AMMONIA AS A MARINE FUEL

SAFETY HANDBOOK

DNV

Green Shipping Programme

Sjøfartsdirektoratet
Norwegian Maritime Authority

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Executive Summary

The Green Shipping Programme's (GSP) intention with publishing an Ammonia as a Marine fuel Safety Handbook is to provide practical guidance on safety aspects of ship design in the development of ammonia fuelled ships for ship owners, yards and designers. The shore-side safety aspects are not part of the scope. This is an updated version of the Handbook which was developed in GSP as a work package on "safety standardization" in the Colorline Pilot on Ammonia as Fuel. The second revision build on additional experience gained from three new ammonia pilots in the GSP and from the ongoing Nordic Roadmap project for introduction of zero emission fuels in shipping[1].

The technology required to propel and power ships with ammonia as fuel is still immature, and extensive regulatory development and policy measures are needed for its use on a larger scale over the next decade.

Effective international statutory safety regulations for the use of ammonia as fuel on board ships are currently not in place and must be established in parallel with the development and maturation of the technology. Ammonia is a toxic chemical, and it is important that the safety challenges are thoroughly addressed before considering ammonia as a marine fuel.

The maritime industry has experience with carriage of ammonia on gas carriers and the use of ammonia as refrigerant. However, the introduction of ammonia as fuel creates new safety challenges related to bunkering, onboard storage, supply and consumption. These challenges may vary depending on ship type.

The current international regulatory framework and maritime industry experience with alternative fuels is mainly related to natural gas (LNG). A comparison of selected safety-related properties of ammonia and natural gas has been made to evaluate whether the safety barriers developed for LNG are relevant for ammonia. Ammonia is less flammable than natural gas and constitutes a lower, but not ignorable, explosion risk. Due to the toxicity, it is still considered essential to be able to control all leakage scenarios in order to design and operate a safe ship. The overall safety principles developed for LNG fuel related to segregation, double barriers, leakage detection and automatic isolation of leakages can also be suitable guidance when establishing safety requirements for ammonia fuelled ships.

On this background, we provide guidance on how the ship arrangement is affected by the ammonia fuel installation and in general terms how to accommodate for ammonia fuel onboard. Operational aspects must also be taken into consideration for safe implementation of ammonia fuel.

[1] https://futurefuelsnordic.com/

Foreword

Ammonia is among the fuels with a great potential to decarbonize the shipping industry, and the number of newbuilds being ordered with some form of "Ammonia ready" class notations indicates that there is a significant interest from shipowners.

Two years ago, the Green Shipping Programme (GSP) published the first version of the «Ammonia as a marine fuel safety handbook», providing the industry with practical guidance on solving the most important safety barriers.

Since then, our experience with and knowledge of ammonia as a fuel has expanded through three new GSP pilots and the ongoing approval process for new Norwegian vessels with ammonia as fuel. This second edition of the handbook reflects the lessons learned, providing new insights with respect to regulatory development, ammonia behaviour affecting safety, and updated guidance on safety aspects of ship design including toxic area plans, safe havens, and operational aspects.

The handbook is developed by DNV on behalf of GSP, with input from the Norwegian Maritime Authority and other partners in the GSP. It is developed in cooperation with the Nordic Roadmap project, using input from their Safety task.

The Green Shipping Programme is a collaborative project between the authorities and the private business community and aims to support increased uptake of environmentally friendly solutions for ships. The goal of the programme is for Norway to become a world leader in environmentally friendly and efficient shipping.

KNUT ARILD HAREIDE

Director General of Shipping and Navigation at the Norwegian Maritime Authority

Member of the Steering Committee, Green Shipping Programme

GSP Pilots on Ammonia as Fuel 2019-2023

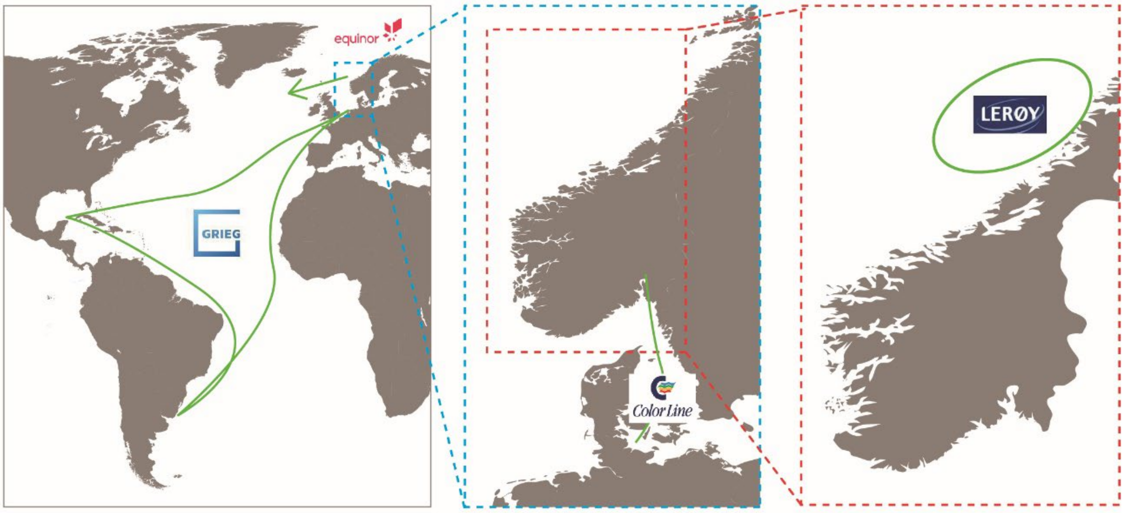

Figure A GSP pilots on ammonia as fuel (https://greenshippingprogramme.com).

Ammonia as fuel, Color Line

The pilot was launched in December 2019. The work – to shed light on potential barriers, such as the environmental footprint, security aspects, technological solutions, costs and possible private and public financing solutions – is complete. The pilot study could not identify any technical or safety barriers that could not be solved. The pilot is under assessment for realization. The pilot has also launched an activity that developed a publicly available handbook for the use of ammonia as a maritime fuel, see Ammonia as Marine Fuel – Safety Handbook Rev 01.

Ammonia Powered Bulk Carrier, Grieg Star

With the goal of realizing the first ocean-going open hatch/bulk carrier to be powered by green ammonia, Grieg Maritime Group and GSP launched the pilot work in the beginning of 2022. The aim of the pilot's study phase has been to assess the technical and commercial feasibility of retrofitting an open hatch bulk carrier for green ammonia operations in a trans-Atlantic route. What are the key barriers, risks, and possibilities? How does the business case look, and is green ammonia viable as fuel on this specific trade? The pilot is completed.

Ammonia Powered Tanker, Equinor

Launched in the beginning of 2022, the main goals of the pilot have been to:

- Investigate the technical and economical applicability of implementing ammonia-eligible engines, fuel- and bunkering systems on a large generic tank ship design.

- Understand operational safety aspects and competence requirements.

-De-risking key elements of the design and identifying barriers.

The ultimate goal of the pilot has been an Equinor-charted tanker powered by ammonia. The pilot is under completion.

Ammonia Powered Trawler, Lerøy Havfisk

Lerøy Havfisk carried out a feasibility study answering the following questions: To what extent can the operational pattern of the current trawler fleet be supported with ammonia as fuel? Can the experience large trawlers have with ammonia as cooling medium in refrigeration plants be of importance for safe implementation of ammonia as fuel? What environmental benefits can be achieved, and to what cost? In total the pilot shall give answer if it is technical possible implement an ammonia fuelled system for a newbuild with similar performance as the current modern trawlers in the Lerøy Havfisk fleet. Launched in 2022 and under completion.

Abbreviations

ARMS	Ammonia Release Mitigation System
ESD	Emergency Shut-Down
FPR	Fuel Preparation Room
GSP	Green Shipping Programme
IACS	International Association of Classification Societies
IBC	International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
IMO	International Maritime Organization
LEL	Lower Explosion Limit
UEL	Upper Explosion Limit
LNG	Liquefied Natural Gas
LSA	Life Saving Appliances
NH_3	Ammonia
PPE	Personal Protective Equipment
ppm	parts per million
SCR	Selective Catalytic Reaction – NOx abatement technology
SOLAS	International Convention for the Safety of Life at Sea
TCS	Tank Connection Space

1 Introduction

Many studies have pointed to ammonia (NH_3) as a potential future fuel for shipping (e.g., Maritime Knowledge Centre, TNO & TU Delft, 2017; OECD, 2018; DNV GL, 2020a; IRENA, 2023).

When produced using renewable energy, ammonia can be considered a carbon-neutral fuel in a well-to-wake perspective. This provides shipowners a fuel option that could assist in meeting the International Maritime Organization's (IMO) 2050 GHG emissions reduction targets.

The technology required to propel and power ships with ammonia as fuel is still immature, and extensive development and policy measures are needed for its use on a larger scale over the next decade.

Several engine manufacturers are currently looking into the challenges of burning ammonia in their engines, with the aim of having engines available 2 to 3 years from now. Fuel cell technology using ammonia as a fuel is also under development.[2,3,4]

Effective international statutory safety regulations for the use of ammonia as fuel on board ships are currently not in place and must be established. Ammonia is a toxic chemical, and it is important that the additional safety challenges from potential exposure are thoroughly addressed before considering ammonia as a marine fuel.

Ammonia has been widely manufactured for over 100 years and is used in considerable amounts in the production of fertilizers and been transported and used as refrigerant at sea. However, the introduction of ammonia as marine fuel creates new safety challenges related to bunkering, onboard storage, supply and consumption. These challenges may vary depending on ship type.

Several class societies published class rules for ammonia fuelled ships in 2021. Due to the current immaturity of ammonia fuel technology, there has been no newbuild projects putting these rules to the test yet. However, several recent studies consider various safety implications of using ammonia as a marine fuel (e.g., DNV,2022a, 2022b, 2022c; EMSA, 2022; IRENA, 2022; MMMCZCS, 2023a, 2023b; Ricardo & DNV,2023; SGMF, 2023).

Safety studies examining the potential ramifications of large ammonia leaks indicate how key design and operational parameters, such as ammonia storage conditions, transfer flow rate, and release duration, can significantly affect the dispersion of ammonia, and the degree of reduction in affected area that can potentially be achieved by changing them (DNV, 2021; Dharmavaram et al, 2023; Clara Kay Leng Ng, 2023; GCMD, 2023).

The first revision of this handbook was developed in the Green Shipping Programme (GSP) as a work package on "safety standardization" in the Colorline Pilot on Ammonia as Fuel with the intention to provide practical guidance on safety aspects of ship design in the

[2]https://www.wartsila.com/media/news/07-09-2022-launch-of-wartsila-25-engine-paves-the-way-towards-maritime-decarbonisation-3152432

[3]https://www.man-es.com/energy-storage/campaigns/ammonia-for-power

[4]https://www.wingd.com/en/news-media/press-releases/wingd-and-cmb-tech-co-develop-large-ammonia-fuelled-engines/

development of ammonia fuelled ships for ship owners, yards and designers. The shore-side safety aspects are not part of the scope. This second revision builds on additional experience gained from three new ammonia pilots in the GSP and from the Nordic Roadmap project for introduction of zero emission fuels in shipping[5].

Compared to the previous revision, this updated version provides new insights with respect to development of safety regulations, ammonia behaviour affecting safety, guidance on safety aspects of ship design including toxic area plans, safe havens, and operational aspects. It also includes further evaluation of the suitability of using the safety concept of the current regulations in the IGF Code for natural gas fuel also for ammonia.

This handbook has the following structure: Chapter 2 provides a brief introduction to the properties of ammonia and a comparison with the properties of natural gas. Chapter 3 examines the health and environmental effects of exposure to ammonia. Chapter 4 gives an overview of the regulatory framework status for ammonia as fuel. Chapter 5 outlines the design implications of differences between ammonia and natural gas. Chapter 6 provides practical guidance on general design of ammonia fuelled ships. The final chapters are devoted to operational aspects: Chapter 7 on development of operational procedures and Chapter 8 on personnel protection.

[5] https://futurefuelsnordic.com/

2 Ammonia as a fuel

While ammonia has been widely manufactured for over 100 years and is used in considerable amounts in the production of fertilizers, and been transported and used as refrigerant at sea, new risks need now to be understood in the context of using ammonia as a fuel in the maritime sector.

2.1 Properties of ammonia

Ammonia in its pure form is referred to as anhydrous ("without water") ammonia. Under atmospheric temperature and pressure, ammonia is a colourless, toxic gas with a sharp and penetrating odour. The basic properties of ammonia are summarized and compared with natural gas in Table 2-1.

Although gaseous, anhydrous ammonia is lighter than air, the rapid evaporation following a sudden release of pressurized, liquid ammonia may cause liquid carry-over to the gas cloud. The ammonia droplets may disperse in the gas, forming a cloud that is heavier than the ambient air. Ammonia may behave in buoyant, neutral, or dense fashion depending on the circumstances of its escape into the atmosphere. Kaiser et al. (1982) shows that the crucial parameter which determines whether the ammonia is likely to form part of a buoyant, neutral, or dense mixture is the airborne liquid fraction. For ammonia releases with a content of airborne liquid fractions below 4% (by mass), a buoyant mixture is always formed, while for high liquid fractions (>20%), the mixture is always dense. In between, the mixture may be buoyant, neutral, or dense, depending on the atmospheric humidity.

Ammonia can cause stress corrosion cracking in steels, which must be addressed in the selection of materials in contact with ammonia, including tanks and materials intended to contain ammonia in the case of leakages. Ammonia has alkaline properties and will also corrode galvanized metals, cast iron, copper, brass and copper alloys. Not all rubbers and polymers typically used for gaskets and sealing are compatible with ammonia use, Hence, careful material selection is required in design of ammonia fuel systems.

Ammonia is flammable, but hard to ignite. Outdoors, ammonia vapours will generally not constitute a fire hazard. Indoors, in confined areas, the risk of ignition will be higher, especially if oil and other combustible materials are present. Pressure vessels used for storage of ammonia may explode if exposed to high heat input.

Ammonia is transported in the liquid state; therefore, it must either be compressed or refrigerated or some combination of the two. Fully refrigerated ammonia storage tanks contain liquid at -33°C at atmospheric pressure, while fully pressurised tanks are designed for 18 bar which corresponds to the ammonia vapour pressure at 45°C.

Ammonia is a hygroscopic compound, which means it seeks water from the nearest source, including the human body. Mucous membranes, like the eyes, respiratory system and skin, have high moisture contents and is especially at risk when put into contact with ammonia. An additional concern with respect to direct exposure is the low boiling point of ammonia, as it will freeze on skin contact. It will cause caustic burns similar to, but more severe than, those caused by dry ice. A direct blast to the face can cause severe damage to the throat and lungs. When large amounts are inhaled, the throat swells shut, and victims may suffocate. Exposure to vapours or liquid may also cause blindness. (Schwab, Charles V. et al., 1993).

The hygroscopic properties of ammonia are also relevant when evaluating the dispersion of released ammonia gases. In an emergency, a water spray may be used to dissolve ammonia gas from the air to reduce the dispersion. The amount of water and the layout of the spray system related to the ammonia discharge sources will require further studies to ensure the desired effect.

It should be noted that applying water directly into a pool of liquefied ammonia will cause a violent reaction which may subject responders to direct contact with ammonia, and it will also increase the evaporation rate of toxic gases. The water and ammonia form ammonium hydroxide, which is a corrosive liquid, so efforts should if possible be made to control the run-off. Further, it should be noted that ammonia leaks and releases to open air occurring in rainy or windy conditions, can react with rain- or sea water and form ammonium hydroxide, which is also moderately toxic and can affect crew and passengers. This should be considered in the arrangement and location of vent masts and ventilation outlets.

2.2 Comparison with natural gas

Current international regulatory framework and maritime industry experience with alternative fuels are mainly related to natural gas[6]. Hence, a comparison between selected safety related properties of natural gas and ammonia may be useful when evaluating whether the safety barriers developed for natural gas are also relevant for ammonia. Since the physical properties of natural gas can vary slightly with its composition, the physical properties used in Table 2-1 are for methane, which is the main component of natural gas.

[6] Natural gas fuel in the context of the IGF Code is either in its liquefied (LNG) or gaseous state (NG). Its composition varies, but the primary component is methane.

Table 2-1 Properties of ammonia compared with methane

Property	Ammonia (NH_3)	Methane (CH_4)
Boiling temperature (1 bar)	-33 °C	-162 °C
Vapour pressure (45 °C)	18 bar	–
Liquid density (at boiling temp.)	0.68 tonnes/m^3	0.43 tonnes/m^3
Specific gravity (Air: 1)	0.51	0.547
Expansion ratio liquid/gas	850	600[7]
Flammability range[8]	15-28%	5.3-17%
Auto ignition temperature	651°C	537°C
Minimum ignition energy[9]	40-170 mJ	0.27 mJ
Laminar burning velocity	0.07 m/s	0.37 m/s
Solubility in water (at 20 °C)	531 g/l	No
Main hazards	Toxic	Explosive
	Corrosive	Cryogenic
	Flammable	Flammable
	Explosive	Asphyxiating

Compared with methane, ammonia has a lower, but not ignorable, explosion risk. However, it is toxic at much smaller concentrations than the lower flammability limit of both ammonia and methane vapours. As opposed to LNG, ammonia is not stored at cryogenic temperatures, but is corrosive to certain groups of materials.

[7] Varies slightly depending on LNG composition

[8] The minimum concentration of a particular combustible gas or vapour necessary to support its combustion in air is defined as the Lower Flammability Limit (LFL). The maximum concentration of a gas or vapor that will burn in air is defined as the Upper Flammability Limit (UFL). Above this level, the mixture is too "rich" to burn. The range between the LFL and UFL is known as the flammable range for that gas or vapour

[9] Reported minimum ignition energy values in the limited literature on the subject varies between 8 mJ and 680 mJ (e.g., Dupont (2009)) and seems to be affected by measurement methods. However, it seems reasonable to conclude that mixtures of ammonia and air are significantly more difficult to ignite than those of methane, with the majority of experimental results supporting a MIE of 40 to 170 mJ (Harris, MacDermott (1977)).

3 Toxicity

Toxicity is in many ways the key hazard related to ammonia. The fact that harmful concentrations range down to a fraction of a percentage makes even smaller leakages hazardous, and the extent of a hazardous gas cloud potentially very large. This must be considered in the development of ammonia fuelled ship designs.

3.1 Health effects

Ammonia is a toxic substance which has a sharp suffocating odour at low concentrations in gaseous form. Acceptable human exposure limits to ammonia are defined by legislation and is typically a function of concentrations and exposure time. The ammonia exposure limit is set between 25-50 ppm with dangerous consequences for exposure to concentrations above 300 ppm (Valera-Medina et al., 2018). Examples of exposure guidance are shown in in Table 3-1 and Table 3-2.

Table 3-1 Exposure guidance (Karabeyoglu A, Brian E., 2012)

Effect	Ammonia concentration in air (by volume)
Readily detectable odour	20 – 50 ppm
No impairment of health for prolonged exposure	50 – 100 ppm
Severe irritation of eyes, ears, nose and throat. No lasting effect on short exposure	400 – 700 ppm
Dangerous, less than ½ hours exposure may be fatal	2000 – 3000 ppm
Serious oedema, strangulation, asphyxia, rapidly fatal	5000-10000 ppm

Based on Acute Exposure Guideline Levels (AEGL) for airborne chemicals defined by the Environmental Protection Agency (EPA) US, the limits to ammonia exposure can be identified as shown in Table 3-2.

Table 3-2 EPA Acute Exposure Guideline Levels (EPA, 2016)

Ammonia CAS number 7664-41-7. Concentration in air (by volume), expressed in ppm					
	10 min	30 min	60 min	4 h	8 h
AEGL 1	30	30	30	30	30
AEGL 2	220	220	160	110	110
AEGL 3	2700	1600	1100	550	390

AEGL 1: Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL 3: Life-threatening health effects or death.

From Tables 3-1 and 3-2 it is obvious that an ammonia release within the hull of a ship has the potential to generate lethal gas concentrations in confined spaces. There is also a potential for dangerous concentrations in open air due to e.g., large spills or tank overpressure.

Toxicity is in many ways the key hazard related to ammonia, and the property that separates it most from natural gas; it is harmful to personnel at concentrations well below its lower flammability limit of 15% in air. For example, UK HSE indicates that an ammonia concentration of 0.36% in air could cause 1% fatalities given 30 minutes of exposure. Concentrations of 5.5% could cause 50% fatalities after 5 minutes of exposure.

Introduction of ammonia as fuel in the maritime sector poses challenges that are different from the ones seen in the onshore industry, the principal difference being the limited safety distances available and a limited possibility of safe evacuation when at sea.

Frequent situations with personnel in close proximity to operations such as bunkering, maintenance of ammonia systems, frequent coupling and de-coupling of equipment are main concerns. Adding to the concern is the possibility of exposing shore-side personnel to ammonia during port calls. Similar operations are performed in the land-based industry and sharing of experience of how to handle them safely will be important.

This must be considered in ship design, with respect to passenger and crew areas, escape ways, mustering stations and location of, and access to, life rafts and PPE. Port layout and facilities must also be designed with potential ammonia leaks in mind.

For natural gas, whose primary risks are related to fires or explosions, safety barriers removing ignition sources can mitigate the consequence of a leakage. For ammonia it is different, as leakages will have a direct effect on exposed personnel.

3.2 Environmental effects

Release of ammonia to the sea has impact on the environment. Ammonia is classified as toxic to aquatic life with long lasting effects according to GHS[10].

Using ammonia as fuel would lead to near zero GHG emissions from the ship (uncertainty remains on N_2O-emissions), but depending on the production pathway of the ammonia, there can be significant upstream or well-to-tank emissions. For some of the high GHG intensity production fuel pathways such as methane reforming without carbon capture and storage (CCS) the total emissions may even be higher than producing and combusting fossil

[10] Globally Harmonized System of Classification and Labelling of Chemicals (GHS). United Nations, New York, and Geneva, 2011. https://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev04/English/ST-SG-AC10-30-Rev4e.pdf

fuels. Combustion of ammonia in internal combustion engines may generate NOx and also N_2O which is a powerful greenhouse gas. It is assumed that existing SCR technology is capable of handling the NOx problem, and that engine manufacturers will need to find solutions to handle N_2O if ammonia is going to be a viable zero emission fuel[11].

[11] https://man-es.com/discover/two-stroke-ammonia-engine

4 Regulatory framework

The successful implementation of ammonia as a marine fuel requires development of international regulations to ensure a safe integration of onboard fuel installations and trained personnel. 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. This chapter gives an overview of the regulatory framework status for ammonia as fuel.

4.1 Current regulations

SOLAS

The use of fuels is regulated by the International Maritime Organization (IMO) through the International Convention for the Safety of Life at Sea (SOLAS). The regulations for conventional fuel oils are prescriptive and based on decades of experience. Utilizing fuels with a flashpoint below 60°C (defined as Low Flashpoint Fuels) has generally been prohibited to prevent tank explosions and fires.

In 2015, the SOLAS Convention was amended to allow the use of gases or low flashpoint fuels for ships complying with the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code).

The IGF Code

The IGF Code provides an international standard for the safety of ships using gases or low-flashpoint fuel, other than gas carriers which have to comply with separate requirements in the IGC Code (see 4.3).

The IGF Code requires that the safety, reliability, and dependability of the systems shall be equivalent to that achieved by new and comparable conventional oil-fuelled main and auxiliary machinery. It is emphasized that operational procedures shall not replace safety barriers through the ship design.

The IGF Code specifies a set of functional requirements applicable for all fuel types covered by the Code, but only contains specific design requirements to LNG.

Until fuel specific regulations are in place, approval of ships using other gaseous or low-flashpoint fuels than LNG will be based on first-principle analysis demonstrating that the design complies with the functional requirements of the IGF Code Part A. This risk-based approval process is referred to as the 'alternative design' approach (part A section 2.3 in the IGF Code), where an equivalent level of safety needs to be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration. The approval process for the alternative design approach is described in IMO MSC.1/Circ.1455.

It can be a time-consuming process with a high degree of uncertainty and therefore potentially have a higher business risk than the prescriptive experience-based rules that the maritime industry is used to working with. This must be considered as a barrier against uptake of alternative fuels in the industry.

The IGC Code

The IGC Code provides an international standard for the safe carriage in bulk of liquefied gases by ships.

The IGC Code includes a separate chapter on the use of cargo as fuel but does not currently permit the use of cargoes identified as toxic products like ammonia for this purpose.

Ammonia is transported as cargo in large quantities in gas carriers. The requirements in the IGC Code can therefore provide useful guidance in how to design fuel storage systems for ammonia.

Class rules

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. A set of class rules may also form basis for development of international regulations in IMO. 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. 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.

4.2 Development of international regulations in IMO

The development of guidelines for the safety of ships using ammonia as fuel was initiated at the 8th session of the sub-committee on carriage of cargoes and containers (CCC8) in September 2022 and is currently under consideration in a correspondence group. The guidelines will be structured as the IGF code with goals and functional requirements, in addition to new chapters regulating the toxicity related safety provisions. Based on the work in the Nordic Roadmap project, Norway on behalf of the Nordic countries, has shared a proposal for a base document for "draft interim guidelines for the safety of ships using ammonia as fuel" with the correspondence group, and will submit an information paper with supporting information to CCC9. The guidelines are scheduled to be discussed at CCC 9 in 2023 and finalized at CCC 10 in 2024.

The IGC code applicable for gas carriers is currently under review. Norway is working on a proposal for safety provisions to be submitted for discussion at CCC 9, aiming for adoption by 1 July 2026 and entry into force on 1 January 2028. This is the earliest possible timeline for updating the IGC code. However, if the safety provisions for allowing the use of toxic cargo as fuel are agreed upon at CCC 9, vessels built to these specifications can be approved based on the equivalent safety provision until the rules enter into force.

4.3 Competency and training

Safe operation of ammonia fuelled ships requires sound safety management procedures and trained personnel. A recent study by the Maritime Technologies Forum (MTF)[12] identifies potential gaps for future safe use of alternative fuels within three existing Conventions / Codes: The International Safety Management (ISM) Code, International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and The Maritime Labour Convention (MLC); and makes recommendations to close the gaps related to safety management, crew training and safety culture (MTF,2023).

A recent DNV study for the Maritime Just Transition Task Force point towards an immediate need to train seafarers (DNV, 2022c). However, the timing and type of training provided will depend on the ambition of decarbonization trajectories and the future fuel mix. As many as 800 000 seafarers may require additional training by the mid-2030s to enable the fuel transition in shipping, but this is currently subject to several constraints:

- The lack of clarity surrounding alternative fuel options and decarbonization trajectories, along with slow regulatory development makes investment in seafarer training challenging
- The need to invest in training facilities and up to date equipment (e.g., simulators providing opportunities for hands-on learning experiences)
- The lack of qualified trainers
- The shortage of experienced seafarers.

[12] The Maritime Technologies Forum (MTF) is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process (https://www.maritimetechnologiesforum.com/).

5 Safety implications of differences between ammonia and natural gas

Most alternative fuels have chemical and physical properties which generate more severe safety challenges and requires a more complex fuel containment system than conventional fuel oils. Additional safety barriers are required to maintain the safety level. Each alternative fuel has its unique properties and associated hazards requiring special consideration.

Both ammonia and natural gas have boiling temperatures incompatible with conventional storage tanks onboard ships. Consequently, both fuel types need a storage and supply system that can manage the pressure increase and boil-off gas generated by heat input to the system.

The low boiling temperature of natural gas (-163°C) introduces a design challenge with respect to selection of materials to ensure ductility at low temperatures. This can also be an issue for ammonia (-33°C) but can be overcome with less sophisticated material selections. On the other hand, the corrosive properties of ammonia require special consideration in the choice of materials.

Due to the high flammability and low minimum ignition energy of natural gas, it is essential to prevent leakages from the fuel storage and supply system. Ignition of leakages in enclosed spaces may result in explosions with severe consequences for the ship and persons onboard. Ammonia is less flammable than natural gas and constitutes a lower explosion risk. Unlike LNG, ammonia is a toxic substance.

5.1 Safety concept of current regulations in the IGF Code for LNG fuel

Figure 5-1 illustrates the safety concept applied in the current regulations in the IGF Code for natural gas fuel. Essential safety barriers are related to:

1. **Segregation:** keeping the installation away from areas where it may be damaged by collision or grounding, protected against mechanical damage from cargo handling and other ship operations, kept away from areas of high fire risk, applying area classification zoning to prevent ignition of fuel leaks and enable safe access, ventilation arrangements and LSA locations.
2. **System integrity:** the fuel storage tank and distribution system must be designed to minimize leakages from the fuel installation.
3. **Double barriers:** arrangements that allows leakages from the fuel system to be managed safely. This will typically be to provide a secondary barrier around any leakage point. In practice, such barriers consist of specially designed spaces (e.g. tank connection spaces, fuel preparation rooms) and double piping arrangements. Ventilation systems and low-temperature protection are inherent parts of double barriers.
4. **Leakage detection:** systems that can detect leakages of gases and liquids from the fuel system. The detection methods are dependent on arrangements, but normally

includes gas detection systems, low temperature measurements, changes in pressure and temperature.

5. **Automatic isolation of leakages:** systems and arrangements that can isolate the leakage from the leakage source when the detection systems above find something wrong with the fuel system. In order to achieve this, a number of isolation devices are required in the system enabling automatic shut-down of the fuel supply to the damaged system.

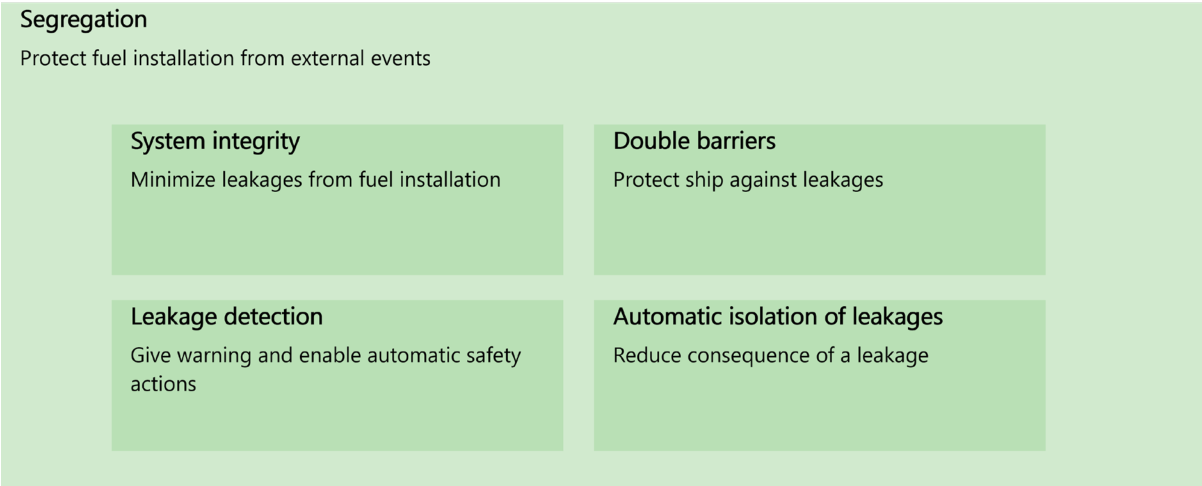

Figure 5-1 Safety concept of the current regulations in the IGF Code for natural gas fuel (DNV, 2022b).

5.2 Application of IGF Code safety concept for ammonia as fuel

The safety concept of the existing IGF Code, which has provided internationally recognized and accepted regulations for LNG-fuelled ships since 2017, can be used as benchmark for safety level when evaluating ammonia used as fuel onboard. An analysis of the physical properties of ammonia is required to evaluate to what degree these safety principles would be suitable for ammonia in the development of prescriptive rules and regulations.

The findings from a project for the Nordic Council of Ministers (DNV, 2022b) indicates that the safety principles described in 5.1 could be used as a foundation for development of prescriptive ammonia regulations. However, other fuel properties like toxicity will require additional safety barriers. Having a clear understanding of the unique properties and their effect on the risk picture is essential to put effective safety barriers in place to mitigate risks of using ammonia as fuel.

As indicated in Figure 5-2, the safety principles in the IGF Code for natural gas can be applied to ammonia, even though substantial modifications to account for the additional toxicity risk upon loss of containment are required. The IGF Code requirements for natural gas fuel do not account for fuel toxicity, which necessitates modification of existing barriers (LNG) and introduction of new safety barriers to protect against ammonia exposure during normal operation and in emergency situations.

IGF can be used	IGF minor changes	IGF major changes	IGF questionable

	Segregation		System integrity		Double barriers				Leakage detection	Automatic isolation of leakages
	Mechanical damage	External fire	System design	Operational and emergency discharges	Piping	ESD machinery space	Double barrier spaces	Ventilation	LEL	ESD valves
Ammonia			corrosivity pressure toxicity	toxicity	toxicity	toxicity	toxicity	toxicity	toxicity	toxicity

Figure 5-2 Suitability of using safety concept of the current regulations in the IGF Code for natural gas fuel also for ammonia (DNV, 2022b).

6 General design implications for ammonia fuelled ships

In this chapter we discuss how the ship arrangement is affected by the ammonia fuel installation and in general terms how to accommodate for ammonia fuel in the different parts of the system.

The different parts of an ammonia fuel installation are illustrated in Figure 6-1. The additional safety barriers and arrangements required to safely integrate it onboard will affect the ship arrangement.

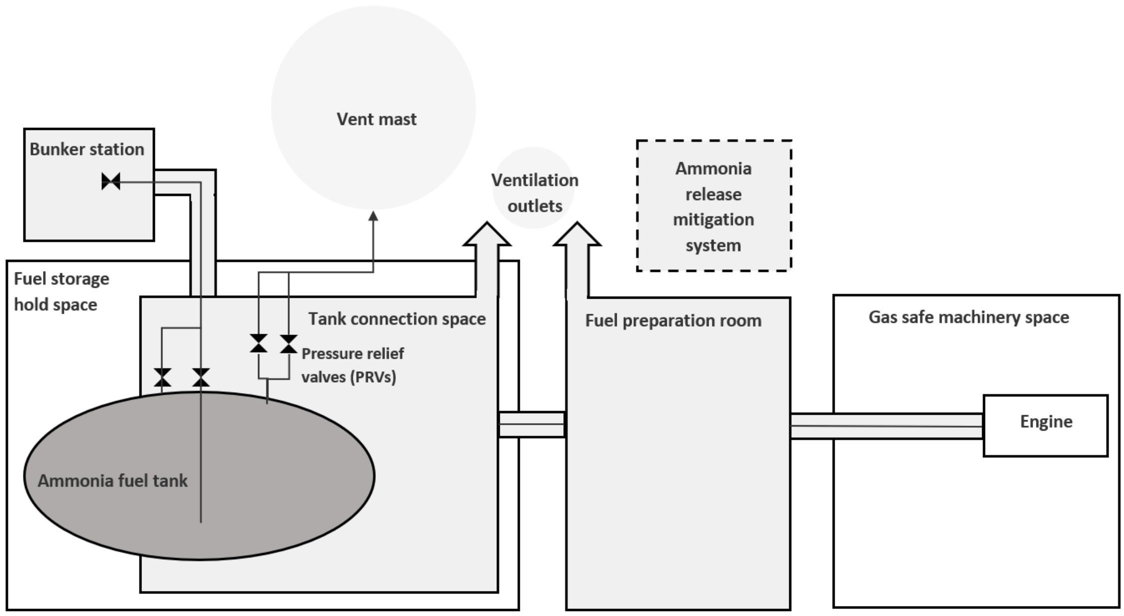

Figure 6-1 Principle diagram of onboard ammonia fuelled installation (Source: DNV).

6.1 Ship design and arrangement

6.1.1 Machinery space

Focus area: Reduce the risk of leakages in machinery spaces which would expose personnel to toxic vapours and make machinery spaces inaccessible.

To prevent gas leaks from spreading to the machinery space, ammonia fuel systems should be arranged with secondary barriers (this includes systems pertaining to engines and other ammonia consumers). For the same reason, there should be no access between the machinery spaces and spaces arranged to contain ammonia leakages.

Special care should be taken to ensure that it is possible to safely isolate equipment in machinery spaces from the fuel system in emergency situations and for maintenance purposes. Manual isolation valves and fuel line purging arrangements should be fitted to enable safe maintenance of ammonia-related equipment located in machinery spaces.

The concept of ESD protected machinery spaces used in some early LNG-fuelled projects is not considered to provide an adequate safety level for ammonia fuelled ships. This is because a single failure may result in a gas release into the space due to the single walled fuel system in ESD protected machinery spaces. A direct major leakage of ammonia in the machinery space will be an unacceptable event irrespective of having the ability to automatically isolate the leakage upon detection.

6.1.2 Tank connection spaces and fuel preparation rooms

Focus area: Safely contain leakages to prevent ammonia from spreading to other areas onboard.

Tank connection spaces (TCS) and fuel preparation rooms (FPR) should be arranged to avoid further spreading of ammonia leakages in areas where a double pipe protection of the ammonia system is not practical to arrange. Consequently, all tank valves should be located in a TCS mounted on the tank, and all equipment necessary to process the fuel should be arranged in a dedicated FPR.

In order to effectively contain leakages, the boundaries towards other spaces in the ship need to be gas tight. Ammonia has a boiling point of -33°C and will have an additional cooling effect on the surroundings if released into TCS or FPR. Experiments have shown that the bulk pool temperature in an ammonia spill can be as low as -70°C (AristaTek 2006). The bulkheads of these spaces should be designed to avoid embrittlement from exposure to low temperatures and potential cracking that will compromise their gas tightness.

Access points and bulkhead penetrations also need consideration to maintain the gas tightness of the boundaries.

The location of the TCS and FPR should be considered in the design of access points. When access from open deck is not possible, additional safety barriers should be applied. The IGF Code requirements for LNG fuelled ships specify that access to the TCS shall be through a bolted hatch unless the access is from open deck. Experience from operation indicates that TCS-access is more regular than initially assumed when the first rules were made. Considering the toxicity of ammonia at low concentrations it will likely be problematic to restore the gas tightness of the TCS if a leakage develops when the bolted hatch is open. It is therefore considered that an additional lobby with a conventional gas-tight door in front of the entry hatch will be a better access solution to TCS on ammonia fuel tanks. The bolted hatch will provide a safe segregation in normal operation while the gas tight lobby (similar to an air-lock arrangement) will provide protection against spreading of toxic gas if a leakage occurs when the bolted hatch is open.

Fuel preparation rooms located without possibility of access from open deck should be accessed through an air-lock arrangement.

In refrigeration machinery spaces using ammonia as a refrigerant, a water-curtain is arranged on the outside of the entrance. The water-curtain is intended to catch escaping ammonia vapours by utilising the hygroscopic nature of ammonia and reduce the concentration of toxic gases on the outside. Water curtains should be arranged outside entrances to TCS and

FPR for the same purpose. It is important to ensure that the water will not come into contact with any accumulated ammonia inside the TCS/FPR.

Other design features which may reduce the consequence of a leakage in TCS or FPR are:

- Leakage detection with automatic closing of isolation valves able to cut off the supply of ammonia to the leakage source.
- Proper mechanical shielding of all leakage points in the space to reduce the risk of direct exposure to ammonia.
- A ventilation system to dilute and discharge ammonia vapours to open air.
- A water spray system providing coverage of the area around ventilation openings to limit dispersion of ammonia vapours on deck.
- A layout which provides easy escape from the space.
- Gas detection alarms arranged in such a way that personnel are warned against leakages inside the space and against entering.

It is assumed that personnel will be equipped with proper PPE when working in such spaces, and that procedures for safe entrance and maintenance work is developed. Proper training is a prerequisite for safe operation.

6.1.3 Safe haven

Focus area: Providing safe refuge to persons onboard in ammonia release scenarios.

Even though numerous safety barriers will be implemented to prevent leakages and to limit the consequences of ammonia discharges, having a well-protected space where the persons onboard can take refuge in a substantial ammonia release scenario will increase the overall safety level.

The design and location of the safe refuge will of course depend on the ship type, but ideally the following should be considered:

- Maximise the distance between the safe haven and ammonia release sources (vent mast, ventilation outlets).
- Optimise the location of ventilation inlets to prevent ammonia ingress.
- Enable manual closing of ventilation inlets from inside the safe haven.
- Protect ventilation inlets with external water spray system to remove ammonia vapours.
- Gas detection on ventilation inlets.

The safe haven could be combined with a mustering function. In any case, location of lifesaving equipment, escape ways and lifeboats should be chosen with view to keep them away from potential gas releases.

6.2 Fuel containment system

Focus area: Storage of ammonia without release to the atmosphere.

Ammonia is transported in the liquid state; therefore, it must either be compressed, refrigerated, or some combination of the two. Fully refrigerated ammonia storage tanks contain liquid at -33°C at atmospheric pressure, while fully pressurised tanks are designed for 18 bar which corresponds to the ammonia vapour pressure at 45°C.

In principle, tank types accepted for cargo carriage in the IGC Code could also be considered as fuel tanks. In practice type A (fully refrigerated) and C (semi- or fully pressurized) tanks as defined in the IGC code are used for transport of ammonia cargo in gas carriers.

There are several safety related factors to consider when choosing type of fuel tank:

- Venting of tank vapours should be prevented at all times. The need for controlling discharges from ammonia fuel tanks is emphasized by its toxicity which will give an immediate hazardous effect upon release. It should be considered to increase the holding time limit of 15 days to infinity. This implies that tanks for ammonia will need a fully redundant boil-off gas (BOG) management system unless they are designed for the full vapour pressure of ammonia at ambient temperatures (18 bar).
- An unavoidable consequence of storing liquefied gas is the need for pressure relief devices to ensure that a rise in temperature (and therefore pressure) does not damage the tank. It is possible to prevent discharge trough these vents in normal operation by adding a system that can safely handle the boil-off gas. However, in case of a safety valve failure or in a fire scenario a large amount of pressurised gas will be discharged through the vent mast. How to handle a full capacity emergency discharge from ammonia tank's pressure relief valves must be carefully considered. Definition of toxic zones and the incorporation of a safe haven for persons onboard should be evaluated as part of the solution.
- For tanks requiring secondary barriers, management of leakage scenarios and the subsequent emergency venting of fuel gases must be specially considered. IMO Type A tanks presents a particular challenge since the design accounts for a failure of the primary barrier. As a consequence, large amounts of ammonia vapours will be discharged through the secondary barrier vents without possibilities to limit or control the leakage.
- The choice of fuel tank may also impact flexibility with regard to compatibility with bunkering facilities with respect to pressure and temperature. For IMO Type C tanks, the choice of design pressure will affect the weight, loading limit and holding time of the tank.
- The choice of storage conditions (design pressure) may affect the dispersion of ammonia vapours released from the vent mast.

Due to the corrosivity of ammonia, special requirements in the IGC Code for materials used in ammonia storage tanks and associated systems should be observed.

Focus area: Protect the ammonia fuel installation from external events that could damage the tank causing accidental release of ammonia.

To reduce the risk of accidental release of ammonia, the tank location should be carefully considered with respect to any external events that could potentially damage the tank.

For collision and grounding protection, the requirements defined in the IGF Code for LNG tanks and piping are considered relevant.

Ammonia tanks should preferably be located away from exposure to ship and cargo operations. Alternatively, appropriate mechanical protection should be considered.

6.3 Bunkering system

Focus area: To ease operability, reduce the risk of ammonia leakages during bunkering and limit risk and consequences of exposure to ammonia.

The bunkering operation with its handling, connection and disconnection of heavy bunkering hoses is subjecting the personnel involved to the risk of being directly exposed to ammonia.

The lay-out of the bunkering station should aim to ease bunkering by providing ample space for the necessary operational steps with lifting equipment and should support the mounting of heavy bunkering hoses.

Bunkering stations located without possibility of access from open deck should be accessed through an air-lock arrangement to limit the risk of toxic vapours spreading to adjacent spaces.

To limit the risk of exposure, the bunkering control station should be in a safe location enabling the crew to remotely oversee the bunkering operation.

The bunkering system onboard should be arranged in such a way that it is possible to drain the ship ammonia bunkering lines to the storage tank and the bunkering hose back to the bunkering facility. The ship bunkering line should be purged with inert gas after fuelling operations to reduce the risk of ammonia leakages when it is not in use.

There are several other design features which may reduce the consequence of a leakage during bunkering:

- Leakage detection with automatic closing of bunker valve.
- Manual emergency stop.
- A ship-shore link (SSL) or an equivalent means for automatic and manual ESD communication to the bunkering source.
- Water spray system above the bunkering manifold to reduce toxic vapours in the bunkering station.
- Proper mechanical shielding of all leakage points on the bunkering manifold including temporary mechanical shielding of the bunkering connection.
- Spill tray below the bunkering manifold.
- Bunkering hose with break-away coupling and quick-disconnect.

- Monitoring of bunkering station by direct line of sight or closed-circuit television (CCTV).

Development of proper bunkering procedures including communication with the bunker supplier and training of crew is considered essential to bunkering safely.

It is recognized that the risk of ammonia exposure cannot be eliminated by good design and proper operating procedures. Therefore, persons involved in the bunkering operations should be equipped with Personal Protective Equipment (PPE) to protect them from exposure to ammonia. Emergency showers and eyewashes should be provided in convenient locations outside the bunkering station.

6.4 Fuel supply to consumers

Focus area: Safely supply fuel to consumers without operational discharges of ammonia and without exposing persons onboard to ammonia leakages.

In order to prevent toxic vapours from reaching areas where personnel can be exposed, the ammonia fuel piping system should be surrounded by a secondary enclosure which should be able to contain any leakages from the system. If the piping system is located in a tank connection space or a fuel preparation room, these spaces will function as a barrier against gas leakages given the difficulties of providing double walled piping due to the piping components necessary to process the fuel.

In the IGF Code the same is required for natural gas pipes. The Code additionally requires that the secondary enclosure of natural gas pipes shall be mechanically ventilated. This necessitates inlet and outlet ducts plus a redundant fan arrangement for segregated pipe segments.

The main objective of the secondary enclosure is to prevent exposure to leaking fuel and we foresee that several other arrangements could also achieve this objective, including nitrogen filling of the annular space. The secondary enclosure should be arranged for gas freeing after leakages.

The material of ammonia pipes and their secondary enclosures must be chosen to ensure resistance to corrosion and low temperatures.

In order to avoid unnecessary operational discharges from the fuel system, liquid ammonia piping should be designed with a minimum design pressure of 18 bar. This corresponds to the vapour pressure of ammonia at 45°C which is what IACS specify as the highest that all machinery shall be designed to operate. It should be noted that ammonia expands 850 times when going from liquid to gaseous state and short exposure can be lethal at concentrations of 5000 ppm. This implies that 1 litre of spilled liquid ammonia can expand into 170 m^3 of ammonia with a concentration of 5000 ppm - and 170 000 m^3 of gas with a detectable smell (5 ppm).

To limit the amount of ammonia being released in case of leakage in TCS, FPR, or the annular space of the piping system, automatic shut-down valves should be arranged at the tank boundaries, at the FPR bulkhead (to prevent the volume between tank and FPR from being discharged inside FPR), and in each supply and return line to consumers in the machinery space.

Operational restrictions and safety considerations may require that the fuel system is drained of ammonia. The de-pressurising and purging process should be possible without discharging the ammonia in the fuel system to open air.

All operational releases should be led to an ammonia release mitigation system (ARMS) which is able to neutralise the toxic effect of ammonia.

Where gaseous ammonia fuel is supplied to a consumer, there is a risk of condensation in the supply lines due to cooling of the fuel vapours from the surroundings. Provisions should be made to prevent ammonia condensate from entering the consumer by the following measures:

- Proper heating of the gas supply.
- Heat tracing of gas supply and gas vent piping.
- Drain pot fitted with level switch on fuel supply piping before consumer.
- Monitoring of fuel pipe wall temperature and fuel pressure.
- Fuel system shut-down and automatic purging in case of inadequate temperature. inadequate temperature.

6.5 Fire safety

Focus area: Protect ammonia storage tanks from excessive heat input and provide passive and active fire protection of spaces

The flammability of ammonia in open air is significantly lower than for natural gas. Consequently, it could be considered justified not to adopt the IGF Code requirement for A60-shielding[13] of superstructure boundaries facing fuel tanks on open deck, or to arrange water spray cooling of structural boundaries heated up by a potential ammonia fire on deck.

On the other hand, we consider all IGF Code requirements aiming to protect storage tanks from heat input as relevant also for ammonia tanks. In order to protect ammonia tanks from excessive heat input in case of fire, they should be segregated from spaces with a high fire risk like e.g., machinery spaces of category A[14] and be protected by a water spray system for cooling if located on open deck.

Fuel preparation rooms containing pumps, compressors or other potential ignition sources should be provided with a fixed fire extinguishing system complying with the provisions of SOLAS regulation II-2/10.4.1.1 and taking into account the necessary concentrations/application rate required for extinguishing gas fires. Fuel preparation rooms should be regarded as machinery spaces category A for fire protection purposes.

[13,14] See SOLAS Ch.II-2 for definition.

6.6 Explosion protection

Focus area: Limit explosion risk by elimination of ignition sources in areas where it is likely that a release may result in flammable vapour concentrations.

As can be deduced from the comparison in Table 2-1, ammonia has a lower, but not ignorable, explosion risk compared to methane. However, it is a lethal toxin at much smaller concentrations than the level where it becomes flammable (0.5% vs 15% mixture in air).

Ammonia's flammability range is from 15 to 28 per cent mixture in air. Ammonia requires minimum ignition energy of 40 to 170 mJ, which is 150 times more energy than methane needs to ignite. Ammonia can self-ignite if the temperature is above 651°C.

Ammonia burns with difficulty in open air and will generally need a supporting flame to keep burning. In confined spaces ammonia constitute an explosion risk, and it should be noted that oil contamination can increase the flammable properties of ammonia vapours.

Considering the above, we do not see a need for hazardous zone definitions on open deck. In enclosed spaces, electrical equipment should be certified for use in zone 1, and for zone 0[15] within tanks and piping systems.

6.7 Toxic exposure protection

Focus area: Limit risk of exposure to toxic vapours from ammonia by reducing the risk of having toxic fuel vapours in areas where persons can be exposed.

In order to protect persons onboard from exposure to ammonia vapours, the primary focus should be to design systems in such a way that venting of ammonia vapours during normal operation is prevented. Vent systems should be provided with arrangements to reduce the amount of ammonia being discharged to open air.

However, it will not be possible to eliminate all discharge of ammonia vapours from vents and ventilation systems to open air. It will therefore be necessary to define toxic zones around sources of ammonia vapour on open deck to avoid spreading to enclosed spaces through air intakes, air outlets or other openings.

In managing the risk of handling toxic fuels in shipping we cannot draw on previous experience collected in rules or regulations. However, toxic cargoes are carried on gas tankers and chemical tankers. Requirements for venting of cargo tanks and ventilation of cargo handling spaces are described in the IGC Code and the IBC Code[16] for such vessels.

The design features described in this safety handbook for ship arrangements and piping design is mainly aimed at preventing exposure to any leaking fuel vapours. There is also a need to ensure that venting from fuel tanks and piping systems can be done with as low risk as possible, and also to consider the possibility of significant amounts of vapours being

[15] In order to facilitate the selection of appropriate electrical apparatus and the design of suitable electrical installations, hazardous areas are divided into zones 0, 1 and 2. Refer to IED 60092-502:1999

[16] IBC Code: International Code for the construction and equipment of ships carrying dangerous chemicals in bulk.

discharged to open air through the ventilation system of tank connection spaces and fuel preparation rooms after a leakage.

When looking for guidance in the statutory codes for gas and chemical tankers transporting toxic cargoes, the following requirements are found:

The IGC Code is generally requiring the following safety distance from vent mast outlets:

Cargo PRV vent exits shall be arranged at a distance at least equal to B[17] *or 25 m, whichever is less, from the nearest air intake, outlet or opening to accommodation spaces, service spaces and control stations, other non-hazardous areas, exhaust outlet from machinery or from furnace installations onboard.*

For ventilation outlets, the IBC Code is requiring that ventilation openings from pump rooms for toxic cargoes comply with the following:

For products which in the IBC code ch.17 column o has a reference to 15.17 (toxic cargoes), the ventilation system as described in Sec.10 [2.3.1], shall have a capacity of at least 45 air changes per hour. The ventilation exhaust outlets shall be situated at least 10 m from ventilation inlets to the accommodation and other non-hazardous spaces and at least 4 m above the tank deck.

The above should also be applied to ammonia fuelled ships as minimum distances. Considering the differences in ship arrangement between tankers and other cargo ships it may be prudent to perform dispersion analyses of the worst-case scenarios like full venting from tank safety valves and ventilation of large amounts of gas following a maximum probable leakage through the ventilation system openings to ensure that the minimum distances are safe to apply. The location of escape ways and life-saving appliances should also be considered in relation to the toxic areas.

For passenger ships, we foresee that special analyses on location of life saving equipment and mustering stations would need to be performed, and that evacuation scenarios with ammonia leakages are properly evaluated. In view of the sharp and penetrating odour of ammonia at very low concentrations, even small leakages may cause alarm with passengers which should also be considered in the design phase.

Focus area: Reducing the amount of vapour on open deck after accidental releases of ammonia.

Water spray systems have proven to be effective in reducing the dispersion of ammonia due to its hygroscopic properties. To reduce the dispersion of ammonia vapours from a leakage, or an opening of tank pressure relief valves, a water spray system could be effective. For designs where the major release sources (vent mast, ventilation outlets from FPR and TCS) are concentrated in one area, a relatively simple water spray system covering the area above and around release sources could easily be arranged.

[17] *Breadth (B)* means the maximum breadth of the ship, measured amidships to the moulded line of the frame in a ship with a metal shell, and to the outer surface of the hull in a ship with a shell of any other material. The breadth *(B)* shall be measured in meters.

Additionally, a gas detection at the vent mast with alarm to warn against significant ammonia releases from the tank safety valves will provide early warning to take protective action.

6.8 Ventilation

Focus area: Prevent overpressure following a liquefied gas leakage in enclosed space, maintain a negative pressure differential between hazardous and non-hazardous spaces, provide a means to remove toxic vapours from the ship interior.

The ventilation arrangement fitted in spaces functioning as secondary barriers for ammonia systems should be designed with the following purposes in mind:

- Preventing the space from being subjected to pressures above its capabilities by providing a passive pressure relief through the ventilation ducts in cases where liquefied gas is released and vaporises (and thereby increasing in volume 850 times).
- Preventing leaked gas from spreading to other spaces by maintaining a negative pressure in the space compared to surrounding areas (extraction ventilation).
- The ability to dilute potential leakages and transport ammonia vapours from the ship interior to a relatively safe space in open air

The ventilation outlets could be a source of substantial ammonia discharge and should be located in areas where the risk of subjecting personnel to toxic vapours is as low as possible, and in areas where the gas will not spread to other spaces in the ship through ventilation inlets and outlets, doors, or other openings. As a means to achieve this, it could be considered to group toxic discharges together on open deck and thereby reduce the extent of toxic zones onboard. Continuous extraction ventilation will protect against back-flow of gases into other spaces not directly affected by the leakage.

An alarm on open deck to warn personnel about discharges from ventilation should also be considered.

An ammonia leakage in one space should not subject personnel in another space to toxic gases. Therefore, each space containing ammonia leakage sources should be fitted with dedicated inlet and outlet ducts not serving other spaces.

The ventilation system is a safety barrier reducing the consequences of loss of containment and should be running continuously as the fuel system must be considered to be in operation at all times. This implies that the ventilation inlets and outlets should be located at height above deck where the Load Line Convention does not require weathertight closing devices. In addition, ventilation fans should be arranged with redundancy, and be dimensioned to manage evaporated ammonia vapours from a liquefied ammonia leakage.

6.9 Control, monitoring and safety systems

Focus area: Detect leakages and automatically close down the fuel supply system upon failure of essential safety barriers in the system.

In order to enable initiation of proper emergency response, systems must be arranged to detect leakages without delay. When a leakage is detected the fuel supply system must be automatically shut-down to reduce its consequences. This type of shut-down will necessarily result in a stop of fuel supply to the engine and therefore redundancy on fuel supply or some other arrangement to prevent an unacceptable loss of power generation and propulsion power is needed.

It is also important to monitor the performance of other active safety barriers, like ventilation, to ensure that the ship is operated safely at all times.

Calibration and testing of instrumentation, automatic safety actions and active safety barriers should be part of the procedures listed in Chapter 7.

7 Operation

Focus area: Ensure that seafarers onboard are adequately qualified, trained, and experienced.

Proper training ensuring that crew is familiar with the specific hazards related to ammonia used as fuel is a prerequisite for safe operation. See Chapter 4.3 on competency and training status.

Focus area: Provide operational procedures for the bunkering, storage, operation, maintenance, and inspection of systems for ammonia fuel to minimize the risk to personnel, the ship, and the environment.

To ensure that a properly trained crew have guidance on how to operate an ammonia fuelled ship safely, care should be taken to develop clear and thorough operational procedures for all ammonia-related tasks, including emergency scenarios. This implies that ship specific information related to the following should be available onboard:

- Maintenance procedures and information for all ammonia related installations.
- Operational procedures including a suitably detailed fuel handling manual, such that trained personnel can safely operate the fuel bunkering, storage and transfer systems
- Suitable emergency procedures.

Drills and emergency exercises onboard should be performed at regular intervals.

As a guidance, a ship-specific fuel handling manual should provide information regarding the following:

1. Overall operation of the ship related to the ammonia installation from dry-dock to dry-dock.
2. Arrangement and lay-out of the ammonia fuel supply system, including:
    - a description of main components in the fuel supply system;
    - a general description of how the fuel system is intended to work;
    - a toxic area plan.
3. Description of the safety system and automatic safety actions for the ammonia fuel supply system, including:
    - Procedures for handling leakages:
        - in the fuel system;
        - in the tank connection spaces;
        - in the fuel preparation rooms;
        - in the bunkering station; and
        - from a fuel tank pressure relief valve.

- Procedures for how to respond to substantial discharges from the outlet from fuel tank pressure relief valves or ventilation openings from toxic spaces, including:
    - evacuation to safe haven;
    - closing of ventilation inlets; and
    - operation of water spray systems to limit extent of toxic vapours.

- Procedures for how to respond to loss of ventilation in:
    - tank connection spaces; and
    - fuel preparation rooms.

- Procedures for how to respond to a fire in:
    - the machinery space;
    - on deck; or
    - fuel preparation room

  in relation to operation of the ammonia fuel system.

4. Description of hazards in connection with exposure to ammonia and procedures for how to avoid exposure to ammonia during:
    - bunkering operations;
    - normal operation;
    - entry of toxic spaces; or
    - when performing maintenance on the ammonia fuel system.

5. Description of hazards in connection with exposure to inert gas and procedures for how to avoid exposure.

6. Description of entry procedures for:
    - tank connection spaces;
    - fuel preparation rooms;
    - bunkering stations;
    - hold spaces; and
    - other spaces where entry may constitute a hazard to the ship or personnel.

7. Description of bunkering operations, including procedures to:

- ensure system readiness (Fire, water spray, gas detection automatic valves, inert gas, pre-bunkering procedures, communication procedures);
- prevent overfilling of tanks (transfer rates, filling limits, high-level alarms);
- control the tank pressure when bunkering (vs. tank design temperature and pressure, spraying, vapour return);
- prevent release of fuel gases to atmosphere;
- purge the bunkering system at termination of bunkering operation; and
- ensure proper use of PPE.

8. Procedures for purging and gas freeing of ammonia fuel systems to ensure safe maintenance.
9. Procedure for operation of fuel containment systems including:
   - cool down and warm up procedures;
   - procedures for emptying tanks to shore; and
   - inerting and gas freeing.

8 Personnel protection

Focus area: Provide protection from ammonia exposure for persons onboard.

Suitable personal protective equipment (PPE) should be available for persons involved in bunkering operations and for working in areas where ammonia exposure is a risk.

Respiratory and eye protection for evacuation purposes should be available for everyone onboard; in each cabin, and ample additional areas on deck and inside the ship. Self-contained breathing apparatus should have at least 15 minutes of service time.

To permit entry and work in a gas-filled space, safety equipment providing adequate personal protection, including gas tight protective clothing and self-contained positive pressure air-breathing apparatus incorporating full face mask, should be available. Sufficient, but at least three complete sets should be provided.

Personal protective and safety equipment should be kept in suitable, clearly marked lockers located in readily accessible places. Persons entering areas where ammonia exposure is a risk should be equipped with suitable PPE.

Time is critical when a person is sprayed with liquid ammonia or exposed to concentrated vapours. When ammonia contacts the skin or eyes, tissue damage occurs rapidly. Immediately flushing the exposed body area(s) with water is crucial. When someone has been exposed to anhydrous ammonia, the best course of action is to move him or her to a safe place and flush the exposed area immediately with water for a minimum of 15 minutes. Contaminated clothing should be removed. Note that anhydrous ammonia can freeze exposed clothing to skin below it. If you remove clothing before you thaw it with rinse water, extensive skin damage can result.

To facilitate essential first-aid procedures decontamination showers and eyewashes should be available near the exits from spaces containing ammonia piping systems. At least the following locations should be included:

- Bunkering stations
- Exit from tank connection spaces
- Exit from fuel preparation rooms
- In machinery spaces
- In way of safe haven.

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10 The development of the Safety Handbook

The updated Ammonia as a Marine Fuel Safety Handbook was developed by a project team in DNV on behalf of the Green Shipping Programme during the spring of 2023, with input from the Norwegian Maritime Authority and other partners in the GSP Ammonia pilots and the Nordic Roadmap project.

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