Proposal for Amendments to IGF code considering risks of ammonia fuel

-Focusing on CFD Modeling

Team Net Zero

Agenda

1 Introduction

- Strengthening Global Eco-Friendly Regulations and the Rise of Ammonia as a Marine Fuel

2 Main Section

- Characteristics and Risks of Ammonia
- Case Studies of Risk Assessments: CFD Modeling
- Amendments of IGF CODE

3 Conclusion

- Summary

Introduction

Environmental issue in maritime shipping

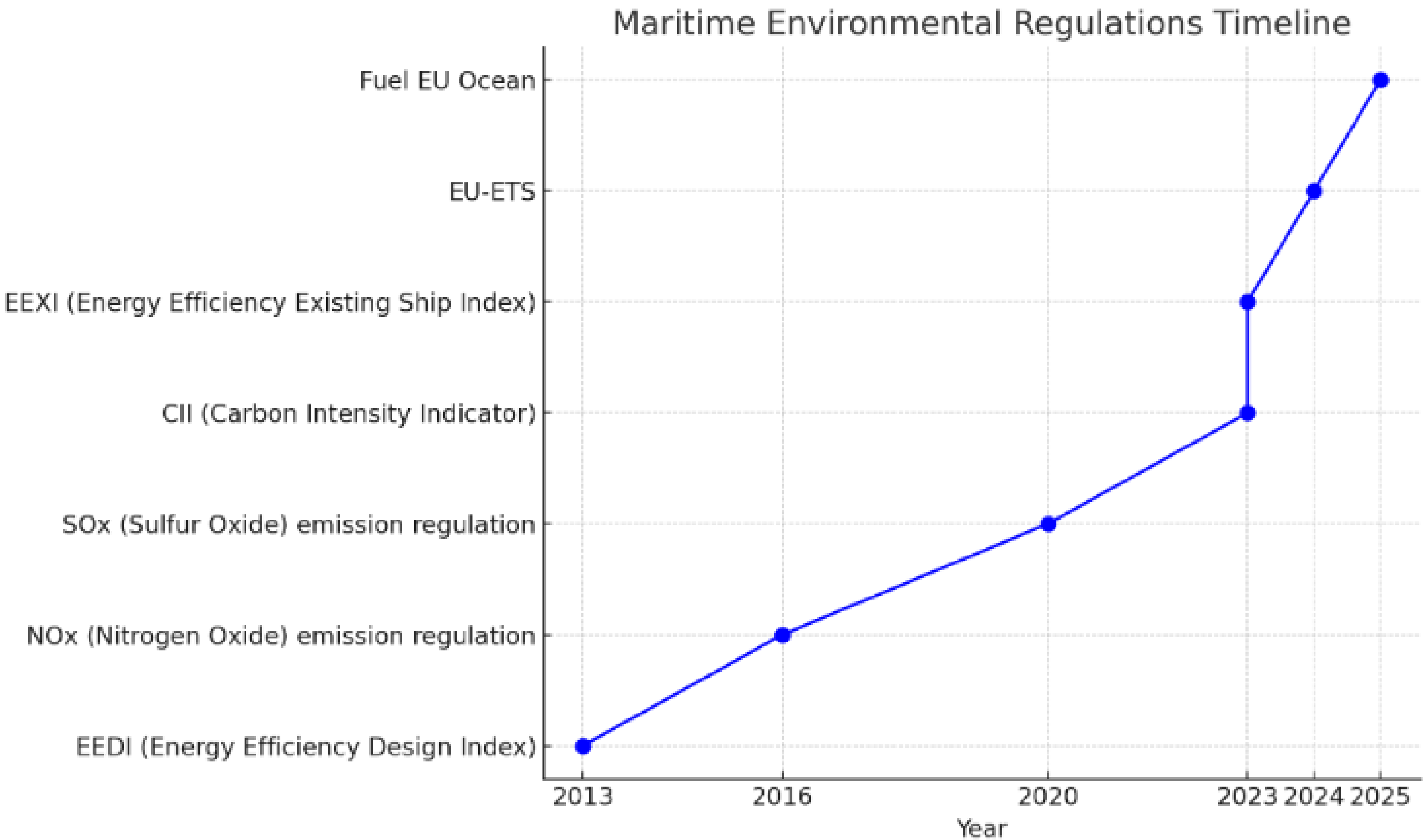
1. In 2023, IMO adopted a revised GHG Strategy, setting a goal to reach **Net-Zero greenhouse gas emissions** from international shipping by 2050.

2. EU 'Fit for 55' package bill will include maritime industry in the ETS from 2024. Establishment of **EU Maritime regulation** to mandate use of eco-friendly fuel

3. Due to strengthening environmental regulations, **the transition of ships with eco-friendly fuel is essential**

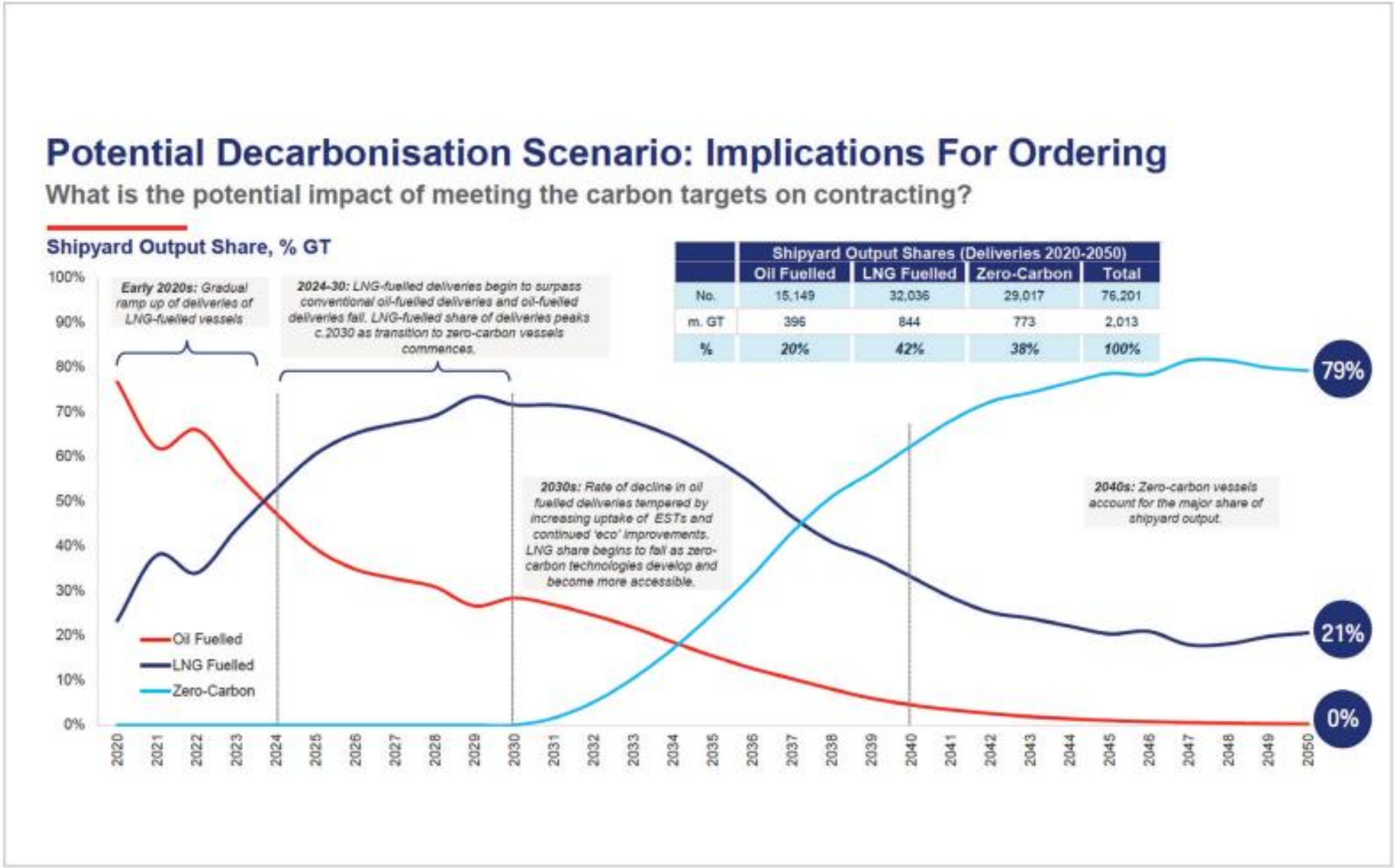
INTERNATIONAL MARITIME ORGANIZATION

Major regulations in shipping



INTERNATIONAL MARITIME ORGANIZATION

Alternative fuel of Maritime Industry

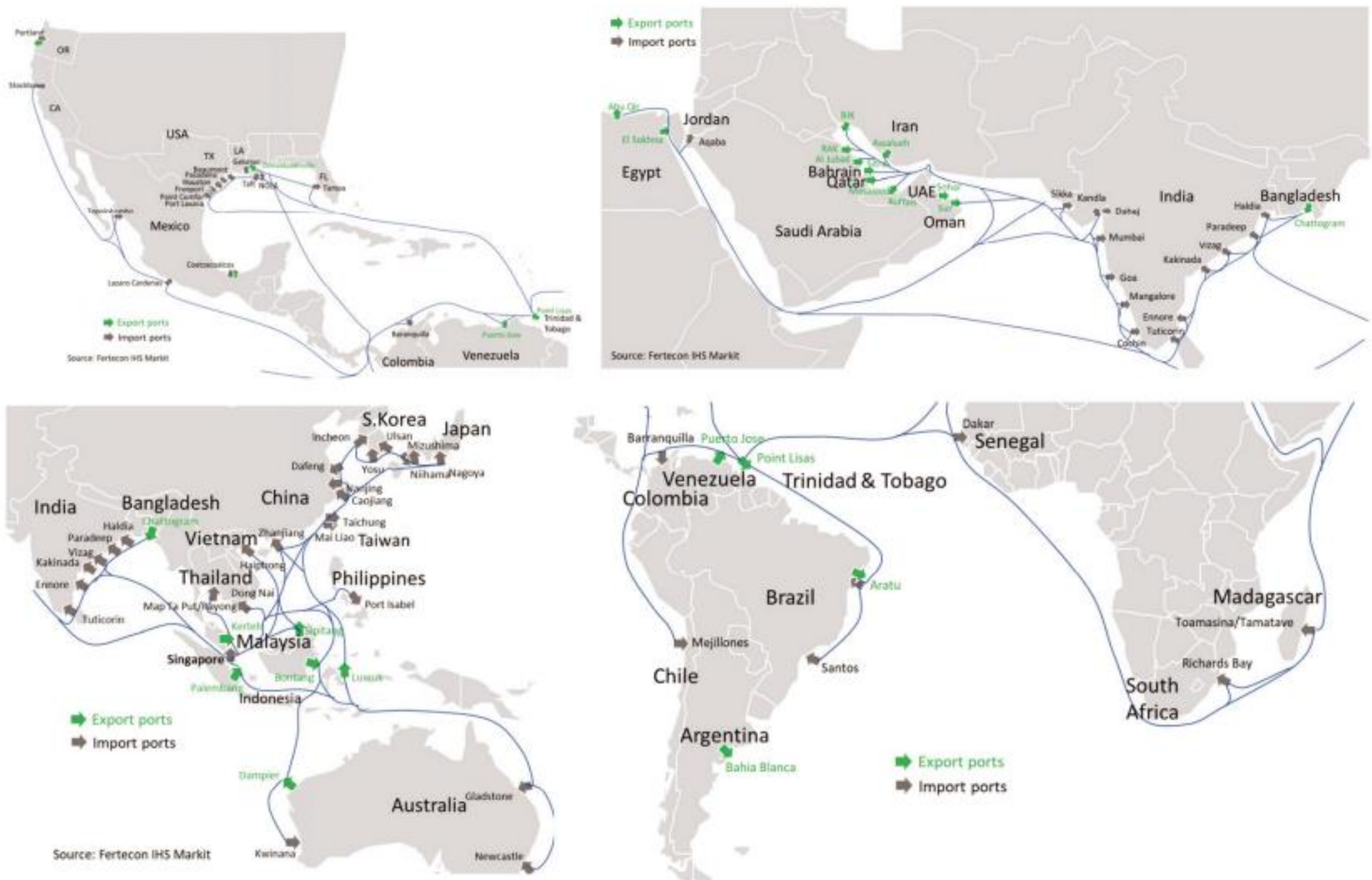


	Shipyard Output Shares (Deliveries 2020-2050)			
	Oil Fuelled	LNG Fuelled	Zero-Carbon	Total
No.	15,149	32,036	29,017	76,201
m. GT	396	844	773	2,013
%	20%	42%	38%	100%

- After 2050, FO(fuel oil) is no longer in use
- Alternative of FO is **LNG, ammonia, methanol, hydrogen**, etc.

INTERNATIONAL MARITIME ORGANIZATION

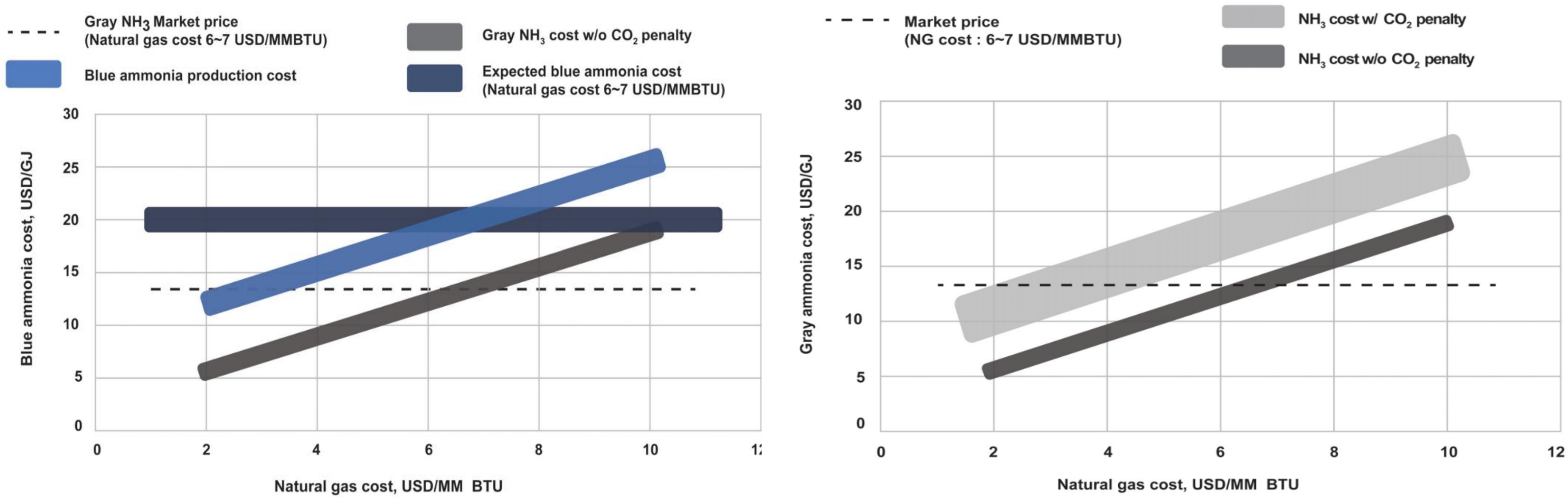
Why Ammonia?-Infrastructure



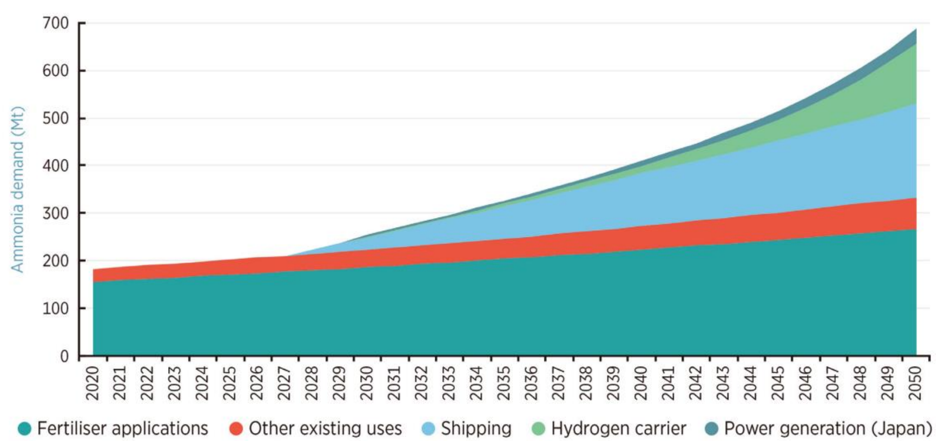
- **Global Production**: 180 million tons of gray ammonia produced annually
- **Established Port Infrastructure**: Well-developed facilities for production & transport

INTERNATIONAL MARITIME ORGANIZATION

Why Ammonia?-Demand/Price



-Cost Changes of Blue/Gray Ammonia Production Based on Natural Gas Prices and CO_2 Fees



-Demand for Clean Ammonia by 2050 for the 1.5°C Scenario

INTERNATIONAL MARITIME ORGANIZATION

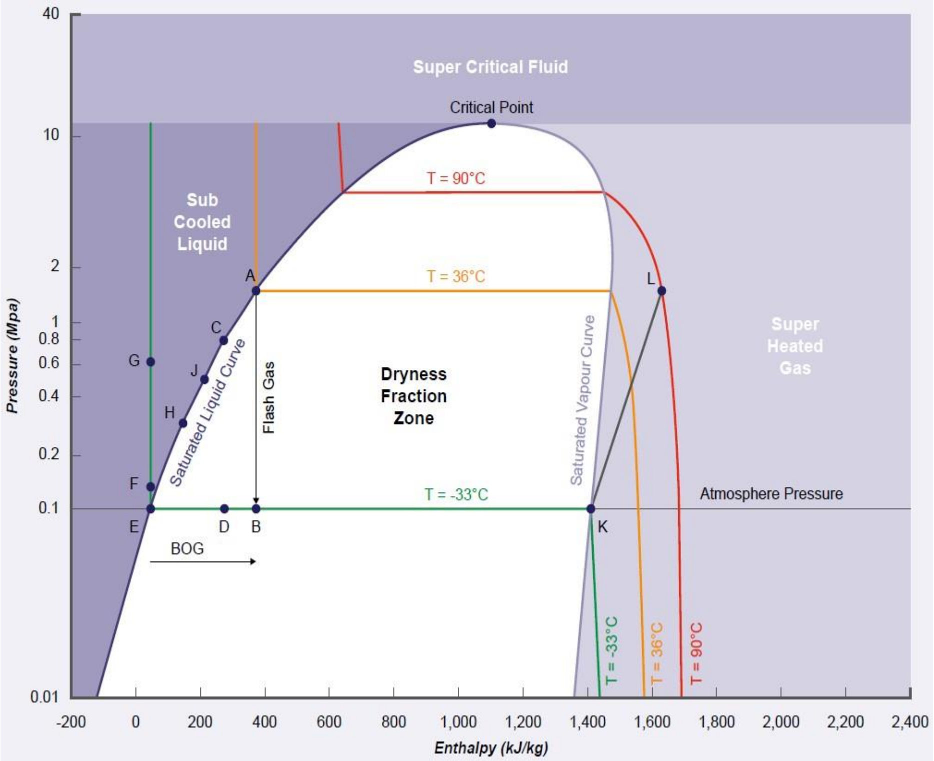
Main Section

- Characteristics and Risks of Ammonia-

Ammonia Transferred As a Saturated Liquid

Ammonia as a saturated liquid:

- Phenomenon associated with ammonia handling can be explained from the pressure-enthalpy chart
  - ✓ Boil off gas calculation
  - ✓ Flash gas calculation
  - ✓ Liquid/gas distribution
  - ✓ Temperature matching
  - ✓ Roll-over
  - ✓ Process energy requirement



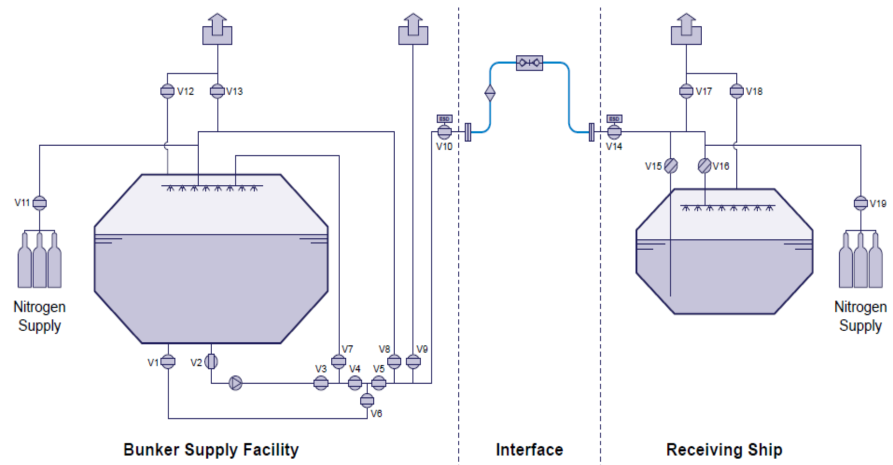
BOG management:

- (K→L): Compress
- (L→A): Condense
- (A→B; B→K & E)
  : Flash, liquid/gas separation

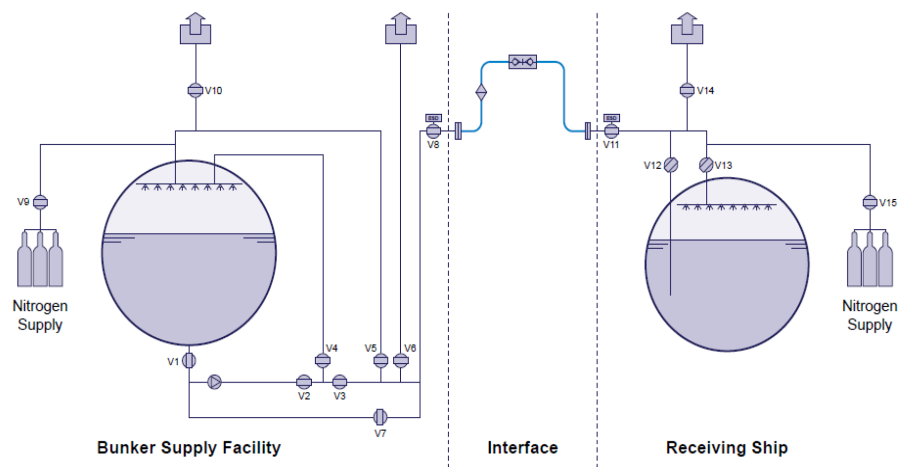
INTERNATIONAL MARITIME ORGANIZATION

Ammonia Bunkering Process

Ammonia bunkering concept - **“FR to FR” or “SR to SR”** application

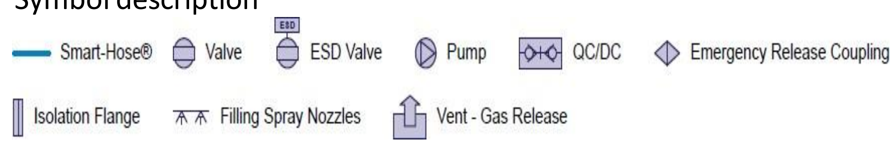


Ammonia bunkering concept - **“NR to NR”** application



Remarks:
Ammonia temperature in NR tank is ambient temperature.
When bunkering ammonia from NR tank to NR tank, an initial precooling process is not required.

Symbol description



Safety Considerations: Toxicity vs Flammability

Smellable	**Around 5 ppm** Pungent suffocating odour

Acute Exposure Guideline Level (AEGL) of ammonia

Exposure	10 min	30 min	1h	4h	8h
AEGL-1	30 ppm	30 ppm	30 ppm	30 ppm	30 ppm
AEGL-2	220 ppm	220 ppm	160 ppm	110 ppm	110 ppm
AEGL-3	2700 ppm	1600 ppm	1100 ppm	550 ppm	390 ppm

AEGL-1	Notable discomfort, irritation, or certain asymptomatic non-sensory effects. Effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL-2	Irreversible or other serious, long-lasting adverse health effects of an impaired ability to escape
AEGL-3	Life-threatening health effects or death

Flammable	**LFL > 150,000 ppm** Minimum concentration to cause fire in presence of ignition source

INTERNATIONAL MARITIME ORGANIZATION

Current Situation-8th CCC convention

- **Use of Ammonia**

Discussed requirements for utilizing ammonia both at sea and on land

- **Main Considerations**

Identified critical factors for using ammonia as a fuel

- **Leakage Modeling**

Highlighted the need for **developing models to accurately calculate ammonia**

→We focus on **CFD Modeling**

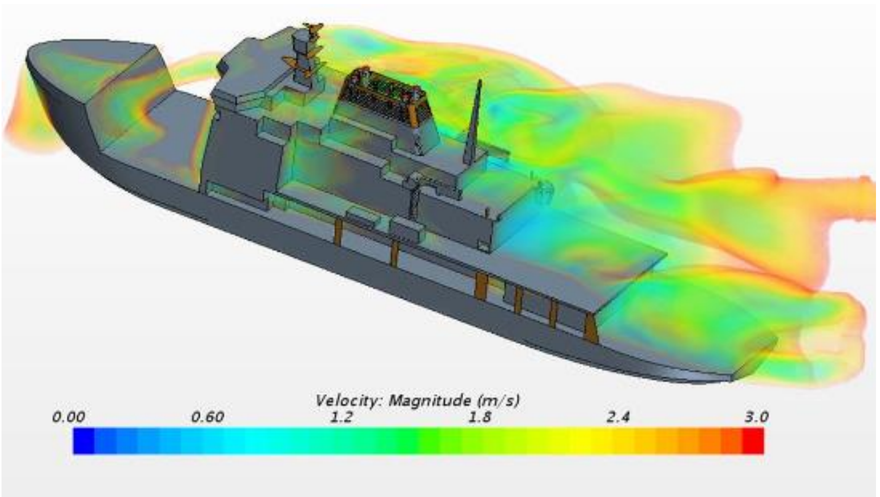
- **IGF Code Development**

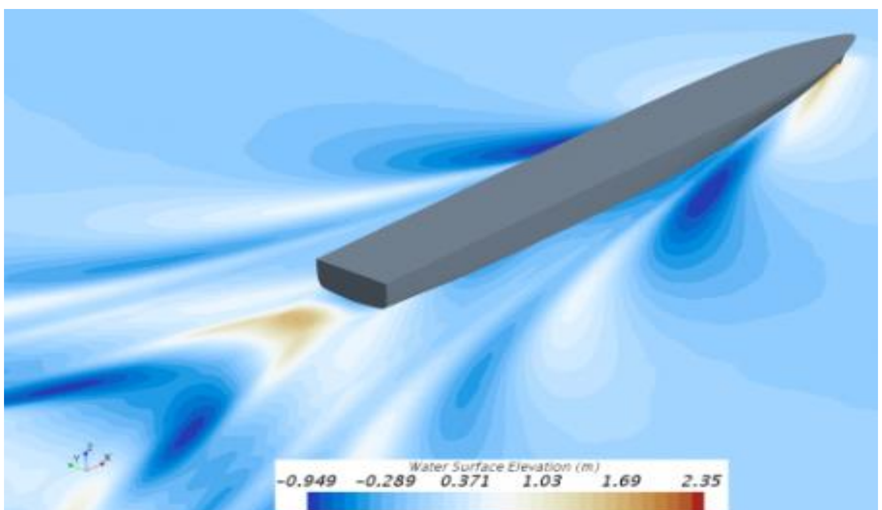
Decided to proceed with developing the IGF Code based on these findings

Main Section

- CFD Modeling as a Countermeasure for Ammonia Risks-

About CFD Modeling

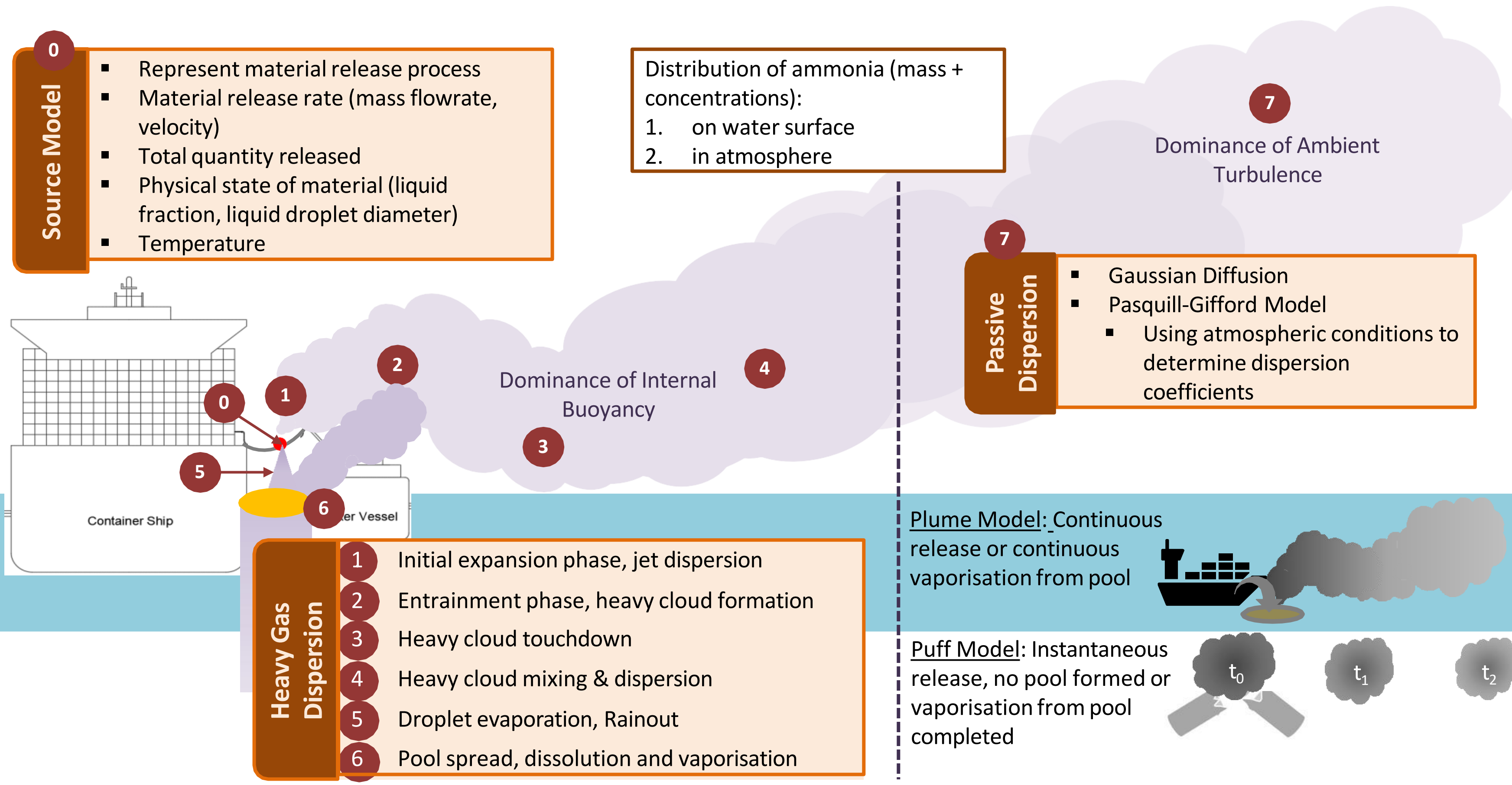




- **Computational fluid dynamics (CFD)** is the science of using computers to predict liquid and gas flows based on the governing equations of conservation of mass, momentum, and energy.
- CFD analyzes different properties of fluid flow, such as temperature, pressure, velocity, and density, and can be applied to a broad range of engineering problems across industries
- Through CFD, we can analyze, understand, and predict the fluids that make up nearly every part of our world.

INTERNATIONAL MARITIME ORGANIZATION

Simulation - Process Hazard Analysis Software Tool (PHAST)



Case Study: Ammonia Release

Ammonia Release – Sensitivity Study*

Scenario A: 8" hose rupture at inlet manifold of receiving vessel for 60s
Scenario B: Storage Conditions is simulated based on 5 mins release from valve attached to storage tank.

Operational Parameters	Results
Storage Conditions (B) FR: -33.4°C, 1 atm SR: -10°C, 2.91 bar NR: 30°C, 12 bar	FR has the smallest lethality footprint
Flow rate (m^3/h) (A) 500, 1000, 1500, 2,000	Doubling the flowrate from 500 m^3/h to 1000 m^3/h result in more than doubling the lethality footprint
Release Elevation (A) 5m, 10m, 15m and 20m above sea level	The higher the elevation of release, the larger the lethality footprint
Release Direction (A) Horizontal Vertical Upwards 45° Downwards 90° Downwards	Vertical upwards release result in the largest lethality footprint, 90° downwards release result in the smallest lethality footprint
Isolation Time (A) 1 min, 2 min, 5 min	Doubling the isolation time result in doubling the lethality footprint

Note: downwind passive dispersion is a mixture of plume and puff model

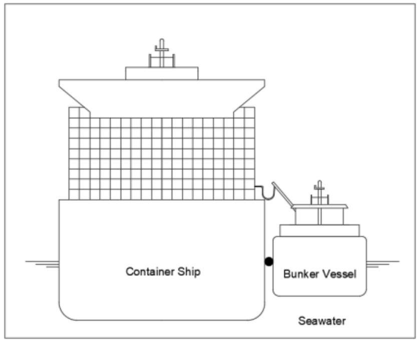
Scenario C: 225mm leak from 10,000m^3 atmospheric storage tank from a height of 3m above ground for 1 hour.

Weather Parameters	Results
Atmospheric Stability (C) Unstable: Class A, B, C (day) Neutral: D (overcast, dawn, dusk) Stable: E (night)	The more unstable the atmosphere, the greater dispersion and/or dilution
Wind Speed (C) Class C: 3, 5, 10, 20m/s Class D: 2, 5, 10, 20m/s Class E: 1, 2, 3m/s	Higher wind speed, greater dispersion downwind
Humidity (C) 60, 70, 80, 90, 100%	Higher humidity, larger lethality footprint (Exception 100%: smallest footprint uplifted to a higher altitude)
Ambient Temperature (C) Day 24-36°C Night 20-32°C	Higher ambient temperature, larger lethality footprint
Surface Temperature (C) Day 28-40°C Night 20-32°C	Higher surface temperature, smaller lethality footprint

Note: continuous release with plume dispersion model during passive stage

INTERNATIONAL MARITIME ORGANIZATION

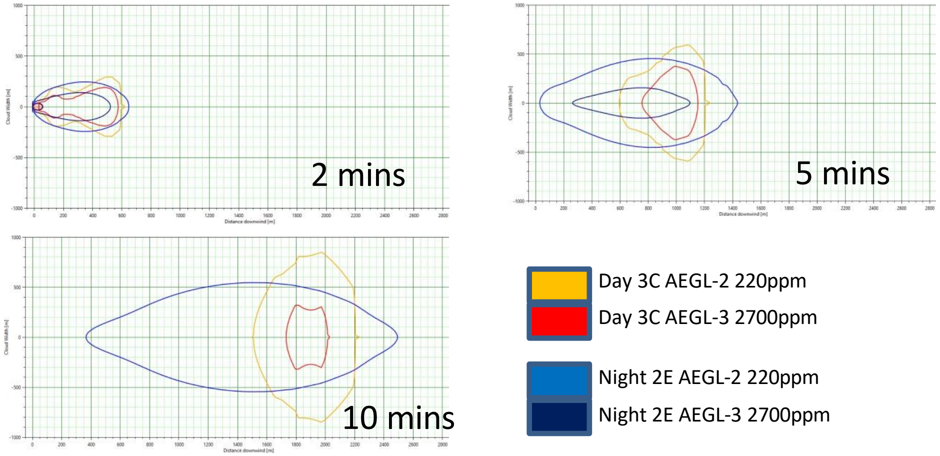
Case Study: Ship-To-Ship Bunkering



Bunker Vessel	:	17,500 m³ NH_3 carrier
Receiving Vessel	:	14,800 TEU container ship
Temperature	:	-33.4°C, 1 atm (FR to FR)
Connection	:	8” (203mm) hose, 40m long
Flowrate	:	1,500m³/h

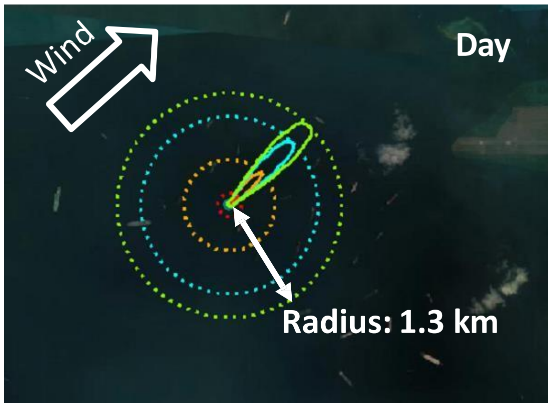
Scenario	Release Elevation	Release Duration
8” Hose Rupture at inlet manifold of container ship	18.35m	60 s

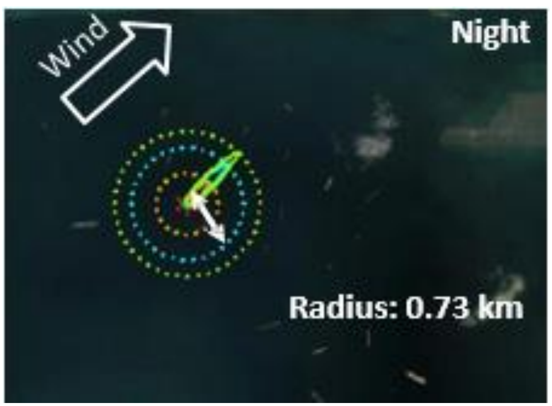
* Hypothetical results only, not meant for setting up a physical facility without verifications



Released Mass (kg)	Day	% of mass released	Night	% of mass released
Total Mass released	17,040	-	17,040	-
Mass flashed as vapor cloud	3,384	20%	2,964	18%
Mass Rainout as pool	13,656	80%	14,076	82%
Mass vaporised from pool	5,260	31%	5,680	33%
Mass dissolved in sea	8,396	49%	8,396	49%

Case Study: Ship-To-Ship Bunkering



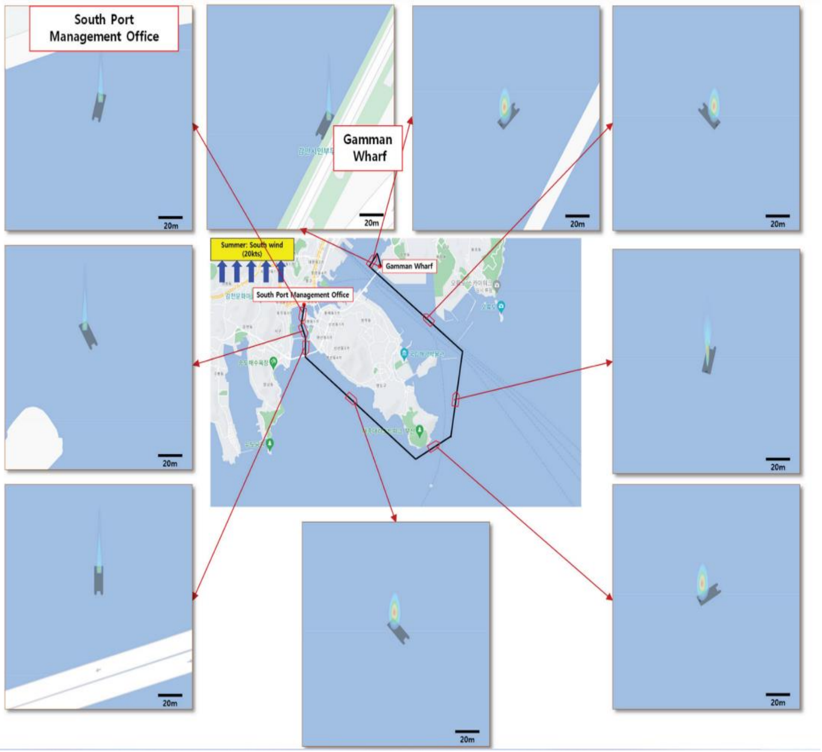


- Lethality footprint instead of cloud coverage provides further understanding of the hazardous impact upon release.
- Lethality footprint is much larger for the release in the day as compared to the release in the night.
- **With mitigation, the lethality footprint can be reduced.**

Simulated lethality footprints

Lethality (%)	Coverage	
	Day	Night
3	280 x 1,275 m	140 x 725 m
10	210 x 1,000 m	120 x 550 m
50	80 x 520 m	80 x 300 m
99	20 x 125 m	30 x 100 m

Case Study: Simulation of diffusion at port



Simulation of diffusion and risk assessment of gaseous and liquid ammonia

This simulation focuses on Gamman Wharf, diffusion of ammonia using **CFD Modeling** under conditions: **summer, southward winds at 20 knots**.

The results revealed that under strong southward winds, <u>ammonia tends to disperse quickly across a wide area, reducing its concentration at ground level but potentially affecting a larger downwind zone.</u>

Main Section

- Amendments of IGF CODE-

About IGF CODE

SOLAS Convention
"International Convention for the Safety of Life at Sea"

↓

SOLAS Chapter II-1
Part G-Ships using low-flashpoint fuels

↓

IGF code
International Code of Safety Using Gases or Other Low-Flashpoint Goods

Amendments of IGF CODE

Direction of amendment: IGF Code

The IGF Code primarily addresses LNG fuel, so we propose to include **Ammonia fuel**.

Simulation based risk assessment should analyze the diffusion pattern of ammonia in the gaseous and liquid states and prepare for the **worst-case scenario**.

Simulation based risk assessment can accurately predict how quickly ammonia spreads and what environmental factors (wind, temperature, humidity, etc.) will be affected when it leaks.

This allows the **risk of diffusion of ammonia** during work to be evaluated in advance, and necessary protective equipment and response procedures can be prepared.

Amendments of IGF CODE

Direction of amendment: IGF Code 2.2

2 GENERAL

2.1 Application

Unless expressly provided otherwise this Code applies to ships to which part G of SOLAS chapter II-1 applies.

2.2 Definitions

Unless otherwise stated below, definitions are as defined in SOLAS chapter II-2.

Problem: The current IGF Code lacks clear definitions regarding ammonia as a fuel and the application of simulation based risk assessment.

Direction of amendment: IGF Code 2.2

Amendment Proposal: Add the following items to section 2.2 Definitions

2.2.42 Ammonia fuel means anhydrous ammonia to be used as fuel on ships.
2.2.43 Simulation based risk assessment means using computer modeling for safety analysis of fuel systems.

Expected Effects: By adding clear definitions for ammonia fuel and simulation based risk assessment, the clarity of applying regulations related to these elements will be improved, ensuring consistency in safety assessments.

Amendments of IGF CODE

Direction of amendment: IGF Code 4.2

4 GENERAL REQUIREMENTS

4.1 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.

4.2 Risk assessment

Problem: The current IGF Code's risk assessment section does not mention use of simulation based risk assessment, which may hinder accurate risk assessments.

Amendments of IGF CODE

Direction of amendment: IGF Code 4.2

Amendment Proposal: Add the following items to section 4.2 Risk Assessment

4.2.4 It is recommended that all ships conduct a simulation based risk assessment 48 hours before entering port when performing ammonia fuel bunkering.

.1 Each port shall provide weather data for incoming ships.
.2 Each port shall establish and communicate criteria for risk assessment.
.3 Each ship shall equip a computer for applying the risk assessment.
.4 Each ship shall send the results of the risk assessment to the port authorities before entering.

Amendments of IGF CODE

Direction of amendment: IGF Code 4.2

Amendment Proposal: Add the following items to section 4.2 Risk Assessment

4.2.5 For ammonia-fueled ships, simulation based risk assessment shall be used to assess the dispersion of ammonia in case of leakage and its potential impacts.

.1 Various leak scenarios considering different weather conditions and ship operating modes.
.2 Evaluation of potential toxic zones and their impact on crew safety and ship operations.
.3 Assessment of the effectiveness of ventilation systems and other mitigation measures.

Expected Effects: Enhanced safety and preparedness for ammonia bunkering through simulation-based risk assessments, better port coordination, and effective ammonia dispersion analysis.

INTERNATIONAL MARITIME ORGANIZATION

Amendments of IGF CODE

Direction of amendment: IGF Code 8.3.1

8.3.1 General

8.3.1.1 The bunkering station shall be located on open deck so that sufficient natural ventilation is provided. Closed or semi-enclosed bunkering stations shall be subject to special consideration within the risk assessment.

8.3.1.2 Connections and piping shall be so positioned and arranged that any damage to the fuel piping does not cause damage to the ship's fuel containment system resulting in an uncontrolled gas discharge.

8.3.1.3 Arrangements shall be made for safe management of any spilled fuel.

8.3.1.4 Suitable means shall be provided to relieve the pressure and remove liquid contents from pump suctions and bunker lines. Liquid is to be discharged to the liquefied gas fuel tanks or other suitable location.

8.3.1.5 The surrounding hull or deck structures shall not be exposed to unacceptable cooling, in case of leakage of fuel.

8.3.1.6 For CNG bunkering stations, low temperature steel shielding shall be considered to determine if the escape of cold jets impinging on surrounding hull structure is possible.

Amendments of IGF CODE

Direction of amendment: IGF Code 8.3.1

Problem: Current IGF Code does not include standards for stopping bunkering operations in the event of an ammonia leak during bunkering.

Amendment Proposal: Add the following items to section 8 Definitions

8.3.1.7
For ammonia bunkering stations, if ammonia levels of 30 ppm or higher are detected by gas detectors during ammonia bunkering, the bunkering operation shall be immediately halted.

Expected Effects: By requiring CFD modeling based simulation of piping system, bunkering station, and bunkering system, the responding ability to ammonia fuel leakage will improve.

Direction of amendment: IGF Code 15.8.1

15.8 Regulations for gas detection

15.8.1 Permanently installed gas detectors shall be fitted in:

.1 the tank connection spaces;

.2 all ducts around fuel pipes;

.3 machinery spaces containing gas piping, gas equipment or gas consumers;

.4 compressor rooms and fuel preparation rooms;

.5 other enclosed spaces containing fuel piping or other fuel equipment without ducting;

.6 other enclosed or semi-enclosed spaces where fuel vapours may accumulate including interbarrier spaces and fuel storage hold spaces of independent tanks other than type C;

.7 airlocks;

.8 gas heating circuit expansion tanks;

.9 motor rooms associated with the fuel systems; and

.10 or at ventilation inlets to accommodation and machinery spaces if required based on the risk assessment required in 4.2.

Amendments of IGF CODE

Direction of amendment: IGF Code 15.8.1

Problem: Current IGF code does not mandate the installation of gas detectors in areas with a high presence of crew members, taking into account the toxicity of ammonia

Amendment Proposal: Add the following items to section 15.8.1 Definitions

.11 For ammonia bunkering ships, gas detectors shall be installed in holds, void spaces, living quarters and other potential hazardous areas

Expected Effects: By requiring installation of gas detector, it is possible to prevent for human exposure to toxicity in the occasion of ammonia leakage.

Conclusion

Summary

- Parent Organ: **MSC**

- Associated Organ: **SSE(Sub-Committee on Ship System and Equipment)**

- Strategic Direction: **SD 2**

- Performance Indicator: **PI 2.3(Amendments to the IGF Code and development of guidelines for alternative fuels and related technologies)**

- The amendments to **IGF Code sections 2.2, 4.2, 8.3.1, and 15.8.1** fall under **IMO SD 2-2.3**, which pertains to <u>amendments to the IGF Code and the development of guidelines for alternative fuels and related technologies</u>.

References

[1] IMO, 2019. “IMO Action to reduce Greenhouse Gas Emissions from International Shipping”.
[2] Clarksons Research, The Shipping Sector To2030: Shipbuilding & Shipping Forecast To 2030, March 2020)
[3] MAN Energy Solutions. “MAN B&W two-stroke engine operating on ammonia.” (2020)
[4] Ahmadi A.H., and Hashemabadi, S.H. 2008. 3D CFD simulation and experimental validation of particle-to-fluid heat transfer in a randomly packed bed of cylindrical particles. International Communications in Heat and Mass Transfer 35(2): 1183-1189.
[5] Anderson, M.P.; and Woessner, W.W. 1992. Applied Groundwater Modelling: Simulation of Flow and Advective Transport (2nd Edition ed.), Academic Press.
[6] A.W. Loginow, Materials Performance 25(12) 1986
[7] IMO CCC 7/INF.8. Forecasting the Alternative Marine Fuel: Ammonia. 2020
[8] MAN Energy Solutions. “MAN B&W two-stroke engine operating on ammonia.” (2020)
[9] Fernando Marcos. March 2022. “MAN B&W Ammonia engine”. Ingenieros navales
[10] Japanese firms working on ammonia-fueled engines, Diesel & Gas Turbine Worldwide, 27 October 2021.
[11] ASABE, Use of CFD modeling for determination of ammonia emission in non-insulated poultry houses with natural ventilation
[12] Daejeong Kim & Byongug Jeong (2024) Investigation on toxicity of ammonia releasing from storage tank onboard through CFD simulations, Journal of International Maritime Safety, Environmental Affairs, and Shipping, 8:1-2, 2339342, DOI: 10.1080/25725084.2024.2339342
[13] Dimitriou, Pavlos, and Rahat Javaid. “A review of ammonia as a compression ignition engine fuel.” International Journal of Hydrogen Energy 45.11 (2020): 7098-7118
[14] 한국선급, “암모니아 연료 선박에 대한 지침서” 2021년
[15] 한국선급. 친환경 미래 선박 연료 전망 – 선박 연료로서의 암모니아. 2019
[16] 한국산업안전보건공단. 무수 암모니아 저장에 관한 기술 지침. 2013.
[17] 한국선급. 저인화점 연료 선박 규칙 저인화점 연료 선박 적용지침. 2022.
[18] 청정 암모니아 심층투자분석보고서, 한국에너지기술연구원

INTERNATIONAL MARITIME ORGANIZATION

THANK YOU

Q&A

INTERNATIONAL
MARITIME
ORGANIZATION