written report to CCC 9 (scheduled September 2023) (CCC8/18).

For the carriage of liquefied hydrogen as cargo, IMO has developed the Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk, the Maritime Safety Committee (MSC) Resolution MSC.420(97). However, the Interim Recommendations were initiated by and developed for a liquid hydrogen supply pilot project, and as such may be limited in application to that project.

The IMO documents related to development of technical provisions for the safety of ships using hydrogen as fuel are listed in Table 5-6.

Table 5-6 IMO documents on hydrogen as maritime fuel

Source	Title	Content
CCC 8/18	REPORT TO THE MARITIME SAFETY COMMITTEE AND THE MARINE ENVIRONMENT PROTECTION COMMITTEE	This document provides the report from CCC8 to MSC and MEPC. The Sub-Committee agreed to re-establish the Correspondence Group on Development of Technical Provisions for Safety of Ships using Alternative Fuels, under the coordination of Germany, 1 and instructed it to: further develop the draft interim guidelines for ships using hydrogen as fuel, based on annex 2 to document CCC 8/WP.3, with a view to finalization at CCC 9; and submit a written report to CCC 9.
CCC8/WP.3	AMENDMENTS TO THE IGF CODE AND DEVELOPMENT OF GUIDELINES FOR LOW-FLASHPOINT FUELS Report of the Working Group	This document provides the report of the working group Working Group on Development of Technical Provisions for Safety of Ships Using Alternative Fuels at CCC8. Main outcome regarding development of guidelines for the safety of ships using hydrogen as fuel: - To use the existing structure and provisions of the IGF Code for drafting hydrogen-specific recommendations. - To use the goal-based approach of part A of the IGF Code as the goals and functional requirements therein were intended to be applied to all low flashpoint fuels. - Only the main concepts and principles of the Interim Guidelines was discussed so that the Correspondence Group could develop provisions based on agreed principles. - Only provisions for compressed and liquid hydrogen to be developed.
CCC 8/3	AMENDMENTS TO THE IGF CODE AND DEVELOPMENT OF GUIDELINESFOR LOW-FLASHPOINT FUELS Report of the Correspondence Group on LPG, Hydrogen, low-	This document provides the report of the Correspondence Group on Development of Technical Provisions for the Safety of Ships using Low-flashpoint Fuels regarding LPG, **Hydrogen**, low-flashpoint oil fuels and amendments to the IGF Code.

	flashpoint oil fuels and amendments to the IGF Code.	
CCC 7/3/9	Comments on CCC 7/3/Rev.1 Report from the Correspondence Group and proposal for developing guidelines for the use of ammonia and hydrogen as a fuel Submitted by Austria, et. al.[23]	This document comments on progress made in the report from the Correspondence Group on Development of Technical Provisions for the Safety of Ships using Low-flashpoint Fuels and proposes to include the development of two separate guidelines for the safety of ships using ammonia and hydrogen as fuel, in the work plan of the CCC Sub- Committee.
CCC 7/15	REPORT TO THE MARITIME SAFETY COMMITTEE AND THE MARINE ENVIRONMENT PROTECTION COMMITTEE	The development of guidelines for ships using hydrogen as fuel was included in the updated work plan for the next phase of the development of the IGF Code (Annex 2). The Re-established Correspondence Group is instructed to initiate the development of guidelines for the safety of ships using hydrogen as fuel by taking into account relevant parts of document CCC 7/3/9;

5.4.2 Class status

There are no class rules or guidelines in place for hydrogen as fuel.

5.4.3 Current experience

Hydrogen has not been commercially transported as a marine cargo, and the experiences as a marine fuel are currently limited to small-scale R&D projects. The safety implications of storing and distributing hydrogen on board ships are not clear. The general understanding of hazards and risk associated with hydrogen, and particularly liquefied hydrogen (LH_2), is limited. Consequently, no class rules or prescriptive international regulations have yet been developed. Several R&D initiatives are currently ongoing to improve the understanding of hydrogen and associated hazards.

The world's first liquefied hydrogen-powered ferry, the MF Hydra, is planned to start operating on hydrogen during the second half of 2022.[24]

Another two hydrogen-powered ferries are planned to operate in Vestfjorden, Norway's longest national road ferry connection, from 2025.[25]

In June 2022, it was announced that Enova supports two hydrogen-powered container ships for Ocean Infinity and a hydrogen-powered bulk carrier for Thor Dahl (TD) bulk.[26,27]

As per June 2022, there are three hydrogen-fuelled newbuilds in the order book.[28]

[23] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and European Commission

[24] https://www.strandbuen.no/norled-har-sokt-om-a-fa-godkjent-bunkringsanlegg-snart-skal-hydra-fa-hydrogen/s/5-107-306065

[25] https://hydrogen-central.com/torghatten-nord-hydrogen-ferry-contract-hydrogen-production-large-scale/

[26] https://presse.enova.no/pressreleases/enova-supports-hydrogen-projects-in-the-maritime-sector-with-nok-1-dot-12-billion-3190919

27 https://www.nrk.no/trondelag/gir-1_1-milliard-til-hydrogenproduksjon-1.16013944

[28] The statistics are taken from DNV's Alternative Fuels Insight platform, launched in 2018 as the industry go-to source for information on uptake of alternative fuels and technologies in shipping, and on bunkering infrastructure for alternative fuels (afi.dnv.com).

5.4.1 Relevant standards

Hydrogen has been used throughout the world for a long time, as an industrial gas and, among other purposes, in the space industry. Therefore, standards and codes covering industrial use of hydrogen are in place, and some of these may be relevant for the use of hydrogen as fuel in ships. Standardization work related to the use of hydrogen as fuel in the land-based transport sector is newer, but the regulatory regime for the required hydrogen filling stations, and for hydrogen FC vehicles, is becoming established. The "Handbook for hydrogen-fuelled vessels" include a comprehensive list of standards related to hydrogen (MarHySafe, 2021). In the Nordic Roadmap project, we will focus on the selected standards listed in Table 5-7 in our efforts to advance the regulatory framework for hydrogen as fuel.

Table 5-7 Relevant standards for hydrogen

Source	Title	Content
IEC	IEC 60079-10-1:2015	This is a standard which covers the classification of areas where flammable gas concentrations may cause an ignition hazard. This standard defines an explosive gas atmosphere as a mixture with air under atmospheric conditions which after ignition permits self-sustaining flame propagation.
ISO	TR 15916 Basic considerations for the safety of hydrogen systems.	This Technical Report describes the hazards associated with the use and presence of hydrogen, discusses the properties of hydrogen relevant to safety, and provides a general discussion of approaches taken to mitigate hydrogen hazards. The aim is to promote the acceptance of hydrogen technologies by providing key information to regulators and by educating people involved with hydrogen safety issues. The considerations presented are broad, general, and attempt to address most aspects of hydrogen safety. The degree to which these guidelines are applied will vary according to the specifics of the application (such as the conditions and quantity of hydrogen involved, and the way in which the hydrogen is used). Not specifically for maritime applications, but a relevant reference source for hydrogen properties and safety hazards.

5.4.2 R&D projects and reports

Selected R&D projects and reports relevant for the safe use of hydrogen as a maritime fuel are summarized in Table 5-8.

Table 5-8 R&D projects and reports on hydrogen

Source	Title	Content
ABS (2021)	Sustainability Whitepaper Hydrogen as a Marine Fuel	This whitepaper provides information for the consideration of hydrogen as marine fuel in both the near-term and long-term. Hydrogen leaks are considered non-toxic, although the wide flammability range and potential for combustion can raise concerns of hydrogen safety and risk management. These concerns are addressed in the hydrogen safety and design consideration sections.
DNV (2022)	Hydrogen Forecast to 2050 Energy Transition Outlook 2022	Hydrogen will be transported by pipelines up to medium distances within and between countries, but almost never between continents. Ammonia is safer and more convenient to transport, e.g. by ship, and 59% of energy-related ammonia will be traded between regions by 2050. Hydrogen derivatives like ammonia, methanol and e-kerosene will play a key role in decarbonizing the heavy transport sector (aviation, maritime, and parts of trucking), but uptake only scales in the late 2030s. Safety (hydrogen) and toxicity (ammonia) are key risks. Public perception risk and financial risk are also important to manage to ensure increased hydrogen uptake.
Hoecke L. et al. (2021)	Challenges in the use of hydrogen for maritime applications, Energy Environ. Sci., 2021,14, 815-843	https://pubs.rsc.org/en/content/articlepdf/2021/ee/d0ee01545h The major challenge with hydrogen however is likely to be the storage. Therefore, several methods of hydrogen storage have been assessed on their usefulness as a storage technique for hydrogen applications in the maritime industry. These storage methods are compressed hydrogen, liquid hydrogen, ammonia, Fischer–Tropsch diesels, synthetic natural gas, methanol, formic acid, aromatic liquid organic hydrogen carriers and several solid-state hydrogen carriers: MgH2, NaAlH4, AB2-laves phase alloys, NaBH4 and NH3BH3. From this assessment it can be concluded that there is no magic bullet solution; not one storage method combines a high energy density, a low energy input, has all resources readily available, is non-toxic and both easy to handle and store. When storing hydrogen as a cryogenic liquid, so either as liquid hydrogen at −253 °C or as S-LNG at −162 °C, suitable materials have to be used that can withstand the cold temperatures so that they do not become brittle. If the cryogenic liquid spills, this can cause damage to the hull of the ship. Larger spills of liquid hydrogen or LNG on the ground cause a fast cooling of the ground surface, due to evaporation of the liquid in the ambient. Spills on board ships can be especially dangerous as this can cause cold fracture of the steel out of which the ship is constructed, and this can lead to hull damage.231 After spills of cryogenic liquids, vapour clouds form that are still at very low temperatures. These vapour clouds can pose serious dangers to people working on board of the ship, due to the low temperatures. Clouds of spilled cryogenic liquids contain a lot of water vapour, making them heavier than air, this means that they do not disperse like gaseous

		fuels do. This later effect thus increases the dangers for asphyxiation and explosions.
IEA (2021)	Hydrogen TCP Task 39 – Hydrogen in the Maritime Final Report	Key messages on standards, safety and regulations: There is a need for more detailed standards, regulations and codes (SRC) for hydrogen as fuel in maritime transport. There is a need for more design and operational experience with hydrogen in the maritime, and liquid hydrogen (LH_2) in particular. This can form the basis for further development of concepts, designs and SRC. Regulatory paths may be considered a barrier against the uptake of alternative fuels in the maritime industry. An "alternative design" approach can be a time-consuming process with potentially higher business risk than the prescriptive. Moreover, prescriptive rules implemented at the current stage, might put restrictions on optimized designs and limit the incentive for innovation. Reducing such barriers will require a learning process involving many stakeholders in which the development of the regulatory framework is continued, ships are designed and built, operational experience is gained, and the new and modified design is implemented.
LR (2020)	Hydrogen and Ammonia Infrastructure. Safety and Risk Information Guidance. Report for: Ocean Hyway Cluster	See Table 5-5
MarHySafe (2021)	Handbook for Hydrogen-Fuelled Vessels	The Handbook provides the basis for outlining a roadmap to hydrogen safety for the maritime industry based on the current risk-based Alternative Design approval framework (Part B, Chapter 6). Experience from gas processing and natural gas as a fuel can provide useful insight but needs modification to be applicable for maritime use of hydrogen (Part A). Important differences in properties, related in particular to reactivity and explosion potential, make it necessary to think differently for hydrogen than for other fuels. There are also many similarities, meaning that processing and safety systems can potentially be reused with some modifications. The Handbook presents and discusses the risk-based approaches and models that are available. It also covers the status of modelling capabilities for hydrogen, verification and validation of the models (Part C), and how they can be utilized to deal with the knowledge gaps in the next phase of the project (Chapter 11). The Handbook also presents and discusses possible risk-mitigation and risk-control measures to contribute to safe design and operation (Chapter 9). Risk management and control measures to prevent, detect and isolate leaks, and to control ignition, are available. However, these measures have not been tested and validated for the use of hydrogen in maritime settings. For critical safety systems, it can therefore be necessary to perform experiments with hydrogen so that the

		performance can be fully understood, and computer models adjusted and validated. A phase 2 of the MarHySafe JDP is initiated and will focus on the safe and efficient introduction of hydrogen-fuelled ships and their bunkering systems, based on the knowledge and knowledge gaps identified in Phase 1 of the project. The Alternative Design approval process, and the risk analyses required during this process, will be needed until sufficient knowledge and confidence are gained to develop rules. Therefore, the new knowledge gained from collaboration with real projects and through pre-modelled quantitative risk assessments will be leveraged to make the Alternative Design approval process more effective and reduce approval times. These learnings are to be shared in an updated Handbook.
Together in Safety (2022)	Future fuels risk assessment	See Table 5-5.
Vladimir Molkov (2012)	Fundamentals of Hydrogen Safety Engineering I and II	This book provides the state-of-the-art in hydrogen safety as a technological issue and introduces a reader to the subject of hydrogen safety engineering. Hydrogen safety engineering is defined as application of scientific and engineering principles to the protection of life, property and environment from adverse effects of incidents/accidents involving hydrogen. The use of hydrogen as an energy carrier presents several unusual hazards. The best investment in hydrogen safety is educated and trained personnel, informed public. This book is a contribution to hydrogen safety knowledge transfer and education of all stakeholders including technology developers and safety engineers, consultants and users, policy makers and investors, etc. It can be used as a textbook for higher education programmes in hydrogen safety, e.g. MSc in Hydrogen Safety Engineering course at the University of Ulster.

6 HOW TO ADVANCE REGULATORY FRAMEWORK

Shipping is an international industry dependent on regulations and standards that are agreed, adopted and implemented on an international basis. The International Maritime Organization (IMO) is the forum which is responsible for such measures. Through IMO, the Organization's Member States, the shipping industry and other stakeholders are working together to develop such regulations and standards, which are later implemented by the Flag States.

As described in Chapter 4 above, the amendments of the IGF Code and development of guidelines for gases and low-flashpoint fuels lies with the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC) which meets in September each year and has a working group on the IGF Code. Development work and discussions between CCC meetings is done in correspondence groups and deadline for submissions to CCC is typically in mid-June. Further regulatory development on alternative fuels in IMO requires initiatives from member states, developing and submitting documents to CCC.

This project intends to provide the Nordic countries with knowledge on safety characteristics of the selected potential zero-carbon fuels and corresponding suitable safety barriers to contain the safety risks. In co-operation with Nordic Maritime Administrations and other Nordic stakeholders this knowledge base can be used to develop submissions to IMO to further international development of regulations for alternative fuels.

The consortium will use the existing IGF Code, providing internationally recognized and accepted regulations for natural gas fuelled ships, as a benchmark for safety level when evaluating the use of ammonia and hydrogen as ship fuels.

This necessitates a comparison study between the physical properties of the benchmark fuel (natural gas represented by its primary component, methane) and the fuels selected in the project which are not covered by prescriptive IMO-regulations (ammonia, hydrogen). This comparison study will be used as a tool to assess when the existing safety barriers for LNG can be applied, and when they need to be modified or changed due to the difference in physical properties.

This approach will provide the Nordic countries with a technical knowledge base on the fuels analysed and a regulatory framework with the same structure as the IGF Code. Having a framework that will be recognizable to other stakeholders involved in regulatory development in IMO can be an advantage in the consortiums goal for project participants to develop common submissions to IMO by the Nordic countries on regulations for alternative fuels. It should be noted that there are other important regulatory barriers not covered by this task. Safety regulations related to onshore storage and bunkering is outside scope of maritime regulations and will not be covered by IMO. Further, this task relates to safe application of fuels, and does not cover environmental regulations ensuring implementation and sustainable application of fuels.

The process is divided into the following steps for each of the selected alternative fuels:

1. **A high-level review of IMO-submissions, class rules and guidelines, and other sources to establish an overview of existing regulatory development initiatives, pilot projects, and other research activities involving the selected fuels and natural gas.**
2. A comparison study of selected fuels, mapping all relevant physical properties linked to the safe use as a fuel on-board ships against the physical properties of natural gas.
3. An analysis of accepted safety barriers put in place by the IGF Code to accommodate natural gas as a fuel.
4. Use the results from step 2 and 3 to evaluate each barrier's suitability to reduce risks to acceptable level for each of the selected fuels analysed in step 2. The results from step 4 will be a structured review of safety gaps identified if the safety principles for natural gas were to be applied for the selected fuel.
5. Analyse the safety gaps identified in step 4 and work to provide alternative safety barriers and eliminate existing barriers that are considered superfluous.
6. Use results from step 1-5 to develop common Nordic submissions to IMO on alternative fuels where detailed and prescriptive regulations are lacking.

LNG and Methanol

International regulations for natural gas and interim guidelines for methanol are in place and are being further developed by IMO, IACS and classification societies as experience is gained. IMO have plans to incorporate the methanol guidelines as mandatory requirements in the IGF Code, but with the existing provisions safety rules and regulations are not seen as a barrier against adoption of these fuels.

Ammonia

International regulations for ammonia as a ship fuel are currently non-existent. However, many classification societies have issued a first version of class rules covering the installation and use of ammonia as fuel. This can be taken as an indication that class societies consider the integration of an ammonia fuel system feasible from a safety perspective. It must be noted that due to the current immaturity of ammonia fuel technology, there has been no newbuild projects putting these rules to the test yet. However, research projects, e.g., AEngine[29], contributes to verifying the rules.

[29] https://www.dnv.com/expert-story/maritime-impact/Harnessing-ammonia-as-ship-fuel.html

Together with the experience in the maritime industry with carriage of ammonia in gas carriers and as a refrigerant in refrigeration plants, this may form basis for further development in IMO. One aim of this project is to advance the regulatory framework for ammonia by providing the Nordic countries with a sound basis for IMO submissions which may accelerate the development process in IMO.

Hydrogen

Hydrogen as fuel has not seen the same initiatives for rule development from classification societies as ammonia. The main reason for the lack of rule development initiatives for hydrogen is that the safety implications of storing and distributing hydrogen on board ships is not considered to be sufficiently clear. The properties of hydrogen are more extreme than other gases and applying the safety regulations in the IGF Code for natural gas will likely not give a satisfactory risk level when hydrogen is used as a fuel.

There are several important reasons why it may be an advantage to wait before introducing prescriptive rules for hydrogen:

- The general understanding of hazards and risk associated with hydrogen, and LH_2 in particular, is limited. Several R&D initiatives are currently ongoing to improve the understanding of LH_2 and associated hazards.
- There is a need for more design- and operational experience with hydrogen, and LH_2 in particular, before proposing rules. The first vessel fuelled on LH_2 is expected in 2022.
- There is a need to stimulate innovation to develop safe and efficient solutions for all application areas and vessel types, from small vessels using compressed hydrogen in diesel engines to car ferries and larger passenger ships using LH_2 and fuel cells. This learning process requires that vessels are designed, operational experience is gained, and new modified designs are implemented in the next generations of vessels. The open design brief provided by the alternative design approach applied to numerous projects could produce solutions that later may be "standardized" as proven safe concepts.

Further work on hydrogen rule development could focus on developing prescriptive regulations when safe concept solutions are identified for specific safety challenges. When a technical standard is in place for parts of the system it would simplify the risk based alternative design process by reducing the scope to the remaining parts of the system. Additionally, one could put effort into making the alternative design process more efficient by standardizing and clarifying what is required from each step in the process, with the aim of reducing uncertainties in the approval process.

Nordic co-operation to ease implementation of alternative fuels

Until IMO have specific requirements for ships utilising other alternative fuels than natural gas in place, the option for the near future will be to verify the safety of new projects and conversions using the alternative design approach laid out in the IGF Code. Creating a common Nordic "playground" with a unified approach to matters relating to alternative maritime fuels may simplify some of the challenges intra-Nordic ship operators will be facing if they choose to explore alternative fuels in the near future. A common understanding among the Nordic Administrations on how to manage the alternative design process, and a common acceptance of such ships flying the flag of a Nordic country will reduce the barriers of other stakeholders to engage in the process of decarbonising shipping operating in the Nordic region. Having a common set of safety regulations relating to bunkering logistics in the Nordic regions would also ease the process of setting up green corridors and their development into a network of bunkering locations supporting Nordic green shipping.

7 REFERENCES

DMA Bek. nr. 1154 (2019)	Order on ship's construction and equipment, etc., implementation of the international convention on the safety of life at sea (SOLAS) 1974, Rule 57.
DMA RO Circular no. 030, 12.05.2021 (2021)	Approval of alternative and/or equivalent energy sources in Danish ships Guidance for Recognized Organizations and Ship owners, Ch. 2.
DNV (2022)	Maritime Forecast to 2050 – Energy Transition Outlook 2022, DNV.
DNV (2021)	Maritime Forecast to 2050 – Energy Transition Outlook 2021, DNV.
DNV GL (2020)	Maritime Forecast to 2050 – Energy Transition Outlook 2020, DNV GL.
FOR-2016-12-27-1883. (2017)	Forskrift om skip som bruker drivstoff med flammepunkt under 60 °C. https://lovdata.no/dokument/ SF/forskrift/2016-12-27-1883
MarHySafe (2021)	Handbook for hydrogen-fuelled vessels. MarHySafe JDP Phase 1. 1st edition (2021-06).
MSC.1/Circ. 1455 (2013)	IMO - Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments. Retrieved from https://www.mardep.gov.hk/en/msnote/pdf/msin1339anx1.pdf

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