2021

Guidelines for Ships Using Ammonia as Fuels

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CONTENTS

CHAPTER 1 GENERAL

Section 1 General

101. Application

1. This Part applies to ships using ammonia as fuel in accordance with **Ch 1, 101. 18** of the **Rules for the Classification of Ships Using Low-flashpoint Fuels**(hereafter referred to as "**the Rules**").
2. The requirements of this Guidelines are prescribed in addition to the requirements in the Rules. Except where specially required in this Guidelines, the relevant requirements in **the Rules** are to be applied.
3. For ships under the Korean flag, these guidelines cannot be used for the purpose of classification. However, For ammonia fuel ready requirements can be applied.

102. Definition

The definitions of terms not specified in the followings are to be as specified in **the Rules**.

1. **Fuel** in this Guidelines means ammonia gaseous or liquid state and is suitable for safe operation of ship.
2. **Bunkering** means the transfer of ammonia fuel from land-based or floating facilities into ship's permanent tanks or connection of portable tanks to the fuel supply system.

103. General

1. This Guidelines contains functional requirements for all appliances and arrangements related to the usage of fuel typically having the characteristics of **Table 1** and **Table 2**.
2. Appliances and arrangements of ammonia fuel systems may deviate from those set out in this Guidelines, provided such appliances and arrangements meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety to the relevant sections.
3. Ch 1, 103. 3 of **the Rules** is to be applied.

Table 1 Properties comparison of ammonia and LNG

properties	LNG	Ammonia	properties of ammonia fuel
Flammable limits in air by volume (%)	5 ~ 15	15~28	· unfavorable to ignite due to formation of flammable atmosphere at higher concentrations
Autoignition temperature (℃)	595	651	· No additional consideration for exhaust gas temperature due to high auto-ignition temperature due to the high combustion temperature, it is necessary to pay attention to the increase in the generation of NOx
Minimum ignition energy (mJ)	0.28	8	· difficult to ignite due to significantly high minimum ignition energy compared with methane
Boiling point at 1 bar absolute (℃)	-161	-33	· Difficult to visually check for leaks
Vapour pressure at 45 ℃ (MPa)	-	1.8	· liquefaction by pressurizing at atmospheric temperature · various boundaries of the phase change according to the composition ratio.
Critical temperature (℃)	-82.95	132.5	· stored at atmospheric temperature under pressure · In case of pressurized liquefied gas storage tank, design pressure should be greater than the maximum vapor pressure of ammonia.

Table 2 Symptoms according to ammonia concentration

concentration (ppm*)	Symptoms
5	Pungent odor
6–20	Eye irritation and nose irritation
40–200	Headache, nausea and loss of appetite
400	Severe throat irritation
700	Loss of sight
1700	Coughing, serious lung damage, shortness of breath
2,500–4,500	Immediately Dangerous to Life or Health
5,000	Death due to respiratory arrest
note) * 1 ppm = 0.0001%	

CHAPTER 2 GOAL AND FUNCTIONAL REQUIREMENTS

Section 1 Goal

The goal of this Guidelines is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using ammonia as fuel.

Section 2 Functional Requirements

In addition to Ch 2, Sec 2 of **the Rules**, the followings are to be applied;.

1. The effectiveness of the ventilation, detection and safety actions for ammonia fuel leakage is to be equivalent that achieved with LNG leakage taking into account toxicity and corrosiveness of fuel.
2. In applying Ch 2, 201. 4 of **the Rules**, Special consideration should be given to the effect of fuel toxicity to the person on board.
3. A direct release of fuel into the atmosphere is to be minimized in order to prevent air pollution. ⚓

CHAPTER 3 GENERAL REQUIREMENTS

Section 1 Goal

The goal of this Chapter is to ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

Section 2 Risk Assessment

201. Risk assessment

1. A risk assessment is to be conducted to ensure that risks arising from use of ammonia fuel affecting the person on board, the environment and the ship are addressed. Consideration is to be given to the hazards associated with physical layout, operation and maintenance, following any reasonably foreseeable failure.
2. The risk assessment is to address the possible leakage of the fuel and the consequences thereof. In particular, consideration is to be given to the hazards associated toxicity and corrosiveness of fuel.
3. Risk assessment is to be conducted in accordance with Annex 3 of **the Rules**. However, since Annex 3, Sec.2 of **the Rules** deals with the properties and risk of LNG, ammonia typically having the characteristics of **Table 1** and **Table 2** are to be applied instead.
4. In risk assessment, in addition to Ch 3, 201. of **the Rules**, the followings are to be as a minimum considered, but not limited to:
   (1) Properties and related risks of ammonia according to **Table 1** and **Table 2** considering the effect on the personnel on board
   (2) When supplying high-pressure liquid fuel to the engine, purging and venting the ammonia liquid in the fuel pipe
   (3) Drip tray according to **Ch 5, Sec 10, 1**
   (4) Dispersion/ventilation characteristics of leaked ammonia according to **Ch 6, Sec 3, 2**
   (5) Bunkering stations according to **Ch 8, Sec 3 301.**
   (6) Enclosed spaces in which gas turbines are installed in **Ch 10, 203.**
   (7) Ventilation in hazardous areas according to **Ch 13, Sec 3**
   (8) Gas detection in ro-ro spaces in accordance with **Ch 15, 801. 1**

202. Limitation of explosion consequences

An explosion in any space containing any potential sources of release and potential ignition sources is to limited in accordance with Ch 3, 301. of **the Rules**. ⚓

CHAPTER 4 CLASSIFICATION AND SURVEYS

Section 1 General

101. General

1. The classification and surveys of ships intended to be classed with the Society or classed with the Society are to be in accordance with the requirements specified in this Chapter.
2. In the case of items not specified in this Chapter, the requirements specified in Pt 1 of **Rules for the classification of steel ships** are to be applied.

Section 2 Classification

201. Class notation

Ships satisfying the requirements of this Part may be given a notation LFFS (DF-Ammonia, SF-Ammonia) as additional special feature notations.

202. Maintenance of classification

1. Ships classed with the Society are to be subjected to the surveys to maintain the classification and are to be maintained in good condition in accordance with the requirements specified in this Chapter.
2. Plans and particulars of any proposed alterations to the approved scantlings or arrangements of hull, machinery or equipment are to be submitted for approval by the Society before the work is commenced and such alterations are to be Surveyed by the Society.

203. Classification Survey during Construction.

1. General

   At the Classification Survey during Construction, the hull, machinery and equipment are to be examined in detail in order to ascertain that they meet the relevant requirements of this Guidelines.
2. Plan and Documents

   For a ship in which ammonia-fuelled engine installations are installed, plans and documents, specified below 3 and 4, are to be submitted and approved before the work is commenced. And, the Society, where considered necessary, may require further plans and documents other than those specified below.
3. Plan and data for approval

   Ch 4, 203. 3 of **the Rules** is to be applied.
4. Plans and documents for reference

   In addition to Ch 4, 203. 4 of **the Rules**, the following plans and documents are to be submitted.
   (1) Design pressure calculation formula for pressurize type of fuel tank where temperature control measures are not provided
   (2) Data for analysis of dispersion and/or ventilation

Section 3 Periodical Surveys

Ch 4, Sec 3 of **the Rules** is to be applied. ⚓

CHAPTER 5 SHIP DESIGN AND ARRANGEMENT

Section 1 General

The goal of this Chapter is to provide for safe location, space arrangements and mechanical protection of power generation equipment, fuel storage system, fuel supply equipment and refuelling systems.

Section 2 Functional Requirements

Ch 5, Sec 2 of **the Rules** is to be applied.

Section 3 Arrangement of Fuel Tanks

Ch 5, Sec 3 of **the Rules** is to be applied.

Section 4 Arrangement of machinery space

401. Gas safe machinery space

1. A single failure of fuel systems is not to lead to a gas release in the machinery space. I.e, gas safe machinery space concept may be accepted.
2. Gas safe machinery space concept is to be in accordance with Ch 5, 401. 1 of **the Rules**.

Section 5 Gas Safe Machinery Space

Ch 5, Sec 5 of **the Rules** is to be applied.

Section 6 ESD-Protected Machinery Spaces

ESD protected machinery space concept is not be permitted.

Section 7 Location and protection of fuel piping

1. Fuel pipes are to not be located less than 800 mm from the ship's side.

2. Fuel piping is to not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention. Electrical equipment rooms includes auto-telephone exchange and air-conditioning duct spaces.

3. Fuel pipes led through ro-ro spaces, special category spaces and on open decks are to be protected against mechanical damage.

Section 8 Fuel Preparation Room

Ch 5, Sec 8 of **the Rules** is to be applied.

Section 9 Bilge Systems

In addition to the requirements in Ch 5, Sec 9 of **the Rules**, the bilge wells are to be as small as possible.

Section 10 Drip Trays

In addition to the requirements in Ch 5, Sec 10 of **the Rules**, the following apply:

1. Drip trays containing fuel spill are to be equipped with means to detect leakage and shut off the fuel if required by the risk assessment.

Section 11 Arrangement of Entrances and Other Openings in Enclosed Spaces

Ch 5, Sec 11 of **the Rules** is to be applied.

Section 12 Airlocks

Ch 5, Sec 12 of **the Rules** is to be applied. ⚓

CHAPTER 6 FUEL CONTAINMENT SYSTEM

Section 1 General

The goal of this chapter is to provide that gas storage is adequate so as to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil fuelled ship.

Section 2 Functional Requirements

In addition to the requirements in Ch 6, Sec 2 of Rules for the Classification of Ships Using Low-flashpoint Fuels, the following apply:

1. The maximum vapour pressure in the fuel tank shall correspond to the maximum temperature in the fuel tank that may reach to due to solar radiation.

Section 3 General Requirements

In addition to the requirements in Ch 6, Sec 3 of **the Rules**, the following apply:

1. In applying Ch 6, 301. 1 of **the Rules**, ammonia may be stored with a maximum allowable relief valve setting (MARVS) of over 1.0 MPa.
2. In applying Ch 6, 301. 4 of **the Rules**, for the fuel tank located in enclosed space, a tank connection space is to be provided separately from a fuel storage hold space. For the fuel tank located on open deck, a tank connection space is also to be provided where escaped gas may accumulate on open deck or enter in non-hazardous area such as accommodation space and machinery space based on the risk assessment.

Section 4 Liquefied gas fuel containment

In addition to the requirements in Ch 6, Sec 4 of **the Rules**, the following apply:

1. In applying Ch 6, 409. 3 (3) (A) (b) of **the Rules**, design vapour pressure P_0 is not to be less than the gauge vapour pressure corresponding to a maximum temperature of fuel that may be increased due to heat ingress from the upper ambient design temperatures.
2. In applying **Ch 6, 413.** of **the Rules, Ch 7, Sec.2** of this guidelines should be taken into account.

Section 5 Portable Liquefied Gas Fuel Tanks

Ch 6, Sec 5 of **the Rules** is to be applied.

Section 6 Compressed Petroleum Gas Fuel Containment

As storage in compressed gas form is not applicable for ammonia.

Section 7 Pressure Relief System

701. General

Ch 6, 701. of **the Rules** is to be applied.

702. Pressure relief systems for liquefied gas fuel tanks

In addition to the requirements in Ch 6, 702. of **the Rules**, the following apply:

1. In applying Ch 6, 702. 7 (1) of **the Rules**, vent exits are to be arranged based on escaped gas does not enter to non-hazardous area.
2. In applying Ch 6, 702. 8 of **the Rules**, the outlet from the pressure relief valves is to normally be located at least a horizontal distance of 15 m from the nearest air intake opening, openings of accommodation spaces, service spaces and control stations, and 4 m above the weather deck. Where equipment for reducing ammonia emission is installed or the length of the ship is less than 90 m, the Society may accept a smaller value of at least 6 m in the horizontal direction. If necessary, gas dispersion analysis or smoke test should be performed.
3. In applying Ch 6, 702. 10 of **the Rules**, the drain line is to be fitted with a stop valve and a self closing valve in series near the vent line and these valves are to be opened sequentially to prevent gas from escaping through the drain line.

703. Sizing of pressure relieving system

Ch 6, 703. of Rules for the Classification of Ships Using Low-flashpoint Fuels is to be applied.

Section 8 Loading Limit for Liquefied Gas Fuel Tanks

Ch 6, Sec8 of **the Rules** is to be applied.

Section 9 Maintaining of fuel storage condition

901. Control of tank pressure and temperature

In addition to the requirements in Ch 6, Sec 9 of **the Rules**, the following apply:

1. In applying Ch 6, 901. 1 of **the Rules**, for the pressurized tank, 'the full gauge vapour pressure of the fuel under conditions of the upper ambient design temperature' is to apply the gauge vapour pressure corresponding to a maximum temperature of fuel that may be increased due to heat ingress from the upper ambient design temperatures.
2. With the exception of Par 1, control means of tank pressure and temperature in accordance with Ch 6, 901. 1 of **the Rules** are to be provided.

Section 10 Atmospheric Control within the Fuel Containment System

Ch 6, Sec 10 of **the Rules** is to be applied.

Section 11 Atmosphere Control within Fuel Storage Hold Spaces (Fuel Containment Systems other than Type C Independent Tanks)

In addition to the requirements in Ch 6, Sec 11 of **the Rules**, the following apply:

1. In applying **Ch 6, 1101.** of the Rules, the spaces referred to in **Par 1** may be maintained with a suitable dry air.

Section 12 Environmental control of spaces surrounding type C independent tanks

Ch 6, Sec 12 of **the Rules** is to be applied.

Section 13 Inerting

Ch 6, Sec 13 of **the Rules** is to be applied.

Section 14 Inert Gas Production and Storage on Board

Ch 6, Sec 14 of **the Rules** is to be applied. ⚓

CHAPTER 7 MATERIAL AND GENERAL PIPE DESIGN

Section 1 General

1. In addition to the requirements in Ch 7 of **the Rules**, this Chapter is to be complied with.
2. In the case of items not specified in this Chapter and **the Rules**, the requirements specified in Pt 2 of Rules for the classification of steel ships are to be applied.

Section 2 **Special requirements due to fuel**

201. **Special requirements due to fuel**

1. containment and process systems made of carbon-manganese steel or nickel steel

(1) Anhydrous ammonia may cause stress corrosion cracking in containment and process systems made of carbon-manganese steel or nickel steel. To minimize the risk of this occurring, measures detailed in (2) to (8) is to be taken, as appropriate.

(2) Where carbon-manganese steel is used, cargo tanks, process pressure vessels and cargo piping are to be made of fine-grained steel with a specified minimum yield strength not exceeding 355 N/mm^2, and with an actual yield strength not exceeding 440 N/mm^2. One of the following constructional or operational measures is also to be taken:

(A) lower strength material with a specified minimum tensile strength not exceeding 410 N/mm^2 is to be used; or

(B) cargo tanks, etc., are to be post-weld stress relief heat treated; or

(C) carriage temperature is to be maintained, preferably at a temperature close to the product's boiling point of -33 °C, but in no case at a temperature above -20 °C; or

(D) the ammonia is to contain not less than 0.1 % w/w water, and the master is to be provided with documentation confirming this.

(3) If carbon-manganese steels with higher yield properties are used other than those specified in (2), the completed cargo tanks, piping, etc., are to be given a post-weld stress relief heat treatment.

(4) Process pressure vessels and piping of the condensate part of the refrigeration system are to be given a post-weld stress relief heat treatment when made of materials mentioned in (1).

(5) The tensile and yield properties of the welding consumables are to exceed those of the tank or piping material by the smallest practical amount.

(6) Nickel steel containing more than 5 % nickel and carbon-manganese steel, not complying with the requirements of (2) and (3), are particularly susceptible to ammonia stress corrosion cracking and are not to be used in containment and piping systems for the carriage of this product.

(7) Nickel steel containing not more than 5 % nickel may be used, provided the carriage temperature complies with the requirements specified in (2) (C).

(8) To minimize the risk of ammonia stress corrosion cracking, it is advisable to keep the dissolved oxygen content below 2.5 $ppm\ w/w$. This can best be achieved by reducing the average oxygen content in the tanks prior to the introduction of liquid ammonia to less than the values given as a function of the carriage temperature T in the **table 3** below:

Table 3 Average amount of oxygen as transport temperature

T (°C)	O_2 (%, v/v)
-30 and below	0.90
-20	0.50
-10	0.28
0	0.16
10	0.10
20	0.05
30	0.03

Oxygen percentages for intermediate temperatures may be obtained by direct interpolation.

2. Materials capable of highly corrosion(copper, zinc, cadmium, or their alloys) are to be not used at locations where ammonia comes in contact. It reacts strongly with copper or copper alloy, so be especially considered.

3. Rubber, plastic, vinyl or aluminium alloys, etc. is to be accepted by the Society considering the service conditions.

4. Materials that can form explosive compounds such as silver, gold, mercury and thallium are to be not used at locations where ammonia comes in contact.

5. The design pressure of the pressure vessel and piping system handling ammonia is to be greater than the maximum operating pressure by the fuel. ⚓

CHAPTER 8 BUNKERING

Section 1 Goal

The goal of this Chapter is to provide for suitable systems on board the ship to ensure that bunkering can be conducted without causing danger to persons, the environment or the ship.

Section 2 Functional Requirements

In addition to Ch 8, 201. of **the Rules**, the followings are to be applied;

1. Bunkering systems are to be suitable temperature, pressure and composition of all expected ammonia.
2. Means are to be provided to manage vapour generated during bunker transfer. Where means of vapour management are not provided in accordance with Ch 6, 901., vapour return connection is to be fitted at bunkering manifold.

Section 3 Bunkering Station

301. General requirements

In addition to Ch 8, 301. of **the Rules**, the followings are to be applied;

1. In applying Ch 6, 301. 1 of **the Rules**, closed or semi-enclosed bunkering stations are to be subject to special consideration within the risk assessment is to be as a minimum include the following, but not be restricted to:
   (1) Segregation towards other areas on the ship
   (2) Hazardous area plans for the ship
   (3) Requirements for forced ventilation
   (4) Requirements for leakage detection (e.g. gas detection and low temperature detection)
   (5) Safety actions related to leakage detection (e.g. gas detection and low temperature detection)
   (6) Access to bunkering station from non-hazardous areas through airlocks
2. In applying Ch 6, 301. 3 & 4 of **the Rules**, coaming and/or drip trays complying with **Ch 6, 901.** of **the Rules** should be suitable for safely collecting of fuel spills.
3. The coaming and/or drip trays surround the bunkering manifold valve shall be at least 10 m away from the non-hazardous area openings or air intake. If the gas detector is installed at the air intake or non-hazardous area opening may be reduced up to 4.5 m.
4. A water spray system should be provided to limit the amount of toxic gas at the leakable point of the bunkering manifold according to the leak scenario as follows.
   (1) The arrangement is to be sufficient that any spilled fuel is diluted leaked fuel
   (2) The water-spray system is to be capable of local and remote manual operation. Remote manual operation is to be arranged such that the remote starting of pumps supplying the water-spray system and remote operation of any normally closed valves in the system can be carried out from a suitable location in bunkering control station, adjacent to the accommodation spaces and readily accessible and operable in the event of fuel leakage.
   (3) Bilge generated by the operation of the water spray system is to be included in the calculation of the drip tray capacity.
   (4) Overflow the bilge mixed with ammonia generated in an emergency is to be diluted or neutralized and then discharged overboard directly, without leading the discharge pipes through accommodation spaces.
5. Bunkering manifolds are to be observable from bunkering control station by providing permanent watch or CCTV during bunker transfer.

302. Ships' fuel hoses

Ch 8, 302. of **the Rules** is to be applied.

Section 4 Manifold

Ch 8, Sec 4 of **the Rules** is to be applied.

Section 5 Bunkering System

Ch 8, Sec 5 of **the Rules** is to be applied. ⚓

CHAPTER 9 FUEL SUPPLY TO CONSUMERS

Section 1 Goal

The goal of this Chapter is to ensure safe and reliable distribution of fuel to the consumers.

Section 2 Functional Requirements

In addition to Ch 9, 201. of Rules for the Classification of Ships Using Low-flashpoint Fuels, the followings are to be applied;

1. Fuel supply systems are to be able to supply fuel at the required pressure, temperature and flow rate.
2. Where fuel supply systems supply ammonia in the liquid phase, purging, drain, vent and leakage are to be subject to special consideration to provide an equivalent level of safety of fuel in the gas phase.
3. Fuel supply systems are design to be prevented unintended phase changes in processing of fuel supply to consumers considering vapour pressure at the working temperature as the followings;
   (1) Where fuel is supplied in the gaseous state, measures are to be taken so that the temperature of fuel is not lowered to the dew point at the working pressure.
   (2) Where fuel is supplied in the liquid state, measures are to be taken so that the pressure of fuel is not lowered to the vapour pressure at the working temperature.
4. Vent, purging and bleed lines of fuel supply systems are to be so designed as to prevent liquid fuel from being released to the atmosphere.

Section 3 Redundancy of Fuel Supply

Ch 9, Sec 3 of **the Rules** is to be applied.

Section 4 Safety Functions of Gas Supply System

In addition to Ch 9, 401. of **the Rules**, the followings are to be applied;

1. Where fuel supply systems supply fuel in the liquid phase, vent pipes and bleed lines are to be led to the fuel tank, knock out drum or equivalent devices to prevent liquid fuel from being released to the atmosphere.
2. A nitrogen purging line is to be connected between two block valves to prevent gas or liquid fuel from remaining in bleed line by automatically purging bleed line when a bleed valve is open.

Section 5 Fuel Distribution Outside of Machinery Space

Ch 9, Sec 5 of **the Rules** is to be applied.

Section 6 Fuel Supply to Consumers in Gas-safe Machinery Spaces

Ch 9, Sec 6 of R**the Rules** is to be applied.

Section 7 Fuel Supply to Consumers in ESD-protected Machinery Spaces

As ESD protected machinery space concept is not be permitted.

Section 8 Design of Ventilated Duct, Outer Pipe Against Inner Pipe Gas Leakage

Ch 9, Sec 8 of **the Rules** is to be applied.

Section 9 Compressors and Pumps

Ch 9, Sec 9 of **the Rules** is to be applied. ⚓

CHAPTER 10 POWER GENERATION INCLUDING PROPULSION AND OTHER GAS CONSUMER

In addition to Ch 10 of **the Rules**, this Chapter is to be complied with.

Section 1 Arrangement of spaces containing fuel consumers

1. A single failure of fuel systems in the machinery space is not to lead to a gas release in the machinery space. Therefore, fuel piping is of a double-wall design and outer pipe or duct is to be continuous. Air inlet of outer pipe or duct is not to be the machinery space.
2. Spaces in which gas consumers are located are to be fitted with a mechanical ventilation system that is arranged to avoid areas where gas may accumulate, taking into account the density of the vapour and potential ignition sources. The ventilation system is to be separated from those serving other spaces.
3. Electrical equipment located in the double wall pipe or duct is to comply with the requirements of Ch 14 of **the Rules**.
4. All vents and bleed lines that may contain or be contaminated by fuel are to be routed to a safe location external to the machinery space and be fitted with a flame screen. Ammonia liquid is not to be released to the atmosphere through vent pipe and bleed pipe.

Section 2 Special requirements for fuel consumer

201. Internal combustion engines

Dual fuel engines are those that employ ammonia fuel (with pilot oil) and oil fuel. Oil fuels may include distillate and residual fuels. Ammonia only engines are those that employ ammonia fuel only.

1. Arrangements
   (1) When gas is supplied in a mixture with air through a common manifold, flame arrestors are to be installed before each cylinder head.
   (2) Each engine is to be fitted with vent systems independent of other engines for crankcases, sumps and cooling systems.
2. Combustion equipment
   (1) Prior to admission of gas fuel, correct operation of the pilot oil injection system on each unit is to be verified.
   (2) For a spark ignition engine, if ignition has not been detected by the engine monitoring system within an engine specific time after opening of the gas supply valve, this is to be automatically shut off and the starting sequence terminated. It is to be ensured that any unburnt gas mixture is purged from the exhaust system.
   (3) For dual-fuel engines fitted with a pilot oil injection system, an automatic system is to be fitted to change over from gas fuel operation to oil fuel operation with minimum fluctuation of the engine power.
   (4) In the case of unstable operation on engines with the arrangement in (3) when gas firing, the engine is to automatically change to oil fuel mode.
3. Safety
   (1) During stopping of the engine, the gas fuel is to be automatically shut off before the ignition source.
   (2) Arrangements are to be provided to ensure that there is no unburnt gas fuel in the exhaust gas system prior to ignition.
   (3) Crankcases, sumps, scavenge spaces and cooling system vents are to be provided with gas detection.
   (4) Provision is to be made within the design of the engine to permit continuous monitoring of pos-

sible sources of ignition within the crank case. Instrumentation fitted inside the crankcase is to be in accordance with the requirements of Ch 14 of **the Rules**.

(5) For engines where the space below the piston is in direct communication with the crankcase a detailed evaluation regarding the hazard potential of fuel gas accumulation in the crankcase is to be carried out and reflected in the safety concept of the engine. Measures to prevent accumulation of ammonia gas in the space below the piston and extract ammonia gas in the space are to be provided taking into account of heavy density of ammonia gas.

(6) A means is to be provided to monitor and detect poor combustion or misfiring that may lead to unburnt gas fuel in the exhaust system during operation. In the event that it is detected, the gas fuel supply is to be shut down. Instrumentation fitted inside the exhaust system is to be in accordance with the requirements of Ch 14 of **the Rules**. Measures to extract unburned gas caused by poor combustion or misfiring are to be provided.

202. Boilers

1. Arrangements

(1) Each boiler is to have a separate exhaust uptake.

(2) Each boiler is to have a dedicated forced draught system. A crossover between boiler force draught systems may be fitted for emergency use providing that any relevant safety functions are maintained.

(3) Combustion chambers and uptakes of boilers are to be designed to prevent any accumulation of gaseous fuel.

2. Combustion equipment

(1) The burner systems are to be of dual type, suitable to burn either: oil fuel or gas fuel alone, or oil and gas fuel simultaneously.

(2) Burners are to be designed to maintain stable combustion under all firing conditions.

(3) An automatic system is to be fitted to change over from gas fuel operation to oil fuel operation without interruption of the boiler firing, in the event of loss of gas fuel supply.

(4) Gas nozzles and the burner control system are to be configured such that gas fuel can only be ignited by an established oil fuel flame, unless the boiler and combustion equipment is designed and approved by Society to light on gas fuel.

3. Safety

(1) There are to be arrangements to ensure that gas fuel flow to the burner is automatically cut-off, unless satisfactory ignition has been established and maintained.

(2) On the pipe of each gas-burner, a manually operated shut-off valve is to be fitted.

(3) Provisions are to be made for automatically purging the gas supply piping to the burners, by means of an inert gas, after the extinguishing of these burners.

(4) The automatic fuel changeover system required by 2 (3) is to be monitored with alarms to ensure continuous availability.

(5) Arrangements are to be made that, in case of flame failure of all operating burners, the combustion chambers of the boilers are automatically purged before relighting.

(6) Arrangements are to be made to enable the boilers to be manually purged.

203. Gas turbine

1. Arrangements

(1) The gas turbine is to be fitted in a gas-tight enclosure arranged in accordance with the ESD principle outlined in **the Rules**. Gas leakage in the gas-tight enclosure and the consequence are to be evaluated based on the risk assessment.

(2) Ventilation for the enclosure is to be arranged with full redundancy (2 x 100 % capacity fans from different electrical circuits).

(3) Each turbine is to have its own separate exhaust.

(4) The exhausts are to be appropriately configured to prevent any accumulation of unburnt gas fuel.

(5) Unless designed with the strength to withstand the worst case overpressure due to ignited gas leaks, pressure relief systems are to be suitably designed and fitted to the exhaust system, taking into consideration explosions due to gas leaks. Pressure relief systems within the exhaust uptakes are to be lead to a nonhazardous location, away from personnel.

2. Combustion equipment

An automatic system is to be fitted to change over easily and quickly from gas fuel operation to oil fuel operation with minimum fluctuation of the engine power.

3. Safety

(1) Means is to be provided to monitor and detect poor combustion that may lead to unburnt gas fuel in the exhaust system during operation. In the event that it is detected, the gas fuel supply is to be shut down.

(2) Each turbine is to be fitted with an automatic shutdown device for high exhaust temperatures.⚓

CHAPTER 11 FIRE SAFETY AND PERSONNEL PROTECTION

Section 1 Fire Safety

Ch 11 of **the Rules** and Pt 8 of Rules for the classification of steel ships are to be applied.

Section 2 Personnel Protection

201. Goal

The goal of this section is to ensure that personnel protection in operations related to the storage, processing, transfer and use of fuel on board.

202. Functional Requirements

This section is related to functional requirements in **Ch 11, 201 2 & 4** of **the Rules**. In particular the following apply.

203. General

1. In addition to **Pt 8** of **Rules for the classification of steel ships**, this section is to be complied with.
2. For the protective equipment, safety equipment and emergency equipment, the kind and quantity is added or reduced when deemed appropriate by the Society, if required in accordance with the relevant requirements of **Pt 7, Ch 5, Ch 6** of **Rules for the classification of steel ships.**

204. Protective equipment

1. For the protection of crew members who are engaged in operations related fuel, the ship should have on board suitable protective equipment consisting of large aprons, special gloves with long sleeves, suitable footwear, coveralls of chemical-resistant material, and tight-fitting goggles or face shields or both. The protective clothing and equipment should cover all skin so that no part of the body is unprotected.

2. Work clothes and protective equipment should be kept in easily accessible places and in special lockers. Such equipment should not be kept within accommodation spaces, with the exception of new, unused equipment and equipment which has not been used since undergoing a thorough cleaning process. The Society may, however, approve storage rooms for such equipment within accommodation spaces if adequately segregated from living spaces such as cabins, passageways dining rooms, bathrooms, etc.

3. Protective equipment should be used in any operation which may entail danger to personnel.

205. Safety equipment

1. Sufficient, but not less than three complete sets of safety equipment are to be provided to permit entry and work in a gas-filled space. Each complete set of safety equipment is to consist of:

(1) one self-contained positive pressure air-breathing apparatus incorporating full face mask, not using stored oxygen and having a capacity of at least 1,200 ℓ of free air. Each set is to be compatible with that required by **Pt 8** of **Rules for the classification of steel ships**
(2) protective clothing, boots and gloves to a recognized standard
(3) steel-cored rescue line with belt
(4) explosion-proof lamp.

2. An adequate supply of compressed air is to be provided and is to consist of:

(1) at least one fully charged spare air bottle for each breathing apparatus required by **1**
(2) an air compressor of adequate capacity capable of continuous operation, suitable for the supply of high pressure air of breathable quality

(3) a charging manifold capable of dealing with sufficient spare breathing apparatus air bottles for the breathing apparatus required by **1**.

206. Emergency equipment

1. Emergency equipment shall be provided with suitable respiratory and eye protection sufficient for every person on board for emergency escape purposes, subject to the following:

(1) filter type respiratory protection is unacceptable;
(2) self-contained breathing apparatus shall have normally at least a duration of service of 15 min;
(3) emergency escape respiratory protection shall not be used for fire-fighting or cargo handling purposes and shall be marked to that effect.

2. The ships shall have on board medical first-aid equipment including oxygen resuscitation equipment and antidotes for cargoes carried, based on the guidelines developed by IMO.

3. A stretcher which is suitable for hoisting an injured person up from spaces such as the fuel preparation room shall be placed in a readily accessible location.

4. Suitably marked decontamination showers and an eyewash shall be installed in areas that may handle the fuel (bunkering station, opening of tank connection space, opening of fuel preparation room and etc.). The showers and eyewash shall be operable in all ambient conditions.

CHAPTER 12 EXPLOSION PREVENTION

Ch 12 of **the Rules** is to be applied.

CHAPTER 13 VENTILATION

Section 1 Goal

The goal of this Chapter is to provide for the ventilation required for safe operation of ammonia-fuelled machinery and equipment.

Section 2 Functional Requirements

In addition to Ch 13, Sec 2 of **the Rules**, the followings are to be applied;

1. Capacity and layout of ventilation system are to be so designed that efficiency of ventilation is ensured considering that the density of ammonia increases when the humidity is higher.
2. Ventilation inlets and outlets for spaces required to be fitted with mechanical ventilation should be located such that according to the International Convention on Load Lines they will not be required to have closing appliances.
3. Double bottoms, cofferdams, duct keels, pipe tunnels, hold spaces and other spaces where the fuel may accumulate should be capable of being ventilated to ensure a safe environment. Before entering these spaces, the presence of ammonia gas should be checked.

Section 3 General Requirements

In addition to Ch 13, Sec 3 of **the Rules**, the followings are to be applied;

1. **Ventilation of hazardous spaces**
   (1) Ventilation ducts serving hazardous areas are not to be led through accommodation, service space, machinery space, control stations and ro-ro space, except as allowed in Ch 13, Sec 8 of **the Rules**.
   (2) The number and location of the ventilation outlets in each space are to be considered taking into account the size, layout of the space. If necessary, it is to be demonstrated based on ventilation analysis that capacity and duct arrangements of ventilation are adequate for the space.
   (3) If necessary, the ventilation system should have a minimum capacity of at least 45 changes of air per hour based upon the total volume of space take into account fuel leak scenario.
2. The air outlet of the hazardous area should be located in a safe place where it does not affect the crew in consideration of the toxicity of ammonia.

Section 4 Tank Connection Space

Ch 13, Sec 4 of **the Rules** is to be applied.

Section 5 Machinery Spaces

The ventilation system for machinery spaces containing gas-fuelled consumers is to be independent of all other ventilation systems. the Spaces enclosed in the boundaries of machinery spaces (such as purifier's room, engine-room workshops and stores) are considered an integral part of machinery spaces containing gas-fuelled consumers and, therefore, their ventilation system does not need to be independent of the one of machinery spaces.

Section 6 Fuel Preparation Room

In addition to Ch 13, 601. of **the Rules**, the followings are to be applied;

1. In applying **Ch 13, 601.** of **the Rules**, type approved automatic fail-safe fire dampers are to be fitted in the ventilation trunk for the fuel preparation room.

Section 7 Bunkering station

Ch 13, Sec 7 of **the Rules** is to be applied.

Section 8 Ducts and Double Pipes

In addition to Ch 13, 801. of **the Rules**, the followings are to be applied;

1. In applying Ch 13, 801. 1 of R**he Rules**, ventilation inlets and outlets of double wall piping and ducts are to be located so that negative pressures is maintained in the whole space between inner pipes and outer ducts/pipes.
2. In applying Ch 13, 801. 3 of **the Rules**, the ventilation inlets for the double wall piping and ducts are always to be located in a non-hazardous open area away from ignition sources. ⚓

CHAPTER 14 ELECTRICAL INSTALLATIONS

Section 1 Goal

The goal of this Chapter is to provide for electrical installations that minimizes the risk of ignition in the presence of a flammable atmosphere.

Section 2 Functional Requirements

Ch 14, Sec 2 of **the Rules** is to be applied.

Section 3 General Requirements

In addition to Ch 14, Sec 3 of **the Rules**, the followings are to be applied;

1. In applying Ch 14, 301. 3 of **the Rules**, equipment for hazardous areas is to be of a certified safe type appropriate for ammonia in accordance with IEC 60079-20, classifies the temperature class and equipment groups for ammonia as the followings;

	Temperature class	Equipment group
Ammonia	T1	IIA

⚓

CHAPTER 15 CONTROL, MONITORING AND SAFETY SYSTEMS

Section 1 Goal

The goal of this Chapter is to provide for the arrangement of control, monitoring and safety systems that support an efficient and safe operation of the gas-fuelled installation as covered in the other chapters of this Guidelines.

Section 2 Functional Requirements

This Chapter is related to functional requirements in **1, 2, 3, 9, 10, 11, 14, 15** and **18** of **201., Ch 2 the Rules**. In particular the following apply.

1. the control, monitoring and safety systems of the gas-fuelled installation are to be so arranged that the remaining power for propulsion and power generation is in accordance with **Ch 9, 301.** of **the Rules** in the event of single failure;

2. a gas safety system is to be arranged to close down the gas supply system automatically, upon failure in systems as described in **Table 4** and upon other fault conditions which may develop too fast for manual intervention;

3. the safety functions are to be arranged in a dedicated gas safety system that is independent of the gas control system in order to avoid possible common cause failures. This includes power supplies and input and output signal;.

4. the safety systems including the field instrumentation are to be arranged to avoid spurious shutdown, e.g. as a result of a faulty gas detector or a wire break in a sensor loop; and

5. where two or more gas supply systems are required to meet the regulations, each system is to be fitted with its own set of independent gas control and gas safety systems.

Section 3 General Requirements

In addition to **Ch 15, Sec 3** of **the Rules**, the followings are to be applied;

1. A bilge well in fuel storage hold spaces of independent tanks other than type C is to be provided with both a level indicator and a temperature sensor. Alarm is to be given at high level in the bilge well. Low temperature indication is to activate the safety system.

2. When a dedicated storage tank for fuel leakage is installed, a level indicator and alarm device should be installed.

Section 4 Bunkering and Liquefied Gas Fuel Tank Monitoring

Ch 15, Sec 4 of **the Rules** is to be applied.

Section 5 Bunkering Control

Ch 15, Sec 5 of **the Rules** is to be applied.

Section 6 Gas Compressor Monitoring

Ch 15, Sec 6 of **the Rules** is to be applied.

Section 7 Gas Engine Monitoring

Ch 15, Sec 7 of **the Rules** is to be applied.

Section 8 Leak Detection

801. Gas detection

1. Permanently installed gas detectors are to be fitted in:

(1) the tank connection spaces;
(2) interbarrier spaces and fuel storage hold spaces of independent tanks other than type C;
(3) cofferdams adjacent to fuel tanks;
(4) fuel preparation rooms;
(5) all ducts and double pipes containing fuel piping for outside the machinery space;
(6) machinery spaces containing gas piping, gas equipment or gas consumers;
(7) other enclosed spaces containing fuel piping or other fuel equipment without ducting;
(8) motor rooms associated with the fuel systems;
(9) airlocks;
(10) fuel heating circuit expansion tanks;
(11) closed or semi-enclosed bunkering station; and
(12) at ventilation inlets to accommodation and machinery spaces if required based on the risk assessment.

2. The number of detectors in each space are to be considered taking into account the size, layout and ventilation of the space.

3. The detection equipment is to be located where gas may accumulate and in the ventilation outlets. Gas dispersal analysis or a physical smoke test is to be used to find the best arrangement.

4. Gas detection equipment is to be designed, installed and tested in accordance with **IEC 60079-29-1** or equivalent.

5. For tank connection space, an audible and visible alarm is to be activated at a gas vapour concentration of 25 ppm. The safety system such as closing of tank valve and shutdown of fuel pump is to be activated at 300 ppm at two detectors.

6. For fuel preparation room, an audible and visible alarm is to be activated at a gas vapour concentration of 25 ppm. The safety system such as shutdown of fuel supply system is to be activated at 300 ppm at two detectors.

7. For ducts and double pipes containing fuel pipes outside the machinery space, an audible and visible alarm is to be activated at a gas vapour concentration of 20 % of the lower explosion limit (LEL). The safety system such as shutdown of fuel supply system is to be activated at 40 % of the lower explosion limit (LEL) at two detectors.

8. For ducts and double pipes containing fuel pipes in the machinery space, an audible and visible alarm is to be activated at a gas vapour concentration of 20 % of the lower explosion limit (LEL). The safety system such as closing of main fuel valve is to be activated at 40 % of the lower explosion limit (LEL) at two detectors.

9. For closed or semi-enclosed bunkering station, an audible and visible alarm is to be activated at a gas vapour concentration of 25 ppm. The valves related bunkering are to be closed at 300 ppm at two detectors.

10. Audible and visible alarms from the gas detection equipment are to be located on the navigation bridge or in the continuously manned central control station. If necessary, alarms from the gas detection equipment are to be activated at location adjacent to the exit of outside the protected space where the gas detector is installed to prevent the crew from entering the area where ammonia leaked.

11. Gas detection required by this Section is to be continuous without delay.

802. Low temperature detection

In cases where it is effective to detect a liquid leakage in ducts and double pipes containing liquid fuel piping, low temperature detection system may be installed. When a leak is detected, all related valves are to be closed to prevent leakage.

Section 9 Fire Detection

Required safety actions at fire detection in the machinery space containing ammonia-fuelled engines and rooms containing independent tanks for fuel storage hold spaces are given in **Table 4** below.

Section 10 Ventilation

Ch 15, Sec 10 of **the Rules** is to be applied.

Section 11 Safety Functions of Fuel Supply Systems

Ch 15, Sec 11 of **the Rules** is to be applied.

Table 15.1 Monitoring of fuel supply system to engines

Parameter	Alarm	Automatic shutdown of main tank valve[6)]	Automatic shutdown of gas supply to machinery space containing gas-fuelled engines	Remarks
Gas detection in tank connection space at 25 ppm	X[1)]			
Gas detection on two detectors tank connection space at 300 ppm	X	X		
Fire detection in ventilation trunk to the tank connection space and in the tank connection space	X			
Bilge well high level in tank connection space	X			
Bilge well low temperature in tank connection space	X	X		
Gas detection in interbarrier spaces of independent tanks other than type C at 150 ppm	X			
Gas detection on two detectors in interbarrier spaces of independent tanks other than type C at 300 ppm	X	X		
Gas detection in fuel storage hold spaces of independent tanks other than type C at 25 ppm	X[1)]			
Gas detection on two detectors in fuel storage hold spaces of independent tanks other than type C at 300 ppm	X	X		
Gas detection in cofferdams adjacent to fuel tanks at 150 ppm	X			
Gas detection on two detectors cofferdams adjacent to fuel tanks at 300 ppm	X	X		
Fire detection in fuel storage hold space	X			
Gas detection in fuel preparation room at 25 ppm	X[1)]			
Gas detection on two detectors fuel preparation room at 300 ppm	X	X[2)]		
Bilge well low temperature in fuel preparation room	X		X	
Gas detection in all ducts and double pipes containing fuel piping for outside the machinery space at 20 % of LEL	X			
Gas detection on two detectors all ducts and double pipes containing fuel piping for outside the machinery space at 40 % of LEL	X	X[2)]		
Gas detection in all ducts and double pipes containing fuel piping for the machinery space at 20 % of LEL	X			
Gas detection on two detectors all ducts and double pipes containing fuel piping for the machinery space at 40 % of LEL [5)]	X		X[3)]	

Table 15.1 Monitoring of fuel supply system to engines (continued)

Parameter	Alarm	Automatic shutdown of main tank valve[5]	Automatic shutdown of gas supply to machinery space containing gas-fuelled engines	Remarks
Gas detection above ammonia engine in machinery space at 25 ppm	X			
Gas detection on two detectors above ammonia engine in machinery space at 300 ppm			X[3]	
Gas detection in enclosed spaces containing fuel piping or other fuel equipment without ducting at 25 ppm	X			
Gas detection on two detectors enclosed spaces containing fuel piping or other fuel equipment without ducting at 300 ppm		X[2]		
Bilge well low temperature in enclosed spaces containing fuel piping or other fuel equipment without ducting	X	X[2]		
Gas detection in airlock at 25 ppm	X			
Gas detection in fuel heating circuit expansion tanks at 25 ppm	X			
Gas detection in closed or semi-enclosed bunkering station 25 ppm	X			
Gas detection on two detectors closed or semi-enclosed bunkering station 300 ppm	X			closed valves relating bunkering and stopped bunkering operation
Loss of ventilation in duct between tank and machinery space containing gas-fuelled engines	X	X[2]		
Loss of ventilation in duct inside machinery space containing gas-fuelled engines[5]	X		X[3]	
Fire detection in machinery space containing gas-fuelled engines	X			
Abnormal gas pressure in gas supply pipe	X			
Failure of valve control actuating medium	X		X[4]	Time delayed as found necessary
Automatic shutdown of engine (engine failure)	X		X[4]	
Manually activated emergency shutdown of engine	X		X	

Note :

1) If the gas concentration can be checked through the indicator outside the space, it can be set to 25 ppm or more. However, the concentration setting value should be less than 150 ppm.
2) If the tank is supplying gas to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected is to close.
3) If the gas is supplied to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct and outside of the machinery space containing gas-fuelled engines, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected is to close.
4) Only double block and bleed valves to be activated.(two block valves to close and a bleed valve to open)
5) If the duct is protected by inert gas (See **Ch 9, 601. 1**) then loss of inert gas overpressure is to lead to the same actions as given in this table.
6) Valves referred to in **Ch 9, 401.** of **the Rules** ⚓

CHAPTER 16   MANUFACTURE, WORKMANSHIP AND TESTING

Ch 16 of **the Rules** is to be applied. ⚓

CHAPTER 17 DRILLS AND EMERGENCY EXERCISES

In addition to Ch 17 of **the Rules**, the followings are to be applied;

1. Ammonia fuel-related drills and exercises should be incorporated into schedule for periodical drills to be adequately qualified, trained and experienced.
   (1) Hazards due to the properties of ammonia and liquefied gas
   (2) safety actions for leakage accidents and consequences of ammonia leakage caused by careless handling of equipment
   (3) How to use protective equipment and safety equipment provided on board the ship
   (4) Location and how to use of shower facilities and eye wash stations for emergency
2. The master, officers, ratings and other personnel on ships using fuels should be trained and qualified in accordance to the regulation V/3 of the STCW Convention and section A-V/3 of the STCW Code, taking into account the specific hazards of fuel. ⚓

CHAPTER 18 OPERATION

In addition to Ch 18 of **the Rules**, the followings are to be applied;

1. Special care should be taken not to contact the ammonia to strong oxidizers such as chlorine, hypo-chlorite bleach, halogen-based substances to avoid potentially explosive reaction. Ammonia mixtures with oil or other combustible materials can cause a big explosion. ⚓

Annex 1 REQUIREMENTS FOR AMMONIA FUEL READY

Section 1 General

101. Application

1. This Annex applies to ships which are prepared for conversion with the design or the partial installation related with ammonia fuel during the new building phase(hereafter referred to as "ammonia fuel ready ships" in the Guidelines) for the purpose of a conversion from a ship using conventional marine fuels to ammonia fuel after delivery.
2. This Annex contains levels of readiness for use of ammonia as fuel(hereafter referred to as "ammonia fuel ready levels" in the Guidelines) and requirements applicable thereto, and the scope of preparation is defined by the agreement between the shipowner and the shipbuilder.
3. The design and the installation of ammonia fuel systems of ammonia fuel ready ships are to apply this Guidelines in force at the time of contract for construction for the new-building. However, where a ammonia fuel ready ship in accordance with this Guidelines is converted to a ammonia fuelled ship after delivery, the ship shall comply with this Guidelines in force at the time of the ship conversion.

102. Ammonia fuel ready levels

1. Ammonia fuel ready levels are defined in 3 steps as follows:
   (1) The level of preparing the concept design
   (2) The level of preparing the generic design
   (3) The level of installing parts of the systems with the detailed design in addition to above (1)
2. The class notations defined in **Sec 2** may be assigned where the ready level in **Para 1** is in compliance with this Annex.

Section 2 Class Notation

201. General

1. The class notations specified in **202.** and **205.** may be assigned according to the ammonia fuel ready level
2. The requirements for the class notations in this Section are to comply with **Sec 3.**

202. Ammonia Ready D(A)

1. Ammonia Ready D(A) as an additional special feature notation may be assigned to ships whose the ammonia fueled ship concept design is prepared for evaluation of the basic suitability.
2. Ammonia Ready D(A) is not to be assigned to ships having LNG Ready D.

203. Ammonia Ready D

1. Ammonia Ready D as an additional special feature notation may be assigned to ships for which the generic design is prepared.
2. Ammonia Ready D is not to be assign to ships having Ammonia Ready I.

204. Ammonia Ready I

1. Ammonia Ready I as an additional special feature notation may be assigned to ships for which parts of the systems are installed with the detailed design in addition to the generic design.
2. In assignment of the Ammonia Ready I, the characters corresponding to the installed items may be

assigned in the bracket one or a combination of them in addition to Ammonia Ready I. The characters corresponding to the installed items are as follows:

(1) Hull structural reinforcement for ammonia fuel tank - SR
(2) Ammonia fuel tank - FT
(3) Ammonia fuel tank venting systems - TV
(4) Ammonia fuel supply systems - FS
(5) Ammonia fuel bunkering systems - BS
(6) Ammonia fired main engines - ME
(7) Ammonia fired auxiliary engines - AE
(8) Ammonia fired boilers - B
(9) Main engines that can be converted to Ammonia fuel operation - ME-C
(10) Auxiliary engines that can be converted to Ammonia fuel operation - AE-C
(11) Boilers that can be converted to Ammonia fuel operation - B-C

For example, Ammonia Ready I(SR, FT) may be assigned to the ship on which structural reinforcement for ammonia fuel tank and ammonia fuel tank are installed, and Ammonia Ready I(FS, ME) may be assigned to the ship on which ammonia fuel supply systems and ammonia fired main engines are installed.

204. LPG and Ammonia Ready

LPG and Ammonia Ready D(A), LPG and Ammonia Ready D, LPG and Ammonia Ready I as an additional special feature notation may be assigned to ready ships whose prepared to use LPG fuel or ammonia fuel.

Section 3 Requirements for Levels of Ammonia Fuel Ready

301. General

1. This Guidelines prescribes plans to be submitted and systems to be installed. The design and installation of structures and systems are to be in accordance with applicable requirements in this Guidelines.

2. Drawing approval and survey for ammonia fuel ready are not accepted as drawing approval and survey for conversion to ammonia fuel ship. When the ship is converted, drawing approval and survey are to be carried out in accordance with this Guidelines in force at the time of the ship conversion. Approved Drawings and certifications from new building stage may be used as reference for conversion.

302. General Level of Preparing Concept Design

1. Plans and documents required for an Approval in Principle (AIP) are to be submitted for Ammonia Ready D(A). List of plans and documents to be submitted may be mediated after consultation with the Society.

2. The plans and documents required in this Section is to be marked "Ammonia Ready" to separate them from the normal plans and documents of new building.

303. General Level of Preparing Generic Design

1. General

(1) This Section prescribes plans and documents to be submitted for Ammonia Ready D. The detail requirements for designs are to be in accordance with applicable requirements in this Guidelines.
(2) The plans and documents required in this Section is to be marked "Ammonia Ready" to separate them from the normal plans and documents of new building.
(3) Where parts of plans and documents required in this Section are not available, alternative documents may be accepted by the Society's review.

2. Plans and documents to be submitted

(1) The following plans and documents are to be submitted to the Society for review

(A) General arrangement plans showing location of:
(a) Machinery spaces, accommodation, service and control station spaces
(b) Ammonia fuel containment systems
(c) Fuel preparation room
(d) Ammonia fuel piping routing with shore connections
(e) Tank hatches, ventilation pipes and any other openings to the ammonia fuel tanks
(f) Ventilating pipes, doors and openings to fuel preparation room and other hazardous areas
(g) Entrances, air inlets and openings to accommodation, service and control station spaces
(h) Hazardous areas of zone 0, 1 and 2

(B) Following plans and data of the ammonia fuel containment system:
(a) Ammonia fuel tank type, dimension and volume
(b) Drawings of support and staying of ammonia fuel tanks
(c) Ammonia fuel tank arrangement including tank connection space
(d) Specification of design loads and structural analysis for the ammonia fuel tank supporting structure
(e) Drawing and specification of ammonia fuel tank thermal insulation with heat transfer calculation

(C) Following plans and data of ammonia fuel supply systems:
(a) Arrangement of engine room, fuel preparation room and other spaces containing ammonia equipment
(b) Ammonia fuel supply piping diagram
(c) Ventilation system arrangement of engine room, fuel preparation room and other spaces containing ammonia equipment

(D) Following plans and data of ammonia fuel bunkering systems:
(a) Arrangement of ammonia fuel bunkering systems
(b) Ammonia fuel bunkering piping diagram
(c) Ventilation system arrangement of ammonia fuel bunkering station

(E) Following plans and particulars for the safety relief valves
(a) Arrangement for ammonia fuel tank relief valves and associated ventilation piping
(b) Calculation of required ammonia fuel tank relief valve capacity

(F) Following plans and data for equipment and systems regarding fire protection :
(a) Arrangement of construction for fire protection in relation to ammonia fuel tank and other spaces containing ammonia equipment
(b) Arrangement and specification of water spray system
(c) Arrangement and specification of dry chemical powder installation

(G) Data for a risk analysis according to Ch 3, Sec 2 of this Guidelines.

(H) Stability calculations with ammonia fuel tanks included

(I) Longitudinal strength calculations with ammonia fuel tanks included

304. Level of Installing Parts of Systems

1. General

(1) This Section prescribes parts of the systems to be installed and plans and documents to be submitted for Ammonia Ready I. The detail requirements for designs and installation of installed systems are to be in accordance with applicable requirements in this Guidelines.

(2) The plans and documents for generic design required in 303. are to be submitted and reviewed by the Society except those required for approval in Para 2 to 6.

(3) Parts of the systems are categorized in the follows:
(A) Hull structural reinforcement for ammonia fuel tank
(B) Ammonia fuel tank
(C) Ammonia fuel tank venting systems
(D) Ammonia fuel supply systems
(F) Ammonia fuel bunkering systems
(G) Ammonia fired main engines
(H) Ammonia fired auxiliary engines
(I) Ammonia fired boilers
(J) Main engines that can be converted to Ammonia fuel operation

(K) Auxiliary engines that can be converted to Ammonia fuel operation
(L) Boilers that can be converted to Ammonia fuel operation

(4) The parts which are installed on board are to be reflected in the normal plans of new building and "Ammonia Ready" is not to be marked on those plans.

2. Hull structural reinforcement for ammonia fuel tank

(1) The structures below the ammonia fuel tanks are to be reinforced in accordance with Ch 6 of this Guidelines.
(2) The following plans and documents are to be submitted to the Society for approval.
(A) Detail drawing of ammonia fuel tanks and support of ammonia fuel tanks
(B) Material specification for tank support and steel grade selection for the hull in way of the tank
(C) Welding procedures, stress relieving procedures and non-destructive testing plans
(D) Specification of design loads and structural analysis for the ammonia fuel tank supporting structure
(E) Drawing and specification of ammonia fuel tank thermal insulation with heat transfer calculation

3. Ammonia fuel tank

(1) Ammonia fuel tanks are to be installed in accordance with Ch 5, Sec 3 and Ch 6 of this Guidelines
(2) The plans and documents in Ch 4, 203. 3 and 4 of this Guidelines and ammonia fuel tank arrangement including tank connection space are to be submitted to the Society for approval.

4. Ammonia fuel tank venting systems

(1) Ammonia fuel tank venting systems are to be installed in accordance with Ch 5, Sec 13 and Ch 6 of this Guidelines.
(2) The plans and documents in Ch 4, 203. 3 and 4 of this Guidelines are to be submitted to the Society for approval.

5. Ammonia fuel supply systems

(1) Ammonia fuel supply systems are to be installed in accordance with Ch 7 and Ch 9 of this Guidelines.
(2) The following plans and documents are to be submitted to the Society for approval.
(A) Arrangement of engine room, fuel preparation room and other spaces containing ammonia equipment
(B) Ventilation system arrangement of engine room, fuel preparation room and other spaces containing ammonia equipment
(C) Drawings and specifications of ammonia supply piping
(D) Drawings and specifications of offsets, loops, bends and mechanical expansion joints, such as bellows, slip joints(only inside tank) or similar means in the ammonia piping
(E) Drawings and specifications of flanges, valves and other fittings in the ammonia piping system. For valves intended for piping systems with a design temperature below − 55 °C, documentation for leak test and functional test at design temperature (type test) is required
(F) Documentation of type tests for expansion components in the ammonia piping system.
(G) Specification of materials, welding, post-weld heat treatment and non-destructive testing of ammonia piping
(H) Specification of pressure tests (structural and tightness tests) of ammonia piping
(I) Program for functional tests of all piping systems including valves, fittings and associated equipment for handling ammonia (liquid or vapour)
(J) Drawings and specifications of insulation for low temperature piping where such insulation is installed
(K) Specification of electrical bonding of piping
(L) Cooling or heating water system in connection with ammonia fuel system, if fitted.

6. Ammonia fuel bunkering systems

(1) Ammonia fuel bunkering systems are to be installed in accordance with Ch 7 and Ch 8 of this Guidelines.
(2) The following plans and documents are to be submitted to the Society for approval.
(A) Arrangement of ammonia fuel bunkering systems
(B) Ventilation system arrangement of ammonia fuel bunkering station
(C) Drawings and specifications of ammonia supply piping

(D) Drawings and specifications of offsets, loops, bends and mechanical expansion joints, such as bellows, slip joints(only inside tank) or similar means in the ammonia piping
(E) Drawings and specifications of flanges, valves and other fittings in the ammonia piping system. For valves intended for piping systems with a design temperature below -55 °C, documentation for leak test and functional test at design temperature (type test) is required
(F) Documentation of type tests for expansion components in the ammonia piping system.
(G) Specification of materials, welding, post-weld heat treatment and non-destructive testing of ammonia piping
(H) Specification of pressure tests (structural and tightness tests) of ammonia piping
(I) Program for functional tests of all piping systems including valves, fittings and associated equipment for handling ammonia (liquid or vapour)
(J) Drawings and specifications of insulation for low temperature piping where such insulation is installed
(K) Specification of electrical bonding of piping
(L) Specification of means for removal of liquid contents from bunkering pipes prior to disconnecting the shore connection

7. Ammonia fired main engines

Main engines are to be installed in accordance with **Ch 10, Sec 3** of this Guidelines.

8. Ammonia fired auxiliary engines

Auxiliary engines are to be installed in accordance with **Ch 10, Sec 3** of this Guidelines.

9. Ammonia fired boilers

Boilers are to be installed in accordance with **Ch 10, Sec 4** of this Guidelines.

10. Main engines that can be converted to gas fuel operation

(1) Main engines of gas-convertible types are to be installed.
(2) Following plans are to be submitted for reference:
(A) details of the gas conversion
(B) list of the components that need to be replaced
(C) list of new components

11. Auxiliary engines that can be converted to gas fuel operation

(1) Auxiliary engines of gas-convertible types are to be installed.
(2) Following plans are to be submitted for reference:
(A) details of the gas conversion
(B) list of the components that need to be replaced
(C) list of new components

12. Boilers that can be converted to gas fuel operation

(1) Boilers of gas-convertible types are to be installed.
(2) Following plans are to be submitted for reference:
(A) details of the gas conversion
(B) list of the components that need to be replaced
(C) list of new components

305. Survey

1. Classification survey during construction

Systems are to be tested at the shops of manufacturer and after installation on board in accordance with this Guidelines.

2. Periodical surveys

In application of this Guidelines, the general condition of the relevant systems installed on board is to be examined visually at periodical surveys for the vessels having Ammonia Ready I notation. The systems are to be surveyed and evaluated for the condition at time of conversion, and the scope of test will be defined depending on time elapsed from new building and maintenance level of the systems. ⚓

Report on Ammonia-Fueled Ships

June 2021 Rev.2

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Table of Contents

1 Research Background and Purpose

1.1 Research Background

Increasing greenhouse gas (GHG) emission, one of the causes of global warming, has resulted in abnormal climate phenomena such as heatwaves and floods. People have recognized that eco-friendliness is essential for the sustainable growth of humankind. Accordingly, research on converting fossil fuels to eco-friendly alternatives is ongoing in all industrial sectors.

The Kyoto Protocol and the Paris Agreement as part of the United Nations Framework Convention on Climate Change (UNFCCC) specifically delegated the International Maritime Organization (IMO) to address all matters for achieving GHG reduction targets in the marine transportation sector. Subsequently, IMO st\rengthened the PM, SOx, and NOx emission regulation and specified the GHG emission reduction target. It decide to halve CO_2 emission from ships by 70% by 2050, compared to 2008, and reduce carbon intensity of international shipping by 40% by 2030 compared to 2008.

However, since CO_2 emission is expected to be 3,000 Mt or more if GHG is emitted in the current trend (Business as Usual (BAU) scenario), it is necessary to reduce it by 85 %.

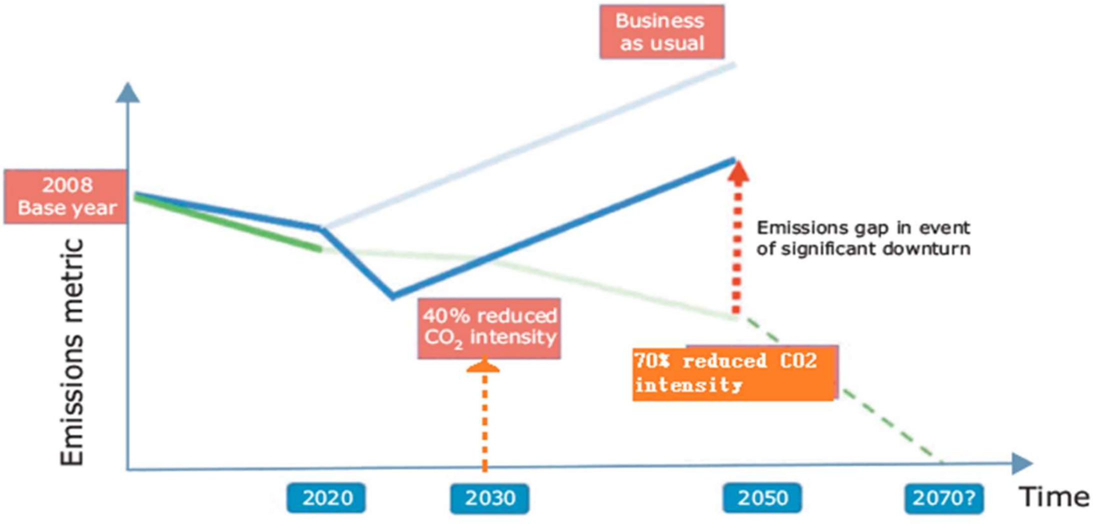

Figure 1 IMO’s Long-Term CO_2 Reduction Plan (Source: MEPC 72/7/3)

IMO's carbon reduction target of 40 % by 2030 is attainable through the currently enforced technological measures such as increasing ship size and improving propulsion system and navigational efficiency increase such as low-speed operation. These two measures alone, however, have limitations since there is no significant change after 2030.

1.2 Research Goal

1.2.1 Purpose

○ The purpose of this study is to investigate the feasibility of whether ammonia can be used as fuel for ships and to establish the direction for regulation of ammonia-fueled ships by identifying the ammonia characteristics to be considered in ship structures and facilities.

1.2.2 Goal

○ The restrictions of using ammonia as a fuel for ships are as follows:

- Although the IGC Code has been amended to allow cargo other than natural gas to be used as ship fuel provided that it can guarantee the same safety level, Paragraph 16.9.2 prohibits cargo classified as toxic from being used as fuel. Therefore, it is necessary to review the clause.

- The IGF Code specifies the detailed requirements of the LNG only, and the recent IMO Sub-Committee on Carriage of Cargoes and Containers (CCC) meeting completed the tentative guidelines on the detailed regulation of methyl/ethyl alcohol. Although it is developing detailed requirements for fuel cell, low flash point diesel, and LPG, there is no plan to develop detailed requirements for ammonia.

- From a safety viewpoint, ammonia is toxic and corrosive. Therefore, it is necessary to establish the standard for securing safety in consideration of the ammonia characteristics to use ammonia as a fuel for ships.

- Ammonia has characteristics of being difficult to ignite and having a slow combustion speed due to a very slow flame speed compared to other fuels. On the other hand, ammonia causes a rapid explosion when it is mixed with fuel such as petroleum, chlorine gas, or urea gas, or when it reacts with heavy metals such as gold and mercury. Since unburned ammonia emissions are much lighter than air, they rise rapidly in dry air. At sea, however, they quickly react with the humidity in the air, remaining close to the ship's surface, which may cause hull corrosion. Therefore, it is a factor to be considered. Moreover, since ammonia is a cause for ultrafine dust, it is necessary to establish the requirements for emission restrictions.

ㅇ Despite the aforementioned difficulties, its cost, safety, cost, safety, availability, and pollutant reduction must be considered comprehensively for the continued use of ammonia. The following detailed goals were set to use ammonia as a marine fuel by considering existing ammonia production methods and future green ammonia production, experience in land use and sea transportation, ammonia supply chain and process, and considerations for application as fuel on-board:

- Analysis of availability and pollutant reduction by investigating properties of ammonia, existing fields using ammonia, and a comparison with other carbon-free fuels

  * Industrial fields using ammonia

  * Properties of ammonia

  * A feasibility study by comparing with other carbon-free fuels such as hydrogen, methanol, a biofuel

- Study on safety of ammonia-fueled ship structure and facility

  * Review of the analysis of risk factors of ammonia-fueled ship structure and facility

  * IGC Code requirement analysis and identification for revision to apply

  * IGF Code requirement analysis and identification of additional requirements to apply

ㅇ We intend to identify the development direction for safety regulation of ammonia-fueled ships based on the detailed goals.

2 Use of Ammonia

2.1 Use of Ammonia

More than 120 ports are already handling ammonia products for import and export, and some even have storage facilities. Such an infrastructure can be an important resource to secure the ammonia’s availability as fuel. A wide range of sectors use ammonia, and the handling procedures and safety education have been widely distributed. Therefore, using it for ships would not be a problem for people who have familiarized with it.

2.1.1 Fertilizer

Ammonia is regarded as a substance as important as carbon compounds to chemical technical specialists since it is the driving force that has increased the marginal global population from 2 billion to 8 billion with the fertilizer synthesis and nitrogen process (Haber-Bosch process). Fertilizers are classified into nitrogen fertilizers, phosphate fertilizers, potassium fertilizers, and complex fertilizers according to the production method. Ammonia accounts for more than 30% of nitrogen fertilizer.

2.1.2 Industrial Fuel

High-purity ammonia has a purity of 99.9995 (5N5) or higher and is produced by additionally refining produced or imported raw material gas with a purity of 99.8 %. NH_3 refined into high purity (blue ammonia) or ultra-high purity (white ammonia) has a completely different value from low-purity materials. Firstly, high-purity NH_3 is treated as a special gas, not ammonia as a simple raw material gas.

High-purity ammonia is mainly used as compound semiconductors such as gallium arsenide (GaAs), silicon germanium (SiGe), indium phosphorus (InP), and silicon carbide (SiC), as well as the light emitting diode (LED) and liquid crystal display (LCD) panel markets. Moreover, new demands have emerged recently in the solar cell industry along with the development of the photovoltaic industry.

Semiconductors and LCD panels have developed notably that it is no exaggeration to say that these two fields have led the ammonia market expansion in recent years. Its application has expanded to ultraviolet light emitting diode (UV-LED), which is emerging as next-generation lighting due to a high luminance and low manufacturing cost, as well as sterilization, wastewater treatment, deodorization, medical use, skin disease treatment, counterfeit detection, and environmental sensors. The demand for ultra-high purity ammonia (white ammonia with more than 99.99999 % purity) is expected to continue to increase.

2.1.3 Refrigerant

Ammonia, along with Freon gas, is used as a refrigerant that has saved humankind from heatwaves. In 1832, M. Faraday established the ammonia vapor-compression theory, and the French scientist F. Carre received a patent for ammonia absorption chiller in 1859. Ammonia is still widely used in large industrial refrigeration units and ships (Sec 12, Ch. 6, Pt 5 and Ch. 1, Pt. 9 the Rules for the Classification of Steel Ships).

Since ammonia is easy to liquefy, it is often used with hydrogen fluorocarbon (HFC)[1] to design general-purpose compressors. Its latent heat of vaporization is second to water and is superior to other refrigerants. As a result, its refrigeration capacity per enclosed unit volume in a system is extremely high. Moreover, the critical temperature is also high at 132.4 ℃, and the refrigerant evaporation temperature can range widely from 0 to 60 ℃ in a refrigeration cycle. In general, materials with a lower molecular weight have a higher thermal conductivity rate. The thermal conductivity rate of ammonia, which has an extremely small molecular weight, enabling the heat exchanger to be miniaturized.

2.1.4 Automobile Fuel Additive

Ammonia can be converted into urea solution to reduce NOx in the exhaust gas. Moreover, it reacts with haloalkyl, such as alkyl chloride (RCI), to form an amine mixture in the form of diethylamine and hexamine, which are used as engine oil or a fuel additive for corrosion prevention and curing.

2.1.5 Selective Catalytic Reduction (SCR) Catalyst

Methods of controlling NOx using a catalyst include a method of directly decomposing NOx (without using a reducing agent) and the catalytic reduction method using a reducing agent. The catalytic reduction method that decomposes NOx on a

[1] HFC, a substitute for Freon gas, does not destroy the ozone layer because it does not contain chlorine in its molecule. However, it is classified as a GHG.

catalyst decomposes NOx into nitrogen and hydrogen without reducing agents. Therefore, it is economically advantageous since it requires less maintenance cost and requires no means to supply the reducing agent. However, it shows an excellent catalytic activity only at high temperature (600 ℃ or higher), and the hydrogen and carbon dioxide in the exhaust gas inhibit NOx decomposition, resulting in low removal efficiency. On the other hand, the SCR process using ammonia can remove more than 90 % of NOx emitted by a fixed source. It has been commercialized as the optimal NOx control technology from the price competitiveness and stability aspect. Refer to the "Guidance for Exhaust Gas Emission Abatement System" by the Korean Register (KR).

2.1.6 Ammonia Engine Development

Considering ammonia as a fuel is not a brand new concept. There is a record of the ammonia-fuel bus in the 19th century, and an ammonia, coal, and gas hybrid engine were developed in Brussels in the 1940s to maintain public transportation in the middle of the war. However, the engine was developed to overcome the shortage of oil rather than to meet the environmental requirement. It was no longer needed after the war since natural gas and oil were available in abundance at lower prices.

2.2 Carbon-Neutral Fuels Compared With Ammonia

The currently available carbon-neutral fuels that can be produced and consumed with zero carbon emission include biofuel, hydrogen, and methanol.

2.2.1 Biofuel

Biodiesel is the carbon-neutral fuel that is the most superior from the storage and transport aspect. It is because it has almost the same properties and energy density as existing fossil fuels. Therefore, its advantage is that the fuel system and tank used in existing ships can be used as it is.

Biogas also has the advantage that it can be used in LNG-fueled ships since it is mostly comprised of methane gas.

Ethanol produced from corn and methanol produced from synthetic gas generated by organic waste are also eco-friendly, but they have a low energy density.

Fuels like biodiesel and biogas obtained from biomass have a unit process that requires massive facility investment and can cause competition with food when used in excess. While the first-generation materials used food, the second-generation materials can use livestock manure, food waste, and agricultural/fishery waste. However, these wastes are incidentally produced by other industries, and it is difficult to increase production by assuming that they will be stably available at all times.

Microalgae, which are recognized as the third-generation biomass in the future following grains (first generation) and wood (second generation), are characterized by biological recovery of carbon dioxide in the atmosphere because they perform photosynthesis. Since it can efficiently convert carbon into biomass, biofuels made from microalgae are called “green gold.” Recent analyses have reported that microalgae-based biofuels can meet the world's energy demand, but it will take time before mass production becomes possible due to the need to develop efficient microalgae containing high lipid. (See Figure 2)

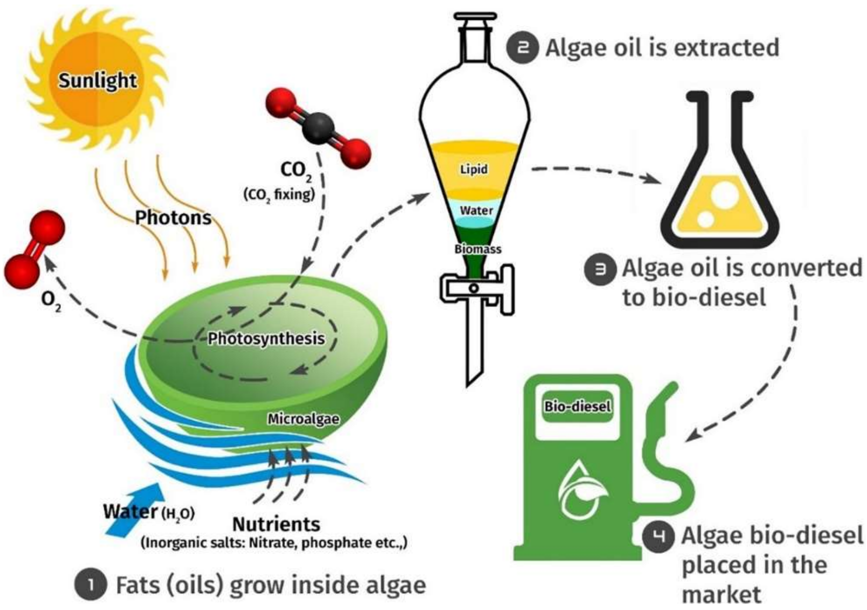

Figure 2 Biofuel Production [Third Generation] (© 2020 Elsevier B.V)

2.2.2 Hydrogen

Hydrogen has the advantage of being immediately producible through water electrolysis using renewable energy. The produced hydrogen, however, must be liquefied at -253 ℃ to store it in large quantities. Therefore, large energy is consumed for the storage and transport process. Liquefying hydrogen requires energy equivalent to about 30 % of the calorific value, and the amount of energy loss due to boil-off gas (BOG) generated during storage and transportation increases even more.

2.2.3 Methanol

Methanol can be produced using biomass or synthesized through the reaction of carbon dioxide or carbon monoxide with hydrogen produced by water electrolysis using renewable energy. Although it can be regarded as very eco-friendly in that it can use the captured carbon dioxide in the long term, carbon dioxide capture technology has been inadequate until now, and hydrogen is also produced using fossil fuels. Moreover, methanol is inefficient to be used as a fuel since its energy density is low.

3 Properties of Ammonia

3.1 Physical Properties of Ammonia

○ Since ammonia's vapor pressure at 37.8 ℃ is 1.46 MPa, the gas is relatively easy to liquefy[2]. Like LPG, ammonia can be liquefied by applying a certain pressure event at room temperature.

○ Table 1 summarizes the general ammonia properties as well as those of other carbon-neutral fuels for comparison.

Property	Ammonia	Hydrogen	Methanol	Methane (LNG)	Propane (LPG)
Flash point (°C)	132	-150	11	-188	-105
Autoignition temperature (°C)	651	535	464	595	459
Ignition energy (mJ)	8	0.011	0.14	0.28	0.25
Basic burning rate (cm/s)	12	312	56	40	46
Flammable concentration range in the air (%)	15-28	4-75	5.5-44	5-15	2.2-9.5
Boiling point at atmospheric pressure (°C)	-33.5	-253	64.7	-161	-42
Critical temperature (°C)	132.4	-239.9	239	-82.95	96
Critical pressure (saturated vapor pressure at critical temperature) (MPa)	11.28	1.297	8.1	4.6	4.26
Static pressure/static specific heat ratio k (Cp/Cv)	1.312	1.405	1.233	1.31	1.13
Vapor pressure at 45 °C	1.78	-	0.045	-	1.5
Liquid/vapor volume ratio	850 times	800 times	-	600 times	300

Table 1 Physical Properties of Ammonia

○ Since ammonia gas is colorless and has a strong odor, it has the advantage of being immediately detected when there is leakage. It has good ventilation because it is lighter than air, it is easy to control leaked ammonia because it tends to concentrate on the ceiling or high places, and it can be used as marine fuel because it has little explosive

[2]The IGF Code defines fluid, having absolute vapor pressure higher than 0.28 MPa at 37.8 ℃, as gas.

property.

○ Ammonia bonded with another substance in the air must be not discharged as it is since it creates the main component of ultrafine dust, as shown in Figure 4. The Korean Ministry of Environment has set the ammonia emission standard, as shown in Table 2.

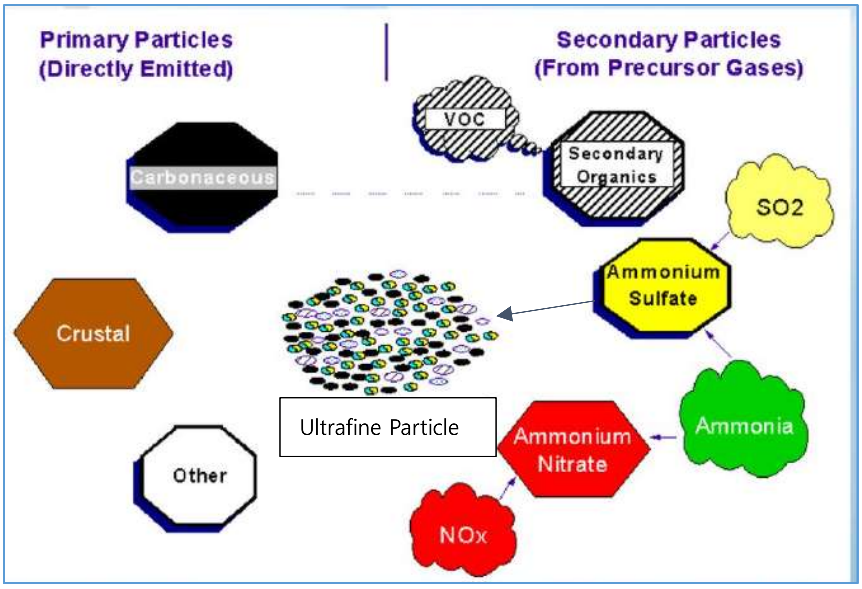

Figure 4 Ultrafine Dust Generation and Ammonia (Source: PECHAN)

Type		Emission Allowance Standard
General (10 Types)	Dust (mg/S㎥)	5–50
	Zinc and its compounds (mg/S㎥)	4
	Carbon monoxide (ppm)	50–300
	Ammonia (ppm)	12–30
	Nitrogen oxide (ppm)	10–250
	Sulfur oxide (ppm)	10–250
	Hydrogen sulfide (ppm)	2–5
	Carbon disulfide (ppm)	10
	Hydrocarbon (ppm)	40–200
	Copper and its compounds (mg/S㎥)	4

Table 2 Atmospheric Pollutant Emission Allowance Standard
(Source: Ministry of Environment)

○ Vaporization occurs not only on the surface but also inside the liquid when the temperature of the liquid is increased or the pressure applied to the gas is decreased. Vaporization that takes place inside the liquid is called boiling, and the boiling point at which ammonia begins to vaporize is -33.5 ℃ at atmospheric pressure.

○ If an ammonia tank is installed on an exposed deck, the container is heated by radiant heat. When the ammonia container is heated, the ammonia's temperature rises, causing the volume to expand and the pressure in the container to rise.

- If the tank is filled with liquid so that the liquid comes into contact with the safety valve designed to discharge gas, the safety valve may not function properly, causing the pressure in the container to continue to rise, and at worst, to rupture the container. Therefore, the maximum filling limit must be set for each container to prevent from this.

○ Ammonia can easily liquefy at high pressure and vaporize at atmospheric temperature. If the tank is ruptured under pressure, most pressurized ammonia is released as vapors or fine aerosols and diffuses into the atmosphere. If a large amount of ammonia is released, ammonia gas generated from a liquid reacts with air to generate mixed gas, which is heavier than air and may cause hull corrosion when deposited on the surface of the ship.

3.2 Fuel Properties of Ammonia

○ Liquefied ammonia has a relatively low volume energy density (see Table 2) and requires about 4.1 times as much tank volume as conventional fossil fuels. The storage performance of future energy is a very important factor in ships with a relatively severe space constraint, and liquefied ammonia can be stored in a pressurized tank or low-temperature tank. Ammonia can be stored in a pressurized tank at about 1 MPa and low-temperature tank at about -34 ℃. Ammonia is weaker than biodiesel or methanol from the fuel storage and transportation aspect, but is superior to biogas or hydrogen from the storage aspect. As such, its transportation cost is lower than other carbon-neutral fuels, and transportation technology is already available.

○ The critical temperature is the upper limit temperature for the gas to be liquefied. In other words, the gas cannot be liquefied above the critical temperature, no matter how much pressure is applied. Since the critical temperature of LNG is -82.95 ℃, it cannot be liquefied at room temperature and thus must be stored in a container at low temperature or a pressurized container at low temperature. On the other hand, ammonia with the critical temperature of 132 ℃ can be liquefied when pressurized at atmospheric temperature (25 ℃) and thus can be conveniently stored.

○ Combustion characteristics such as the calorific value, octane number, and flame speed shown in Table 3 must also be considered. The following table shows the characteristics of next-generation fuels. While the calorific value is very low compared to hydrogen, it is similar to methanol.

Fuel	Ammonia	Liquefied Hydrogen	Hydrogen Gas	LNG	MGO/ Diesel Oil	Methanol
Storage condition	Liquid	Liquid	Gas	Liquid	Liquid	Liquid
Storage temperature (℃)	25	-253	25	-162	25	25
Storage pressure (kPa)	1000-1700	101-3600	25000	101-125	101	101
Density (kg/m^3)	603 (Liquid at 25 ℃)	71	17.5	430-470	840	786
Calorific value (MJ/kg)	18.6-18.8	120	120	49	43	19.7
Octane number	＞130	＞130	＞130	120	-	109
Flame speed	0.015	3.5	3.5	0.34	-	0.43

Table 3 Properties of Next-Generation Fuels

3.3 Comparison of Combustion Properties of Next-Generation Fuels

3.3.1 Importance of Combustion Properties

Understanding the fuel's combustion properties of fuel used by the ship is very important for assuring the ship safety from fire and explosion. When fuel is leaked due to an unsafe protective system condition or human error in handling, processing, or using the fuel, it can result in a fire or explosion if the leaked fuel mixes with air to form a gas mixture and there is an ignition source around it. Typical fire and explosion characteristics include flammable concentration range, flash point, autoignition temperature, ignition energy, and heat of combustion.

In general, an explosion occurs when combustible gas or vapor is mixed with air to form a large gaseous phase volume, and it comes into contact with an ignition source in a closed space state. It can occur in the engines and piping devices of a ship. When flammable gas or evaporated liquid is released into the atmosphere, the gas cloud formed from the leak is diluted or disappears into the atmosphere if the gas cloud is not within the explosive range or if the ignition source is insufficient.

The main variables affecting the gas explosion include the type of fuel and oxidizer, the concentration and size of the fuel in the vapor cloud, the intensity and location of the ignition source, the size, location, and shape of the explosion emission area, the location and size of the structural elements and facilities, the ignition delay, and the geometric conditions of the surroundings due to the closed system and open system. Consequently, it is not easy to predict the explosion phenomenon since the gas explosion is very sensitive to these factors.

Typical ways of preventing gas explosion include lowering the oxidizer or combustible gas concentration. Ways to prevent loss include an explosion suppression technology that detects and prevents early development of pressure that can result in explosion, deflagration pressure containment technology that designs the container and accessories to withstand the pressure generated by deflagration inside the container, and the equipment to extinguish sparks that can be an ignition source of the explosion. Moreover, the facility design must consider factors such as the effectiveness of the prevention method, the facility's reliability, and the risk to human life.

Fire and explosion characteristics of fuel used in ships can be obtained through Material Safety Data Sheet (MSDS) provided by the Korea Occupational Safety and Health Agency (KOSHA). In addition, the lower/upper limits of the explosion, flash point, autoignition temperature, and heat of combustion can be obtained through the Fire and Explosion Parameters in the Properties in the Environmental, Safety and Health Database of the American Institute of Chemical Engineers (AIChE)'s Design Institute for Physical Property Data (DIPPR). However, it requires much research and consideration to extract accurate fire and explosion characteristics data through testing under various conditions.

3.3.2 Ammonia

The flashpoint of ammonia is 132℃, so it does not correspond to the low flash point fuels in the rules for low flash point fuel ships. The autoignition temperature is related to the temperature limit in the environment in which gas can be leaked by exhaust gas temperature. While the IGC Code limits the exhaust gas temperature to 535 ℃ that for ammonia is 651 ℃, which is higher than that for LNG. Therefore, there is no further consideration for the temperature limit.

Like hydrogen, ammonia does not contain carbon, but it has one more hydrogen than a hydrogen molecule and remains liquid when the pressure of about 1 MPa is applied at room temperature; thus, the existing ammonia and LPG infrastructure can be used as-is. As a fuel, ammonia's stability is known to be better than propane and similar to gasoline fuel.

The use of ammonia as vehicle fuel dates back to the 1930s, and studies for use as domestic fuel have also been conducted. Ammonia fuel has a calorific value of 18.6 MJ/kg, which is 0.44 times more calories per kg than gasoline. Despite that, it has not been widely used as fuel because of its disadvantages that the flame propagation speed is significantly lower than that of gasoline fuel. Furthermore, NOx can be generated depending on the fuel characteristics, and ammonia slip can occur according to engine control and can be discharged together with the exhaust gas.

3.3.3 Hydrogen

Hydrogen has emerged as a pollution-free energy source to replace fossil fuel since its combustion generates only water and no pollutant. Moreover, its heat of combustion is about three times higher than that of oil, making it a very efficient energy source. Therefore, it can also be used as the household energy source if its combustion can be controlled under an appropriate condition. However, it is very difficult to handle hydrogen since the material can melt metals, its storage and transport are very difficult, and its leakage can cause a huge explosion.

Hydrogen is mostly used by petrochemical or oil refining industries on land and is regulated as high-pressure gas according to the High-Pressure Gas Safety Control Act. Since a hydrogen-filled vehicle container's pressure can be up to 70 MPa, its leakage into the confined space can cause a major accident.

Hydrogen is the lightest of all elements. As a fuel, it is faster than currently used fuels, including LNG, LPG, and gasoline, and its buoyancy increases very quickly as well. Moreover, it is a colorless, odorless, and tasteless combustible gas at room temperature and has similar properties as LNG or LPG as a non-toxic gas. It can be said that its explosion risk can be higher than other fuels because of its wide explosive range; detonation risk is also regarded to be high since it correlates with an explosion risk. In the case of an open area, however, unlike closed area, it has been reported to have a similar risk as other fuels. Since its minimum ignition energy is lower than conventional fuels, hydrogen has a higher explosion risk as it requires less energy for the explosion. Moreover, the flame speed is 6 to 7 times faster than that of LNG or LPG.

3.3.4 Methanol

Methanol, also called methyl alcohol, has a very low flash point of 11 °C, at which the methanol and air mixers are present on surfaces that can be ignited by an ignition flame or small sparks. When it is diffused in the form of a flam on a surface, the surface temperature increases to the boiling point, and the evaporation rate or the combustion rate also increases accordingly.

3.3.5 Ethanol

Ethanol, also called ethyl alcohol, has a flash point of 13 ℃ and an autoignition temperature of 363 ℃, which is lower than methanol. It is easy to burn and can explode when ignited in a vapor form. It is necessary to control acetaldehyde and other products generated during combustion which are harmful to the human body.

3.4 Risk of Ammonia

3.4.1 General

○ The risk of ammonia as a fuel is different from the properties and risk of conventional fuels like HFO and MDO and liquefied gas fuels like LNG and LPG. Therefore, it is more rational to identify risks of using it as fuel for ships by identifying risks of transporting it as cargo according to the IGC Code and risks of using it as a refrigerant or catalyst rather than identifying additional risks compared to conventional fuels.

○ It is important to understand the risk factors among general properties of ammonia to study the ammonia-fueled ships' structural and facility safety.

3.4.2 Toxicity

Ammonia liquid strongly irritates the mucous membrane and, if inhaled, causes laryngeal spasm, laryngitis, bronchitis, etc. If not treated promptly, it can be toxic to cause asphyxial death. Since ammonia is alkaline and irritates living tissues, it may damage the eyes, liver, kidneys, or lungs if the body is exposed to it for a long time. It can cause a burning sensation and turns the skin red if it comes into contact with the skin. If the skin is exposed to it for a long time, it can cause sore oozes or other damages to the skin tissue. It can cause hair loss if it comes into contact with the scalp. Drinking it can cause pain in the mouth and throat and can lead to stomach pain, nausea, and a state of despondency. It can lead to the following symptoms according to the concentration. The actual symptoms may differ depending on the person.

Concentration(ppm)	Symptom
5	It has a characteristic smell.
6-20	It causes eye irritation or the problem in the respiratory system.
40-200	It causes headaches, nausea, loss of appetite, and airway, nose, and throat irritation.
400	It irritates the neck.
700	It can damage the eyes.
1700	It causes coughing and trouble breathing. It causes momentary trouble breathing.
2500-4500	Even brief exposure can be fatal.
5000 or higher	It can lead to death due to respiratory arrest.

Since ammonia is a toxic gas, most countries control it by establishing the allowable concentration limit in workplaces or daily life. The allowable concentration is classified into the short-term exposure limit (STEL) for the case of 15-minute contact and the time-weight-average (TWA) concentration for an 8-hour work period. For ammonia, STEL is 35 ppm, and TWA is 25 ppm. It is managed according to the Occupational Safety and Health Act, and in the United States, the allowable concentration is managed by the regulation of the Occupational Safety and Health Administration (OSHA).

3.4.3 Corrosion

Gas carriers transport gases by liquefying them with the temperature or pressure control. Therefore, it is necessary to manufacture a gas tank to withstand the pressure with steel that does not break even at low temperatures. An ammonia carrier is built in a similar specification as LPG carriers, and the tanks in the carrier are manufactured with steel[3] to withstand the boiling points (-42 ℃ for LPG and -33 ℃ for ammonia) and pressure at the same time. If a tank is stressed by gas pressure, the affected metal structure is deteriorated to be corroded. As a result, cracks can occur which may cause gas leakage. It is important to prevent the deterioration of strength and toughness after the post-weld heat treatment (PWHT) to remove the stress generated after welding the steel material for tank manufacturing.

Ammonia vapor in contact with moisture can corrode copper, zinc and its alloys, as well as rubber and plastics. Heavy metals such as silver, gold, mercury, and thallium must be handled with care since they can form explosive compounds.

3.4.4 Gas Vapor Pressure

When the ammonia liquid vaporizes, its volume expands more than 850 times, causing a pressure increase in the closed facility. The design tank pressure is inevitably increased if an ammonia fuel tank applies the independent tank type C, and the tank pressure is controlled only by pressure.

3.4.5 Fire and Explosion Risk

Although ammonia's fire risk is low, it increases if flammable material like oil is present. Ammonia can generate an explosive compound if it is in contact with a strong oxidizer like chlorine and hypochlorite bleach.

3.4.6 Odor

Ammonia has a very strong, unique odor, and its odor threshold is 5–50 ppm in the air. It is no longer used as a refrigerant in refrigerators as it did in the past because of an irritating order. Conversely, the strong odor makes it easy to detect its leakage.

[3] POSCO has completed a test for ammonia on high manganese steel developed for LNG.

4 Safety Features of Ammonia Handling Facilities

4.1 General

○ Ammonia has been used on land for various purposes by industries. The regulations on safe ammonia handling include the "High-Pressure Gas Safety Control Act," "Rules on Occupational Safety and Health Standard," and "Toxic Chemicals Control Act."

○ Land facilities cannot be directly applied to ships, considering differences in ship structure and arrangement. Therefore, we reviewed the appropriateness and replacement requirements for application to ships after understanding the purpose of on-land safety standards.

4.2 Marine Transport of Ammonia

Millions of tonnes of ammonia are distributed worldwide through liquefied gas carriers equipped with low-temperature pressure or low-temperature tank subject to Ch 5, Pt 7 of the Rules for the Classification of Steel Ships (IGC Code). As described above, ammonia is generally consumed for agricultural or industrial purposes. Although it can be directly delivered to consumers, it is often unloaded to dedicated ammonia storage at ports.

4.2.1 Low-Temperature Transportation

According to the existing hull strength analysis method, the independent tank type A usually applied to low-temperature transport of ammonia refers to a tank designed according to the accredited standard. The design vapor must be less than 0.07 MPa if the tank is mainly constructed in a flat structure. A complete secondary barrier must be installed, and low-temperature steel that can withstand -45 through -50 ℃ is typically used if the cargo temperature is less than -10 ℃ at atmospheric pressure.

4.2.2 Pressurized Transportation

The independent tank type C is used for pressurized ammonia transportation; it is the simplest format. The design pressure is usually 1.75 MPa, which is equivalent to the propane saturation pressure. It has a volume limitation and is costly because it is heavy. Since it is a high-pressure application, there is no need to consider the re-liquefaction facility.

4.2.3 Semi-Pressurized, Semi-Low-Temperature Transportation

It is classified as the independent tank type C under the IGC Code. The design pressure of semi-pressurized transportation is 0.5–0.7 MPa. Since the design pressure is low compared to pressurized tanks, the thinner steel that can withstand –10 ℃ is used.

4.3 Ammonia Above-Ground Storage Facility

The ports must have the bunkering facility to service conventional ships that do not transport ammonia but use ammonia fuel. About 120 ports worldwide have the storage facilities to import and export ammonia, and they can be used for bunkering.

The challenge to overcome for ammonia bunkering is a large ammonia discharge. Although LNG and LPG are also classified as GHG, they are not particularly harmful unless they contact the human body; they have no color or odor. However, ammonia has a strong odor and causes ultrafine dust when it is released into the air; it can be a new pollution source in ports unless special measures are implemented. Therefore, the ports must seek additional measures to prevent major leakage during bunkering by referring to the above-ground storage facilities' safety measures.

Figure 5 Ammonia Storage Tank <Source: LOTTE FINE CHEMICAL >

4.3.1 Technical Guidelines on Anhydrous Ammonia Storage

The KOSHA has issued the "Technical Guidelines on the Storage of Anhydrous Ammonia" that establishes requirements for the toxic anhydrous ammonia storage to prevent serious industrial accidents caused by ammonia leakage. The guidelines are applied to the design, inspection, location selection, and installation of facilities that store liquid anhydrous ammonia. Anhydrous ammonia refers to anhydrous ammonia gas or liquid and excludes ammonia dissolved in water.

4.3.2 Safety Measures in the Guidelines

- Storage facilities

  - The storage tank capacity is in the range of 500 to 3,000 tonnes when stored in an old container at a non-low-temperature in consideration of economy and safety. A large capacity of 5,000 tonnes or more, typically 20,000 to 35,000 tonnes, is used for low-temperature storage.

  - Storage facilities are laid out with consideration to the wind direction to minimize the effect of ammonia leakage.

  - The storage facilities must be installed in a place where operators can easily access them for operation inspection and maintenance.

  - They must be installed far enough from other process facilities to minimize potential damage from external impact or leakage of explosion and fire corrosive materials.

  - All storage tank nozzles must be flange type and must be installed on the manhole cover or on the top of the storage tank.

- Materials of ammonia storage facilities

  - The design tensile strength of the steel plate must not exceed the maximum allowable value.

  - Copper and copper alloy materials must not be used.

  - It is necessary to conduct a 100 % non-destructive test of welded joints of storage facilities.

  - 100 % magnetic particle inspection must be conducted before the internal welding part's operation and the areas where temporary attachments were installed.

- The welded area where the nozzle is attached to the main body must be subjected to ultrasonic inspection.

- The acoustic emission test must be carried out during the storage tank test period.

- After the successful non-destructive inspection, PWHT must be performed on the weld joint.

○ artificial barricade[4]

- Artificial barricade to prevent leakage must be installed around the storage tank, and the effective capacity of the oil fence must be calculated according to the KOSHA Guide, "Technical Guidelines for artificial barricade Installation."

- The material for the artificial barricade and its inner bottom must be able to prevent liquid ammonia penetration, and the cross-section area must be minimized to suppress the vaporization of leaked ammonia.

- Installation of the facility to collect liquid ammonia leaked into the oil fence or transport it to another area must be considered in preparing the emergency situation of liquid ammonia leakage.

- Drainage facilities must be installed to prevent the accumulation of rainwater inside the oil fence.

○ Pipeline

- The pipeline must be installed on the ground considering the mechanical damage, corrosion, and fire.

- All pipes must have the indication that they are processing ammonia.

- The edge of the storage tank's liquid ammonia inlet pipe must be higher than the maximum liquid level of the storage facility to prevent backflow of liquid ammonia due to the inlet pipe's rupture, etc. If the edge of the liquid ammonia inlet pipe is to be lower than the storage facility's liquid level, a hole must be made in the upper section of the liquid ammonia inlet pipe inside the storage facility to prevent backflow.

- An emergency shut-off valve with a remote control must be installed in the liquid ammonia discharge pipe to prevent ammonia leakage due to pipe rupture.

[4] An oil fence is a wall made of concrete or others when installing storage tanks. It prevents leakage out of the facility due to earthquake damage, etc.

- The number of joints must be minimized. Welded joints are preferable when connecting pipes, and flange joints must be used only for connection with devices such as storage containers.

- Thermal expansion safety valves must be installed in the pipeline for liquid ammonia.

- The material used for piping must not cause brittle fracture even at temperatures below 0 ℃.

- Valves must generally be a flange type, and the carbon steel welded valves must pass the impact test.

○ Ammonia transport

- The pump's discharge-side pipe must be installed to circulate the minimum flow line to the storage tank according to the pump and operation characteristics.

- The pumps must be interlocked to stop if the liquid level of the storage facility is low, or the pressure on the discharge side of the pump is low.

- The liquid outlet line from the tank to the pump must be kept as short as possible and sufficiently cooled.

○ Electrical equipment

- A ventilation facility must be installed in areas equipped with electrical facilities such as the ammonia compressor and building to discharge ammonia leakage into the atmosphere.

- Motors that expose copper to the outside must not be used.

○ Field safety equipment

- Anti-collision walls must be installed to prevent damage to pipes or ammonia handling equipment from external impact.

- A cleansing facility must be located around the ammonia facility.

- The following safety equipment must be provided at the site for immediate use:

(A) Gas masks used when people enter ammonia storage areas.
(B) Two sets of lifesaving breathing apparatus.
(C) Emergency and lifesaving protective clothing
(D) Plastic or rubber gloves and boots
(E) Safety goggles

(F) First-aid box

○ Employee education

- Ammonia and liquefied gas characteristics
- Risk and result of ammonia liquid and gas leakage due to careless equipment handling
- Actions when ammonia is leaked
- Proper use of protective equipment, fire extinguishers, and gas masks

○ Operation

- Storage tank's oxygen content should be reduced to within 0.025 % of the capacity before injecting ammonia into the storage tank.
- In order to remove oxygen as much as possible while minimizing ammonia loss, internal air should be replaced with water first and again, water with nitrogen before injecting ammonia. The residual moisture must not exceed 100 ppm.
- Check the oxygen concentration in liquid ammonia at least once a month and confirm that it does not exceed 2.5 ppm by mass.

○ Shutdown

- When shutting down the ammonia storage facility for inspection, discharge the liquid ammonia as much as possible using a normal pump first and completely discharge the remaining liquid using a transport method by pressure difference.
- Draw in the air at the lowest point and release ammonia gas at the vessel's highest point.
- Although the risk of ignition is generally low, inject nitrogen instead of air into the container if any risk is expected.
- Do not perform the ammonia/air replacement in the event of lightning.

4.4 Ammonia as a Vehicle Fuel

Since pure ammonia has similar thermochemical properties as propane, the main component of LPG, it is possible to use it for internal combustion engines like an automobile engine. However, since ammonia has a high ignition point and a slow combustion rate, there is still a technical limitation to be used as fuel by itself. Therefore, the development has focused on engines that mix two fuels, such as gasoline-ammonia and natural gas-ammonia.

Korea has developed a car that uses ammonia as a fuel for the third time in the world and successfully tested it. It was remodeled to use a 7:3 mixture of ammonia and gasoline, resulting in a carbon dioxide emission ratio reduction from 13.5 % to 3.5 % or less compared to gasoline cars.

4.4.1 Ammonia Emission Reduction

○ Ammonia discharge is reduced by an oxidation catalyst installed at the rear end of the exhaust pipe to secure the cleanness of exhaust gas by blocking the discharge of unburned ammonia.

Figure 6 Ammonia Emission Reduction System

4.5 Comparison With Ship Safety Features

○ The risk and safety features of using ammonia in above-ground storage tanks and automobiles mostly address the protection of the storage facilities and gas leakage as the IGF Code does. In this case, they consider especially the toxicity and corrosiveness.

○ Comparison of the requirements specified by each code for on-land storage tanks and ship's cargo storage tanks shows the following differences:

- The installation environments of storage tanks on land and in ships differ in many factors, such as the space limitation, effect of wind in marine navigation, effect of fire and explosion, and structures around the gas facility (obstruction of the leaked gas dispersion). Therefore, the regulation on safety features required by ships may also differ.

- Requirements for fire protection on land and ships are different. Ships must ensure the separation of flame and fuel tank in a limited space and install cofferdams or A-60 class heat sink to protect tanks from a fire in high-fire hazard areas.

- For the double-walled storage tanks on land for low-temperature ammonia, the insulator must be filled between the inner and outer walls or installed outside the storage tank. Insulators must be non-reactive with ammonia and must not burn in a fire. When constructing the insulator outside the tank, the exterior of the insulator must be protected with the material not corroded by ammonia.

- Installation of the appropriate cleaning system is considered to prevent ammonia discharge from the discharge pipe and vent pipe of the on-land storage tank safety valve to the atmosphere.

○ Comparing the requirements specified by each code for the fuel supplying systems in automobiles and ships shows the following differences:

- Automobiles do not require a sprinkler system for tank cooling. The sprinkler system for cooling prevents the temperature increase inside the tank by radiant heat when the tank is exposed to the outside. The automobile's fuel tank does not need the spray system since it is installed inside or below the automobile and thus is not significantly affected by radiant heat.

- Since automobile discharge leaked gas to the open space, they install ventilation pipes under the chassis to allow natural ventilation instead of forced ventilation. This is because the leaked gas is naturally discharged out of the automobile due to the pressure difference with the outdoor air as the automobile moves. Because of its structure, ships cannot install a ventilation duct under it and thus requires forced ventilation for effective ventilation.

5 Ammonia Fuel Cell and Internal Combustion Engine

5.1 General

Ammonia is used as an energy source in various forms. It is burned directly as the fuel of an internal combustion engine, used directly as a fuel for a fuel cell, or is used as a hydrogen energy carrier in a hydrogen fuel cell.

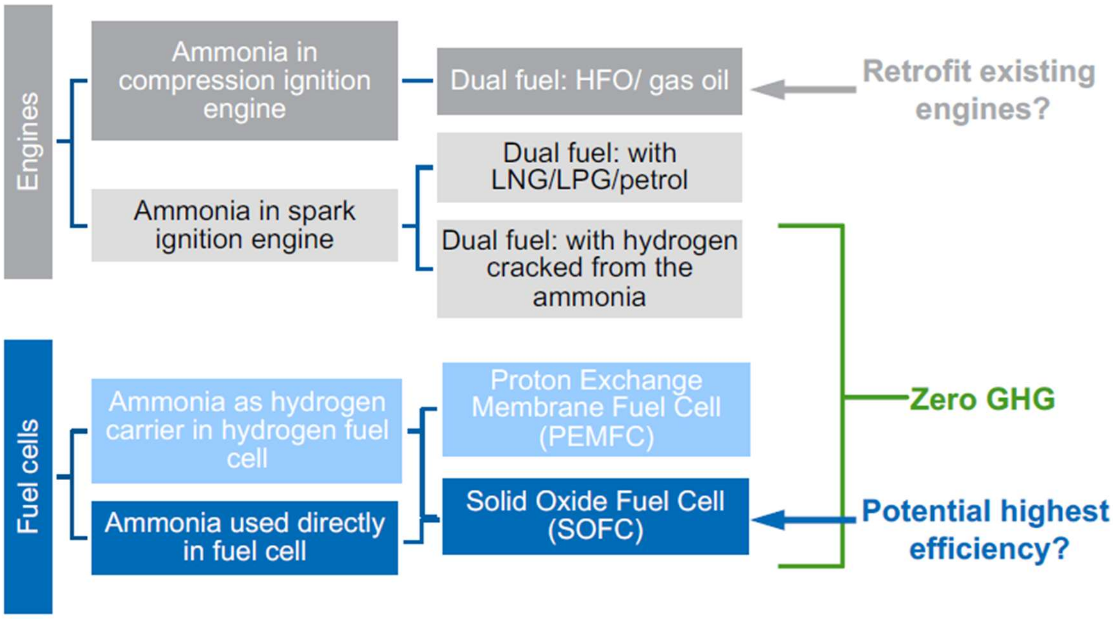

Figure 7 Various Forms of Ammonia Fuel (Source: Ricardo)

Although hydrogen is the ultimate eco-friendly energy source, there are many constraints in the current hydrogen energy supply industry. The main disadvantage is the difficulty of economical storage in large capacity and the long-distance transportation because of the small storage capacity per hydrogen volume. Although storing and transporting hydrogen in a liquid form is the most efficient in terms of energy conservation, the process of liquefying cost of hydrogen is increased in the process of liquefying and maintaining hydrogen is costly, resulting in price increase. Studies on hydrogen energy carriers that change hydrogen into other compound types to increase the storage capacity per volume and reduce the storage cost are ongoing to overcome it.

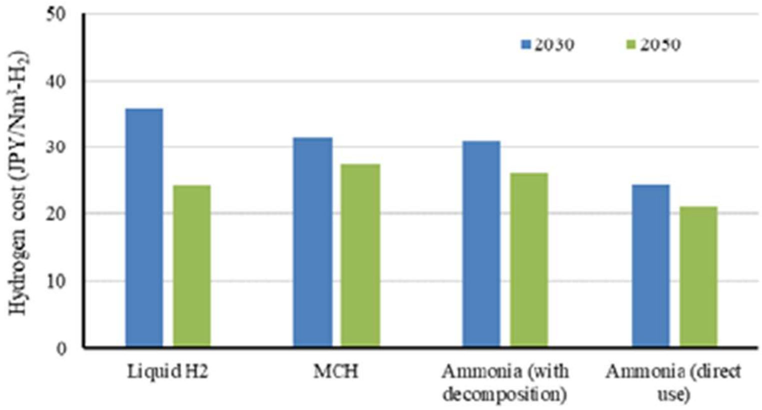

Figure 8 Comparison of Hydrogen Prices According to Production Method

5.2 Fuel Cell

The direct ammonia fuel cell is based on the principle of generating power between the electrodes by directly supplying ammonia gas, which is a fuel for power generation, to an anode installed on one side of zirconia, which is an electrolyte, and air to the cathode on the opposite side. Ammonia fuel leaked from a pipe joint can cause pipe corrosion. It can be solved by developing a special glass to join the ammonia fuel without leakage. The direct ammonia fuel cell is confirmed to have a similar level of power generation characteristics compared to hydrogen fuel cells.

5.3 Internal combustion engine

It is necessary to analyze how ammonia is handled on ships and combusted in reciprocating engines. The industry is currently developing ammonia engines; MAN Energy Solution and Wärtsilä have the roadmaps to implement them by 2022 and 2023, respectively.[5] Dual fuel technology is a proven solution for ammonia combustion. It offers an advantage of enabling gradual adoption of ammonia for ship fuel because of the possibility to use the mixture of alternative and conventional fuels. Moreover, the solutions adopted by commercialized LPG and LNG engines are the beginning point of the safety features and the fuel supply process for ammonia engines.

[5] Shipping News Net (SNN) /July 7, 2020

5.3.1 Analysis of Engines and Fuel Supply System

5.3.2 General

○ MAN Energy Solution and Wärtsilä are currently developing ammonia-fueled engines applicable to commercial ships.

○ This section discusses the risks of ammonia engines installed in ships for navigation based on the currently available information.

○ It focuses on whether the engines offer sufficient safety features in consideration of ammonia's characteristics.

5.3.3 MAN Energy Solution, ME-LGIA (2-Stroke Diesel Cycle Engine)

○ Overview

- The ME-LGIA Engine ("Engine") has no installation reference. Its development is based on the ME-LGIP engine.

  - The design concept of MAN’s 2-stroke ammonia-fueled engine is similar to that of existing engines based on liquid gas injection propane (ME-LGIP, LPG) and liquid gas injection methanol (ME-LGIM). The concept of the LGIM engine is based on that of the LGIP engine. The development of the LGIM engine addressed several problems related to ammonia: corrosion, toxicity, and low flammability.

- The Engine is a two-stroke diesel cycle engine using ammonia. Since ammonia has a low-autoignition temperature and a low-combustion rate, the ammonia engine uses MDO/HFO as the pilot oil.

- The fuel is supplied in a liquid state at 70 bar to up to the Engine connector, pressurized to 600–700 bar through the booster fuel injection valve, and injected into the cylinder. Therefore, the fuel supply system is configured at a relatively lower pressure than the ME-GI engine.

- The exothermic ammonia combustion that generates nitrogen and water can be explained in the following reaction:

$4NH_3 + 3O2 \rightarrow 2N_2 + 6H_2O + \text{Heat}$

- It is possible to reduce the NOx discharge with the exhaust gas post-processing technology and the SCR system. NH_3, a reducing agent, is injected into the exhaust gas to generate only nitrogen and water as waste.

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

$6NO_2 + 8NH3 \rightarrow 7N_2 + 12H_2O$

- Since ammonia can corrode alloys with a 6 % or higher concentration of copper, copper alloy, nickel, and plastic, the fuel system using ammonia must avoid such substances. The sealing lining of an ammonia Engine is made of Teflon.

○ Fuel supply

- The ammonia fuel service tank is installed to separate the fuel/cargo tank from the pollution source.

- The liquid fuel supply system (LFSS) generally consists of the pump, compressor, heat exchanger, filter, and instruments. The carburetor is excluded since the liquid ammonia is used as fuel. A pump pressurizes ammonia to about 70 bar, and a heat exchanger heats it to the temperature range (25 ℃–55 ℃) required by the Engine.

- The fuel valve train (FVT) is a group of valves, such as double shut-off and discharge valves, vent valves, nitrogen supply valves, and pressure control valves, and various sensors. The IGF code specifies the valve group to shut off fuel effectively and discharging it in abnormal conditions.

○ Safety features

- The safety features of the Engine are the same as those of a ME-GI engine. It applies the following specifications, most of which are required by the IGF Code:

* Double shut-off and discharge valves: the valves installed in the fuel supply pipes block double valves and vents the pipes between them to separate the fuel supply pipes from the Engine to block the fuel supply.

* Main fuel valves: the valves block the main supply pipe to prevent the fuel supply at the time of abnormal conditions, such as gas detection and ventilation failure.

* Ventilation: the separate mechanical ventilation system with the capacity of

ventilating 30 times per hour ventilates the enclosed gas pipe, including the space around the valves and flanges.

* Nitrogen purging system: a nitrogen purging system is installed to discharge residual gas in the fuel pipeline and tanks. The fuel pipeline's purging is used to discharge residual fuel in the pipeline when the main fuel valve is closed, while the tank purging is used to make the tank free of gas for inspection and repair.

* Double pipes: the fuel pipes in the enclosed area are enclosed by an outer pipe or duct to prevent gas from being discharged into the area even when gas is leaked from the fuel pipe. A gas detector and enforced ventilation are installed between the inner and outer pipes to detect and discharge leaked gas.

- Pressure relief valve (PRV) and leak gas detection devices to prevent explosion are installed in the same way as the LNG-fueled ME-GI engines' safety features.

○ Additional considerations: while the Engine has no additional or different features from a ME-GI engine, it is necessary to review the following matters in consideration of the ammonia fuel characteristics:

- Fuel supplied in liquid state:

* Discharge of liquid ammonia into a bleed pipe (connection to the vent mast not feasible)

* Purging of liquid or gas with a high specific gravity during nitrogen purging (consideration of purging pressure and capacity)

- Ammonia being toxic and becoming the cause of atmospheric pollution when discharged as it is:

* Since ammonia is toxic, it must never be leaked into the area where the crew may be around.

* Ammonia is one of the causes of ultrafine dust. Therefore, it must never be released in more than a certain concentration into the atmosphere.

6 Analysis of IGC Code/IGF Code Requirements

6.1 General

○ The IGF Code has been applied to ships using fuel with a low flash point since January 1, 2017.

○ A fuel with a low flash point refers to a liquid fuel having a flash point lower than gas or fuel oil permitted by SOLAS II-2, including LNG (gas fuel), methyl alcohol/ethyl alcohol (liquid fuel), LPG (gas or liquid fuel[6]), or ammonia.

○ Although the IGF Code was developed for the use of fuels with a low flash point, the detailed specifications are currently applicable to LNG. The IMO has developed the detailed requirements for methyl alcohol/ethyl alcohol (to be issued as MSC Circular) and is currently developing detailed fuel cells and LPG requirements; yet it has no development plan for ammonia.

○ IGC Code 16.9 does not allow the use of cargo identified as a toxic product.

6.2 IGC Code Requirements Applicable Due to Ammonia Properties

The following requirements are specifically applied because of the anhydrous ammonia cargo's characteristics and the requirements may be used for the IGF Code revision.

6.3 IGF Code Requirements

○ The concept of requirements in the IGF Code can be checked for the purpose of requirements applied to all gas and low flash point fuel and the ships' functional requirements. Functional requirement refers to the minimum functions required by ships from the safety, environmental, and performance aspects. They are the basis of the ship design safety concept. The detailed requirements for ammonia must be developed to meet the minimum functional requirements in consideration of the ammonia characteristics.

○ The detailed requirements for the LNG fuel to meet the above functional requirements can be summarized as follows:

1. "10. Power Generation including propulsion and other gas consumers" of IGF Code specifies the detailed requirements related to ensuring the performance and safety reliability of the main and auxiliary engines. It specifies the requirements of the internal combustion engines, boilers, and gas turbines for each engine type.

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[6] LPG can be gas or liquid state depending on the engine since it becomes a liquid state if pressurized at room temperature.

* The requirements related to the internal combustion engine include (1) the safety system to prevent explosion due to unburned gas in the exhaust gas (explosion relief devices), (2) the safety device against explosions caused by unintended gas leakage in the engine (explosion relief system), (3) monitoring of ignition failure or incomplete combustion and shutting off the gas supply, and (4) monitoring of gas leakage in the engine (gas detection system).

* The requirements related to the boiler include (1) preventing fuel gas accumulation in the combustion chamber and flue, (2) shutting off the gas supply in case of abnormal ignition, and (3) purging unburned gas in the boiler combustion chamber and gas supply pipe.

* The requirements related to the gas turbine include (1) the safety system against explosion caused by unburned gas in the exhaust gas (explosion relief system), (2) installation of the gas turbine in a separate airtight area according to the emergency shutdown principle, (3) redundant ventilation requirement (2 units with 100 % capacity), (4) monitoring of incomplete combustion (gas detection system) and shutting off the gas supply, and (5) monitoring of exhaust temperature and automatic shutdown system at the time of high temperature.

2. The detailed requirements related to “minimize the risk of fuel hazards through ventilation, detection, and other safety measures” are the ventilation and gas detection requirements of potential gas leaking areas. The requirements address the areas requiring ventilation, ventilation capacity, arrangement of the ventilation inlet and outlet, and installation of the airlocks. The detailed requirements are described as follows:

* The process from supplying fuel to the engine is <manifold → fuel tank → connection of the fuel tank with the valves and fuel supply pipes (tank connection area) → fuel supply equipment such as the compressor and heat exchanger (fuel preparation room) → gas valve unit → engine>.

* The parts with a high possibility of gas leakage include bunkering manifolds, flange connections between equipment, tanks and pipes, valves, tanks (excluding the independent tank type C since they are manufactured for no leakage), gas engines (excluding the engines manufactured with the concept of gas safety engine zone (double pipes)), damaged parts of fuel pipes (enclosing of the outer wall of the fuel pipe with pipe or duct in consideration of damage when the fuel pipe passes through an enclosed zone).

* Therefore, a gas detection system and an exhaust type forced ventilation system must be installed to prevent the accumulation of leaked gas in the areas with a high possibility of leakage.

* The areas with a high possibility of leakage include the tank connection area, the area with the gas fuel engine protected by the emergency shutdown, the fuel preparation room, and the double pipes and ducts that enclose the fuel supply location and the fuel pipe. Each area is required to install an exhaust ventilation system with a ventilation capacity of 30 times per hour (two minutes per ventilation based on a simple calculation using the capacity). The following safety measures are required for leakage:

* Leakage behavior and safety measures in the fuel preparation room for LNG

① Assuming that the liquefied gas is leaked through the fuel pipe, the liquid gas (-160 °C) is rapidly vaporized as it flows down to the floor.
② Since LNG is heavier than air from the initial stage of vaporization to -100 ℃, it settles to the floor and condenses the steam in the air to form a steam cloud that is visible to the naked eyes.
③ As the temperature gradually increases, the volume ratio of gas to liquid expands 600 times, and the gas is dispersed as it rises upward. The concentration of the gas decreases, reaching 5 % to 15 % of the flammable atmosphere.
④ Since the exhaust ventilation system is continuously operated in the fuel preparation room, the leaked gas is discharged to the open deck through the exhaust duct. Although the IGF Code does not specify the detailed requirements for ventilation arrangements, considering the fact that LNG accumulates at the top of the area as gas is dispersed, the inlet of the duct is placed at the top of the area.

⑤ An alarm is activated at 20 % of lower explosive limit (LEL) when the gas detector detects a gas leak, and the tank valve is automatically shut off at 40 % of the LEL, stopping the fuel supply.
⑥ While the IGF Code specifies the gas detector to be located in a place where gas can accumulate and at the ventilation outlet side, it also specifies the physical smoke test or gas dispersion analysis to find the best arrangement. Considering that LNG gas accumulates at the top of the area as it disperses, the detectors are installed at the top of the area and on the duct's inlet side.

3. A detailed requirement related to "prevent power loss with safety measures" is the fuel supply system's redundancy.

* The propulsion engine and power generation engine in the engine area protected by the emergency shutdown are required to be installed separately in two zones,

and the power is not lost even if the fuel supply to either zone is cut off.

* The fuel supply system requires complete redundancy across the entire system from the tank to the engine. (The independent tank type C allows one tank but requires only the tank connection area to be separated.)

4. The detailed requirements related to “minimize the impact of danger zone on safety” specify the following requirements for the danger zone:

* It defines the range of the danger zone and restricts the installation of electrical equipment in the danger zone.

* It specifies the minimum distance requirement between the ventilation opening in the danger zone and the opening in the non-danger zone to prevent the inflow of gas from the danger zone.

* Access between the danger and non-danger zones is regulated to be allowed through the airlock.

* It requires the installation of gas detection and exhaust enforced ventilation systems in the danger zone.

* It requires the safety functions, such as the alarm and shutting off the gas supply system when gas leakage in a danger zone is detected.

5. For the detailed requirement related to “minimize equipment installation in the danger zone and install only approved, safe equipment,” IGF Code 14. Electrical installation requires compliance with IEC 60092-502 for the electrical equipment installed in a danger zone.

6. The detailed requirement related to “prevent the unintended accumulation of gas” specifies the requirements for leakage prevention, ventilation, gas detection, gas-exposed unit arrangement, and opening of the non-danger zones.

* The engine area's arrangement concept specifies the concept of arranging two types (gas safety engine area and engine area protected with the emergency shutdown system).

* It specifies the fuel pipe area enclosed by double pipes to allow penetration of the fuel pipe.

* It specifies the requirements for ventilation and gas detection mentioned in Requirement 2 above.

* It specifies the structure and height requirement of the ventilation mast.

* It specifies the minimum distance between the gas-leaked part and the opening in the non-danger zone.

7. The detailed requirement related to “prevent equipment from external damage” includes protecting the tank and the fuel pipe.

* It specifies the fuel tank’s minimum distance from the side and bottom of the ship to prevent damage to the fuel tank when the ship collides.

* It specifies the fuel installed on open decks and ro-ro spaces to be protected with protective covers.

8. The detailed requirement related to “minimize flame source in danger zones” is related to Requirement 5 above and restricts the use of mobile devices such as mobile phones, flashlights, and cameras that can be the ignition source in danger zones.

9. The detailed requirements related to “prevent ventilation from the fuel tank to the atmosphere and leakage from the fuel containment, supply, and receiving units” include the tank/pressure control inside the tank, secondary barrier, purging of the fuel and bunkering systems, and tank connecting area.

* PRV is installed in the tank to prevent the fuel tank pressure from exceeding the design pressure due to the vaporization of the liquefied fuel during bunkering or navigation. The gas inside the tank is discharged into the atmosphere when the tank pressure reaches the PRV set pressure. IGF Code 6.9.1 prohibits the fuel gas emission to the atmosphere except in emergencies and requires the means to control the pressure and temperature inside the tank to prevent the PRV opening (re-liquefaction, combustion, pressure accumulation, or cooling).

* The fuel containment facility must be equipped with a secondary barrier to prevent leakage from the fuel containment, supply, and receipt systems (except for independent tank type C).

* The fuel pipes must be welded, and the fuel pipe passing through the enclosed area must be enclosed with a double pipe or duct.

* Tank connections with a high probability of leakage must be enclosed in a separate space (tank connection zone) unless installed on an open deck.

10. The detailed requirement related to “design, manufacture, and install the pipe system, containment, and relief vale appropriately” includes the tank and pipe

material selection and test, thickness calculation, stress analysis, prevention of excessive stress caused by heat expansion, and capacity and layout of relief valves.

11. The detailed requirement related to “ensure safe and reliable operation of the engine and parts” specifies the tank and system design requirement.

* It specifies the requirements for the fuel tank’s secondary barrier design load and structural analysis.

* It specifies the requirements for the pipe design condition, thickness, assembly, and joint method.

* It specifies the requirements for the redundancy of fuel supply and the outer pipe design of the fuel supply pipe.

* It specifies the requirements for the gas leakage, incomplete combustion, and explosion prevention of the internal combustion engine, boiler and gas turbines.

12. The detailed requirement related to “secure redundancy to prepare for fire or explosion” includes the boundary between the fuel tank areas and the redundancy and boundary requirement of the engine area protected by the emergency shutdown system.

* Two fuel tanks must be installed in an area separated by the A-60 class heat sink or cofferdam.

* Two engines must be installed in the separated zones protected by the emergency shutdown system.

* The Class A engine area and the high-risk fire area must be separated by the Class A-60 heat sink and cofferdams.

13. The detailed requirement related to "install the control, alarm, monitoring, and blocking systems for safe operation" specifies the safety system's operation for the fuel tank, fuel supply, gas/fire detection, and abnormal status.

* It requires the installation of the system to prevent fuel tank flooding and the pressure monitoring system.

* It specifies the alarm requirements for abnormal conditions during bunkering.

* It specifies the requirements for the location of the gas detector installation and the detected concentration.

* It specifies the requirements for the safety system that must be operated in abnormal conditions.

14. The detailed requirement related to “install the fixed gas detection system in the area vulnerable to gas leakage” is related to Requirements 2 and 4 above. It specifies the zones, quantity, and installation location of the fixed gas detection system.

15. The detailed requirement related to "install the fire detection, fire extinguishing, and firefighting systems" specifies the fire detectors' installation location, the firefighting structure, and the fire extinguishing system installation.

* It specifies the heat dissipation structure requirement between the fuel preparation room, the fuel storage area, the Class A engine area, and the high fire risk area.

* It specifies the requirements for a water spray system for tank cooling, a fire extinguishing system with dry chemical powder, and a fire detection system.

16. The detailed requirement related to “test operate and maintain/repair for the safety, availability, and reliability of the fuel systems” specifies the test and inspection of the safety system operation related to functions required by the fuel system.

17. Although the detailed requirement related to “generate the technical documents to confirm that the systems and components comply with the rules and standards” is not an IGF Code requirement, it is the KR requirement that specifies the drawing and data submittal.

18. The detailed requirement related to “take measures to ensure that a single failure does not deteriorate the safety and reliability of the system” specifies redundancy of the fuel supply and gas detection systems.

* In a single fuel system, the fuel supply system must be arranged so that complete redundancy and separation are provided throughout all systems from the fuel tank to the fuel consumption system.

* Double gas detection systems must be installed in the engine area protected by the emergency shutdown system, the area between the double pipes, the tank connection area, and the fuel preparation room.

* Two engines must be installed in the separated zones protected by the emergency shutdown system.

*

6.3.2 Interim Guidelines on Ships Using Methyl/Ethyl Alcohol as Fuel

○ The safety regulation added to the LNG detailed requirements in consideration of the methyl/ethyl alcohol fuel characteristics is described based on MSC.1/Circ.1621 Interim Guidelines for the Safety of ships Using Methyl/Ethyl Alcohol as Fuel.

1. The detailed requirements related to the "fuel tank" are provided in “5. Ship design and arrangement” and “6. Fuel containment system.” Since methyl/ethyl alcohol, unlike cryogenic LNG, exists in a stable liquid state at room temperature, the regulation for it is simpler than that for LNG.
2. The detailed requirements related to the "material and pipe design" are provided in “7. Material and general pipe design." Like the fuel tank, it does not consider the cryogenic temperatures and only considers the corrosion due to fuel.
3. The detailed requirements related to "bunkering" are provided in “8. Bunkering” and specify the following in consideration of the fuel characteristics.

   * They include emergency showers and eyewash stations to be installed near areas that can come into contact with fuel.

   * The ship's fuel hoses must be stored on an open deck or in a storage room with an independent mechanical exhaust ventilation system and ventilated at least six times per hour.

   * Means should be provided to drain the liquid from the bunkering piping after the completion of the bunkering.
4. The detailed requirements related to fire extinguishing are provided in "11. Fire safety" and require installing an alcohol-resistant fire extinguishing system at the fuel tank bottom, in the bunkering station, etc.

6.3.3 Detailed Requirements Requiring Correction and Supplementation for Ammonia Application

○ As mentioned above, the detailed regulations of the IGF Code are based on LNG, but ammonia is considered to be more similar to methyl/ethyl alcohol than LNG in terms of toxicity and corrosiveness.

- The most concerning factor among the ammonia’s properties about human safety is toxicity. For the ammonia's toxicity, the requirements for personnel protection should be carefully reviewed with reference to the IGC Code and methyl alcohol fuel requirements.

- Ammonia is corrosive. Ammonia vapor in contact with moisture can corrode copper, zinc and its alloys, as well as rubber and plastics. Moreover, heavy metals such as silver, gold, mercury, and thallium must be handled with care since they can form explosive compounds. The industry recommends 6 % or higher in consideration of corrosion when using nickel steel.

- Since ammonia's autoignition temperature is very high at 651 ℃ and the lower flammable limit (LFL) in the air is significantly high at 15 %–28 %, there is a high risk of incomplete combustion. It means that the possibility of the ammonia slip is high, and it is considered that there may be unintended emissions. Ammonia must be handled with special care since, if it is discharged as it is, it is corrosive when it encounters moisture in the sea or generates ultrafine dust by reacting with NOx.

- Ammonia is toxic and has a strong odor, so it is not free from complaints in the local community. Therefore, this should be considered when bunkering.

○ When considering the aforementioned ammonia characteristics, the following detailed requirements do not apply directly to ammonia fuel unless additional requirements are applied.

- IGF Code requirements related to toxicity

5.4.1 Layout of Engine Area

• The layout concept of the engine area is the "gas safety engine area" and "engine area protected by emergency shut off." The "engine area protected by emergency shut off" is premised that the leaked gas must be effectively discharged when gas is leaked in the engine area. Although ammonia vapor is not heavy and is not difficult to ventilate, the leaked gas severely affects the human body. Therefore, it is necessary to exclude the "engine area protected by emergency shut off" in an engine area's layout concept.

- IGF Code requirements related to corrosion

6.7.2 Ventilation Pipe of Fuel Tank's Pressure Relief Valve

• Ammonia released from the fuel tank's pressure relief valve is discharged to the vent mast through the ventilation pipe. Since LNG gas is lighter than air, it is discharged into the atmosphere through the vent mast even without pressurization. Although ammonia can be discharged into the atmosphere in a dry state, it can get heavier when it reacts with moisture and settle down offshore; it can cause corrosion on the ship. Moreover, exposed ammonia can be a catalyst to generate ultrafine dust. Therefore, it is necessary to provide countermeasures to it.

*Note: In the US CFR regulations, the maximum allowable set pressure (MARVS) is different from the IGF Code by applying a stress factor.

- IGF Code requirements related to odor and toxicity

8. Bunkering

• Although the bunkering manifold is highly vulnerable to gas leakage, its requirement does not address matters related to gas leakage detection. In the case of LNG, the gas detector is less effective because the leaked liquefied gas vaporizes and diffuses to the upper section, and the leaked LNG condenses surrounding air and forms a vapor cloud that can be confirmed with the naked eyes. Although it is easy to identify ammonia leakage because of its peculiar smell, it may cause civil complaints even at a concentration that does not affect the human body if it is leaked from a port. Therefore, a regulation on emission is required even for bunkering. It is necessary to block ammonia emissions above a certain concentration that harms the human body.

• Ammonia has similar properties to LPG. The LPG transport system in an on-land LPG base uses a loading arm and has the gas detection and emergency shutdown systems for gas leakage. However, no emergency separation system[7] is installed. Therefore, while the requirements should cite the LPG transfer system requirements, installing an emergency separation system should be considered to protect the transfer system and manifold from excessive loads and prevent ammonia leakage.

• The risk of gas fuel is maximized in bunkering operations. Therefore, the requirements should consider the safety system for bunkering facilities and training on crew member safety during ammonia bunkering work.

• Since LNG is cryogenic, ammonia bunkering is likely to be less risky than LNG bunkering. Therefore, the requirements currently applied to LNG can be applied to ammonia, provided that those not applicable to ammonia (rollover, cryogenic requirements, etc.) are excluded, and those specifically needed for ammonia (safety measures for people in case of ammonia leakage) are added.

[7]It is a device that safely separates the transfer system from the ship so that the load applied to the transfer system and manifold does not exceed the design load due to the ship's excessive motion. An emergency separation system is installed in the LNG transfer device.

13. Ventilation

- Measures to vent ammonia include either diluting the concentration of ammonia to less than 10 ppm, collecting the ammonia, or extending the vent mast to a safe height. If an unpleasant odor is generated from the flue due to the ammonia combustion, the exhaust gas should be heated to increase the exhaust gas buoyancy.

- IGF Code requirements related to fuel storage temperature

6.4 Storage of Liquefied Gas Fuel

- The design temperature of the LNG fuel storage tank must be lower than -83 ℃ since the critical temperature of LNG is -83 ℃. Therefore, the IGF Code only considers the cryogenic fuel temperature in the fuel tank (-55 ℃ or less).
- Ammonia has a fuel temperature of -33 °C in atmospheric pressure and room temperature when a pressure tank is used. Therefore, extending the ammonia fuel tank's design temperature to higher than the temperature range specified in the IGF Code is necessary.

- Applicable IGC Code requirements: 14. Personnel Protection[8]

14.2. Protective equipment

- Protective gears including eye protection in consideration of the characteristics of the transported cargo must be available to protect crew members engaged in cargo work.

14.3 Emergency equipment

- Stretchers must be stored in an accessible location to rescue the injured.
- Oxygen resuscitation device, etc.

14.4 Safety Protective equipment

- Three or more sets of safety gear in addition to the firefighter's equipment should be stored.

14.5 Personnel protection regulations for individual cargoes

- Respiratory protection and safety glasses suitable for emergency escape should be available for all crew members.
- Installation of decontamination shower and eye washer

[8] Refer to IGC Code or IBC Code

- Applicable IGC Code requirements: 17.13 Ammonia

• 1. Anhydrous ammonia can cause stress corrosion fracture in containers or manufacturing equipment made of carbon-manganese steel or nickel steel. It is necessary to follow the following countermeasures to minimize the risk of fractures.

• 2. Cargo tanks, manufacturing pressure vessels, and cargo piping systems using carbon-manganese steel must be made of fine-grained steel with a minimum yield stress of 355 N mm or less and actual yield stress of 440 N mm or less. It must conform to one of the following structural or operational measures.

(1) It must use low-strength materials with a minimum tensile strength of 410 N mm or less.
(2) The cargo tank must be heat-treated to remove stress after welding.
(3) The temperature during transportation must be close to the product's boiling point of -33 °C, and in no case must exceed -20 °C.
(4) Ammonia must contain a moisture content of 0.1 % or more by mass, and the captain must have documents confirming it available.

• 3. If using carbon-manganese steel having higher yield stress than that used in Paragraph 2, the finished cargo tanks and pipe system must be heat-treated to remove stress after welding.

• 4. If the process pressure vessel and pipe system in the condensation unit of the refrigeration system use the material specified in Paragraph 1, it must be heat-treated to remove stress after welding.

• 5. The welding rod's tensile and yield properties are the smallest actual values which must be greater than those of the tank or piping materials.

• 6. Nickel steel with a nickel content of more than 5 % and carbon-manganese steel that does not meet the requirements of Paragraphs 2 and 3 can easily cause ammonia stress corrosion fracture, thus must not be used as a container or pipe system for this product.

• 7. Nickel steel with a nickel content exceeding 5 % may be used, provided that the conveying temperature meets the specification of Subparagraph (3) of Paragraph 2.

• 8. It is recommended to maintain dissolved oxygen content of less than 2.5 ppm by mass to minimize the risk of ammonia stress corrosion fracture. The best method for it is to reduce the average O_2 composition to less than the value specified as a function of the transport temperature in the following table before putting the ammonia liquid into the tank.

T (°C)	O_2 (%, v/v)
-30 and below	0.90
-20	0.50
-10	0.28
0	0.16
10	0.10
20	0.05
30	0.03

Oxygen percentages for intermediate temperatures may be obtained by direct interpolation.

6.3.4 Application of Risk Assessment of Ammonia Fuel

○ The detailed requirements of the IGF Code specify only for LNG and methyl/ethyl alcohol. For other fuels, it specifies fulfilling the purpose and functional requirements of the IGF Code, securing the same safety level.

○ The method for verifying the fulfillment of functional requirements and ensuring the same safety level is a risk assessment and risk-based approval. Therefore, it is necessary to identify all risk factors of ammonia fuel, perform a risk assessment, and prepare the risk-based approval. In this case, the approval criteria may differ since the risk assessment scope is wide, and the assessment results may be different for each project. Therefore, this study's final goal is to reduce the number of items required for risk assessment by creating reliable and consistent, detailed criteria.

○ In the case of LNG fuel, the following items require a risk assessment:

- 5.10.5 Drip tray (Determining the drip tray capacity)

- 5.12.3 Airlock (Confirming that gas is not discharged into the gas safety areas even during the accident in the gas danger zone)

- 6.4.15.4.7 Accident design criteria (Determining the accident scenario according to the risk assessment)

- 8.3.1.1 Bunkering area (Risk assessment and enforced ventilation in case of enclosure or semi-enclosure)

- 13.4.1 Tank connecting area (Change of the ventilation capacity according to other explosion preventive measures)

- 15.8.1.10 Additional gas detection systems (Installation of the gas detector in the ventilation inlet of the accommodation area and engine room, if necessary)

- Attachment 4.4 Reduction of accident result classifications

- Attachment 6.8 Determination of additional accident scenarios

○ For methyl/ethyl alcohol fuels, toxicity and corrosiveness must be considered in addition to LNG requirements.

○ Considering the ammonia characteristics, we suggest the following requirements of the risk assessment.

- Applying IGF Code 4.2 for ammonia fuel should include at least the following in the risk assessment scope:

* The risk assessment of using ammonia fuel should be performed to identify possible hazards to the hull, ship equipment, and crew in consideration of the surface characteristics.

* In relation to gas leakage, risk assessment of the following areas should be performed to ensure safety equivalent to that of LNG fuel against gas leakage. Ventilation and gas dispersion analyses may be required, depending on the result of the risk assessment.

• Tank connection area, fuel preparation room, bunkering area, around vent mast, space between double pipes, gas valve unit enclosed area, and tank storage area (except for independent tank type C)

6.3.5 Drill and training

○ The IGF Code (Part D 19) requires education on the STCW Convention and Code.

○ IMO Res. Requirements for the training and qualifications of captains, officers, and crew engaged in ships subject to the IGF Code were added to the STCW Convention (Regulation V/3) and the STCW Code (Section AV/3) in accordance with IMO Res. MSC.397(95).

○ The requirements of STCW Convention's Regulation V/3 and STCW Code's Sections A-V/3 apply to all low flash point fuels subject to the IGF Code.

○ STCW Code's Section A-V/3 classifies the education level into basic training and advanced training. The crew responsible for safety missions must receive basic training, and the captain, marine engineer, and fuel handlers must receive advanced training. Moreover, all crew members aboard ships subject to the IGF Code must be trained to familiarize themselves with ships and equipment.

IGF Code's "18. Operation" specifies the role of the person in charge of LNG bunkering work, safety system inspection, devices, inspection items before work, communication with the bunkering supplier, and actions taken during bunkering.