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ABBREVIATION/ACRONYMS

[P]ERC	[Powered] Emergency Release Coupling
ABV	Ammonia Bunker Vessel
AEGL	Acute Exposure Guideline Level
AFSU	Ammonia Floating Storage Unit
AIS	Automatic Identification System
ALARP	As Low as Reasonably Practicable
APR	Air-Purifying Respirators
APS	Ammonia Powered Ships
ARMS	Ammonia Release Mitigation System
ASF	Ammonia Storage Facility
ASTM	ASTM International
ATT	Ammonia Trailer Truck
BDN	Bunker Delivery Note
BLEVE	Boiling Liquid Expanding Vapour Explosion
BoE	Basis of Estimate
BOG	Boil-Off Gas
BOR	Boil-Off Rate
CAPEX	Capital Expenditure
CBRN	Chemical, Biological, Radiological, and Nuclear
CCD	Charge Coupled Device
CDC	Centre for Disease Control and Prevention
CDI	The Chemical Distribution Institute
CGA	Compressed Gas Association
CP/FP	Constant Pressure Floating Piston
CQRA	Coarse Quantitative Risk Analysis
CRM	Certified Reference Gas Material
CTMS	Custody Transfer Measurement System
CTS	Custody Transfer System
DCP	Dry Chemical Powder
DNV	DNV Maritime Advisory
EN	European Standards
EPA	Environmental Protection Agency
ERC	Emergency Release Coupling
ERP	Emergency Response Plans
ERS	Emergency Release System
ESD	Emergency Shutdown
ESDS	Emergency Shutdown System
ETO	Energy Transition Outlook
FEED	Font-End Engineering Design
FMEA	Failure Modes and Effects Analysis
FR	Fully Refrigerated
FSA	Formal Safety Assessment

FSRU	Floating Storage and Regasification Unit
GC	Gas Chromatography
GCMD	The Global Centre for Maritime Decarbonisation
GCV	Gross Calorific Value
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GPA	Gas Processors Association
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HCV	Higher Calorific Value
HFO	Heavy Fuel Oil
HSE	Health Safety & Environment
IACS	International Association of Classification Societies
ICS	The International Chamber of Shipping
IDLH	Immediate Dangerous to Life of Health
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IGC Code	The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF Code	International Code of Safety for Ship Using Gases or Other Low-Flashpoint Fuels
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
IOGP	International Oil and Gas Producers
IP	International Standard Test Methods for Petroleum and Related Products
iQRA	Installation Quantitative Risk Analysis
IR	Individual Risk
ISM Code	The International Safety Management Code
ISO	International Organization for Standardization
ISPS	International Ship and Port Facility Security
JOP	Joint Operation Plan
LAC	Liquid Ammonia Carrier
LCV	Lower Calorific Value
LEL	Lower Explosive Limit
LFL	Lower Flammable Limit
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LPG	Liquefied Petroleum Gas
LR	Lloyd's Register
MSC	Maritime Safety Committee
MARVS	Maximum Allowable Relief Valve Setting
MEG4	Mooring Equipment Guidelines, the 4th Edition
MESD CoE	Maritime Energy and Sustainable Development Centre of Excellence
MEZ	Marine Exclusion Zone
MFM	Mass Flow Meter
MHD	Major Hazards Department

MLA	Marine Loading Arm
MLC2006	Maritime Labour Convention 2006
MMQ	Minimum Measured Quantity
MOF	Marine Offloading Facility
MOM	Ministry of Manpower
MPA	Maritime & Port Authority of Singapore
MPE	Maximum Permissible Error
MRA	Mutual Recognition Agreement
MT	Million Tonnes
NEA	National Environment Agency
NIOSH	National Institute for Occupational Safety and Health
NMI	National Metrology Institute
NPSH	Net Positive Suction Head
NTP	Normal Temperature and Pressure
OCIMF	Oil Companies International Marine Forum
OIML	The International Organization of Legal Metrology
OJT	On-the-Job Training
OPEX	Operational Expenditure
PAPR	Powered Air Purifying Respirator
PFD	Process Flow Diagram
PIANC	World Association for Waterborne Transport Infrastructure
PIC	Person-In-Charge
PPE	Personal Protective Equipment
PQU	Physical Quantity Unit
PRV	Pressure Relief Valve
QRA	Quantitative Risk Assessment
RACI	Responsible (R), Accountable (A), Consulted (C), Informed (I)
REG	Regulatory
REP	Reputation
RIVM	Rijksinstituut Voor Volksgezondheid En Milieu (National Institute for Public Health and the Environment)
SBC	Singapore Bunker Claims
SCBA	Self-Contained Breathing Apparatus
SCC	Stress Corrosion Cracking
SCDF	Singapore Civil Defence Force
SDS	Safety Data Sheet
SGMF	The Society for Gas as a Marine Fuel
SHTS	Shore-to-Ship
SI	International System of Units
SIGTTO	The Society of International Gas Tanker and Terminal Operators
SIMOPS	Simultaneous Operations
SJ	Surbana Jurong
SMA	Singapore Maritime Academy
SMS	Safety Management System
SR	Semi-Refrigerated

SS	Singapore Standard
SSL	Ship-Shore Link
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
STS	Ship-to-Ship
TCS	Tank Connection Space
TECP	Totally Encapsulating Chemical Protective
TR	Technical Reference
TTS	Truck-to-Ship
UEL	Upper Explosive Limit
UFL	Upper Flammable Limit
UHF	Ultra High Frequency
VFM	Volumetric Flow Meter
VHF	Very High Frequency
WMS	Working Measurement Standard
WSH	Workplace Safety and Health

FOREWORD

The decision to conduct this study came in the early days of the Global Centre for Maritime Decarbonisation (GCMD). While ammonia as an alternative marine fuel was already being discussed at that time, it wasn't known whether, where, or how ammonia bunkering could be carried out safely.

The team at GCMD thus saw this study as a no-regrets move to identify the configurations and associated risks for ammonia bunkering, to assess whether these risks could be mitigated, and if so, to highlight measures for an eventual pilot. Learnings from this study would also inform and shape the development of standards for the safe transfer of ammonia during breakbulk and bunkering operations and a competency framework to prepare seafarers and operators to handle ammonia as a bunker fuel.

Quantitative Risk Assessment (QRA) required the identification of a suitable location for ammonia bunkering. Using 43 criteria across 5 categories, DNV Maritime Advisory and Surbana Jurong shortlisted two sites in Singapore where pilots involving cross-dock breakbulk and shore-to-ship bunkering could take place with minimal upfront investment. The study also looked at ship-to-ship breakbulk and bunkering at Raffles Reserve Anchorage as a third site.

Hazard Identification (HAZID) and coarse QRA were conducted at these three sites. The 400 operational and locational risks that were identified across shore and sea bunkering sites were found to be low or mitigable. Due to commercial sensitivities, we have chosen not to identify the selected land sites or publicise associated site-specific findings in this public report; these details will be released at a later stage. Central to this public report are the HAZID and coarse QRA for breakbulk and bunkering at anchorage.

This study is not meant to be exhaustive or definitive, it is meant to pave the way for GCMD's pilot to demonstrate ammonia transfer in the port waters of Singapore. Other sites that may be suitable for ammonia bunkering pilots with additional infrastructure buildout were not part of this study.

A guidebook detailing custody transfer requirements, bunkering procedures, and safety precautions, as well as a competency framework to train personnel, was developed based on the findings of this study and is part of this public report.

With this study completed, GCMD aims to conduct a proxy pilot involving the first ship-to-ship transfer of ammonia in the port waters of Singapore, subject to regulatory approval, to build stakeholder confidence and user competence for an eventual bunkering exercise when ammonia-fuelled ships become available.

In view of this, the competency framework has been developed into a curriculum in partnership with the Singapore Maritime Academy. The first training course that includes handling of ammonia under the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) took place in March 2023, and registration is open for the next course run.

Concurrently, we are working with Oil Spill Response Limited to develop emergency response procedures. We are submitting the report as a draft technical reference to the Standards Development Organisation of the Singapore Standards Council's Chemical Standards Committee (CSC) to help guide the safe transfer of ammonia during breakbulk and bunkering operations locally. And we have initiated discussions with organisations, such as the Oil Companies International Marine Forum, the Society for Gas as a Marine Fuel, the Society of Gas Tankers and Terminal Operators, to help shape standards for safe ammonia bunkering internationally.

The completion of this study in nine months is a testament to the immense support of willing partners across the stakeholder value chain in the maritime community. We thank the 22 Study Partners who generously contributed their knowledge and experience, and the 130 members of the Industry Consultation and Alignment Panel who provided feedback on the initial draft of this public report. We are also grateful to the numerous regulatory agencies whose inputs helped refine our analysis.

Progress is incremental. We see this report as a critical step, of many still to come, in readying the maritime ecosystem for ammonia bunkering. And it is by starting now and working together that we can successfully navigate the complexities of the energy transition.

Professor Lynn Loo
Chief Executive Officer
The Global Centre for Maritime Decarbonisation
11 May 2023

1 EXECUTIVE SUMMARY

1.1 Overview

The Global Centre for Maritime Decarbonisation (GCMD) is supporting international shipping to meet or exceed the International Maritime Organization's (IMO) 2030 and 2050 goals of reducing its greenhouse gas emissions. As part of this effort, one of GCMD's focuses is to identify and help close technical and operational gaps in adopting alternative fuels, such as green ammonia.

In January 2022, GCMD commissioned a study to define the safety and operations envelops under which ammonia bunkering pilots can be carried out in the port waters of Singapore, the world's largest bunkering hub and second largest container port.

DNV Maritime Advisory (DNV) was appointed to undertake this study. Supported by Surbana Jurong (SJ) and the Singapore Maritime Academy (SMA), this study aims to establish the basis to execute a pilot that would eventually enable the bunkering of ammonia with industry-wide applicability. The DNV-led consortium consulted extensively with a GCMD-curated group of 22 study partners and obtained feedback from more than 130 Industry and Consultation Alignment Panel (iCAP) members. The consortium also had discussions with relevant regulators to help refine their analyses. The scope of the study includes:

1. Forecasting ammonia marine fuel demand to establish capacity needs in Singapore
2. Analysing and recommending feasible operating concepts for an ammonia bunkering pilot
3. Screening, evaluating, and selecting suitable sites for an ammonia bunkering pilot
4. Identifying hazards and key risks and establishing mitigation protocols for the pilot
5. Estimating total capital expenditure (CAPEX) for an ammonia bunkering pilot
6. Compiling an ammonia bunkering safety study guidebook for ammonia bunkering pilots

1.2 Ammonia bunker demand forecast in Singapore

The demand for ammonia as a fuel impacts ammonia storage capacity calculations (throughput assessment), regulatory considerations, and infrastructural needs. To forecast the ammonia bunker demand in Singapore, a DNV-led consortium applied a comprehensive bottom-up and top-down approach accounting for the probability of vessels adopting ammonia as fuel, its potential share in a ship's total energy consumption, carbon taxes, fleet growth, and energy prices.

Three scenarios (optimistic, pessimistic, and realistic) were developed based on past global bunker consumption data and anticipated market conditions. The realistic scenario predicts that ammonia will comprise 10% of all marine fuels bunkered in Singapore by 2035, rising to 37% by 2050. Given that Singapore's demand for conventional marine fuels was consistently 20% of the global marine fuel demand from 2012–2021, this study assumes Singapore's demand for ammonia as a fuel will reach a corresponding 20% of the global demand for ammonia by 2045.

This projection corresponds to a total ammonia marine fuel demand of approximately 50 million tonnes (MT) by 2050 in Singapore and a significant corresponding increase in the number of bunker vessels, port infrastructure, and storage capacity required in that same period. Therefore, regulators should consider developing a regulatory framework enabling the growth of an ammonia bunkering ecosystem and encouraging private sector investment from fuel suppliers, bunker operators, storage facility operators, and shipowners. This regulatory framework should be developed without delay, considering the time required for infrastructure buildout, competency development and operational readiness of the bunkering ecosystem given the safety concerns around handling ammonia as a bunker fuel.

1.3 Concept selection

Ammonia must be safely transferred from producers to marine fuel suppliers and eventually to vessels powered by ammonia bunker fuel. Based on DNV's ammonia bunker demand forecast, the consortium performed detailed technical analyses on the following modes of ammonia transfer:

1. Ship-to-ship (STS) breakbulk at an anchorage or jetty-based location
2. Shore-to-ship (SHTS) breakbulk at a jetty-based location
3. STS bunkering at an anchorage or jetty-based location
4. SHTS bunkering at a jetty-based location
5. Truck-to-ship bunkering at a jetty-based location

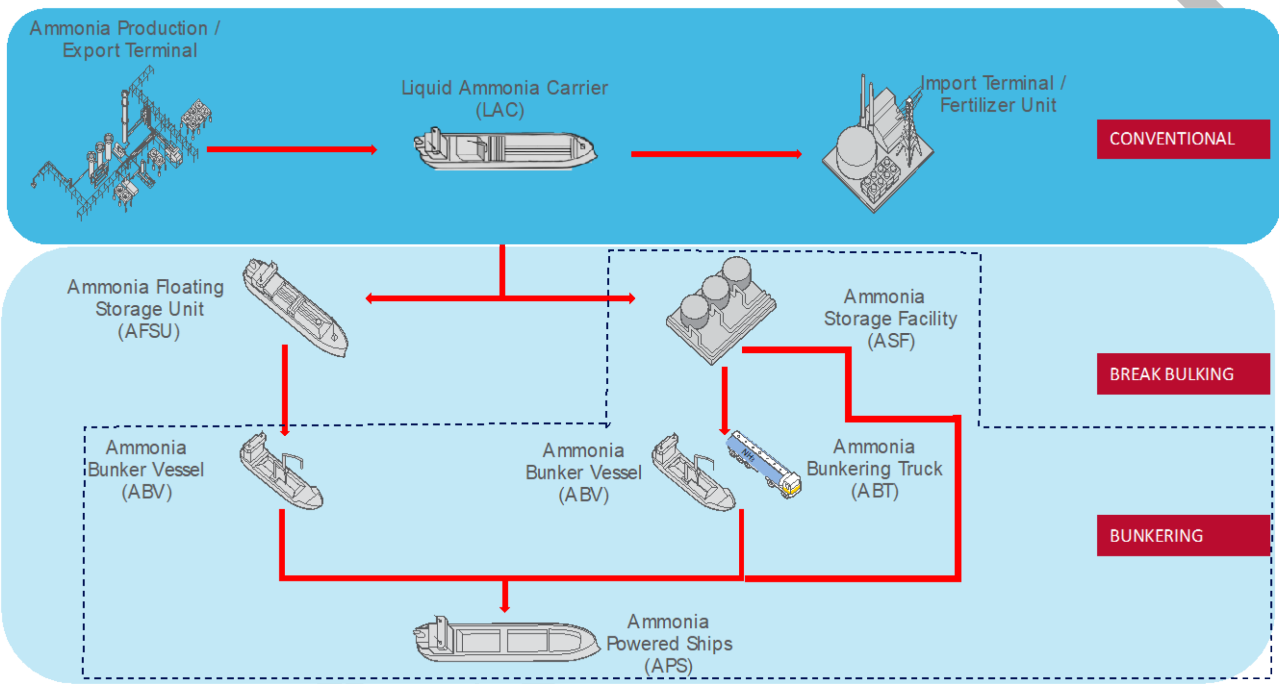

Figure 1.1 Concept for ammonia bunkering operations

Two feasible operational concepts were shortlisted for breakbulk, or fuel transfer between sources of supply or storage. Additionally, four technically feasible concepts were shortlisted for bunkering operations that involve transferring ammonia to vessels. Of the above six shortlisted operational concepts, there are five operating models the industry could pursue. The following four concepts are recommended as part of GCMD's pilot to demonstrate the transfer of ammonia as a marine fuel:

1. Concept 1 - Liquid Ammonia Carrier (LAC) to Ammonia Bunker Vessel (ABV) / LAC, i.e., STS, at a breakbulk terminal in Singapore (Terminal A)
2. Concept 2 - LAC to ABV, i.e., STS, breakbulk activity at anchorage
3. Concept 3 - ABV to Ammonia Powered Ship (APS), i.e., STS, bunkering at anchorage
4. Concept 4 - Ammonia Shore Facility (ASF) to APS i.e., SHTS, bunkering at a tank terminal in Singapore (Terminal D)

These operating models include transfers from ships supplying liquid ammonia to ammonia bunkering vessels at jetty-based locations and anchorages, transfers from smaller ammonia bunkering vessels to ships powered by ammonia, and transfers from shore-based ammonia storage facilities to ships powered by ammonia.

1.4 Site selection study

Raffles Reserve Anchorage was identified to pilot concepts 2 and 3. To determine suitable land-based sites for piloting concepts 1 and 4, a detailed three-step analysis was carried out:

1. **Site screening:** Shortlist potential sites based on a set of conditions required or beneficial for the development of ammonia transfer pilots
2. **Site evaluation:** Quantitative evaluation based on a penalty system to rank potential sites and shortlist the two most suitable ones for pilot concept development
3. **Validation:** Alignment with relevant stakeholders to verify the suitability of these sites for the intended pilot, subject to regulatory approvals

Seven potential land-based sites, Terminals A to E and Port A and Port B, were initially identified with the help of industry stakeholders. Thereafter, these sites were evaluated quantitatively using 43 criteria across five categories (Marine, Land, Health Safety & Environment (HSE), Accessibility & Constructability). Ultimately, a jetty-based facility and a tank terminal (both based in Jurong Island in Singapore) were deemed more appropriate than the other sites for this pilot, contingent on further upfront investment requirements. The identified sites are designated in this report as Terminal A and Terminal D. Both facilities are sheltered, close to major navigation channels, and equipped with adequate jetty and sea space for ship manoeuvrability. No potential disruptions to current operations were identified.

Further analysis was performed to determine the optimal combination of site and pilot concept, based on which the following combinations were selected, in addition to STS breakbulk and bunkering at Raffles Reserve Anchorage:

1. LAC to ABV / LAC, i.e. STS, breakbulk at Terminal A
2. ASF to APS, i.e. SHTS, bunkering at Terminal D

Due to a lack of road access to the berth and restricted vehicle access near the storage tank area, neither site would be suitable for a truck-to-ship ammonia bunkering pilot. The tank-to-ship concept is thus assessed for pilot demonstration at Terminal D, given an existing ammonia tank and supporting infrastructure, which would minimise the impact on current operations and development costs. Terminal A is suitable for piloting the cross-dock breakbulk concept as it minimises the impact on current terminal operations and marine traffic.

1.5 Hazard identification and risk assessment

During the Hazard Identification (HAZID) exercise, about 400 potential risks were identified based on the four operating concepts and three selected sites (two land sites and one at anchorage). Most of the potential risks were medium-risk and mitigable based on risk-ranking results. None of the risks identified were classified as high-risk.

A Coarse QRA was conducted to estimate the risk of injury or fatality according to the QRA Technical Guidance (Revision 9 November 2016). All four pilot concepts at the three selected sites meet the criteria set out by the Major Hazards Department (MHD) under the Ministry of Manpower of the government of Singapore.

For a breakbulk pilot at anchorage, the safety zone ranges from 200 m to 320 m, subject to an “As Low as Reasonably Practicable” (ALARP) evaluation. For a bunkering pilot at anchorage, the safety zone ranges from 150 m to 320 m, subject to an ALARP evaluation. These values are to be taken as indicative and not absolute, as regulatory requirements for ammonia bunkering do not currently exist. Therefore, before the size of the safety zone is finalised, an ALARP evaluation by the owner/operator of the vessels should be carried out to determine “reasonableness”.

The hazard identification and Coarse QRA were conducted based on pilot project requirements and do not reflect the hazards of full-scale commercial operations. Further studies will be required to address the safety of full-scale ammonia bunkering operations for the four concepts at three locations. The study is also based on the selected pilot models and available data, and risks must be reassessed for future changes to the concept design or operations.

Due to potential commercial sensitivities, the hazard identification and Coarse QRA for pilot concepts at Terminal A and Terminal D will not be made available at this stage. Nonetheless, assessments carried out for STS breakbulk and bunkering concepts at Raffles Reserve Anchorage have been included in this report to highlight the factors that have been considered for pilot concepts at Terminals A and D, with which the learnings can accelerate the operationalisation of pilots and trials.

1.6 Capital expenditure (CAPEX) estimates

Having shortlisted operating concepts, and sites, and identified key mitigations required to manage risks, a Basis of Estimate (BoE) was developed. The land-side project cost was broken down into direct and indirect costs. Direct material costs include equipment, instrument, electrical, piping, and associated components. Indirect costs include construction, project management, third-party, and other preliminary costs. The cost estimate factored in costings of the relevant disciplines (for example, piping, civil, electrical, and instrumentation) and combined budgetary quotes from construction contractors and equipment suppliers (e.g. loading arms) based on Surbana Jurong's in-house cost data from similar projects.

Considering the early stage of this pilot project, a cost accuracy of approximately 40% is expected. Estimated costs are not disclosed as they are sensitive to the location of deployment, brownfield modifications, materials cost, procurement strategy, local taxes and other related parameters. However, based on the two pilot concepts at the identified land sites where the model was applied, the range of results illustrates the high dependency on the already invested infrastructure. The cost estimates for the two land-side developments are on the order of SG$1 to $10 million; the differentiating primary cost drivers are installing mechanical equipment at Terminal A and the higher cost of project management and procurement services at Terminal D.

1.7 Guidebook for ammonia bunkering

Chapter 8 of this report is a guidebook applicable to vessels conducting ammonia transfers and bunkering pilots. The guidebook outlines the properties of ammonia, the requirements for custody transfer, the measuring of ammonia quantity and ammonia quality, etc. It also contains recommendations for pilot bunkering procedures and safety and competency requirements for personnel operating in the ammonia marine fuel ecosystem.

Leveraging its experience with LNG bunkering and liquefied gas tanker courses, the Singapore Maritime Academy has included since March 2023 ammonia handling in its training courses related to alternative fuels under the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) and other industry guidelines. This new course will be further enhanced with the development of ammonia-powered engines and vessels.

This report will be submitted as a draft technical reference to the Singapore Standards Council's Chemical Standards Committee (CSC) Technical Committee for Bunkering (Cryogenic and Gaseous Fuel) to ensure that the learnings from this GCMD study will benefit the drafting of guidelines, standards, and policies to bunker ammonia locally. This report will also be submitted to international standards development organisations at a future date to support the development of guidelines surrounding ammonia bunkering internationally.

2 AMMONIA BUNKER DEMAND FORECAST IN SINGAPORE

2.1 Overview

This ammonia bunker demand forecast serves as input for the conceptual study of the ammonia bunker facility, which aims to determine the necessary industrial space and design requirements for setting up an ammonia storage facility in Singapore. The study evaluates three scenarios, including an optimistic scenario that assumes full decarbonisation by 2040, a pessimistic scenario based on current IMO ambitions, and a realistic scenario that considers current IMO ambitions and other regional and industry initiatives.

In the optimistic scenario, aggressive initiatives from authorities and industry players drive shipping decarbonisation, leading to full decarbonisation by 2040. In contrast, the pessimistic scenario assumes a lack of decarbonisation initiatives from maritime industry players and relies solely on the IMO's ambitions to achieve shipping decarbonisation. Finally, the realistic scenario incorporates IMO ambitions and is accelerated by several regional and local authorities of various nations and industry players' initiatives.

Given that Singapore's demand for conventional marine fuels was consistently 20% of the global marine fuel demand from 2012–2021 [1, 2], the study assumes the following:

- The ammonia bunker demand in Singapore is expected to reach a corresponding 20% of global ammonia demand by 2045
- The ammonia bunker demand in Singapore will remain low until 2035, with projected demands of 2.0 million tonnes (MT), 1.1 MT, and 0.40 MT in the optimistic, realistic, and pessimistic scenarios, respectively. This is due to several factors, including limited supply chains, lack of infrastructure readiness, high costs, regulatory uncertainty, and technical challenges such as considerations on retrofitting existing ships, building new ships with specialised engines and fuel systems. However, as the supply chain develops, infrastructure matures, and regulatory and technical uncertainties are resolved, the annual demand for ammonia bunkering in Singapore is expected to increase from 2035 to 2050. In the optimistic, realistic, and pessimistic scenarios, the ammonia bunker demand is projected to reach 57 MT, 50 MT, and 43 MT, respectively

The study further recommends the following:

- Based on this demand forecast, regulators should establish safety guidelines for storing, handling, and transporting ammonia as a bunker fuel and for ships and ports without delay. In addition, regulators should encourage infrastructure investment supporting the production, storage, and distribution of ammonia bunker fuel. For example, incentives can be provided in the form of tax credits or rebates to companies to encourage the take-up of ammonia as a bunker fuel
- Various stakeholders in the value chain, including fuel suppliers, bunker vessel operators, storage facility operators, and shipowners, should collaborate and create a more sustainable and cost-effective bunkering ecosystem for the production, storage, distribution, and supply of ammonia bunker fuel. This can be done once the safety guidelines and incentives for ammonia transfers and bunkering pilots in Singapore are in place
- Conduct an annual review to ensure the accuracy of the ammonia bunker demand forecast, which is influenced by regulations, new-build requirements, operational requirements, and carbon prices. The current forecast was based on the best available information in December 2022

2.2 Methodology

The ammonia bunker demand forecast for Singapore from 2024 until 2050 was derived from bottom-up and top-down approaches, leveraging various data sources and in-house forecasting methodologies.

The bottom-up approach was used to estimate ammonia bunker demand for Singapore from 2024 until 2035 based on primary and secondary data sources, considering several factors, including the probability of vessel projects using ammonia as fuel, market penetration, and the likelihood of ammonia bunkering in Singapore.

The top-down approach to estimate ammonia bunker demand from 2045 until 2050 leverages scenarios reported in the DNV Maritime Forecast to 2050 – Energy Transition Outlook (ETO) publication [3] and considers design and operational requirements, carbon price, fleet growth, and electricity price. Subsequently, polynomial interpolation[1] was applied to harmonise the bottom-up and top-down approaches from 2035 until 2045.

2.3 Bunker demand forecast

To ensure consistency between the bottom-up and top-down approaches, polynomial interpolation was used to harmonise the datasets performed for the period 2035 to 2045. By 2045, the ammonia bunker demand in Singapore is projected to reach 20% of the global market share, which is consistent with Singapore's share of the current conventional fuels market. As seen in Figure 2-1, in the realistic scenario, ammonia bunker demand will continue to grow to 50 MT by 2050.

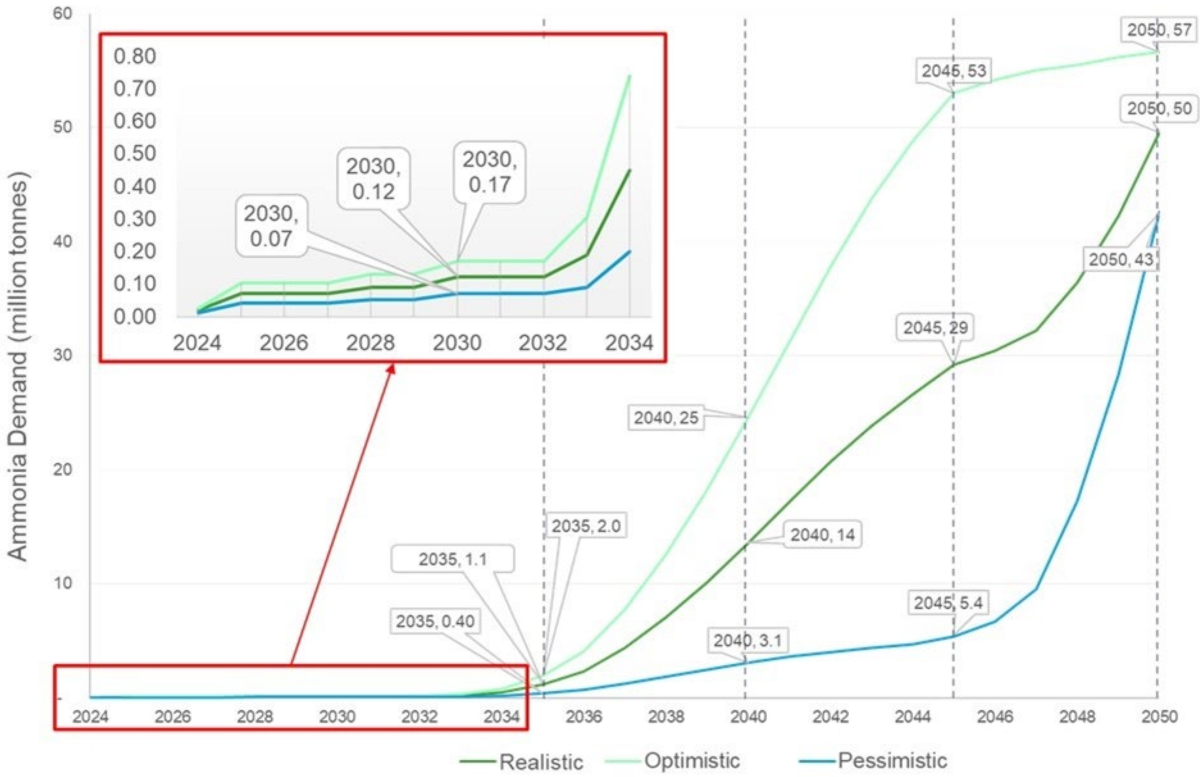

Figure 2-1 Ammonia bunker demand forecast in Singapore

To calculate the share of ammonia bunkering in Singapore, the historic bunker volume data between 2012 and 2021 from the MPA's datasheet [1] was retrieved. Then, the tonnage to GJ (1 tonne of HFO = 40.2 GJ) was converted to obtain the energy equivalence, which was uased as the basis to project future energy demand to 2050. The energy demand was projected using low fleet growth rates provided in the DNV Maritime Forecast to 2050 – Energy Transition Outlook (ETO) every ten years (2020-2030: 1.4%; 2030-2040: 1.2%; 2041-2050: -0.2%), accounting for slow economic growth and geopolitical issues.

[1] Polynomial interpolation is the typical method used for curve fitting because of its simplicity and flexibility.

Then, the ammonia demand projections in the realistic, optimistic, and pessimistic scenarios were converted back to mass equivalence from the energy equivalent values, using the energy density of ammonia (1 tonne of ammonia = 18.8 GJ). Figure 2-2 shows the high-level estimation of ammonia bunker demand as a share of bunker supply in Singapore:

- In the pessimistic scenario, the share of ammonia bunker demand conservatively increases from 2% of total energy demand in 2040 to 4% in 2045 and rise to 32% in 2050
- In the optimistic scenario, the share of ammonia bunker demand rises significantly from 18% in 2040 to 39% in 2045 and eventually reaches 42% in 2050
- In the realistic scenario, the share of ammonia bunker demand increases from 10% in 2040 to 37% in 2050

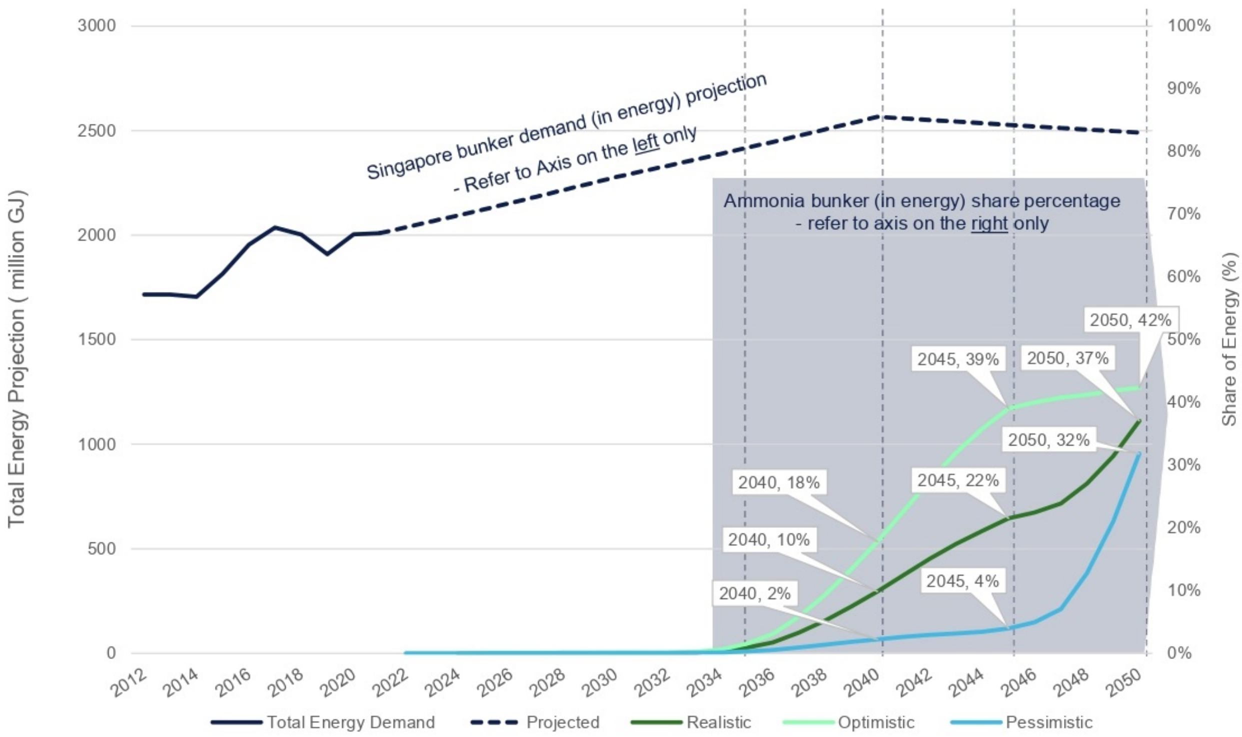

Figure 2-2 High-level estimation of the share of ammonia bunker demand in Singapore

Figure 2-3 illustrates the ammonia bunker demand for various ship types passing through Singapore in the realistic, optimistic, and pessimistic scenarios. In the realistic scenario, ammonia bunker demands for the most representative merchant vessel segments (bulker, container, and tanker) in Singapore will be approximately 17 MT, 16 MT, and 13 MT, respectively, by 2050.

The first LNG bunker vessel deployed in Singapore[2] had a capacity of 7,500 m^3. Therefore, to deliver the same energy equivalence, an ammonia bunker vessel would need a bunker tank with a minimum volume of 15,000 m^3, given the lower energy density of ammonia (about 0.6 times lower than LNG). As a result, a larger volume of ammonia needs to be stored to generate the same amount of energy. However, actual bunker fuel volume requirements may vary due to fuel-specific energy content, vessel design and efficiency, and operating conditions. Therefore, based on a minimum volume of 15,000 m^3, the number of ammonia bunker vessels required for each scenario (optimistic, realistic, and pessimistic) was determined.

[2] The FueLNG Bellina was built in 2021.

As shown in Figure 2-4, all three scenarios will require one bunker vessel initially (until 2035), with the number of bunker vessels gradually increasing to 19, 17 and 14 in the optimistic, realistic, and pessimistic scenarios, respectively, by 2050.

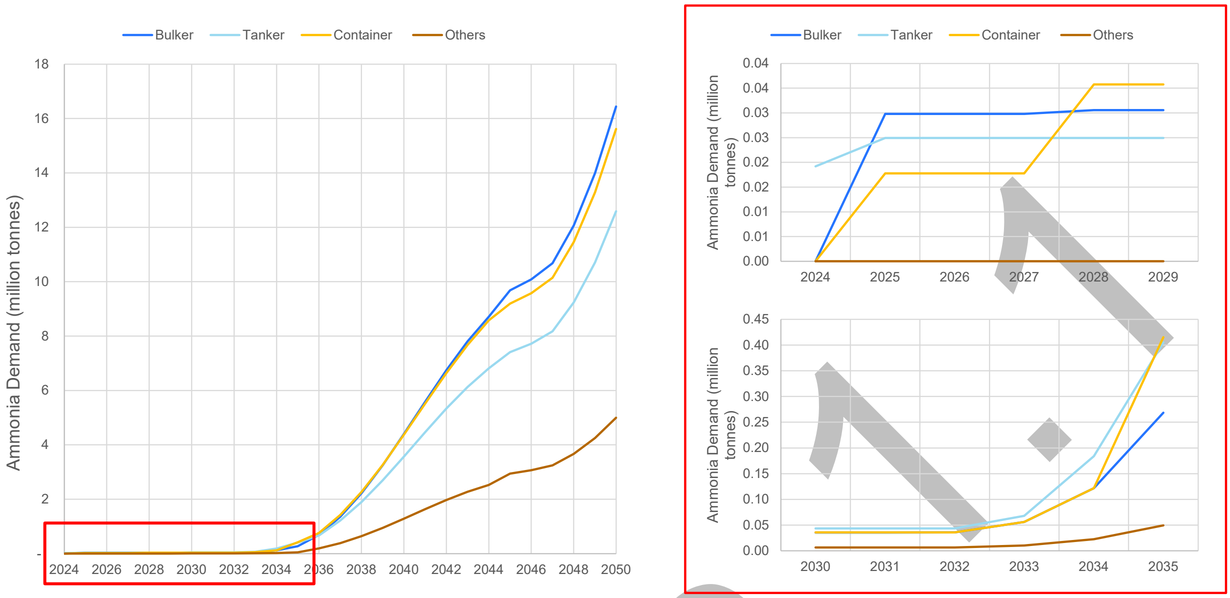

Figure 2-3 Ammonia bunker volumes by ship type in Singapore under the realistic scenario

[The graphs on the right are expanded views of the highlighted box on the left. The top right graph presents the period from 2024 to 2029; the bottom right graph shows the period from 2030-2035]

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

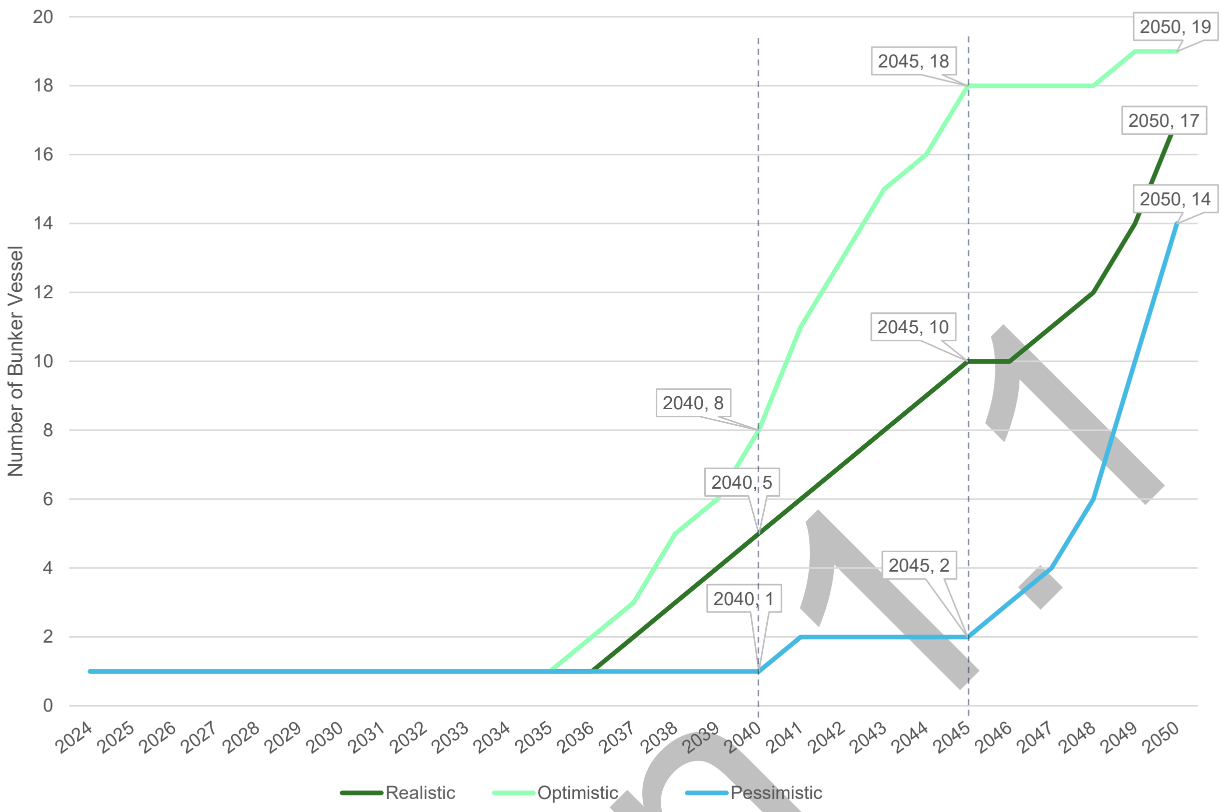

Figure 2-4 Potential deployment of ammonia bunker vessel based on Singapore's bunker demand forecast under the realistic scenario

2.4 References

[1] MPA. (2021). Bunkering Statistics. https://www.mpa.gov.sg/port-marine-ops/marine-services/ bunkering/ bunkering-statistics

[2] IEA. (2021) Marine bunkers product demand. https://www.iea.org/data-and-statistics/charts/marine-bunkers-product-demand-2015-2024

[3] DNV. (2020). Maritime Forecast to 2050 - Energy Transition Outlook 2020

3 CONCEPT SELECTION

3.1 Overview

The Concept Selection section aims to identify and evaluate feasible designs for modes of ammonia breakbulk and bunkering, including SHTS, truck-to-ship, STS, and cassette configurations in Singapore. The process involved collaboration with industry partners and drawing upon existing industry practices for LNG bunkering, adapting them for ammonia bunkering. The DNV-led consortium also examined different storage conditions for ammonia and their interoperability. This section establishes the expected supply chain for the bunkering industry and explores different approaches for transferring ammonia to ships fuelled or powered by ammonia.

3.2 Methodology

The high-level methodology of concept selection involves several steps as shown in Figure 3-1, beginning with the collection of raw input data from study partners.

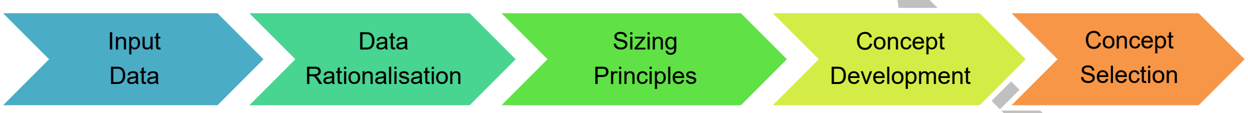

Figure 3-1 Concept selection methodology overview

Data was gathered from interviews with industry players having operational experience in ammonia cargo handling and those involved in developing future ammonia-powered ships, such as ammonia floating storage units (AFSU), ABVs and APSs. The data was subsequently rationalised to establish a basis for the ammonia transfer modes while focusing on the characteristics of the ammonia vessel. Then, the principles used for sizing hoses, lines and marine loading arms were laid out. Finally, design concepts were developed and ultimately selected. Design concepts were then developed for different modes of ammonia transfer, breakbulk and bunkering of ammonia, and cassette bunkering.

The design concepts were selected based on two criteria:

- The availability of a pilot project from a technical perspective
- The possibility of concept development in Singapore, given the selected sites

3.3 Concept evaluation and selection

Seven modes of ammonia transfer operations were evaluated in Table 3-1.

Table 3-1 Transfer mode selection for pilot demonstration

No.	Transfer mode	Category	Reason for selection/ non-selection	The selected concept for the pilot demonstration
1	LAC to AFSU	Breakbulk	AFSU availability during pilot activities is unlikely.	Similar to transfer mode 2
2	AFSU to ABV	Breakbulk	The concept is available. Both ships can berth against jetties or use a double banking configuration for ammonia transfer.	An ABV or LAC as an AFSU for a break-bulking pilot demo in both the anchorage and terminal configuration is selected for the pilot demonstration.
3	ASF to ABV	Breakbulk	A suitable ASF with a sufficiently high filling rate ammonia export facility is unavailable in Singapore.	Not selected

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

4	ABV to APS	Bunkering	The concept is available. Both ships can use a double banking mechanism for ammonia transfer. This mode can also be demonstrated at a cross-dock jetty-based location.	ABV to APS bunkering at anchorage is selected for the pilot demonstration.
5	ASF to APS	Bunkering	The concept is available.	ASF to APS bunkering at the terminal is selected for the pilot demonstration.
6	ABT to small APS	Bunkering	The ABT needs to fill from an existing ASF and berth near an existing jetty to connect to an APS, which is unavailable in Singapore.	Not selected
7	Cassette	Bunkering	A compatible APS is not expected to be available for pilot demonstration in Singapore.	Not selected

Four transfer and their accompanying safety studies modes have been recommended for pilot demonstration. The selected transfer modes for pilot demonstration are as follows:

1. Concept 1 - LAC to ABV/LAC (STS) breakbulk at the terminal
2. Concept 2 - LAC to ABV (STS) breakbulk at anchorage
3. Concept 3 - ABV to APS (STS) bunkering at anchorage
4. Concept 4 - ASF to APS (SHTS) bunkering at the terminal

It is recommended to conduct a pilot demonstration for fully or semi-refrigerated ammonia, as the transfer of ammonia is likely to occur in such storage states. Based on the input of study partners, vessels suitable for this pilot demonstration are listed in Table 3-2 Vessel mix for pilot demonstration.

Table 3-2 Vessel mix for pilot demonstration

Transfer Mode	Supplier Vessel	Receiver Vessel
LAC to ABV/LAC	23,000 m^3 carrier	21,000 m^3 bunker tanker
LAC to ABV/LAC	23,000 m^3 carrier	21,000 m^3 bunker tanker
ABV to APS	21,000 m^3 bunker tanker	6,700 m^3 multi-deck container
ASF to APS	10,000 m^3 onshore tank	110 m^3 dual fuel tug

4 SITE SELECTION

4.1 Overview

After identifying four distinct ammonia transfer concepts for pilot development, the next phase was site selection. Potential anchorages within Singapore waters were evaluated based on their suitability for pilot demonstration, with criteria including buffer distance from industrial or residential areas. One anchorage that met these requirements was the Raffles Reserve Anchorage.

For concepts 1 and 4, the most suitable jetty-based locations had to be determined from a list of possible sites. The sites had to meet several criteria, including strategic location, operational and environmental feasibility, accessibility, and constructibility within a reasonable project schedule. Therefore, a site selection study was conducted to identify the two most feasible sites for a jetty-based ammonia transfer pilot development, and conceptual designs for all four different pilots were matched to these sites.

4.2 Methodology

The site selection was conducted using a three-step process:

1. **Site screening:** Shortlist potential sites based on a set of conditions that are required or beneficial to develop the pilot for ammonia transfer
2. **Site evaluation:** Quantitative evaluation using a penalty system to rank and select the two most suitable sites to pilot the concepts
3. **Validation:** Alignment with relevant stakeholders to ensure site suitability and no disruptions when piloting the bunkering concept

The sites were selected based on general suitability for the pilots, after which the best combination of concept and site was specified.

4.2.1 Site screening

To ensure the successful development of the ammonia transfer pilots, the selected site must meet the following requirements:

- Sufficient space to develop the required onshore facilities
- Accessible for the type and size of vessels recommended for pilot operations, supported by adequate sea access, space and water depth
- Allows for safe operations by having sufficient buffer distance to sensitive receptors (>500 m)
- Supports the required demonstration timeline and bunkering capacity

The following would also be beneficial:

- A brownfield site with existing jetties to reduce development costs
- Ability to scale beyond the pilot phase and to support future commercial operations
- Presence of potential downstream users and onshore chemical storage area
- Ability to accommodate both SHTS and STS ammonia transfer operations

The above considerations were used to initiate discussions with industry stakeholders and assist with site selection. Site operators' buy-in is crucial, and their input will be valuable for future talks. After careful consideration, seven potential sites were shortlisted for further evaluation, including two port locations and five tank terminals in Singapore.

4.2.1.1 Site characteristics

Site 1: Terminal A

The proposed site at Terminal A is situated within an existing breakwater and offers two possible locations for development. The first proposed location is at existing berths that can accommodate ammonia vessels with capacities of up to 38,000 m^3. The

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

second proposed location is along the breakwater, where new jetties can be built to accommodate ammonia vessels with capacities of up to 30,000 m^3.

However, ammonia bunkering at this location may likely impact jetty operations at nearby facilities. Therefore, movement restrictions are anticipated during ammonia bunkering and vessel manoeuvring.

Site 2: Terminal B

The proposed site at Terminal B is located on Jurong Island. Terminal B has three jetties that could be used for ammonia bunkering. The site is considered acceptable for STS operations because of the available sea room.

Due to its location, adverse effects (sea state and squalls) may need to be considered. Speed restrictions or minimum passing distances of traffic in the vicinity may be required during manoeuvring or ammonia bunkering operations.

Site 3: Port A

The proposed site at Port A has ample waterfront space for ammonia bunkering and can accommodate ammonia vessels with a capacity of up to 60,000 m^3 without requiring capital dredging. The site's sea room availability is suitable for STS operations. However, future bunkering facilities beyond 2030–2040 may face challenges as the area has been zoned for future container port operations.

During ammonia bunkering operations and vessel turning, potential interference with passing traffic, such as movement restrictions, impact on the existing port operations and end-users at the berth, is anticipated. As a result, speed restrictions or minimum passing distances of traffic in the vicinity may be necessary during manoeuvring or ammonia bunkering operations.

The berth is reasonably sheltered from metocean effects. However, vessels manoeuvring in a nearby fairway may have an adverse impact on sea state and squalls.

Site 4: Port B

The proposed site at Port B has berths for various cargo types. Two berths along an existing wharf can be used for ammonia bunkering. The site can accommodate ammonia vessels with capacities of up to 85,000 m^3 without capital dredging and is viable for future expansion. STS operations can be conducted with the available sea room at the site.

The site is not exposed to the open sea. Therefore, it is reasonably sheltered from adverse metocean effects, although passing squalls may need to be considered whilst vessels are manoeuvring to or from the berth. There is available sea room to accommodate a nominal-sized turning circle adjacent to the proposed site. However, due to its location, there may be interference with nearby marine traffic transiting to and from other berths, and movement restrictions may be imposed during AC and ABV manoeuvring. In addition, speed restrictions or minimum passing distances of traffic in the vicinity may be required during manoeuvring or ammonia bunkering operations.

Site 5: Terminal C

The proposed site at Terminal C is on Jurong Island at one of the existing wharves. The site has sufficient waterfront space to develop ammonia bunkering and can accommodate a 20,000 m^3 ammonia vessel without capital dredging. As the proposed site is located within an adjacent basin, vessels can leave a main navigational channel and manoeuvre to enter the basin, and interference with passing traffic transiting the fairway may be encountered. The berth is located within this basin, so it is reasonably sheltered from metocean effects. But when vessels are manoeuvring outside of the basin in the fairway, adverse effects (sea state and squalls) may need to be considered.

Speed restrictions or minimum passing distances of traffic in the vicinity may be required during manoeuvring or ammonia bunkering operations.

Site 6: Terminal D

The proposed Terminal D site is also located on Jurong Island, offering great potential for ammonia bunkering with its two existing berths and ample waterfront space that can accommodate ammonia vessels up to 85,000 m^3 without the need for capital dredging. The site's location in a basin also makes STS operations acceptable. However, it’s worth noting that the existing jetty operations may be impacted during ammonia bunkering and vessel manoeuvring. To mitigate any potential risks, speed restrictions or minimum passing distances of traffic in the vicinity may be necessary during manoeuvring or ammonia bunkering operations.

The berths are located where they are reasonably sheltered from metocean effects. But when vessels are manoeuvring outside of the basin in the fairway, adverse effects (sea state and squalls) may need to be considered.

Site 7: Terminal E

The proposed site has an existing berth that can be used for ammonia bunkering operations. The site has sufficient waterfront space to develop ammonia bunkering and can accommodate ammonia vessels with capacities of up to 78,000 m^3 without capital dredging. STS operations are acceptable with the amount of available sea room. Still, significant modifications are required to create land space to accommodate new bunkering facilities. Due to its location, interference with passing traffic is envisaged during ammonia bunkering operations and ammonia vessel manoeuvring. Therefore, speed restrictions or minimum passing distances of traffic in the vicinity may be required during manoeuvring or ammonia bunkering operations.

As the berth is located where it is reasonably exposed to prevailing metocean conditions, there may have adverse effects (sea state and squalls), particularly when vessels are manoeuvring in the fairway.

4.2.2 Site evaluation

To select the two most feasible pilot sites, a thorough quantitative site evaluation was conducted based on a set of criteria. The criteria was derived from the Society of International Gas Tanker and Terminal Operators (SIGTTO) guidelines on “Site Selection and Design for LNG Ports and Jetties”. However, these guidelines were adapted to account for differences between LNG and ammonia operations.

The primary objectives for site selection included minimising the risk of collision events, reducing the impact from passing vessels, and mitigating the risks of dynamic wave forces on mooring lines. To achieve this, sheltered water locations were preferred where potential dynamic forces from sea waves that could damage mooring lines were limited. The World Association for Waterborne Transport Infrastructure (PIANC) guidelines and technical notes were also considered, particularly with passing vessel effects in navigation channels where moored vessels are present. The evaluation criteria used in this study is outlined in Table 4-1.

Table 4-1 Site evaluation criteria

Sr No	Category	Sub-category	Description
1	Marine	(a) General	The presence of safe navigational vessel access to the proposed jetty and the adequacy of the sea space for the proposed deployment of the ammonia vessel
		(b) Bathymetry	The charted water depth at the location relative to the proposed vessel’s draught and, thus, Under Keel Clearance will determine the size of LAC/AFSU/ABV/APS that the berth can safely accommodate
		(c) Locations	Safe navigational access with regards to prevailing metocean conditions that may adversely affect the manoeuvring vessels and then when moored alongside. If it is exposed and susceptible to these conditions, protection, e.g. a breakwater would be required

Sr No	Category	Sub-category	Description
		(d) Navigational	For the proposed site, being adjacent to or near an existing established channel or fairway would be advantageous, as would sufficient sea room to provide adequate manoeuvring, e.g. a turning circle. But the impact on existing operations would need to be considered
		(e) Infrastructure / Utilities	Proximity to existing recreation/residential facility and any need to upgrade the existing infrastructure
2	Land	(a) Land availability	Availability of land space for deploying land-side storage facilities (e.g. ammonia storage tank, truck loading facilities, etc.) with safety distances compliant with Singapore regulations
		(b) Land suitability	Suitability of the land for developing land-side facilities
		(c) Infrastructure / Utilities	Availability of proper infrastructure/utilities, such as road access, sub-station space, electricity grid connectivity, temporary construction laydown area space, firewater source, a workshop for maintenance, and administration building within plant battery limit
3	HSE & Demography	(a) Proximity	The distance to the nearest residential/ public access/ leisure areas, military areas, explosives/munition depots, adjacent hydrocarbon production/storage facilities, airports and aircraft flight paths
		(b) Effluent discharge	Effluent discharge in three states (liquid, gaseous and solids) and their potential effects on surrounding marine, air and ground conditions
		(c) Ecology	The site's proximity to any ecological-related protection zone, both onshore and offshore
		(d) Safety	Typical safety requirements, including Marine Exclusion Zone (MEZ) for the bunkering industry. A detailed safety study was carried out for the selected sites
		(e) Other	Proximity to heritage sites, which may involve objects or sites with archaeological value
4	Accessibility	(a) Existing roads (b) Existing marine offloading facility (MOF)	Accessibility to existing roads for the transportation of equipment and existing marine offloading facility (MOF) for the transport of equipment by sea
5	Constructability	(a) Constructability high level	Ease of construction, construction schedule, and installation requirements for the site and the complexity of the design

Sr No	Category	Sub-category	Description
		(b) Site prep schedule and phasing (c) Construction schedule	involved for each site based on the varying needs of each location

4.2.2.1 Assumed pilot specifications

The availability of sufficient space for the pilot is the most important consideration in the site evaluation to accommodate the needs of the supplier and receiving vessels and the required auxiliaries. The frequency of operation used is only for pilot operations, which is fewer than the frequency of usual bunkering operations. Based on inputs from the study partners, the selected vessels with specifications showcased in Table 4-2 are recommended for pilot demonstration.

The facility size largely determines the onshore land requirements for an ammonia transfer site, which is mainly based on the needed amount of ammonia storage. For a pilot site, a 10,000 m^3 ammonia storage requirement is assumed, necessitating approximately 1 to 1.3 hectares of land. This factor is the primary consideration in site evaluation. However, a site with ample space available for future commercial scale operations beyond the pilot would provide an additional benefit over one that did not, assuming they score equally. Hence, the potential for scalability has been included as one of the 18 criteria. The evaluation of this criterion assumes an ammonia storage size of up to 40,000 m^3 or approximately 3.2 to 3.5 hectares of land.

Table 4-2 Vessel specifications for consideration

Vessel	LOA	Beam	Draught
LAC	165 m	26 m	7.5 m
ABV	150 m	32 m	7.5 m
APS (Multi-deck container)	200 m	38 m	10 m
APS (Tug)	35 m	13 m	6.0 m

4.2.2.2 Scoring methodology

The seven potential sites were assessed based on the 43 criteria and scored using a combination of traffic light analysis and penalty point system, with each criterion equally weighted. In cases where multiple issues were identified, multiple penalty points could be applied to a single criterion.

The colour-coded rating system reflects potential risks, limitations or additional costs that may be associated with each site. Penalty points are assigned based on the rating colour, with a 'Green' rating receiving zero points and a 'Red' rating immediately eliminating the site from further evaluation. 'Orange' ratings receive the highest penalty of five points, while 'Yellow' ratings indicate minor issues and receive one point.

Since the shortlisted sites performed well across most categories, a more precise differentiation between the sites was necessary. Therefore, a penalty-based system with significant scoring differences between minor issues ('Yellow') and critical issues ('Orange') was employed to provide a clearer overall evaluation. Additional details about the risk scoring methodology can be found in Table 4-3.

Table 4-3 Scoring methodology employed for site evaluation

Evaluation	Score	Description

Green	0	Good position	Comparable with good practice, well understood, easy access, "normal" cost/schedule impact, good certainty of estimates
Yellow	1	Shortcomings	Adequate, but it may not be best practice, some hurdles to development, cost/schedule impact on resolving, reasonable certainty of estimates
Orange	5	Important issues	Improvement needed to reach best practice, significant hurdles to development, high cost/schedule impact on resolving, poor certainty of estimates
Red	N/A	Not feasible	Well short of best practice, hurdles that can halt the project, major cost/schedule impact on resolving, little or no certainty in estimates

4.3 Site evaluation results

The results of the quantitative site evaluation can be found in Figure 4-1, with a breakdown by category in Table 4-4. Terminal D and Terminal A have been identified as the most feasible sites to develop the ammonia transfer pilot, with scores of 6 and 10, respectively.

- Terminal D scored well across all categories, with the main differentiators being land and health, safety & environment (HSE). The terminal has sufficient space on both land and sea, is in a sheltered basin and is more than 200 m away from buildings and access roads. Also, it is located near safe navigational access and is reasonably sheltered from adverse metocean effects. The site has strong potential for ammonia storage tank.

- Terminal A has similar benefits in terms of the availability of land and sea and is in a sheltered location. The location narrowly beats Terminal D with a ship turning circle clear of marine traffic and the option to develop additional jetties for ammonia transfer operations. The identified berth is located near an area where it is reasonably sheltered from adverse metocean effects.

Apart from Terminal E, all the other sites are feasible for ammonia bunkering. These other sites will need more investments to be made viable compared to Terminals A and D. Terminal E was disqualified with “Red” evaluations in the Land, Accessibility and Constructability categories because of a lack of existing land access, electrical grid connection, or available land space for the development of facilities.

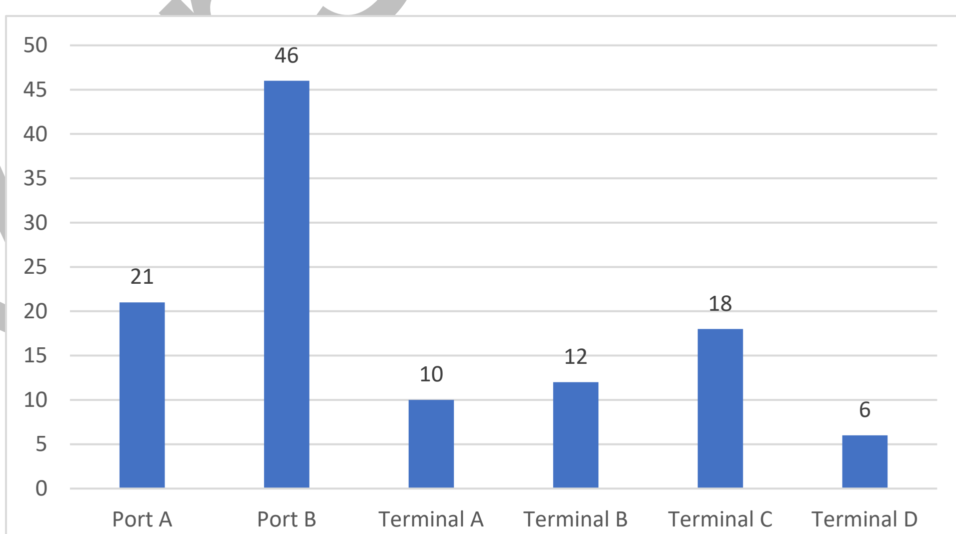

Figure 4-1 Results of the quantitative evaluation of sites; Terminal E excluded

Table 4-4 Breakdown of the evaluation by category; a lower score signifies a better suit for piloting purposes

Location	*Port A*	*Port B*	*Terminal A*	*Terminal B*	*Terminal C*	*Terminal D*	*Terminal E*
Marine	12	4	3	5	5	4	4
Land	8	31	1	1	6	1	N/A
HSE & Demography	0	5	5	5	5	0	0
Accessibility	0	0	1	1	1	0	N/A
Constructability	1	6	0	0	1	1	N/A
Total score	**21**	**46**	**10**	**12**	**18**	**6**	**N/A**

4.3.1 Discussion with agencies and regulator

During the stakeholder engagement process, relevant Singapore government agencies were involved in the site screening and selection stages to determine any potential obstacles to deploying pilot demonstrations at the identified sites.

Following the discussions, it was concluded that:

- All four evaluated pilot concepts for ammonia bunkering are technically feasible to be carried out in Singapore
- There were no significant concerns raised regarding the site selection for ammonia bunkering at the shortlisted sites (Terminal A and Terminal D)
- No obstacles for bunkering pilots at Terminal A and Terminal D were anticipated. However, commercial considerations and discussions with facility owners would be necessary when planning the bunkering pilots
- Currently, there is no regulatory framework or licensing regime in place for ammonia bunkering and associated operations

4.4 Pilot selection

From the seven modes of ammonia transfer pilots discussed in the concept selection report, four modes were recommended for carrying out pilot demonstrations:

1. STS breakbulk at a jetty-based location
2. STS breakbulk at an anchorage
3. STS bunkering at an anchorage
4. SHTS bunkering at a jetty-based location

LNG operations were used as a preliminary benchmark for the feasibility of ammonia bunkering pilot operations. The Raffles Reserve Anchorage was suggested for concepts 2 and 3 due to its distance from residential zones and sensitive receptors. In the event of any incident, the public would not be alarmed.

For concepts 1 and 4, Terminal A and Terminal D were selected as the preferred sites to showcase safe operating practices for ammonia transfer. However, to understand and ensure safety during these operations, safety studies such as HAZID and QRA. In addition, the risks and mitigation measures required are operation and location-specific. Therefore, an optimal combination of the piloting concept and location must be determined for bunkering concepts 1 and 4. The following section describes the considerations and recommendations for both.

4.4.1 Concept and site combination (concept 1 and 4)

Based on discussions with the terminal operators, the following combination to pilot was decided upon:

- Concept 1: LAC to ABV/LAC (STS) breakbulk at Terminal A
- Concept 4: ASF to APS (SHTS) bunkering at Terminal D

Both Terminal A and Terminal D lacked direct road access to their berths, making it impossible to transfer ammonia from a truck to a receiving vessel. Additionally, both terminals restrict vehicle access near the storage tanks for safety reasons. Therefore, truck-to-ship transfer for concept 4 is not feasible, and tank-to-ship is the preferred option.

Terminal D's operator was consulted to evaluate the CAPEX implications of different infrastructure options. One option is installing a pipeline to transfer ammonia from a storage tank to the jetty, which can be done with minor modifications without disrupting existing operations. Alternatively, modifying a loading arm may be required to accommodate the height and dimensions of the receiving vessel, as it may differ from the existing vessels berthing at Terminal D. Another option is using a submerged pump with a low flow rate specification to transfer bunker to smaller receiving vessels, but are not practical for larger vessels (i.e. LAC and ABV) due to extended transfer durations. To minimise CAPEX for the ammonia bunkering pilot, a new pump with higher transfer capacities was not considered.

The evaluation concluded that ammonia transfer from a storage tank to a small receiving vessel is possible at Terminal D at a significantly lower cost than Terminal A. In addition, small ammonia-fuelled vessels are likely to be in service before larger receiving vessels are retrofitted or built. Therefore, utilising Terminal D for piloting concept 4 allows early testing to enable first movers to conduct ammonia bunkering.

Given the stated constraints, only STS transfer would be preferentially tested at Terminal A, and site suitability verification would still be required. The following configurations are commonly used for the transfer of fuel between two ships:

- Cross-dock transfer
- Side-by-side transfer

A cross-dock transfer system is a double berth jetty designed for simultaneous mooring of both the mother and daughter vessels. On the dual berth jetty head, two sets of fixed loading arms are connected using piping to transfer ammonia. A typical arrangement is shown in Figure 4-2.

Figure 4-2 Cross-dock transfer arrangement
[Source: Petrobras]

A side-by-side transfer arrangement is typically achieved by mooring the LAC beside the ABV, which is also known as double-banking. In its simplest form, the two vessels are moored alongside each other and are separated by mooring fenders. In addition, flexible cryogenic hoses can facilitate the transfer of ammonia from the LAC to the ABV, as reflected in Figure 4-3, for a side-by-side configuration.

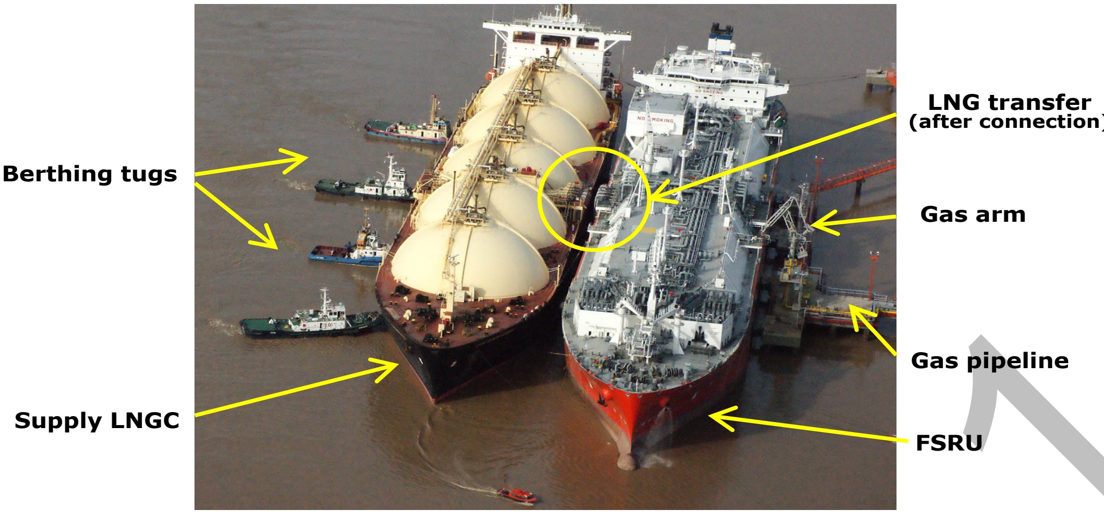

Figure 4-3 Side-by-side configurations (Buques LNG)

Figure 4-4 provides a more detailed up-close visual of a cryogenic hose transfer.

Figure 4-4 Flexible cryogenic hose system used in a side-by-side transfer configuration. [Source: The still taken from the Excelerate video]

The limited sea space at Terminal A means that side-by-side transfer arrangements could impact marine traffic at other jetties. Additionally, the risk of loss of containment from hoses is considered to be higher than from loading arms. To mitigate these risks, a cross-dock system could be deployed for the pilot.

Feedback from the Terminal A operator indicates that the cross-dock system would not affect existing operations and could be utilised for higher throughput, facilitating future expansion. Moreover, the design and installation of a cross-dock system are not expected to be capital-intensive. The greater water depth at the terminal can also be utilised for berthing larger vessels, enabling economies of scale.

Based on existing maritime practices in Singapore, receiving vessels do not berth at designated terminals solely for bunkering. Therefore, the cross-dock concept at Terminal A can be deployed for breakbulk operations between the LAC and the ABV, making it a suitable site for piloting bunkering concept 1.

4.4.2 Pilot design concepts

4.4.2.1 LAC to ABV/LAC (STS) breakbulk at Terminal A

Terminal A features common jetties that can berth vessels on either side. Marine loading arms (MLA) can be used to connect both ships while loading lines can be used for the liquid and vapour transfer.

Process description

Transfer pumps within the LAC tanks will pump ammonia from the LAC to the ABV tanks. During the transfer process, boil-off gas (BOG) generated will be sent back from the ABV to the LAC through a dedicated vapour arm and line. Although the transfer the lines and arms have been sized for a 1500 m^3/hr transfer rate, the maximum transfer rate for the pilot will be capped at 700 m^3/hr. A detailed process diagram can be found in Figure 4-5.

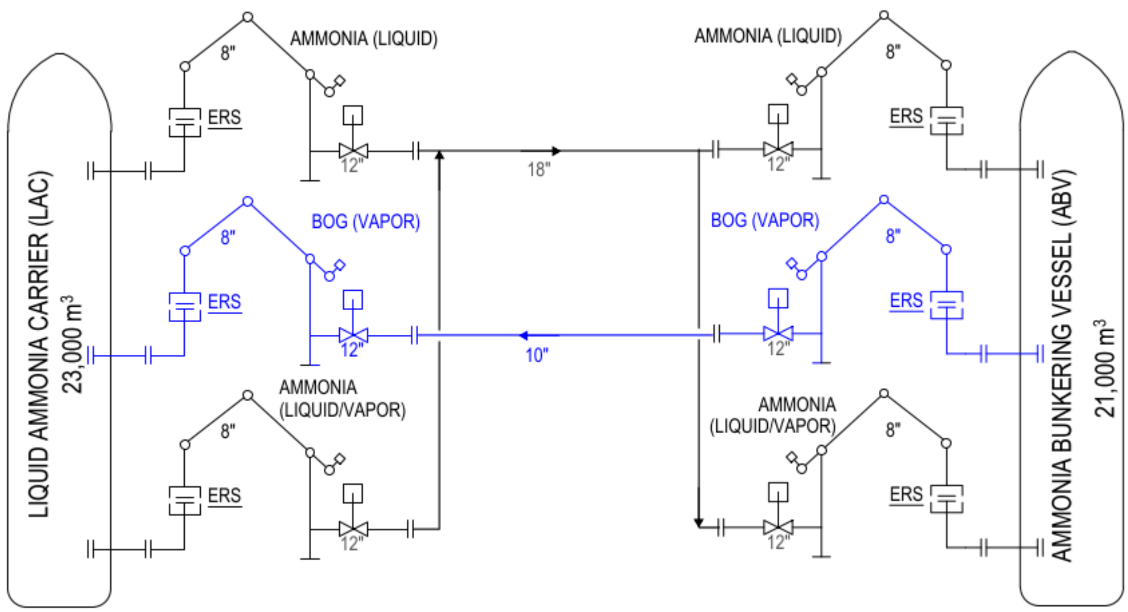

Figure 4-5 Process flow diagram for LAC to ABV breakbulk at Terminal A

Table 4-5 Fully refrigerated LAC to ABV breakbulk

	LAC	ABV	Unit
Storage Temperature	-33	-33	^{0}C
Storage Pressure	0	0.12	Bar_g
Storage Capacity	23,000	21,000	m^3
Total Liquid Transfer Rate	1500		m^3/hr
BOG Rate	1460		Kg/hr
No. of Arms	2 Liquid + 1 Vapor		
Arm Sizes	8		Inch

Boil Off Rate	0.06	0.06	Vol%/day

To minimise the BOG during the flashing process, it is crucial to maintain a slightly higher pressure of 0.12 barg in the ABV tank than the LAC tank, which is kept at 0 barg. This compensates for the temperature rise due to heat leaks from the pumps and transfer systems. Keeping the pressure slightly higher in the ABV tank ensures the incoming ammonia is subcooled at the ABV tank operating pressure. The LAC and ABV are assumed to have reliquefication units to condense the BOG generated due to heat leaks within the LAC tanks.

4.4.2.2 LAC to ABV/LAC (STS) breakbulk operations at anchorage

The LAC to ABV breakbulk operations of ammonia at the anchorage should use flexible transfer hoses.

Process description

The transfer of ammonia from the LAC to the ABV tanks is accomplished using transfer pumps located within the LAC tanks. During the transfer process, BOG is generated and sent back from the ABV tank to the LAC tank through a dedicated vapour hose. However, it is important to note that probability of hose failure is higher compared to that of marine loading arms. Therefore, the transfer rate is limited to 700 m^3/hr with each liquid hose having a transfer rate of 350 m^3/hr. A detailed process diagram can be found in Figure 4-6.

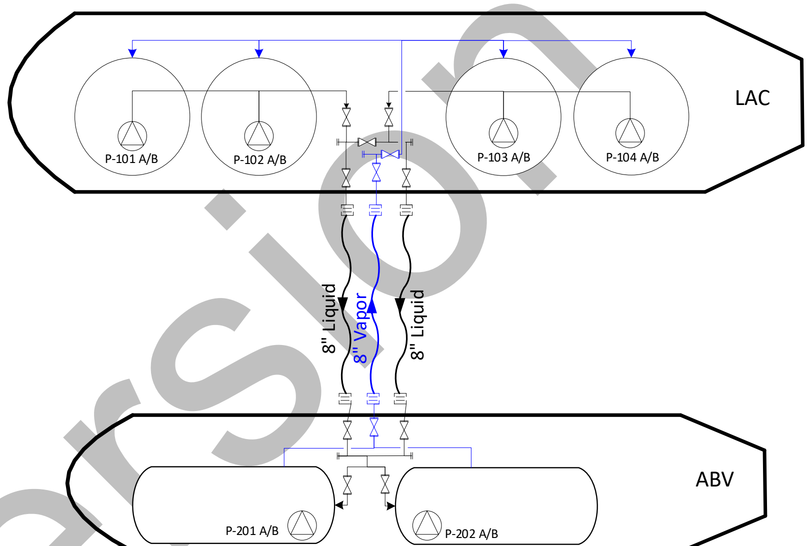

Figure 4-6 Process flow diagram for LAC to ABV breakbulk at the Terminal A

Table 4-6 Fully refrigerated LAC to ABV breakbulk

	LAC	ABV	Unit
Storage Temperature	-33	-33	^{0}C
Storage Pressure	0	0.12	Bar_g
Storage Capacity	23,000	21,000	m^3
Total Liquid Transfer Rate	700		m^3/hr
BOG Rate	680		Kg/hr
No. of Hoses	2 Liquid + 1 Vapor		

Hose Sizes	8		Inch
Boil Off Rate	0.06	0.06	Vol%/day

To minimise the BOG during the flashing process, it is crucial to maintain a slightly higher pressure of 0.12 barg in the ABV tank than the LAC tank, which is kept at 0 barg. This compensates for the temperature rise due to heat leaks from pumps and the transfer system. Keeping the pressure slightly higher in the ABV tank ensures that the incoming ammonia is subcooled at the ABV tank operating pressure. The LAC is assumed to have a reliquefication unit to condense the BOG generated due to heat leaks within the tanks.

4.4.2.3 ABV to APS (STS) bunkering at anchorage

ABV to APS bunkering of ammonia at anchorage should use flexible hoses for transfer.

Process description

The transfer of ammonia from the ABV tanks to the APS tanks is facilitated by transfer pumps located within the ABV tanks. During the transfer process, BOG is generated and sent from the APS tank to the ABV tank via a dedicated vapour hose. Bunkering pilot operations at the anchorage should be carried out at a maximum transfer rate of 700 m^3/hr (or 350 m^3/hr for each liquid hose). A detailed process diagram can be found in Figure 4-7.

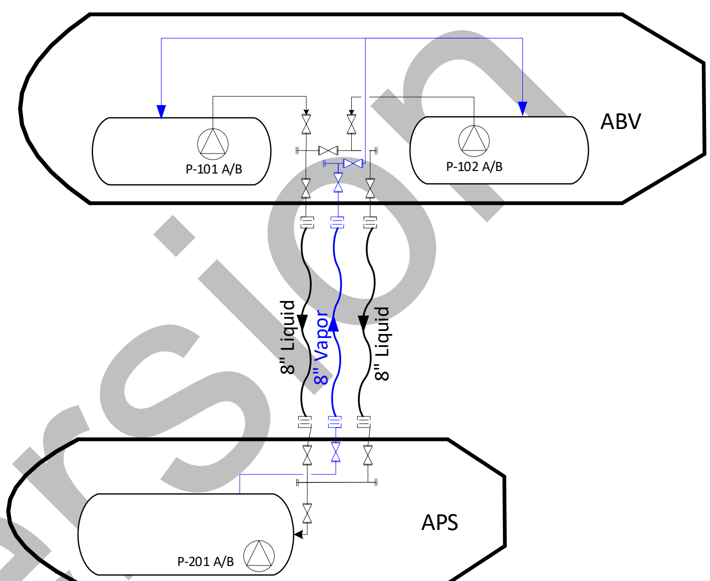

Figure 4-7 Process flow diagram for ABV to APS bunkering at anchorage

Table 4-7 Fully refrigerated ABV to APS bunkering

	ABV	APS	Unit
Storage Temperature	-33	-33	^{0}C
Storage Pressure	0	0.12	Bar_g
Storage Capacity	21,000	6,700	m^3
Total Liquid Transfer Rate	700		m^3/hr
BOG Rate	680		kg/hr
No. of Hoses	2 Liquid + 1 Vapor		

Hose Sizes	8		Inch
Boil Off Rate	0.06	0.06	Vol%/day

To minimise the BOG during the flashing process, it is crucial to maintain a slightly higher pressure of 0.12 barg in the APS tank than the ABV tank, which is kept at 0 barg. This compensates for the temperature rise due to heat leaks from the pumps and the transfer system. Keeping the pressure slightly higher in the APS tank ensures that the incoming ammonia is subcooled at the APS tank operating pressure.

4.4.2.4 ASF to APS (SHTS) bunkering at Terminal D

Terminal D could export small amounts of ammonia via liquid arms and a 3-inch recirculation line present at the terminal. This setup could be used to bunker small APS, like tugboats.

Process description

In the event that Terminal D tanks are equipped with transfer pumps capable of pumping ammonia to an ammonia-powered tugboat tank, there would be no need for a vapour connection. This is because tugboats have no vapour return capability. However, during ammonia filling, the tanks in the tugboats are expected to pressurise, which is acceptable given the small capacity (110 m^3), low transfer rate (9 m^3/hr) and the use of type C tanks. A detailed process diagram on the transfer process can be found in Figure 4-8.

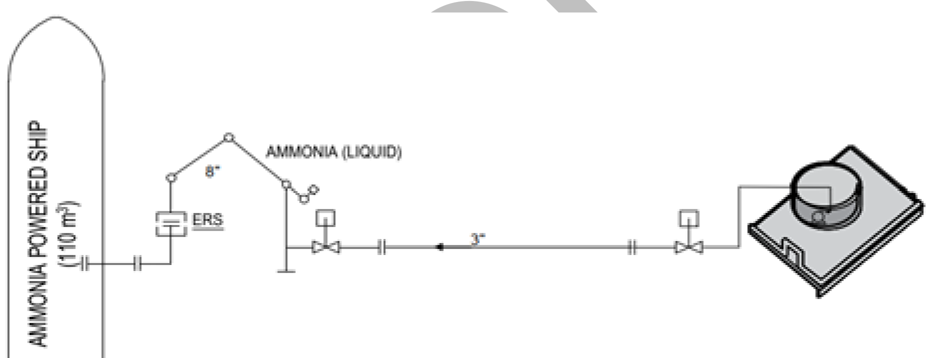

Figure 4-8 Process flow diagram for ASF to APS bunkering at Terminal D

Table 4-8 Fully refrigerated ASF to APS bunkering

	ASF	APS	Unit
Storage Temperature	-33	-33	^{0}C
Storage Pressure	0	0.12	Bar_g
Storage Capacity	10,000	110	m^3
Total Liquid Transfer Rate	9		m^3/hr
No. of Arms	1 Liquid		
Line Sizes	3		inch
Arm Size	8		inch

5 HAZID STUDY

5.1 Overview

The HAZID study is a systematic and structured approach to identifying all potential hazards associated with a specific concept, design, operation, or activity, including the likely causes, possible consequences, and appropriate safeguards. Its goal is to assess and control or mitigate the identified hazards to ensure the required safety level is met per internationally recognized standard requirements.

The HAZID study aims to:

- Identify hazards and hazardous events that may give rise to risks
- Identify potential causes and consequences of hazardous events
- Identify preventive measures (e.g., measures to prevent hazardous events from occurring)
- Identify mitigating measures (e.g., measures to help prevent escalation)
- Assess risks semi-quantitatively by using a risk matrix (i.e., risk ranking)
- Recommend additional measures to ensure the required safety level is met and is in line with internationally recognised standard requirements, such as IGF/IGC code and DNV Ship Rules Pt 6 Ch 2 Sec 14 “Gas Fuelled Ammonia”

5.2 Methodology

The HAZID study for the ammonia bunkering concepts started with a brainstorming session at the HAZID workshops, attended by a multidisciplinary team (the HAZID team). DNV conducted hybrid-format workshops with virtual MS Teams and physical attendees at DNV’s premises in Singapore from 13 to 16 September 2022. Representatives from 22 study partners participated in the workshops to provide technical expertise on the subject matter.

The HAZID workshop procedure involved a rigorous process for identifying and assessing hazards associated with specific areas or operations. The process utilised a series of steps, beginning with identifying HAZID nodes. Next, DNV classified the areas and operations of these nodes, and for each node, the following steps were performed:

1. ***Node briefing:*** A brief introduction of the node in question was given to all HAZID team members to obtain a common understanding of the intended operation.
2. ***Identification of hazards and hazardous events****:* The HAZID team identified hazards and hazardous events, considering each node based on documents and drawings provided by the study partners and their past experiences.
3. ***Identification of causes****:* For each hazardous event, potential causes of the hazard were highlighted and discussed. However, double jeopardy, or a combination of multiple independent events co-occurring, was not considered during the HAZID workshop.
4. ***Identification of consequences****:* All potential effects for each hazardous event and cause were identified, assuming no preventive or mitigating measures were in place. Results were not limited by the HAZID node definitions or scope boundaries in evaluating the results of a given event.
5. ***Identification of preventive and mitigating measures (safeguards)****:* Existing measures expected to prevent a hazardous event from occurring (preventive measures) and those intended to control its development or mitigate its consequences (mitigating measures) were identified.
6. ***Risk ranking****:* The identified accident scenarios were categorised according to risk level. DNV performed the risk ranking using a risk matrix agreed upon by the HAZID team, considering existing preventive measures. Hazards with insufficient provision of necessary steps were identified and ranked with a higher probability of an accident. The workshop participants subsequently reviewed the risk ranking.
7. ***Identification of recommendations****:* If the current provision of preventive or mitigating measures was considered

insufficient to manage risks or further assessments were required to understand hazard/hazardous events better, recommendations were raised during the HAZID workshop and assigned to the responsible parties.

5.3 Nodes and risk ranking

The HAZID nodes are presented in Table 5-1.

Table 5-1 HAZID nodes

No.	Description
	Operations
Node 1	Prior to operations
Node 2	Prior to arrival
Node 3	Arrival
Node 4	Pre-transfer
Node 5	Transfer of ammonia
Node 6	Post-transfer
Node 7	Unmooring and departure
Node 8	Other hazards
	Locations
Node 1	Local establishment, regulations, and requirements
Node 2	Exposure of location to prevailing environmental conditions
Node 3	Navigational hazard near the location
Node 4	Ship traffic density near the location
Node 5	Spill and dispersion trajectories and potential impact
Node 6	Requirement for and availability of any additional spill response resources at the location
Node 7	Other hazards

The risk ranking was performed for each identified scenario using the risk matrix presented in Figure 5-1.

Risk matrix

				Consequence				
				1	2	3	4	5
				None	**Minor**	**Significant**	**Severe**	**Catastrophic**
			Safety (SAFE)	No or superficial injuries	Slight injury, a few lost work days	Major injury, long term absence	Single fatality or permanent disability	Multiple fatalities
			Delay (DEL)	< 2 hours	< 1 day	1 - 10 days	10 - 60 days	> 60 days
			Asset (AST)	Slight damage	Minor damage	Localized damage	Major damage	Extensive damage
			Reputation (REP)	Slight impact; local public awareness but no public concern	Limited impact; local public concern - may include media	Considerable impact; regional public/slight national media attention	National impact and public concern; mobilization of action groups	Extensive negative attention in international media
			Environment (ENV)	Slight effect on environment	Minor effect	Localized effect. Spill response required	Major effect. Significant spill response	Massive effect damage over large area
			Quality and performance (QUA)	Minimal or no impact	Minor decrease in performance/quality	Moderate decrease in performance/quality	Substantial decrease in performance/quality	Non-functioning
			Regulatory (REG)	Approval	Approval with minor comments	Approval with comments (moderate modifications needed)	Non-compliance or approval with substantial comments (major modifications needed and/or alternative design)	Non-compliance and no alternative design arrangements possible (i.e. "show stopper"!)
			Cost (COST)	Minimal or no impact	Minor decrease in cost	Moderate decrease in cost	Substantial decrease in cost	Substantial impact on company's financial position
Frequency	5	**Frequently**	Occurs several times per year per facility (10–1 < pf)	M	M	H	H	H
	4	**Very likely**	Occurs several times per year per operator (10–2 < pf < 10–1)	M	M	M	H	H
	3	**Likely**	Has been experienced by most operators (10–3 < pf < 10–2)	L	M	M	M	H
	2	**Unlikely**	An incident has occurred in industry or related industry (10–4 < pf < 10–3)	L	L	M	M	M
	1	**Remote**	Failure is not expected (pf < 10–4)	L	L	L	M	M

Figure 5-1 Risk matrix

The scenarios have been classified into categories based on their level of risk:

- **Low Risk** (green): In this category, the risk is considered acceptable, and no additional preventive or mitigating measures are required unless they can be implemented at a very low cost (in terms of time, money, and effort). However, it is important to continuously monitor the risk to ensure that it maintains at an acceptable level
- **Medium Risk** (yellow): In this category, risk-reducing measures must be implemented to reduce the risk to As Low as Reasonably Practicable (ALARP). This means that the level of risk must be demonstrated to be ALARP
- **High Risk** (red): The risk is deemed unacceptable or intolerable in this category. Therefore, risk-reducing measures must be implemented to reduce the risk to a tolerable level or below
- **Not Risk Ranked**: Events in this category were not ranked because no risk was identified

The following assumptions were used for risk ranking:

- The frequency and consequence ratings were determined based on the knowledge and experience of the HAZID team
- The frequency and consequence ratings were specific to the outcomes and not the initial event
- Existing preventive measures were taken into account when determining frequency ratings
- Mitigating measures **were not** taken into account when determining consequence ratings
- Where there were differences in opinion on a rating, the worst credible rating was used

5.4 Key findings

It should be noted that the risks associated with ammonia is due to its toxicity, which is different from that of LNG where the primary risk is its flammability.

The risk ranking for the four concepts have been summarised in Tables 5-2 to 5-5.

Table 5-2 Risk rank summary for the LAC – ABV cross-dock at Terminal A (Concept 1)

Risk Ranking	Operation Risk (Number of Items)	Location Risk (Number of Items)
Low	4	7
Medium	34	25
High	0	0
Not Risk Ranked	4	16

Table 5-3 Risk rank summary for breakbulk LAC – ABV at anchorage (Concept 2)

Risk Ranking	Operation Risk (Number of Items)	Location Risk (Number of Items)
Low	3	3
Medium	33	37
High	0	0
Not Risk Ranked	4	13

The detailed risk results and HAZID log can be found in Appendix A.

Table 5-4 Risk rank summary for STS ABV – APS at anchorage (Concept 3)

Risk Ranking	Operation Risk (Number of Items)	Location Risk (Number of Items)
Low	1	3
Medium	38	36
High	0	0
Not Risk Ranked	3	13

The detailed risk results and HAZID log can be found in Appendix B.

Table 5-5 Risk rank summary for ASF to APS at Terminal D (Concept 4)

Risk Ranking	Operation Risk (Number of Items)	Location Risk (Number of Items)
Low	5	9
Medium	41	23
High	0	0
Not Risk Ranked	4	15

5.5 Recommendations

The recommendations made by the participants have been summarised in this section.

5.5.1 Operational measures

- **Transfer procedures and organisation:** Existing transfer procedures, including established organisations, Joint Operation Plans (JOP), and Safety Management Systems (SMS), should be revisited for ammonia transfer. This primarily concerns existing cargo carriers subject to retrofitting at Terminal A and Terminal D
- **Checklists and testing during normal operation:** Existing checklists and required tests carried out during pre-arrival, arrival, pre-transfer, and post-transfer should be revisited after taking ammonia-specific aspects into consideration
- **Personnel competence and training:** Due to the limited experience in ammonia handling, required competence and training provisions should be implemented and assured
- **Emergency response plan:** An emergency response plan should be established and dimensioned for all major accident scenarios associated with ammonia transfer operations. Furthermore, a temporary refuge on land or ship should be considered to protect personnel from major ammonia releases (applicable to land-based facilities only)
- **Metocean restrictions and abort criteria:** Operators should develop specific restricting/limiting metocean (i.e. wind, wave and current) and non-metocean parameters (e.g. wake) for ammonia transfer operations
- **Compatibility assessment**: The compatibility of bunkering infrastructure and mooring, including fendering and berthing, and other materials with ammonia should be addressed. This mainly concerns operations at Terminal A and existing LPG/LNG carriers that are subject to retrofits
- **Simultaneous Operations (SIMOPS):** The type and compatibility of SIMOPS allowed concurrently with ammonia transfer operations should be reviewed by the regulators, such as the Maritime and Port Authority of Singapore (MPA). A SIMOPS assessment is conducted to identify all compatible and incompatible SIMOPS

5.5.2 Safety measures

- **ESD system (ESDS)**: According to the International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), automatic emergency shutdown valves for ammonia cargo carriers are not required. However, relying on personnel present to report leaks could result in delays to activate the ESD. Instead, an automatic ESD is recommended, which can be triggered by liquid/thermal sensors in the drip tray or gas detectors. Additionally, linked ESDs are recommended to stop bunkering and close bunker valves simultaneously. These measures should also be extended to the ABV to limit the potential escalation of toxic ammonia clouds towards the APS
- **BOG management:** Reliquefication units should be provided for Type A tanks to control the tank pressure, and BOG management systems should be provided for Type C tanks, such as reliquefication units or having a tank design with a ceiling pressure of 18 bars, to minimise activation of pressure relief valves (PRVs)
- **Ammonia release mitigation system (ARMS):** To prevent ammonia release during regular operation, scrubbing technology or a re-collection system should be installed to isolate leaks from entering the external environment. ARMS requirement is adopted for APS per DNV Ship Rules Pt 6 Ch 2 Sec 14, limiting the maximum toxic release concentration to the air to 30 ppm. Integration of ARMS to ABV is also recommended to limit the potential escalation of toxic ammonia cloud towards the APS
- **Spill containment system:** A dry drip tray with a drain leading to an enclosed tank is recommended to quickly reroute spilt ammonia, limiting the amount of ammonia available to vaporise and preventing direct contact of

ammonia with personnel or materials. This measure may also limit the risk of escalation of ammonia cloud towards unprotected areas on the APS

- **Water spray system:** The water spray system should be designed for credible release scenarios. A water spray system is considered efficient for a limited spill only; a large amount of water neutralises vapourised spill. For significant spill mitigation, the efficiency of the water spray system is of concern because the resulting aqueous ammonia solution (ammonium hydroxide) is caustic and can corrode surfaces. A large cloud dispersion will be much affected by ambient conditions, including ambient humidity and wind speed and direction. A dry drip tray (with a drain leading to an enclosed tank) for spill mitigation or a foam / DCP system can be considered. Overall, the efficiency of available solutions for ammonia release mitigation should be further studied, including its effect on human safety

- **Disposal of aqueous ammonia:** Disposal of aqueous ammonia solution to the water should abide by Port Authority requirements and limits on allowable toxic concentration. This restriction may set conditions for spill containment and rerouting

- **Hazardous zone definition:** Existing LPG/LNG carriers/ABV built after the IGC Code has been codified have a dedicated hazardous zone to accommodate potential flammable consequences. However, as mentioned earlier, ammonia's risks are associated with its toxicity. Therefore, leak scenarios should always be mitigated, or a larger hazardous zone should be allocated to avoid toxic gas ingress in non-hazardous spaces. A dispersion analysis may give such an indication

- **Vent arrangement:** Dispersion of toxic gas and potential exposure of ventilation inlets and non-hazardous areas should particularly consider air humidity. This limit can set additional requirements for the location of vent inlets/outlets

- **Ship collision:** Given the high marine traffic in Singapore waters, the MPA should develop traffic separation schemes for STS dedicated to ammonia transfers or consider remote locations with a limited amount of passing traffic

- **Required safety zone:** A QRA should be conducted to provide an indication of separation distances and required safety zones to limit potential exposure of neighbouring facilities and operations

- **Personnel protective equipment (PPE):** Personnel involved in ammonia transfers must work with appropriate PPE. Emergency showers and eyewash should be available at convenient locations outside the bunkering station to provide first aid. Further reduction of risk of exposure to personnel involved in bunkering operations can be achieved by implementing lifting arrangements for heavy bunkering hoses, quick-disconnect couplings and break-away devices, remote control stations for overseeing operations, flushing and draining systems for residual removal, temporary mechanical shielding at connection points, and others

5.5.3 Regulatory

Adopting ammonia as a fuel source is essential to the transition to more sustainable energy, but developing a robust regulatory regime is just as important. Compliance with international standards such as the International Convention for the Safety of Life at Sea (SOLAS), IMO, and IGF/IGC code is crucial. However, flag and relevant port authorities may also need to establish additional safety requirements to ensure safe and responsible use of ammonia, including measures to restrict toxic releases into air or water, and the creation of safety zones. To meet these requirements, it is essential that all stakeholders collaborate closely.

5.6 References

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APPENDIX A: CONCEPT 2 RISK RESULTS AND HAZID LOG

A1 HAZID Results

The HAZID study produced a comprehensive documentation of its results, which included the identification of hazards, hazardous events, causes, consequences, preventive & mitigating measures, recommendations, and responsibility. All of these were carefully recorded in the HAZID log below, which was then reviewed by the workshop participants including the proposed risk rating.

A1.1 Risk Results

The HAZID study was conducted using available arrangement drawings and documents, and design philosophies available at the time of the HAZID workshop. It is strongly recommended that any significant changes in the design or operation that could affect hazard and risk levels should be reassessed.

The results of the HAZID study were documented in the HAZID log, which can be found in Appendix A of this report. In total, the study identified ninety-three (93) hazardous events, with seventy (70) categorised as medium risk and six (6) as acceptable or low risk. Seventeen (17) events were not ranked as no risk was identified.

Importantly, **no hazardous events were categorised as high risk,** indicating a positive outcome. Table A1-1 shows the risk summarisation of concept 2.

Table A1-1 Concept 2 Risk Summarisation

Risk Ranking	Concept 2 STS LAC – ABV at Anchorage	
	Operation Risk	Location Risk
Low	3	3
Medium	33	37
High	0	0
Not Risk Ranked	4	13

A1.2 HAZID recommendations

One hundred and two (102) HAZID recommendations were made during the HAZID workshop for concept 2. Recommendations are further summarised in Table A1-2 and Table A1-3.

Table A1-2 HAZID recommendations concept 2 (operational risk)

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
1	1.1	Compatibility assessment - Failing to follow procedures/standards prior to operation	Conduct compatibility assessment (LAC/ ABV) (all parties are involved in developing compatibility assessment; all operational modes, including SIMOPS identified and addressed) In addition to bunkering infrastructure, berthing and fendering
2			Potential hose misalignment between manifolds is to be covered as part of the compatibility assessment
3			Review established requirements for compatibility assessment for ammonia application
4			Check ammonia composition
5			Establish Ship-to-Ship checklist for ammonia transfer
6			Identify relevant protective personnel equipment (PPE) for ammonia application
7			Automatic and linked ESD (two different sets of ESD for loading and unloading to be considered)
8			Established operating limits and weather windows for ammonia bunkering application
9			Certify crane for crew transfer
10			Emergency response, escape, and evacuation procedures are to be established in case of an ammonia release
11			A custody transfer procedure for ammonia transfer is to be established
12			Master meter for ammonia transfer to be considered
13			Sampling procedures for liquid and vapour return shall be established, including available technology, verification, and personnel training. It is proposed at the sending ship side. Compressed Gas Association (CGA) can be referred for associated procedure.
14			Provide required competence and training to personnel
15	1.2	Mooring assessment - Failing to follow procedures/standards prior to operation	Perform a mooring assessment for the site location (possibly OPTIMOOR), including mooring compatibility
16			Consider introducing a powered emergency release coupling (PERC)
17	1.3	STS procedures and organisation - Failing to follow procedures/standards prior to operation	Establish an associated procedure for the ammonia transfer operation

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
18			Establish a joint plan of operations (JPO) (LAC/ABV) for the ammonia transfer operation
19			STS vessel-specific safety management plan should be provided
20			Vessel-specific STS plan to be approved by the flag
21	2.1	Failing to follow procedures prior to operation: - Pre-arrival checklist - Tests and notices - Communication - The Pilot and Master meeting prior to the approach	Update all established checklists for ammonia application
22	4.1	Failing to follow procedures: - Testing communication - Checklists onboard	Update all established bunkering/transfer procedures for ammonia application
23			Establish a procedure for hose drying and inerting
24			If inerting is introduced, nitrogen banks will be provided on the ship. Purged gas can be sent to ammonia neutralizing unit/ GCU/ boiler
25	4.5	Human error - Vessel separation detection (VSD) connection failure	Consider VDS; provide required competence and training to operate VDS, including required checks
26	4.9	Human error - Incomplete PERC system set-up	Consider PERC (if not included initially)
27	4.12	Human error – Lack of competence/training	Provision of competence and training to personnel is required for personnel involved in ammonia operations
28	5.1	Breakaway - Breakaway, vessel separation	Consider a dry drip tray for ammonia spill containment and draining
29			The capacity of the water spray system (including shoreside and terminal) is to be defined based on ammonia spilt vs water amount required. The water spray system is considered efficient for limited liquid ammonia spill only; the leak is considered neutralised by a large amount of water. A dry drip tray, or foam / DCP system, can be considered for extensive spill mitigation
30			Emergency response procedures to include ammonia transfer
31			Include a procedure for hose recovery in case of ESD2 from a daughter vessel
33			Escort tugs are to be kept on standby for the duration of the operation
34	5.2/5.8	Leak - Ammonia leakage from transfer hose (connection to manifold)	Placement of gas detectors to consider light and heavy toxic cloud behaviour
35			Consider a spill containment system for a pressurised ammonia release capable of containing the spill for multiple release directions
36			Thermal detection inside the bund

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
37			Fixed gas detection fitted on the vessels
38			Identify means for ammonia water solutions disposal; at some ports, release to the sea is permitted; to define in consultation with MPA for allowable toxic concentration for release to the sea
39			Identify the required capacity of the fire water system
40			Due to the exothermic reaction of ammonia with water, identify the spill amount that the water spray system can neutralise; for a larger release, part of the spill will be dissolved, remaining will be quickly vapourised travelling downwind. See hazard ID 5.1 for alternative solutions
41			Consider remote monitoring CCTV
42	5.3/5.8	Leak - Ammonia leakage from the cargo manifold	Closure of vent inlets to safe areas/rooms
43			Provision of toxic detectors in HVACs
45			Double-door arrangements for accommodation and safe rooms
46			Mechanical shielding for flanged connections
47	5.7	External leak - Spill of ammonia into the water	Hose periodic testing and inspection before transfer
48			Hose rigged per best industry practices
49	5.9	Damage - Piping thermal expansion or contraction	Include tightening of the flanged connections
50	5.10	Damage - Stress corrosion cracking	Assess material compatibility with ammonia
51	5.11	Arrangement - Bunker station arrangement	For future bunker vessel/carrier design, a semi-open or closed bunker station design with provided mechanical ventilation is considered. Discuss the QRA effect on dispersion results associated with a leak at the bunker station
52	5.15	Fire/explosion - Fire/explosion in the manifold area	Identify potential ignition sources based on operations conducted by neighbouring jetties, including passing vessels. (Bunker vessel, bunker barge as a potential ignition source to consider for QRA application)
53	5.17	Overpressure storage tank	Investigate to what extent humidity will affect ammonia gas dispersion
54			A flag may request dispersion analysis for the risk of toxic gas ingress to ventilation in the accommodation area
55			Consider a liquid level detector to be installed in the vent mast
56			Vent mast arrangement should be designed to prohibit water ingress from rain or sea spray

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
57			Investigate the inclusion of a water spray system for the vent mast. Also consider the drainage/ containment of aqueous ammonia
58			Procedures for alarms and monitoring system testing and operation (including fault handling and sensor's by-passing) to be included in the vessel's SMS; responsible personnel to familiarise with requirements
59	5.18	Overfilling storage tank	Per hazard ID 5.17: Procedures for alarms and monitoring system testing and operation (including fault handling and sensor's by-passing) to be included in Vessel's SMS; responsible personnel to familiarise with requirements
60	5.19	Design - Tank design (LAC/ABV)	More than 25mm diameter of pipe must be welded
61			Water spray system on tank dome
62			Melting plugs
63	5.20	General SIMOPS activities - vessel ballasting, vessel crane operations, crew and visitors embarking/ disembarking, disposal (garbage, sludge, sewage, blackwater etc.), lifeboat or mob boat drills/handling, firefighting drills, general cleaning and maintenance, underwater service/repairs, testing fin stabilisers, hot work and maintenance, helicopter operations, power generation onboard, running engine and machinery (supply and receiving vessels), cargo handling	Consider SIMOPS at the terminal
64			Consider SIMOPS on a case-to-case basis and required mitigating measures (as a basis, no SIMOPS leading to additional loss of containment scenarios are assumed)
65			No crew change during STS is recommended
66	6.1/6.2/6.3	Drain - Fail to drain (ammonia remains in transfer equipment/not liquid-free)	Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation
67	7.1	Navigational hazards (grounding, collision, and contact) during departure/manoeuvring from STS location, see location risk assessment	An early departure procedure (EDP) should be considered after the completion of the cargo operation
68	8.1	Toxic zone definition - Toxic gas in non-hazardous areas	Consider air humidity on ammonia gas behaviour and potential for ingress to non-hazardous areas

Table A1-3 HAZID recommendations concept 2 (location risk)

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
1	1.4	Experience with this location. Used currently or in the past for STS – New locations may pose a higher risk than existing locations with solid experience	For the pilot phase, pilotage, testing, and personnel training will be provided (MPA to confirm)
2			Emergency procedures are to be established
3	1.5	Ship dimension limitations (Minimum under-keel clearance requirement/ Maximum arrival draft) - Grounding	Consider smaller size vessels for the pilot phase of the project
4	1.6	Safety and security zones - Activities close to the bunkering operation	Potential overlap between the toxic zones for ammonia bunkering and safety zones other STS bunker operations to be resolved
5			Consider the risk of ship collision imposed by passing vessels
6	1.7	Dedicated waiting area/anchorage area - Conflict with Other ship traffic	MPA to consider additional anchorage points for vessels that must await completion of other STS operations at the dedicated anchorage point
7	1.8	Mandatory pilotage - Navigational accident during the approach, manoeuvring or departure in the waterway (e.g. grounding, collision or contact)	Dedicated pilotage of vessel types involved in ammonia bunkering will be carried out
8	1.10	Standby tug requirement (fire fighting, rescue services, emergency towing or pushing up, delivery of personnel or equipment, guarding the vessel, assisting with pollution and other services) - An emergency event during STS transfer	Investigate if additional requirements of tugs for emergency response are associated with ammonia leaks
9	1.12/3.2/3.3/ 3.4	Vessel traffic services (VTS) - information services (INS), navigation assistance service (NAS), traffic organization services (TOS) - Navigational accident (e.g. grounding, collision, or contact)	Consider navigational risk assessment during Font-End Engineering Design (FEED)
10	1.14	Mooring requirements (mooring study, bow direction, weather restriction)	Exiting mooring arrangements should be assessed for all sizes of ships
11			Assess mooring requirements on each planned operation by involving STS organisers or by the managers of both vessels
12	1.15	Loss of position – Anchor dragging	Assess the required mooring anchor's capacity and redundancy
13			Consider the provision of the standby tug to prevent separation
14	1.19	All regulating bodies are identified, and requirements accounted for. - Unsafe operations (by not following regulations)	Investigate additional local regulating body requirements associated with ammonia transfer operations, including limitation of toxic release to air or water
15			Restriction on toxicity (ppm) associated with water ammonia solution that can be disposed to sea

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
16	1.20	All company-specific requirements accounted for - Unsafe operations (by not following company-specific procedures)	To be addressed in the FEED phase
17	1.22	Approval of operations - Lack of approval may cause increased risk to the public	Approval of operation is required by regulating body
18			Requirements for vessel specific STS plan approval by Flag to be verified with MPA
19	2.9	Operational weather limits, including abort criteria - Accidental release of ammonia (loss of containment) due to insufficient or lack of weather limits	Identify abort criteria for an ammonia transfer operation
20	2.10	Visibility (daylight, fog, etc.) - Navigational accident (e.g. grounding, collision or contact) due to lack of visibility	Visibility to be addressed in vessels' SMS and procedures
21	2.11	Electrical storm (thunderstorms) - Electrical storms (thunderstorms) may affect cargo transfer operation	Identify abort criteria for an ammonia transfer operation
22	2.12	Waves - Wave from passing traffic	Identify abort criteria for wave height generated by passing traffic for the ammonia transfer operation
23	2.13	The environmental hazards (cold fronts, hurricanes, tsunamis, etc.) - Frequent changes in the wind (speed, direction)	Consider the risk of wind gusts for the site location and the definition of associated abort criteria. Include vessels' SMS and procedures
24			Consider stand-by tugs nearby
25	3.1	Fairway to STS location (sufficient water depth and width. aton sufficient, critical waypoints or depths, squat effects) - Navigational accident (e.g. grounding, collision or contact) due to narrow waters	During the FEED phase, address required space for maneuvering, turning, etc., given multiple (simultaneous) operations in the area
26	3.5	Emergency unmooring – Unable to Unmoor	Consider measures to initiate unmooring if mooring systems become unavailable (Suggestion: quick release of axe)
27	4.1/4.2	Close vicinity/nearby traffic lanes Traffic amount and composition - Collision with ships in the area (passing, crossing, head-on, overtaking, being rammed while STS, etc.)	Assess the risk of ship collision for the STS location; establish the required Safety Zone
28			Ensure appropriate communication to the traffic in the area (VTS, NavCharts, Radio, NavWarning etc.)

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
29	**4.3**	Distance to other STS locations in the vicinity (SIMOPS) - SIMOPS should be detailed in an operations risk assessment	Investigate the QRA potential overlap and escalation risk due to SIMOPS at multiple anchorage points
30	**5.1/5.2**	Terminals or facilities nearby - Toxic vapour cloud that travels downwind towards the terminal or other operations nearby	Multiple anchorage points - the risk of escalation to be covered by the QRA
31	**5.3**	Populated areas/private ship traffic - Potential ammonia spill may reach shorelines, with population, sensitive areas, etc.	Look into applicable regulations/restrictions for 3rd party (private) ships crossing the Raffles Reserve Anchorage area
32	**6.1/6.2**	Toxic emergency/ response services and units - Lack of toxic emergency units nearby may cause incidents to escalate	Review existing ERP activities for ammonia spill application.
33			Investigate the required capacity of emergency/support tugs and firefighting tugs to mitigate toxic gas dispersion. To be discussed with the MPA and SCDF on applicable requirements
34	**6.3**	Marine pollution - Breach of bunker/ammonia release due to collision	Perform environmental risk assessment due to ammonia spill caused by a ship collision

A1.3 Operation risk assessment - LAC-ABV ammonia transfer at anchorage (HAZID Log)

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
Node 1 Prior to operations											
1.1	Compatibility assessment	- Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Misalignment - Ship contact damages - Excessive forces on manifolds - Possibility to exceed operating envelop of equipment - Mooring issues	- Established STS recommendation following SIGTTO guidelines	SAFE	3	3	M	- Conduct compatibility assessment (LAC/ ABV) (all parties are involved in developing compatibility assessment; all operational modes, including SIMOPS identified and addressed). In addition to bunkering infrastructure, berthing and fendering - Potential hose misalignment between manifolds is to be covered as part of the compatibility assessment - Review established requirements for compatibility assessment for ammonia application. - Check on ammonia composition - Establish ship to ship checklist for ammonia transfer - Identify relevant PPE for ammonia application - Automatic and linked ESD (two different sets of ESD for loading and unloading to be considered) - Established operating limits and weather windows for ammonia bunkering application - Certify crane for crew transfer - Emergency response, escape, and evacuation procedures are to be established in case of an ammonia release - A custody transfer procedure for ammonia transfer is to be established. - Master meter for ammonia transfer to be considered - A sampling procedure for liquid and vapour return shall be established, including available technology, verification, and personnel training. It is proposed at the sending ship side (CGA can be referred for associated procedure) - Provide required competence and training to personnel	-As a basis, existing LAC/ABV design to be considered for the QRA application
1.2	Mooring assessment	- Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Ship drift away, drift grounding - Contact damage - Disrupt operations	- ESD	SAFE	2	3	M	- Perform a mooring assessment for the site location (possibly OPTIMOOR), including mooring compatibility - Consider introducing a PERC	
1.3	STS procedures and organization	- Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Loss of containment		SAFE	2	3	M	- Establish an associated procedure for the ammonia transfer operation - Establish a joint plan of operations (JPO) (LAC/ABV) for the ammonia transfer operation. - STS vessel-specific safety management plan should be provided - Vessel-specific STS Plan to be approved by Flag	
Node 2 Prior to arrival											
2.1	- Pre-arrival checklist, tests and notice - Communication - The Pilot and Master meeting prior to the approach	Failing to follow procedures prior to operation	- Failing to follow procedures may lead to incidents	- Loss of containment during operations	- Established checklists for LAC/ABV preparation activities, pre-arrival, equipment checklist, berthing checklist for the vessel, and others	SAFE	2	3	M	- Update all established checklists for ammonia application	
Node 3 Arrival (Inc. Mooring)											
3.1	- Navigational hazards	Navigational hazard is location specific, thus covered in Location Risk Assessment									
3.2	- Mooring between LAC //Jetty//ABV	Mooring hazards are location specific, thus covered in Location Risk Assessment									

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
Node 4 Pre-transfer											
4.1	- Testing communication - Checklists onboard	Failing to follow procedures	- Failing to follow procedures may lead to incidents	- Potential spillage during ammonia transfer	- Established transfer/bunkering procedures	SAFE	2	3	M	- Update all established bunkering/transfer procedures for ammonia application - Establish a procedure for hose drying and inerting - If inerting is introduced, nitrogen banks will be provided on the ship. Purged gas can be sent to ammonia neutralizing unit/GCU/ or boiler	
4.2	Human error	Coupling/loading arm/hose connection failure	- Incorrect connection or locking	- Potential ammonia leaks		SAFE	1	4	M		
4.4	Human error	ESD link connection error	- Incorrectly plugged or plug connection damaged/dirty	- Fail to function on demand - Potential ammonia leaks	- ESD test	SAFE	1	4	M		
4.5	Human error	Vessel separation detection (VSD) connection failure	- Incorrectly plugged or plug connection damaged/dirty - Wrongly placed	- Fail to function on demand - Potential ammonia leaks	-Part of the checklist/procedure to ensure the connection is in place -System is function tested before operation -Compatibility analysis -Supervised operation -The listing angle of 2 degrees is considered for VSD	SAFE	1	4	M	- Consider VDS; provide required competence and training to operate VDS, including any required checks	
4.6	Electric isolation	Electric isolation	- Wear and tear - No insulation flange	- An ignition source, sparks	- Electric isolation between connected vessels in compliance with the ISGOTT and SIGTTO "Liquefied Gas Handling Principles on Ships and in Terminals"	QUA	1	3	L		
4.7	Human error	Forgot to reset the ESD systems after testing	- Failing to follow procedures	- Fail to function on demand - Potential ammonia leaks	- Established transfer procedures - Training and competence of personnel						If ESD is not resettled, not possible to operate any valve or pump, and no risk of leakage exists
4.8	Human error	Insufficient cooldown of piping	- Failing to follow procedures	- Pipeline damage	- Established transfer procedures - Training and competence of personnel	ASS	1	3	L		-Pipe cooling with cold ammonia to be considered for the QRA application
4.9	Human error	Incomplete PERC system set-up	- Failing to follow procedures	- PERC fail to function on demand - Ammonia spill	- Consider PERC with fail-safe function, active interlock	SAFE	1	4	M	- Consider PERC (if not included initially)	
4.10	Human error	Incomplete leak test	- Failing to follow procedures	- Leakages during operation	-Established transfer procedures	SAFE	1	4	M		
4.11	Utility failure	Fail to quantify/measure the quantity of fuel transferred	- Technical failure	- No health/safety risk	- According to established industry standards requirements	QUA	1	3	L		
4.12	Human error	Human error	- Lack of experience with handling ammonia	- Leakages during operation		SAFE	2	4	M	- Provision of competence and personnel training is required for ammonia operations personnel	
Node 5 Transfer of Ammonia											
Cargo manifold											

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.1	Breakaway	Breakaway, vessel separation	- Excessive relative motion between ships beyond the operational window - Mooring failure	- Equipment/asset damage/operational delay - Personnel injuries	- Marine loading arm /Hose ERS - ESD system with two-stage alarm and shutdown system. The first stage (ESD1) shall initiate the shutdown of the transfer operations and close valves, and the second stage (ESD2) shall activate the PERCs. - Water curtain/ water spray system at the ship side and the Terminal - Drip tray 50% filled with water to dissolved ammonia if spilt	SAFE	2	4	M	- Consider a dry drip tray for ammonia spill containment and draining - The capacity of the water spray system (including shoreside and terminal) is to be defined based on ammonia spilt vs water amount required. The water spray system is considered efficient for limited liquid ammonia spill only; the leak is considered neutralised by a large amount of water. A dry drip tray, or foam / DCP system, can be considered for extensive spill mitigation - Emergency response procedures to include ammonia transfer - Include a procedure for hose recovery in case of ESD2 from a daughter vessel - Per hazard ID 4.5 - Escort tugs are to be kept on standby for the duration of the operation	To be considered for the QRA application
5.2	Leak	Ammonia leakage from transfer hose (connection to manifold)	- Design, fabrication or installation error - Abnormal operating condition (exceeding design limits) due to equipment malfunction or operator error - Material defect - Excessive relative motion between ships beyond the operational window of the marine loading arms - Drift-off	- Toxic spill - Toxic gas dispersion due to evaporated spill - Personnel injuries; cold burns - Potential for damage of hull structure exposed - Potential for ignited toxic release if a strong ignition source is reached	- Manual ESD activation points are provided to rapidly shut down the cargo transfer system. The ESD can be initiated both locally and remotely - ESD system with two-stage alarm and shutdown system. The first stage (ESD1) shall initiate the shutdown of the transfer operations and close valves, and the second stage (ESD2) shall activate the PERCs - Water curtains/spray - Pressure/leak testing - Bund for loading arm with a sump (small pit) installed with suction head	SAFE	2	4	M	- Placement of gas detectors to consider light and heavy toxic cloud behaviour - Consider a spill containment system for a pressurised ammonia release capable of containing the spill for multiple release directions -Thermal detection inside the bund - Fixed gas detection fitted on the vessels - Automatic ESD (per hazard ID 1.1) - Linked ESD (per hazard ID 1.1) - Identify means for ammonia water solutions disposal; at some ports, release to the sea is permitted; to define in consultation with MPA for allowable toxic concentration for release to the sea. - Identify the required capacity of the fire water system - Due to the exothermic reaction of ammonia with water, identify the spill amount that the water spray system can neutralise; for a larger release, part of the spill will be dissolved, remaining will be quickly vapourised travelling downwind. See hazard ID 5.1 for alternative solutions - Consider remote monitoring CCTV	To be considered for the QRA application
5.3	Leak	Ammonia leakage from the cargo manifold	- Per hazard ID 5.2	- Per hazard ID 5.2	- Duty person for leak detection - Manually activated ESD - Water spray system - Drip trays in manifold area - ERP - Eyewash to personnel	SAFE	2	4	M	- Per hazard ID 5.2 - Closure of vent inlets to safe areas/rooms - Provision of toxic detectors in HVACs - Double-door arrangements for accommodation and safe rooms - Mechanical shielding for flanged connections	To be considered for the QRA application
5.4	Trapped liquid	The trapped liquid between the bunker valve and the tank valve	- Intended or unintended activation of ESD	- Ammonia trapped between valves. When trapped liquid ammonia is heated, the result is high pressure which can cause equipment or gasket failure. - Equipment/ system damage - Ammonia leak	- Pressure relief valve on each segment - Depressurization of the segment after the transfer	SAFE	2	3	M		

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.5	Backflow	Backflow of NH_3 into the N_2 system	- Valve failure	- Exposure to the crew (when opening up for maintenance etc.) - Damage to the nitrogen system - Toxic hazard - Fire/explosion if a strong ignition source is present	- Required to have double block and bleed valves on connections to the nitrogen system.	SAFE	2	3	M		- Piping is not purged with nitrogen; instead filled with ammonia gas. If not used for transfer and by keeping on open valve system will be naturally depressurised
5.6	Wrong flow	The flow of NH_3 to other bunkering stations	- Valve failure	- Toxic hazard - Fire/explosion if a strong ignition source is present	- Double valve segregation	SAFE	2	3	M		
5.7	External leak	- Spill of ammonia into the water	- Hose rupture	-Rapid formation of toxic cloud	- Water spray system on the ship side	ENV	1	4	M	- Hose periodic testing and inspection before transfer - Hose rigged per best industry practices	- Release of the QRA modelling 6m above sea level is anticipated.
5.8	External leakage on single piping between bunker station and storage tank	- Technical failure - External hazards	- Design, fabrication or installation error - Wear and tear - Mechanical damage, dropped objects	- Spillage on deck	- Water spray system on the ship side	SAFE	1	4	M	- Per hazard ID 5.2 & 5.3	To be considered for the QRA application
5.9	Damage	Piping thermal expansion or contraction	- Extreme temperatures of the fuel and high ambient temperatures	Pipe leak or rupture	- PRV - Heat stress analysis	SAFE	1	4	M	- Include tightening of the flanged connections	
5.10	Damage	Stress corrosion cracking	- Design fault, incorrect material properties	- Pipeline damage	- Material selection part of the IGC code (clause 17.1.2) - Condition monitoring on the piping inspections	SAFE	1	4	M	- Assess material compatibility with ammonia	
5.11	Arrangement	Bunker station arrangement	- Insufficient ventilation		- Open (natural ventilation)	SAFE	1	4	M	- For future bunker vessel/carrier design, a semi-open or closed bunker station design with provided mechanical ventilation is considered. Discuss the effect on dispersion results associated with a leak at the bunker station in the QRA	
5.14	Impact	Mechanical impact on piping, e.g. dropped object	- Lifting activity - Dropped objects	- Rupture of pipe - Release of NH_3 - Toxic hazard - Fire/explosion if a strong ignition source is present	- No crane operations in parallel with cargo operations.	SAFE	1	4	M		To be considered for the QRA application
5.15	Fire/explosion	Fire/explosion in the manifold area	- Toxic gas release reaching the strong ignition source	- Ignited leak - Flash fire	- The manifold area is located in a hazardous zone; ex-rated equipment's no ignition sources are allowed.	SAFE	1	4	M	- Identify potential ignition sources based on operations conducted by neighbouring jetties, including passing vessels. (bunker vessel, bunker barge as a potential ignition source to consider for the QRA application)	To be considered for the QRA application
5.16	Fire/explosion	Heat transfer to ammonia cargo transfer station from fire	- Fire/explosion in other areas	- Overpressure the release of toxic gas	- PRV set at 18 bar - Water spray to cool down manifold piping	SAFE	1	4	M		To be considered for the QRA application
Cargo containment and vent systems											

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.17	Overpressure	Overpressure	- Opening of PSVs due to pressure increase in the cargo tanks	- Toxic gas dispersion on the upper deck area - Consequently, the potential for injuries, fatalities, asset damage or accident escalation to adjacent areas	- Cargo tank pressure monitoring and control system - BOG management (ensuring that reliquefication system capacity is based on maximum BOG generation) - Gas detection system for the vent mast - N_2 purging connection for the vent masts - Gas detection system for the air intakes for the accommodation -Compatibility assessment to exclude a probability of hazardous zone overlap and ventilation intakes exposure to a toxic gas - The drain valve on the vent is activated after rainy condition - Vapour return connection between two vessels	SAFE	1	4	M	- Investigate to what extent humidity will affect ammonia gas dispersion - A Flag may request dispersion analysis for the risk of toxic gas ingress to ventilation in the accommodation area - Consider a Liquid level detector to be installed in the vent mast - Vent mast arrangement should be designed to prohibit water ingress from rain or sea spray - Investigate the inclusion of a water spray system for the vent mast. Consider drainage/containment of aqueous ammonia as well - Procedures for alarms and monitoring system testing and operation (including fault handling and sensor's by-passing) to be included in the vessel's SMS; responsible personnel to familiarise with requirements	To be considered for the QRA application
5.18	Overfilling	Overfilling	- Overfilling of cargo tanks during ammonia transfer	- Toxic liquid out of vent mast - Consequently, the potential for injuries, fatalities, asset damage or accident escalation to adjacent areas	- Tank level monitoring and limits w/shutdown - An agreed amount of Ammonia to be transferred - "Run-down" procedures - Stop cargo loading operation or reduce operation rate - Cargo tank pressure monitoring and control system - High and high high-level alarm in the tank	SAFE	2	4	M	- Per hazard ID 5.17: Procedures for alarms and monitoring system testing and operation (including fault handling and sensor's by-passing) to be included in the vessel's SMS; responsible personnel are to familiarise with requirements	To be considered for the QRA application, i.e. Release via vent mast due to tank overfilling scenario
5.19	Design	Tank design (LAC/ABV)	- Insufficient design	- Continuous ammonia release		SAFE	1	4	M	- More than 25mm of pipe must be welded - Water spray system on tank dome - Melting plugs	
SIMOPS											
5.20	General SIMOPS activities	- Vessel ballasting - Vessel crane operations - Crew and visitors embarking/ disembarking - Disposal (garbage, sludge, sewage, blackwater etc.) - Lifeboat or MOB boat drills/handling - Firefighting drills - General cleaning and maintenance - Underwater service/repairs - Testing fin stabilisers - Hot work and maintenance - Helicopter operations - Power generation onboard, running engine and machinery (supply and receiving vessels) -Cargo handling	- SIMOPS	- Toxic release, the potential for fire or explosion - Consequently, the potential for injuries, fatalities, asset damage or accident escalation to adjacent areas	- No multiple SIMOPS activities	SAFE	1	4	M	- Consider SIMOPS at the terminal - Consider SIMOPS on a case-to-case basis and required mitigating measures (as a basis, no SIMOPS leading to additional loss of containment scenarios are assumed) - No crew change during STS is recommended - Limited SIMOPS are to be agreed upon by all parties before transfer	Some operations are usually allowed during LPG STS: - Ballasting of both Vessels is an essential part of operations, as this may considerably affect mooring and hose connection. - Periodic Mooring adjustment - Personnel transfer by service boat between two vessels

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
Node 6 Post-Transfer											
6.1	Drain	Fail to drain (ammonia remains in transfer equipment/not liquid-free)	- Fail to follow procedures - Technical error	- Toxic condition in transfer equipment while disconnection (gas or trapped liquid) - Exposure of flammable material to crew	- PPE - Emergency Preparedness - Procedures adapted to vessel compatibility - Pressure relief valve - Procedure for connection liquid-free status verification established -Procedure for connection liquid-free status verification established	SAFE	2	3	M	- Per hazard ID 4.1 - Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation	
6.2	Purge	Fail to purge (fail to maintain % content)	- Fail to follow procedures - Technical error	- Toxic condition in transfer equipment while disconnection (gas or trapped liquid) - Exposure of flammable material to crew	- Work procedures for draining, purging, inerting - Training and competence of personnel - PPE - Emergency Preparedness - Procedures adapted to vessel compatibility - Purging with hot gas to remove all ammonia to the tank (ship side)	SAFE	2	3	M	- Per hazard ID 4.1 - Per hazard ID 6.1, Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation	
6.3	Disconnection	Toxic condition	- Per hazard ID 6.1 and 6.2	- Per hazard ID 6.1 and 6.2		SAFE	2	3	M	- Per hazard ID 6.1 and 6.2	
Node 7 Unmooring and departure											
7.1		Navigational hazards (grounding, collision, and contact) during departure/maneuvering from STS location, see Location Risk Assessment	-	-	-					- An EDP should be considered after the completion of the cargo operation.	
Node 8 Other hazards											
8.1	Toxic zone definition	-Toxic gas in non-hazardous areas	- Toxic zone is defined as insufficient	- Toxic gas in non-hazardous areas	- Defined toxic zones according to applicable requirements	SAFE	2	3	M	- Consider air humidity on ammonia gas behaviour and potential for ingress to non-hazardous areas	

A1.4 Location risk assessment - LAC-ABV ammonia transfer at anchorage (HAZID Log)

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1. Local establishment, regulations and requirements											
1.1	Fish farms/ fishery or aquaculture establishments	Conflict with fish farms/aquaculture establishments	- Other activities may hinder or cause hazards for the STS operation, or vice versa	- Ammonia spill (toxic hazard) - Potential for fire/explosion - Operational restrictions - Operational delays	- No commercial fishing activities						- Not applicable; thus, no risk rating is provided
1.2	Ballast water	Ballast water restrictions			- No restrictions for ballast water exchange in that area						- No ballast water restrictions; thus, no risk rating is provided
1.3	Military areas	Conflict with military areas	- Other activities may hinder or cause hazards for the STS operation, or vice versa	- Ammonia spill (toxic hazard) due to potential collision impact between vessels - Impact due to military activities - Operational restrictions - Operational delays	- No military areas						- Not applicable; thus, no risk rating is provided
1.4	Experience with this location Used currently or in the past for transhipment	New locations may pose a higher risk than existing locations with solid experience	- Loss of containment due to lack of experience	- Loss of containment - Ammonia spill (toxic hazard)	- Area has been used for typical transfer activities (not ammonia specific)	SAFE	2	3	M	- For the pilot phase, pilotage, testing, and personnel training to be provided. - Emergency procedures are to be established	
1.5	Ship dimension limitations: - Minimum under-keel clearance requirement - Maximum arrival draft	Grounding	- Violation of clearance or draft requirements	- Ammonia spill (toxic hazard) - Asset damage - Delay in operation	- Grounding is not considered likely for anchorage location	SAFE	2	3	M	- Consider smaller size vessels for the pilot phase of the project	
1.6	Safety and security zones	Activities close to the bunkering operation	- Other activities may hinder or cause hazards for the STS bunkering operation, or vice versa	- Operational restrictions - Operational delays	- An average 150m safety zone is required for LPG and LNG cargo.	SAFE	2	3	M	- Address the QRA potential overlap between toxic zones for ammonia and establish a safety zone for other STS locations - Consider the risk of ship collision imposed by passing vessels	
1.7	Dedicated waiting area/anchorage area	Conflict with other ship traffic	- Geography/landscape/ depth	- Drift grounding - Contact or collision with other ships	- Entry procedures mean no entrance until allowed.	SAFE	1	4	M	- MPA to consider additional anchorage points for vessels that must await completion of other STS operations at the dedicated anchorage point	

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1.8	Mandatory pilotage	A navigational accident during the approach, maneuvering or departure in the waterway (e.g. grounding, collision or contact)	- Human error - Lack of pilotage	- The credible consequence is severe ship damage and damage to ballast bottom or wing tanks (i.e. no ammonia spill). - Worst case consequence: Penetration of ship hull (inner and outer) and penetration of cargo containment. Uncontrolled escape/outflow of ammonia, pool formation, gas dispersion and rapid phase transition (RPT). Potential for ignition and pool fire, with significant heat intensity.		SAFE	2	3	M	- Dedicated pilotage of vessel types involved in ammonia bunkering to be carried out	
1.9	Escort tug requirement	A navigational accident during the approach, maneuvering or departure in the waterway (e.g. grounding, collision or contact)	- Human error - Lack of tugs	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- No escort tugs are assumed to be used for STS						- Not applicable; thus, no risk rating is provided
1.10	Standby tug requirement - Fire fighting - Rescue services - Emergency towing or pushing up - Delivery of personnel or equipment - Guarding the vessel - Assisting with Pollution - Other Services as Determined	Emergency event during STS transfer	- Human error - Technical error	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion		SAFE	1	4	M	- Investigate if additional requirements of tugs for emergency response are associated with ammonia leaks	
1.11	IMO routing measures (e.g. Traffic Separation Scheme, deep water route, etc.)	Navigational accident (e.g. grounding, collision or contact)	- Human error - Lack of TTS	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- MPA guidelines requirements are followed, and depth is sufficient	SAFE	1	3	L		
1.12	Vessel Traffic Services (VTS) - Information service (INS) - Navigation assistance service (NAS) - Traffic organization service (TOS)	Navigational accident (e.g. grounding, collision or contact)	- Human error - Lack of VTS	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- Vessel separation traffic VST service - Ship traffic data	SAFE	1	3	L	- Consider navigational risk assessment during FEED	
1.13	Speed restrictions	Navigational accident (e.g. grounding, collision or contact)	- Human error - Technical error	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- See hazard ID 1.12	SAFE	1	3	L	- See hazard ID 1.12	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1.14	Mooring requirements - Mooring study - Bow direction - Weather restriction	Drift grounding	- Technical error - Environmental forces	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- For mooring and unmooring will occur one activity at a time	SAFE	2	3	M	- Exiting mooring arrangement should be assessed for all sizes of ships - Assess mooring requirements on each planned operation by involving STS organisers or by the managers of both vessels	
1.15	Loss of position	Anchor Dragging	- Seabed condition	- Vessel separation	- Personnel watching and radar monitoring, navigation systems. - The engine is on standby which can start immediately	SAFE	2	3	M	- Assess the required mooring anchor's capacity and redundancy - Consider the provision of the standby tug to prevent separation	
1.16	Underwater pipelines, cables	Anchor damaging pipelines	- Technical (accidental dropped anchor) or human error (dropped anchor over pipeline)	- Pipeline damage and loss of pipeline containment	- No pipeline or cables identified						- Not applicable; thus, no risk rating is provided
1.17	Environmental sensitive areas	Ammonia spill in environmentally sensitive areas	- Technical or human error	- In small spills, most of the ammonia will vaporise before reaching the water due to heat transfer with the air. - For large spills, air cannot transfer enough heat to vaporise much ammonia, so almost all of the spill will likely end up in a pool. The spilt Ammonia will undergo several physical processes simultaneously (pool formation, spread and boil-off) - Ammonia spills are much less severe for the environment compared to oil spill							- Not applicable; thus, no risk rating is provided
1.18	Airports nearby	Conflict with the airport nearby	- Location of airport	- Ships may be obstacles for flights arriving/ departing. - Ship lights may conflict with runway lights arrangement	- No airport nearby						- Not applicable; thus, no risk rating is provided
1.19	All regulating bodies identified, and requirements accounted for	Unsafe operations (by not following regulations)	- Requirements not identified or insufficient	- Ammonia spill (toxic hazard) - Operational delays (requirements identified late in the process)		REG	2	3	M	- Investigate additional local regulating body requirements associated with ammonia transfer operations, including limiting the toxic release to air or water - Restriction on toxicity (ppm) associated with water ammonia solution that can be disposed to sea	
1.20	All company-specific requirements accounted for	Unsafe operations (by not following company-specific procedures)	- Requirements not identified or insufficient	- Ammonia spill (toxic hazard) - Operational delays (requirements identified late in the process)		DEL	2	3	M	- To be addressed in the FEED phase	
1.21	All stakeholders informed	Lack of information among stakeholders	- Stakeholders not identified	- Operational delays - Ammonia spill - Potential for fire/explosion		DEL	2	3	M		
1.22	Approval of operations	Lack of approval may cause increased risk to the public	- Lack of regulating body	- Ammonia spill - Potential for fire/explosion		REG	2	3	M	- Approval of operation is required by regulating body - Requirements for vessel-specific STS plan approval by the flag to be verified with the MPA	
2. Exposure of location too, or shelter, prevailing environmental conditions including, where appropriate, met ocean analysis											

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
2.1	Overall swell height, period and direction Sea characteristics	Large swells	- Environmental	- This may cause excessive strain on the transfer hoses. - Suspension of operation - Activation of PERC - Mooring line failure	- Environmental assessment has been conducted for prior operations in the bay - The area is rather congested, so no swell is anticipated						Not applicable; thus, no risk rating is provided
2.2	Prevailing wind direction Wind force averages	Strong wind may cause drift-off, separation or drift grounding	- Environmental	- This may cause excessive strain on the transfer hoses. - Suspension of operation - Activation of PERC - Mooring line failure	- Monsoon season maximum wind speed anticipated around 4-5 and higher - Weather limitations established for the draft and commissioning at the jetty.	DEL	2	3	M		
2.3	Tide	Strong tides/currents may cause drift-off, separation or drift grounding	- Environmental	- This may cause excessive strain on the transfer hoses. - Suspension of operation - Activation of PERC - Mooring line failure	- No tide hazard	DEL	2	3	M		
2.4	Current	Accidental release of Ammonia (loss of containment) due to currents	- Strong tides/currents may cause drift-off, separation or drift grounding	- This may cause excessive strain on the transfer hoses. - Suspension of operation - Activation of PERC - Mooring line failure	- A protected, sheltered area						Not applicable; thus, no risk rating is provided
2.5	The seabed (holding ground)	Drift grounding due to poor holding ground	- Strong wind, strong currents and harder sea bottom may cause drift grounding - The vessel anchor is not holding on to the holding ground. - Failure of anchor chain	- Severe ship damage - Loss of containment - Toxic release - Fire/explosion	- Sea bed (holding ground) clay and sand	SAFE	2	3	M		
2.6	Stability of seabed, such as sand waves forming	Grounding due to changes in seabed	- Strong wind, strong currents and harder sea bottom may cause drift grounding - The vessel anchor is not holding on to the holding ground. - Failure of anchor chain	- Severe ship damage - Loss of containment - Toxic release - Fire/explosion							Not applicable; thus, no risk rating is provided
2.9	Operational weather limits, including abort criteria	Accidental release of Ammonia (loss of containment) due to insufficient or lack of weather limits	- Incidents due to weather criteria not being followed	- Ammonia spill		DEL	2	3	M	- Identify abort criteria for the ammonia transfer operation	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
2.10	Visibility (daylight, fog, etc.)	Navigational accident (e.g. grounding, collision or contact) due to lack of visibility	- Visibility may hinder navigation	- Ship damage - Operational restrictions or delays	- Permanent full-scale navigational watch	DEL	2	3	M	- Visibility to be addressed for each vessel's SMS and procedure	Not applicable; thus, no risk rating is provided
2.11	Electrical storms (thunderstorms)	Electrical storms (thunderstorms) may affect cargo transfer operation	- Environmental hazards	- Ammonia spill (fire/explosion) - Operational restrictions - Operational delays		DEL	2	3	M	- Identify abort criteria for the ammonia transfer operation	
2.12	Waves	Wave from passing traffic	- Passing traffic nearby the anchorage point	- May cause excessive strain on the transfer hoses		DEL	2	3	M	- Identify abort criteria for wave height generated by passing traffic for an ammonia transfer operation	
2.13	Other environmental hazards (cold fronts, hurricanes, tsunamis, etc.)	Frequent changes in the wind (speed, direction)	- Environmental hazards	- Ammonia spill (fire/explosion) - Operational restrictions - Operational delays	- No hurricane, tsunami, or cold fonts	DEL	2	3	M	- Consider the risk of wind gusts for the site location and definition of associated abort criteria. Include the vessels' SMS and procedures - Consider stand-by tugs nearby	
3. Navigational hazards in the vicinity of the location											
3.1	Fairway to STS location: - Sufficient water depth and width - Aton sufficient - Critical waypoints or depths - Squat effects	Navigational accident (e.g. grounding, collision or contact) due to narrow waters	- Human error	- Experience has shown that the double-bottom structure of the ammonia carrier can accept severe grounding damage without affecting the integrity of the cargo containment system (however, a double-bottom is not required with a C-type ammonia tank)		SAFE	3	4	M	- During the FEED phase, address required space for maneuvering, turning, etc., given multiple (simultaneous) operations in the area	
3.2	STS location / Space for maneuvering in port/ terminal - Turning circles - Operational water zones Critical depths or coastal areas, rocks	- Ship grounding, collision or contact accident due to lack of maneuvering space	- Human error			SAFE	3	4	M	- Per hazard ID 3.1	
3.3	Mooring at location	Mooring LAC	- Technical error - Human error	- Insufficient mooring - Contact damage between ships - Drift away	- Fenders - Established guidelines (STS transfer guide for petroleum SIGTTO) to be followed	SAFE	2	4	M	- Per operations' risk hazard ID 1.2	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
3.4	Mooring at location	Mooring ABV	- Technical error - Human error	- Insufficient mooring - Contact damage between ships -Drift away	- Fenders - Established guidelines (STS transfer guide for petroleum SIGGTO) to be followed	SAFE	2	4	M	- Per operations' risk hazard ID 1.2	
3.5	Emergency unmooring	Unable to unmoor	- Technical error - Human error	- Asset damage/loss - Injuries/fatalities		SAFE	2	4	M	- Consider measures to initiate unmooring if mooring systems become unavailable (Suggestion: quick release of axe)	
4. Ship traffic density in the vicinity of the location, including the presence of other STS activities											
4.1	Close vicinity/nearby traffic lanes Traffic amount and composition	- Collision with ships in the area (passing, crossing, head-on, overtaking, being rammed while STS, etc.)	- Technical or human error	- Impact with larger ships will cause increased impact energies and damage potential		SAFE	3	4	M	- Assess the risk of ship collision for the STS location; establish the required safety zone - Ensure appropriate communication to the traffic in the area (VTS, NavCharts, Radio, NavWarning etc.)	
4.2	Fishing activities and pleasure crafts interfering with the STS operation	Fishing activities and pleasure crafts interfering with the STS operation	- Intentional or lack of awareness of safety zone			SAFE	2	3	M	- Per hazard ID 4.1	
4.3	Distance to other STS locations in the vicinity (SIMOPS)	- SIMOPS should be detailed in the operations risk assessment				SAFE	2	3	M	- Investigate the QRA potential overlap and escalation risk due to SIMOPS at multiple anchorage points	
5. Spill and dispersion trajectories and potential impacts											
5.1	Terminals or facilities nearby	Toxic vapour cloud that travels downwind towards the terminal or other operations nearby	- Accidental release of ammonia	- Toxic hazard - Potential for ignition somewhere within the terminal		SAFE	2	3	M	- Multiple anchorage points - the risk of escalation to be covered by the QRA	
5.2	Terminals or facilities nearby	Fire/explosion or emergency situation at the terminal or other operation areas nearby	- Flammable cargo handling activities - Bunkering operation/vessel represents an additional source of ignition	- Potential for escalation to bunkering operation		SAFE	2	3	M	See Hazard ID 5.1	
5.3	Populated areas/private ship traffic	- Potential Ammonia spill may reach shorelines, with population, sensitive areas, etc.	- Technical/human error	- Toxic hazard	- No populated area in the vicinity	SAFE	2	3	M	- Relevant port authorities should investigate applicable regulations/restrictions for third- party (private) ships crossing the Raffles Reserve Anchorage area	
6. Requirement for and availability of any additional spill response resources at the location											
6.1	Toxic emergency/ response services and units	- Lack of toxic emergency units nearby may cause incidents to escalate	- Lack of emergency units	- Escalation of events		SAFE	1	4	M	- Review existing ERP activities for ammonia spill application. - Investigate the required capacity of emergency/support tugs and firefighting tugs to mitigate toxic gas dispersion. To be discussed with MPA and SCDF on applicable requirements	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
6.2	Towing/tug emergency	- Lack of towing emergency units nearby may cause incidents to escalate	- Lack of emergency units	- Escalation of events		SAFE	1	4	M	- Per hazard ID 6.1	
6.3	Marine Pollution	- Breach of bunker/ammonia release due to collision	- Collision Impact	- Ammonia spill into the water	- Ammonia internal transfer between tanks reviews damage control. - Listing and DE ballasting	SAFE	1	4	M	- Perform environmental risk assessment due to ammonia spill caused by a ship collision	
7. Other											
7.1	Shore logistical daily support (tugs, support crafts, etc.)	Lack of shore logistical daily support (tugs, support crafts, etc.)	- Lack of logistical support may affect operations (safety, delays etc.)	- Operational delays	- Shore support required for operations is identified and arranged prior Vessel's arrival at the STS location	SAFE	2	3	M		
7.2	STS Superintendents subcontracted	Lack of experience and competence	- Lack of training and competence (qualification of personnel)	- Ammonia spill (toxic hazard)		SAFE	1	4	M	- Per operations' risk hazard ID 4.12	
7.3	Security threats in the area	Security threats	- War, sabotage, and terrorism risks	- Ammonia spill (toxic hazard)							- Not Applicable
7.4	Radio/Tele-communication coverage	Lack of radio/ telecommunication coverage	- Lack of tele-communication capacity	- Ammonia spill (toxic hazard)							- Not Applicable
7.5	Time	The time window for operation and slot requirements	- Multiple activities at the terminal	- Stress and potential human failures	- Established operations schemes	SAFE	2	3	M		

APPENDIX B: CONCEPT 3 RISK RESULTS AND HAZID LOG

B1 HAZID Results

The HAZID study's results (i.e. hazards, hazardous events, causes, consequences, preventive & mitigating measures, recommendations and responsibility) were documented in the HAZID Log below. Workshop participants reviewed all the content documented in The HAZID Log, including the proposed risk rating.

B1.1 Risk Results

The HAZID was conducted based on arrangement drawings and documents, and design philosophies available at the time of the HAZID workshop. It is strongly recommended that any significant future changes to the design or operation which may impact the hazard and risk levels should be reassessed.

All results of the HAZID study (i.e., hazards, hazardous events, causes, consequences, preventive & mitigating measures, recommendations, and responsibility) were documented in the HAZID Log presented in Appendix B of this report. In total, ninety-four (94) hazardous events were identified, where seventy-four (74) hazardous events were categorised as medium risk, and four (4) hazardous events were categorised as acceptable or low risk. The remaining sixteen (16) events were not ranked because no risk was identified. The risk summarisation of concept 3 are as shown in Table B1-1.

No hazardous events were categorised as high risk

Table B1-1 Concept 3 Risk Summarisation

Risk Ranking	Concept 3 – STS ABV – APS at Anchorage	
	Operation Risk	Location Risk
Low	1	3
Medium	38	36
High	0	0
Not Risk Ranked	3	13

B1.2 HAZID recommendations

One Hundred and thirteen (113) HAZID recommendations were made during the HAZID workshop for concept 3. Recommendations are further summarised in Table B1-2 and Table B1-3.

Table B1-2 HAZID recommendations concept 3 (operational risk)

No	Hazard ID	Guideword-Hazardous event	Recommendation/ Follow-up action
1	1.1	Compatibility assessment (between ships) - Failing to follow procedures/standards prior to operation	Conduct compatibility assessment (ABV/APS) (all parties are involved in developing compatibility assessment; all operational modes, including SIMOPS identified and addressed). In addition to bunkering infrastructure, berthing and fendering
2			Potential hose misalignment between manifolds is to be covered as part of the compatibility assessment
3			Automatic ESD (ABV)
4			Linked ESD System (ship to ship link)
5			For type A tank reliquefication unit is to be provided to control tank pressure. For tank type C BOG management system to be provided, including but not limited to a reliquefication unit, GCU/boilers are recommended to avoid opening of PRV. Alternatively, a tank design pressure of 18 bar (45 deg C) can be considered
6			Emergency response, escape, and evacuation procedures are to be established in case of an ammonia release
7			Required PPE is provided, including shower & eyewash stations
8			An ammonia release mitigation system (ARMS) should be provided for APS. ABV should also consider the integration of ARMS. Any release of ammonia vapour on APS as part of regular operation should not exceed 30 ppm in toxic concentration
9			Material compatibility assessment
10			Ammonia sampling at ABV
11			A sampling procedure for liquid and vapour return shall be established, including available technology, verification, and personnel training. It is proposed at the sending ship side (CGA can be referred for associated procedure)
12			Established operating limits and weather windows for ammonia bunkering application
13			A custody transfer procedure for ammonia transfer is to be established
14			Master meter for ammonia transfer to be considered
15			Provide required competence and training to personnel

No	Hazard ID	Guideword-Hazardous event	Recommendation/ Follow-up action
16	1.2	Mooring assessment - Failing to follow procedures/standards prior to operation	Mooring compatibility assessment (anchorage point arrangement). Fendering arrangement based on vessel size
17	1.3	Bunker procedures and organization - Failing to follow procedures/standards prior to operation	Establish an associated procedure for the ammonia transfer operation
18			Establish a joint plan of operations (JPO) ABV/APS for the ammonia transfer operation
19			Safety management system (SMS) to include ammonia transfer operation
20	2.1	Failing to follow procedures prior to operation: - Pre-arrival checklist - Tests and notices - Communication - The pilot and master meeting prior to the approach	Update all established checklists for ammonia application (ABV)
21	4.1	Failing to follow procedures: - Testing communication - Checklists onboard	Tank preparation procedure (air drying, purging) at the APS before ammonia transfer
22			All established checklists should be reviewed for ammonia application (ABV)
23			Investigate means for vapour return handling (either on APS or ABV)
24	4.5	Human error - Vessel separation detection (VSD) connection failure	Consider VDS; provide required competence and training to operate a VDS, including any required checks
25	4.9	Human error - Insufficient cooldown of piping	Cold ammonia gas from the reliquefication unit can cool down pipes and remove nitrogen; that gas should further be sent to the ammonia catch system (APS)
26	4.12	Human error – Lack of competence/training	Provision of competence and training to personnel is required for personnel involved in ammonia operations
27	5.1	Breakaway - Breakaway, vessel separation	Consider a dry drip tray for ammonia spill containment and draining (ABV)
28			The capacity of the water spray system (including shoreside and terminal) is to be defined based on ammonia spilt vs water amount required. The water spray system is considered efficient for limited liquid ammonia spill only; the leak is considered neutralised by a large amount of water. For extensive spill mitigation, a dry drip tray or foam / DCP system can be considered (ABV)
29			The thermal sensor in the drip tray (APS design)
30			Gas detectors at the bunker station (APS design)
31			Include a procedure for hose recovery in case of ESD2 from a daughter vessel

No	Hazard ID	Guideword-Hazardous event	Recommendation/ Follow-up action
32	5.2	Leak - Ammonia leakage from transfer hose, marine loading arm during cargo loading or offloading operation	Placement of gas detectors to consider light and heavy toxic cloud behaviour (ABV)
33			Consider a spill containment system for a pressurised ammonia release capable of containing the spill for multiple release directions (ABV)
34			Thermal detection inside the bund (ABV)
35			Fixed gas detection fitted on the vessels (ABV)
36			Automatic ESD (ABV)
37			Identify means for ammonia water solutions disposal; at some ports, release to the sea is permitted; to define in consultation with MPA for allowable toxic concentration for release to sea (ABV)
38			Identify the required capacity of the fire water system (ABV)
39			Due to the exothermic reaction of ammonia with water, identify the spill amount that the water spray system can neutralise; for a larger release, part of the spill will be dissolved, remaining will be quickly vapourised, travelling downwind. See hazard ID 5.1 for alternative solutions (ABV)
40	5.3	Leak - Ammonia leakage from cargo loading/offloading manifold	Closure of vent inlets to safe areas/rooms
41			Provision of toxic detectors in HVACs
42			Eyewash to personnel
43			Double-door arrangements for accommodation and safe rooms
44			Mechanical shielding for flanged connections (ABV)
45	5.9	Leak - Ammonia leakage from a pipe on a deck	Closure of vent inlets to safe areas/rooms (ABV)
46			Provision of toxic detectors in HVACs (ABV)
47			Eyewash to personnel (ABV)
48			Double-door arrangements for accommodation and safe rooms (ABV)
49			Mechanical shielding for flanged connections (ABV)
50			Based pipe routing is considered a double barrier if it goes close or passes to safe areas (APS)

No	Hazard ID	Guideword-Hazardous event	Recommendation/ Follow-up action
51			Mechanical protection for piping is required if piping routing goes via areas with a present hazard of dropped objects (APS)
52			Consider the required capacity of mechanical protection based on the lifting operation conducted (APS)
53			Toxic gas detection in the inlet and safe areas must be considered if exposed to toxic release. Dispersion simulation can be conducted to assess potential exposure (APS/ABV)
54	5.13	Impact - Mechanical impact on piping, e.g. dropped object	Mechanical protection for piping on the main deck defines the required capacity for mechanical protection (APS)
55	5.14	Overpressure of the storage tank	Investigate to what extent humidity will affect NH_3 gas dispersion
56			A flag may request dispersion analysis for the risk of toxic gas ingress to ventilation in the accommodation area
57			Consider a liquid level detector to be installed in the vent mast
58			Vent mast arrangement should be designed to prohibit water ingress from, e.g. rain or sea spray
59			Investigate the inclusion of a water spray system for the vent mast. Consider drainage/containment of aqueous ammonia as well
60	5.15	Overfilling of the storage tank	Investigate ESD link logic to trigger a shutdown of ABV supply pumps and manifold valves
61	5.17	BOG management - Overpressure	Investigate the required capacity of the BOG management system on the APS
62	5.18	Leak - Leak inside TCS	Remotely operated valves as much as possible
63			Fully welded connections as much as possible
64			Ammonia water solution disposal is to be defined by local authorities; otherwise, a drain tank should be made available on the ship
65	5.19	Design - Tank design (ABV)	More than 25 mm of pipe must be welded
66			Water spray system on tank dome
67			Melting plugs

No	Hazard ID	Guideword-Hazardous event	Recommendation/ Follow-up action
68	5.19	General SIMOPS activities - vessel ballasting, vessel crane operations, crew and visitors embarking/ disembarking, disposal (garbage, sludge, sewage, blackwater etc.), lifeboat or MOB boat drills/handling, firefighting drills, general cleaning and maintenance, underwater service/repairs, testing fin stabilisers, hot work and maintenance, helicopter operations, power generation onboard, running engine and machinery (supply and receiving vessels), cargo handling	Consider SIMOPS at the terminal
69			No parallel operations with cargo operations (at the same anchorage point)
70			Consider SIMOPS on a case-to-case basis and required mitigating measures (as a basis, no SIMOPS leading to additional loss of containment scenarios are assumed)
71			A matrix of permitted operations (MOPO) to be developed in conjunction with MPA and non-essential operations to be avoided
72			No crew change during STS is recommended
73	6.1	Drain - Fail to drain (ammonia remains in transfer equipment/not liquid-free)	Per hazard ID 4.1
74			Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation
75	6.2	Purge - Fail to purge (fail to maintain % content)	Per hazard ID 4.1
76			Per hazard ID 6.1, Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation
77			For APS purge gas to be sent to AMRS or back to the bunker vessel (not allowed to be vented)
78	7.1	Navigational hazards (grounding, collision and contact) during departure/maneuvering from STS location, see Location Risk Assessment	An EDP should be considered after the completion of the cargo operation
79	8.1	Toxic zone definition - Toxic gas in non-hazardous areas	Consider air humidity on ammonia gas behaviour and potential for ingress to non-hazardous areas (ABV)

Table B1-3 HAZID recommendations concept 3 (location risk)

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
1	1.4	Experience with this location. Used currently or in the past for STS - New locations may pose a higher risk than existing locations with solid experience	For the pilot phase, pilotage, testing, and personnel training will be provided (MPA to confirm)
2			Emergency procedures are to be established
3	1.5	Ship dimension limitations (Minimum under-keel clearance requirement/ Maximum arrival draft) - Grounding	Consider smaller size vessels for the pilot phase of the project
4	1.6	Safety and security zones - Activities close to the bunkering operation	Safety zone to be developed based on the results from the QRA
5			Consider the risk of ship collision imposed by passing vessels
6	1.7	Dedicated waiting area/anchorage area - Conflict with other ship traffic	MPA to consider anchorage locations for other vessels that must await completion of STS operations at the dedicated anchorage point
7	1.8	Mandatory pilotage - Navigational accident during approach, maneuvering or departure in the waterway (e.g., grounding, collision, or contact)	Dedicated pilotage of vessel types involved in ammonia bunkering will be carried out
8	1.10	Standby tug requirement (fire fighting, rescue services, emergency towing or pushing up, delivery of personnel or equipment, guarding the vessel, assisting with pollution, and others) - An emergency event during STS transfer	Investigate if additional requirements of tugs for emergency response are associated with ammonia leaks
9	1.12	Vessel traffic services (VTS) - information services (INS), navigation assistance services (NAS), traffic organization services (TOS) - Navigational accident (e.g. grounding, collision or contact)	Consider navigational risk assessment during FEED
10	1.14	Mooring requirements (mooring study, bow direction, weather restriction)	Existing mooring arrangements should be assessed for all sizes of ships

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
11			Assess mooring requirements on each planned operation by involving STS organisers or by the managers of both vessels
12	1.15	Loss of position – anchor dragging	Assess the required mooring anchor's capacity and redundancy
13			Consider the provision of the standby tug to prevent separation
14	1.19	All regulating bodies are identified, and requirements accounted for unsafe operations (by not following regulations)	Investigate additional local regulating body requirements associated with ammonia transfer operations, including limitation of toxic release to air or water
15			Restriction on toxicity (ppm) associated with water ammonia solution that can be disposed to sea
16	1.20	All company-specific requirements accounted for unsafe operations (by not following company-specific procedures)	To be addressed in the FEED phase
17	1.22	Approval of operations - Lack of approval may cause increased risk to the public	Approval of operation is required by regulating body
18			Requirements for Vessel specific STS Plan approval by the flag to be verified with the MPA
19	2.9	Operational weather limits, including abort criteria - Accidental release of Ammonia (loss of containment) due to insufficient or lack of weather limits	Identify abort criteria for an ammonia transfer operation
20	2.10	Visibility (daylight, fog, etc.) - Navigational accident (e.g. grounding, collision or contact) due to lack of visibility	Visibility to be addressed each vessel's SMS and procedures
21	2.11	Electrical storm (thunderstorms) - Electrical storms (thunderstorms) may affect cargo transfer operation	Identify abort criteria for the ammonia transfer operation
22	2.12	Waves - Wave from passing traffic	Identify abort criteria for wave height generated by passing traffic for an ammonia transfer operation
23	2.13	Other environmental hazards (cold fronts, hurricanes, tsunamis, etc.) - Frequent changes in the wind (speed, direction)	Consider the risk of wind gusts for the site location and the definition of associated abort criteria. Include the vessels' SMS and procedures

No	Hazard ID	Hazardous event / Consequences	Recommendation/ Follow-up action
24			Consider stand-by tugs in proximity
25	**3.1/3.2**	Fairway to STS location (sufficient water depth and width, aton sufficient, critical waypoints or depths, squat effects) - Navigational accident (e.g., grounding, collision or contact) due to narrow waters	During the FEED phase, address required space for maneuvering, turning, etc., given multiple (simultaneous) operations in the area
26	**3.5**	Emergency unmooring – Unable to unmoor	Consider measures to initiate unmooring if mooring systems become unavailable (Suggestion: quick release of axe)
27	**4.1/4.2**	Close vicinity/nearby traffic lanes Traffic amount and composition - Collision with ships in the area (passing, crossing, head-on, overtaking, being rammed while STS, etc.)	Assess the risk of ship collision for the STS location; establish the required Safety Zone
28			Ensure appropriate communication to the traffic in the area (VTS, NavCharts, Radio, NavWarning etc.)
29	**4.3**	Distance to other STS locations in the vicinity (SIMOPS) - SIMOPS should be detailed in the operations risk assessment	Investigate the QRA potential overlap and escalation risk due to SIMOPS at multiple anchorage points
30	**5.1/5.2**	Terminals or facilities nearby - Toxic vapour cloud that travels downwind towards the terminal or other operations nearby	Multiple anchorage points - the risk of escalation to be covered by the QRA
31	**5.3**	Populated areas/private ship traffic - Potential ammonia spill may reach shorelines, with population, sensitive areas, etc.	Look into applicable regulations/restrictions for 3rd party (private) ships crossing the Raffles Reserve Anchorage area
32	**6.1/6.2**	Toxic emergency/ response services and units - Lack of toxic emergency units nearby may cause incidents to escalate	Review existing ERP activities for ammonia spill application
33			Investigate the required capacity of emergency/support tugs and firefighting tugs to mitigate toxic gas dispersion. To be discussed with MPA and SCDF on applicable requirements
34	**6.3**	Marine pollution - Breach of bunker/ammonia release due to collision	Perform environmental risk assessment due to ammonia spill caused by a ship collision

B1.3 Operation Risk Assessment - ABV - APS ammonia transfer at Anchorage (HAZID Log)

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
Node 1 Prior to operations											
1.1	Compatibility assessment (between ships)	Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Misalignment - Ship contact damages - Excessive forces on manifolds - Possibility to exceed operating envelop of equipment - Mooring issues - Loss of containment	- Class rules and LNG bunkering requirements (IGF/IGC) can be used as a reference for bunkering transfer and associated requirements (APS) - Ammonia composition is checked based on the quality certificate	SAFE	3	3	M	- Conduct compatibility assessment (ABV/APS) (all parties are involved in developing compatibility assessment; all operational modes, including SIMOPS identified and addressed). In addition to bunkering infrastructure, berthing and fendering - Potential hose misalignment between manifolds is to be covered as part of the compatibility assessment - Automatic ESD (ABV) - Linked ESD System (Ship to ship link) - A tank reliquefication unit is to be provided to control tank pressure. For thank type C BOG management system to be provided, including but not limited to a reliquefication unit, GCU/boilers are recommended to avoid opening of PRV. Alternatively, a tank design pressure of 18 bar (45 deg C) can be considered - Emergency response, escape, and evacuation procedures are to be established in case of an ammonia release - Required PPE is provided, including shower & eyewash stations - An ammonia release mitigation system (ARMS) should be provided for APS. ABV should as well consider the integration of ARMS. Any release of ammonia vapour on APS as part of regular operation should not exceed 30 ppm in toxic concentration - Material compatibility assessment - Ammonia sampling at ABV - A sampling procedure for liquid and vapour return shall be established, including available technology, verification, and personnel training. It is proposed at the sending ship side (CGA can be referred for associated procedure) - Established operating limits and weather windows for ammonia bunkering application - A custody transfer procedure for ammonia transfer is to be established. - Master meter for ammonia transfer to be considered - Provide required competence and training to personnel	- For the QRA APS ammonia fuel supply system design fully compliant with IGC and DNV Ammonia Ships Rules is assumed <u>General remark</u> The presented concept of an Ammonia transfer (bunkering) system is based on traditional/LPG/LNG fuels transfer. Due to the toxic nature of Ammonia, suggest looking at a different transfer philosophy approach: use smaller diameter hose(s) of 2-3" with higher flow speed in the transfer link. There are multiple benefits to such a system: - Smaller and lighter hoses make it less possible to sustain mechanical damage - Hose connections are simpler, quicker, and safer - Handling hoses is much easier - A significant advantage in the safety aspect: in cases of hose burst amount of residual Ammonia in the hose (which is the primary quantity of Ammonia spilt) is much smaller in comparison to a bigger diameter hose - Depending on the size of the bunker parcel, 1, 2 or 3 hoses can be used simultaneously (all are fixed on one bunker boom/arm), which adds to the flexibility and redundancy of the transfer system
1.2	Mooring assessment	Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Ship drift away, drift grounding - Contact damage - Disrupt operations	- ESD and PERC	SAFE	2	3	M	- Mooring compatibility assessment (anchorage point arrangement). Fendering arrangement based on vessel size	
1.3	Bunker procedures and organization	Failing to follow procedures/standards prior to operation	- Commercial pressure - Human error - Lack of company standards	- Loss of containment		SAFE	2	3	M	- Establish an associated procedure for the ammonia transfer operation - Establish a joint plan of operations ABV/APS for the ammonia transfer operation - Safety management system (SMS) to include ammonia transfer operation	
Node 2 Prior to arrival											
2.1	- Pre-arrival checklist, bunkering and notice - Communication - The Pilot and Master meeting prior to the approach	Failing to follow procedures prior to operation	- Failing to follow procedures may lead to incidents	- Loss of containment during operations	- Established check bunkering for ABV/APS preparation activities, pre-arrival, equipment checklist and berthing checklist for the vessel	SAFE	2	3	M	- Update all established checklists for ammonia application (ABV)	- APS is assumed to have dedicated procedures in place for ammonia
Node 3 Arrival (Inc. Mooring)											

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
3.1	- Navigational hazards	Navigational hazards are location specific, thus covered in the location risk assessment									
3.2	- Mooring between ABV/APS	Mooring hazards are location specific, thus covered in the location risk assessment									
Node 4 Pre-transfer											
4.1	- Testing communication - Checklists bunkering onboard	Failing to follow procedures	- Failing to follow procedures may lead to incidents	- Potential spillage during bunkering transfer	- Bunkering transfer/bunkering procedures - Gas sampling (inside the tank) - Safety management system and safety checklist	SAFE	2	3	M	- Tank preparation procedure (air drying, purging) at APS before ammonia transfer - All established checklists should be reviewed for ammonia application (ABV) - Investigate means for vapour return handling (either on APS or ABV)	
4.2	Human error	Coupling/loading arm/hose connection failure	- Incorrect connection or locking	- Potential Ammonia leaks	- Bunkering transfer/bunkering procedures	SAFE	2	4	M		
4.4	Human error	ESD link connection error	- Incorrectly plugged or plug connection damaged/dirty	- Fail to function on demand Potential ammonia leaks	- ESD test	SAFE	1	4	M		
4.5	Human error	Vessel separation detection (VSD) connection failure	- Incorrectly plugged or plug connection damaged/dirty - Wrongly placed	- Fail to function on demand Potential ammonia leaks	- Part of the checklist/procedure to ensure the connection is in place - System is function tested before operation - Compatibility analysis - Supervised operation - ESD2 is initiated in case of excessive forces on the loading arm (to be confirmed)	SAFE	1	4	M	- Consider VDS; provide required competence and training to operate VDS, including any required checks	
4.6	Electric isolation	Electric isolation	- Wear and tear - No insulation flange	- Ignition source, sparks	- Electric isolation between connected vessels in compliance with the ISGOTT and SIGTTO "Liquefied Gas Handling Principles on Ships and in Terminals"	SAFE	1	4	M		
4.7	Utility failure	Fail to quantify/measure the quantity of fuel transferred	- Technical failure	- No health/safety risk	- Established related industry standards requirements	QUA	1	3	L		
4.8	Human error	Forgot to reset the ESD systems after testing	- Failing to follow procedures	- Fail to function on demand Potential ammonia leaks	- Bunkering transfer procedures - Training and competence of personnel	SAFE	1	4	M		
4.9	Human error	Insufficient cooldown of piping	- Failing to follow procedures	- Pipeline damage	- Bunkering transfer procedures - Training and competence of personnel	SAFE	1	4	M	- Cold ammonia gas from the reliquefication unit can be used to cool down pipes and remove nitrogen that gas should be sent to the ammonia catch system (APS)	

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
4.10	Human error	Incomplete PERC system set-up	- Failing to follow procedures	- PERC fail to function on demand (potential damage to bunkering hoses in case of vessel separation) - Ammonia spill	- PERC with fail-safe function, interlock until active	SAFE	1	4	M		
4.11	Human error	Incomplete leak test	- Failing to follow procedures	- Leakages during operation	- Bunkering procedures	SAFE	1	4	M		
4.12	Human error	Human error	- Lack of experience with handling ammonia	- Leakages during operation		SAFE	2	4	M	- Provision of competence and personnel training is required for ammonia operations personnel	
Node 5 Transfer of Ammonia											
Bunker manifold											
5.1	Breakaway	Breakaway, vessel separation	- Excessive relative motion between ships beyond the operational window - Mooring failure	- Equipment/asset damage/operational delay - Personnel injuries	- Marine loading arm /Hose ERS - ESD system with two-stage alarm and shutdown system. The first stage (ESD1) shall initiate the shutdown of the transfer operations and close valves, and the second stage (ESD2) shall activate the PERCs - Water curtain/ water spray system at the ship side and the Terminal - Drip tray 50% filled with water to dissolve ammonia during spillage - Dry breakaway decoupling (APS design) - Gas detectors for semi-enclosed bunker station arrangement (APS design) - For the semi-enclosed bunker, the station provided mechanical ventilation (APS design) - Water spray system for bunker satiation to mitigate the toxic gas release. - Automatic ESD system on gas detection (APS design)	SAFE	2	4	M	- Consider a dry drip tray for ammonia spill containment and draining (ABV) - The capacity of the water spray system (including shoreside and terminal) is to be defined based on ammonia spillage vs water amount required. The water spray system is considered efficient for limited liquid ammonia spill only; the leak is considered neutralised by a large amount of water. For extensive spill mitigation, a dry drip tray or foam / DCP system can be considered (ABV) - A thermal sensor in the drip tray (APS design) - Gas detectors at the bunker station (APS design) - Include a procedure for hose recovery in case of ESD2 from a daughter vessel	-To be assessed in the QRA

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.2	Leak	Ammonia leakage from transfer hose, marine loading arm during cargo loading or offloading operation	- Design, fabrication or installation error - Abnormal operating condition (exceeding design limits) due to equipment malfunction or operator error - Material defect - Excessive relative motion between ships beyond the operational window of the marine loading arms - Drift-off	- Toxic spill - Toxic gas dispersion due to evaporated spill - Personnel injuries; cold burns - Potential for damage of hull structure exposed to a cryogenic spill - Potential for ignited toxic release if a strong ignition source is reached	- Manual ESD activation points at ABV are provided to rapidly shut down the cargo transfer system. The ESD can be initiated both locally and remotely - ESD system with two-stage alarm and shutdown system. The first stage (ESD1) shall initiate the shutdown of the transfer operations and close valves, and the second stage (ESD2) shall activate the PERCs (ABV) - Water curtains/spray (ABV) - Pressure/leak testing (ABV) - Bund for loading arm with a sump (small pit) installed with suction head (ABV) - Dry breakaway decoupling (APS design) - Gas detectors for semi-enclosed bunker station arrangement (APS design) - For the semi-enclosed bunker, the station provided mechanical ventilation (APS design) - Mechanical shielding for flange connection (APS design) - Automatic ESD system on gas detection (APS design)	SAFE	2	4	M	- Placement of gas detectors to consider light and heavy toxic cloud behaviour (ABV) - Consider a spill containment system for a pressurised ammonia release capable of containing the spill for multiple release directions (ABV) - Thermal detection inside the bund (ABV) - Fixed gas detection fitted on the vessels (ABV) - Automatic ESD (ABV) - Identify means for ammonia water solutions disposal; at some ports, release to the sea is permitted; to define in consultation with MPA for allowable toxic concentration for release to sea (ABV) - Identify the required capacity of the fire water system (ABV) - Due to the exothermic reaction of ammonia with water, identify the spill amount that the water spray system can neutralise; for a larger release, part of the spill will be dissolved, remaining will be quickly vapourised travelling downwind. See hazard ID 5.1 for alternative solutions (ABV)	-To be assessed in the QRA
5.3	Leak	Ammonia leakage from cargo loading/offloading manifold	- Design, fabrication or installation error - Abnormal operating condition (exceeding design limits) due to equipment malfunction or operator error - Material defect	- Toxic spill - Toxic gas dispersion due to evaporated spill - Personnel injuries; cold burns - Potential for damage of hull structure exposed - Potential for ignited toxic release if a strong ignition source is reached	- Duty person for leak detection (ABV) - Manually activated ESD (ABV) - Water spray system (ABV) - Drip tray 50% filled with water to dissolve ammonia if spilt (ABV) - Gas detectors for semi-enclosed bunker station arrangement (APS design) - For the semi-enclosed bunker, the station provided mechanical ventilation (APS design) - Mechanical shielding for flange connection (APS design) - Automatic ESD system on gas detection (APS design) - Dry drip tray with liquid sensors (APS design)	SAFE	2	4	M	- Per hazard ID 5.2 - Closure of vent inlets to safe areas/rooms - Provision of toxic detectors in HVACs - Eyewash to personnel - Double-door arrangements for accommodation and safe rooms - Mechanical shielding for flanged connections (ABV)	- To be assessed in the QRA
5.3	Trapped liquid	The trapped liquid between the bunker valve and the tank valve	- Intended or unintended activation of ESD	- Ammonia trapped between valves. When trapped liquid ammonia is heated, the result is high pressure which can cause equipment or gasket failure - Equipment/ system damage - Ammonia leak	- PRV is provided for each piping segment; the trapped liquid is sent either to the fuel tank or ammonia release mitigation system ARMS. (APS design) - The design pressure for the ammonia system required 18 bar. - Depressurisation of the segment after the transfer (ABV)	SAFE	1	4	M		- All ammonia gas released as part of a standard operation must be sent to ARMS; only tank vapour is released via PRV

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.4	Backflow	Backflow of NH_3 into the N2 system	- Valve failure	- Exposure to the crew (when opening up for maintenance etc.) - Damage to the nitrogen system - Toxic hazard - Fire/explosion if a strong ignition source is present	- Required to have double block and bleed valves on connections to the nitrogen system.	SAFE	1	4	M		
5.5	Wrong flow	The flow of NH_3 to other bunkering stations	- Valve failure	- Toxic hazard - Fire/explosion if a strong ignition source is present	- Double valve segregation - Additional valve beside the double valve segregation barrier (APS design)	SAFE	1	4	M		
5.6	Damage	Piping thermal expansion or contraction	- Extreme temperatures of the fuel and high ambient temperatures	- Pipe leak or rupture	- PRV - Heat stress analysis	SAFE	1	4	M		
5.7	Damage	Stress corrosion cracking	- Design fault, incorrect material properties		- Material selection per IGC code (clause 17.1.2) and DNV ammonia ship rules (APS Design) - Piping inspections and condition monitoring	SAFE	1	4	M		
5.8	Arrangement	Bunkering station arrangement	- Insufficient ventilation		- See hazard ID 5.1	SAFE	1	4	M		-To be assessed in the QRA
5.9	Leak	Ammonia leakage from a pipe on a deck	- Design, fabrication or installation error - Abnormal operating condition (exceeding design limits) due to equipment malfunction or operator error - Material defect	- Toxic spill - Toxic gas dispersion due to evaporated spill - Personnel injuries; cold burns - Potential for damage of hull structure exposed to a cryogenic spill - Potential for ignited toxic release if a strong ignition source is reached	- Water spray system on the ship side - Single wall pipe fully welded (APS design)	SAFE	1	4	M	- Per hazard ID 5.2 - Closure of vent inlets to safe areas/rooms (ABV) - Provision of toxic detectors in HVACs (ABV) - Eyewash to personnel (ABV) - Double-door arrangements for accommodation and safe rooms (ABV) - Mechanical shielding for flanged connections (ABV) - Based pipe routing is considered a double barrier if it goes close or passes to safe areas (APS) - Mechanical protection for piping is required if piping routing goes via areas with a present hazard of dropped objects (APS) - Consider the required capacity of mechanical protection based on the lifting operation conducted (APS) - Toxic gas detection in the inlet and safe areas must be considered if exposed to toxic release. Dispersion simulation can be conducted to assess potential exposure (APS/ABV)	-To be assessed in the QRA
5.10	Fire/explosion	Fire/explosion in the manifold area	- Toxic gas release accounting for a strong ignition source	- Ignited leak - Flash fire	- The manifold area is located in a hazardous zone, and ex-rated equipment's no ignition sources are allowed (ABV). - The fixed and portable dry-powered system at the bunker station (APS design)	SAFE	1	4	M		
5.11	Fire/explosion	Heat transfer to the bunkering station from the fire	- Fire/explosion in other areas	- Overpressure the release of toxic gas	- The fixed and portable dry-powered system at the bunker station (APS Design) - Passive fire protection at bunkering station A60 insulation adjacent to the machinery system	SAFE	1	4	M		
5.12	External leak	Spill of ammonia into the water	- Hose rupture	- Rapid formation of toxic cloud	- Water spray system at ship's side for vapour mitigation	ENV	1	4	M		-To be assessed in the QRA

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
5.13	Impact	Mechanical impact on piping, e.g. dropped object	- Lifting activity - Dropped objects	- Rupture of pipe - Release of NH_3 - Toxic hazard - Fire/explosion if a strong ignition source is present	- No crane operations in parallel with cargo operations (ABV)	SAFE	1	4	M	- Mechanical protection for piping on the main deck; define the required capacity for mechanical protection (APS)	-To be assessed in the QRA
Cargo containment and vent systems											
5.14	Overpressure	Overpressure	- Heat ingress - Ammonia supplied at different conditions (P, T)	- Opening of PSVs due to pressure increase in the cargo tanks / fuel tank -Toxic gas release	- High-pressure alarm - BOG management system GCU, Reliquification unit - Control venting - Tank design pressure - Installation of harbour setters in port to increase MARVS (Maximum allowable relief valve setting)	SAFE	1	4	M	- Investigate to what extent humidity will affect NH_3 gas dispersion. - A flag may request dispersion analysis for the risk of toxic gas ingress to ventilation in the accommodation area - Consider a liquid level detector to be installed in the vent mast. - Vent mast arrangement should be designed to prohibit water ingress from rain or sea spray - Investigate the inclusion of a water spray system for the vent mast. Consider drainage/containment of aqueous ammonia as well	-To be assessed in the QRA
5.15	Overfilling	Overfilling	- Overfilling of fuel tanks during transfer	- Toxic liquid out of vent mast. Consequently, the potential for injuries, fatalities, asset damage or accident escalation to adjacent areas.	- High and independent high-level alarm to close the bunkering valve and stop transfer pumps - The agreed amount of ammonia to be transferred	SAFE	2	4	M	- Investigate ESD link logic to trigger the shutdown of ABV supply pumps and manifold valves	- To be assessed in the QRA
5.17	BOG management	Overpressure	- Generation of BOG in the ammonia transfer (especially in the initial stage)	- Unintended release of gas via vent mast - Increase tank pressure	- See hazard ID 5.14	SAFE	1	4	M	- Investigate the required capacity of the BOG management system on APS	
5.18	Leak	Leak inside TCS	- Design, fabrication or installation error - Abnormal operating condition (exceeding design limits) due to equipment malfunction or operator error - Material defect	- Toxic gas out of vent mast	- Gas detection inside TCS will trigger the shutdown of the tank valve - Liquid leakage detection will trigger the shutdown of the tank valve - Trigger catastrophe ventilation 45 ach - Mechanical shielding on the flanged connection inside the TCS - Fully welded connection to the tank up to the first valve - The alarm on the open deck if gas is detected in TCS or spaces that are ventilated to that area. - A toxic zone is defined as the minimum distance in the event of a toxic release - A water curtain on the door to TCS - An airlock if TCS goes into another enclosed space	SAFE	1	4	M	- Remotely operated valves as much as possible - Fully welded connections as much as possible - Ammonia water solution disposal is to be defined by local authorities; otherwise, a drain tank should be made available on the ship	
5.19	Design	Tank design (ABV)	- Insufficient design	- Continuous release		SAFE	1	5	M	- More than 25mm of pipe must be welded - Water spray system on tank dome - Melting plugs	

No.	Guideword	Hazard/event	Potential causes	Potential consequence	Existing or planned safety measures	T	P	C	R	Recommendations (and responsibilities)	Notes
SIMOPS											
5.20	General SIMOPS activities	- Vessel ballasting - Vessel crane operations - Crew and visitors embarking/ disembarking - Disposal (garbage, sludge, sewage, blackwater etc.) - Lifeboat or MOB boat drills/handling - Firefighting drills - General cleaning and maintenance - Underwater service/repairs - Testing fin stabilisers - Hot work and maintenance - Helicopter operations - Power generation onboard, running engine and machinery (supply and receiving vessels) - Cargo handling	- SIMOPS	- Potential for fire (jet, pool or flash fire) or explosion. Consequently, the potential for injuries, fatalities, asset damage or accident escalation to adjacent areas	- No SIMOPS will occur during bunkering	SAFE	1	4	M	- Consider SIMOPS at the terminal - No parallel operations with cargo operations (at the same anchorage point). - Consider SIMOPS on a case-to-case basis and required mitigating measures (as a basis, no SIMOPS leading to additional loss of containment scenarios are assumed) - A MOPO will be developed in conjunction with the MPA and non-essential operations will be avoided - No crew change during STS is recommended	
Node 6 Post-Transfer											
6.1	Drain	Fail to drain (ammonia remains in transfer equipment/not liquid-free)	- Fail to follow procedures - Technical error	- Toxic condition in transfer equipment while disconnection (gas or trapped liquid) - Exposure of flammable material to crew	- PPE - Emergency Preparedness - Procedures adapted to vessel compatibility - Pressure relief valve - Draining of lines after completion of transfer operations - Procedure for connection liquid-free status verification established	SAFE	2	3	M	- Per hazard ID 4.1 - Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation	
6.2	Purge	Fail to purge (fail to maintain % content)	- Fail to follow procedures - Technical error	- Toxic condition in transfer equipment while disconnection (gas or trapped liquid) - Exposure of flammable material to crew	- Work procedures for draining, purging, inerting - Training and competence of personnel - PPE - Emergency Preparedness - Procedures adapted to vessel compatibility - Purging with hot gas to remove all ammonia to the tank (ship side)	SAFE	2	3	M	- Per hazard ID 4.1 - Per hazard ID, 6.1 Installation of adequate freshwater eyewash in the vicinity of manifold, break off in accommodation - For APS purge gas to be sent to AMRS or back to the bunker vessel (not allowed to be vented).	
6.3	Disconnection	Toxic condition	- Per hazard ID 6.1 and 6.2	- Per hazard ID 6.1 and 6.2	- Sampling of gas for toxic content after purging	SAFE	2	3	M	- Per hazard ID 6.1 and 6.2	
Node 7 Unmooring and departure											
7.1		Navigational hazards (grounding, collision and contact) during departure/maneuvering from STS location, see Location Risk Assessment	-	-	-					- An EDP should be considered after the completion of the cargo operation	
Node 8 Other hazards											
8.1	Toxic zone definition	-Toxic gas in non-hazardous areas	- Toxic zone is defined as insufficient	- Toxic gas in non-hazardous areas		SAFE	2	4	M	- Consider air humidity on ammonia gas behaviour and potential for ingress to non-hazardous areas (ABV)	

B1.4 Location Risk Assessment - ABV-APS ammonia transfer at anchorage (HAZID Log)

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1. Local establishment, regulations and requirements											
1.1	Fish farms/ fishery or aquaculture establishments	Conflict with fish farms/aquaculture establishments	- Other activities may hinder or cause hazards to the STS operation, or vice versa	- Ammonia spill (toxic hazard) - Potential for fire/explosion - Operational restrictions - Operational delays	- No commercial fishing activities						- Not applicable; thus, no risk rating is provided
1.2	Ballast water	Ballast water restrictions			- No restrictions for ballast water exchange in that area						- No ballast water restrictions; thus, no risk rating is provided
1.3	Military areas	Conflict with military areas	- Other activities may hinder or cause hazards to the STS operation, or vice versa	- Ammonia spill (toxic hazard) due to potential collision impact between vessels - Impact due to military activities - Operational restrictions - Operational delays	- No military areas						- Not applicable; thus, no risk rating is provided
1.4	Experience with this location Used currently or in the past for transshipment	New locations may pose a higher risk than existing locations with solid experience	- Loss of containment due to lack of experience	- Loss of containment Ammonia spill (toxic hazard)	- Area has been used for typical transfer activities (not ammonia specific)	SAFE	2	3	M	- For The pilot phase, pilotage, testing, and personnel training will be provided (MPA to confirm) - Emergency procedures are to be established	
1.5	Ship dimension limitations: - Minimum under-keel clearance requirement - Maximum arrival draft	Grounding	- Violation of clearance or draft requirements	- Ammonia spill (toxic hazard) - Asset damage - Delay in operation	- Grounding is not considered likely for anchorage location	SAFE	2	3	M	- Consider smaller size vessels for the pilot phase of the project	
1.6	Safety and security zones	Activities close to the bunkering operation	- Other activities may hinder or cause hazards for the STS bunkering operation, or vice versa	- Operational restrictions - Operational delays	- An average 150m safety zone is required for LPG and LNG cargo	SAFE	2	3	M	- Address the QRA potential overlap between toxic zones for ammonia and establish a safety zone for other STS locations - Consider the risk of ship collision imposed by passing vessels	
1.7	Dedicated waiting area/anchorage area	Conflict with other ship traffic	- Geography/landscape/ depth	- Drift grounding - Contact or collision with other ships	- Entry procedures mean no entrance until allowed	SAFE	1	4	M	- MPA to consider additional anchorage points for vessels that must await completion of other STS operations at the dedicated anchorage point	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1.8	Mandatory pilotage	A navigational accident during the approach, maneuvering or departure in the waterway (e.g., grounding, collision or contact)	- Human error - Lack of pilotage	- The credible consequence is severe ship damage and damage to ballast bottom or wing tanks (i.e. no ammonia spill) - Worst case consequence: Penetration of ship hull (inner and outer) and penetration of cargo containment. Uncontrolled escape/outflow of ammonia, pool formation, gas dispersion and rapid phase transition (RPT). Potential for ignition and pool fire, with significant heat intensity		SAFE	2	3	M	- Dedicated pilotage of vessel types involved in ammonia bunkering to be carried out	
1.9	Escort tug requirement	A navigational accident during the approach, maneuvering or departure in the waterway (e.g., grounding, collision or contact)	- Human error - Lack of tugs	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- No escort tugs are assumed to be used for STS						- Not applicable; thus, no risk rating is provided
1.10	Standby tug requirement - Fire Fighting - Rescue Services; - Emergency towing or pushing up - Delivery of personnel or equipment - Guarding the vessel - Assisting with Pollution - Other Services as Determined.	Emergency event during STS transfer	- Human error - Technical error	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion		SAFE	1	4	M	- Investigate if additional requirements of tugs for emergency response are associated with ammonia leaks	
1.11	IMO routing measures (e.g., Traffic Separation Scheme, deep water route, etc.)	Navigational accident (e.g., grounding, collision or contact)	- Human error - Lack of TTS	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- MPA guidelines requirements are followed, and depth is sufficient	SAFE	1	3	L		
1.12	Vessel traffic services (VTS) - Information services (INS) - Navigation assistance service (NAS) - Traffic organization service (TOS)	Navigational accident (e.g., grounding, collision or contact)	- Human error - Lack of VTS	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- Vessel separation traffic VST service - Ship traffic data	SAFE	1	3	L	- Consider navigational risk assessment during FEED	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1.13	Speed restrictions	Navigational accident (e.g., grounding, collision or contact)	- Human error - Technical error	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- See Hazard ID 1.12	SAFE	1	3	L	- See hazard ID 1.12	
1.14	Mooring requirements - Mooring study - Bow direction - Weather restriction	Drift grounding	- Technical error - Environmental forces	- Severe ship damage - Loss of containment - Toxic hazard - Fire/explosion	- For mooring and un- mooring will occur one activity at a time	SAFE	2	3	M	- Exiting mooring arrangement should be assessed for all sizes of ships - Assess mooring requirements on each planned operation by involving STS organisers or by the managers of both vessels	
1.15	Loss of position	Anchor Dragging	-Seabed condition	-Vessel separation	- Personnel watching and radar monitoring, navigation systems - The engine is on standby which can start immediately	SAFE	2	3	M	- Assess the required mooring anchor's capacity and redundancy. - Consider the provision of the standby tug to prevent separation.	
1.16	Underwater pipelines, cables	Anchor damaging pipelines	Technical (accidental dropped anchor) or human error (dropped anchor over pipeline)	Pipeline damage and loss of pipeline containment	- no pipeline or cables identified in the area of operations.						- Not applicable; thus, no risk rating is provided
1.17	Environmental sensitive areas	Ammonia spill in environmentally sensitive areas	Technical or human error	- In small spills, most of the Ammonia will vaporise before reaching the water due to heat transfer with the air - For large spills, air cannot transfer enough heat to vaporise much Ammonia, so almost all of the spill will likely end up in a pool. The spilt ammonia will undergo several physical processes simultaneously (pool formation, spread and boil-off) - Ammonia spills are much less severe for the environment compared to an oil spill							- Not applicable; thus, no risk rating is provided
1.18	Airports nearby	Conflict with the airport nearby	Location of airport	- Ships may be obstacles for flights arriving/ departing - Ship lights may conflict with runway lights arrangement	- No airport nearby						- Not applicable; thus, no risk rating is provided
1.19	All regulating bodies identified, and requirements accounted for	Unsafe operations (by not following regulations)	Requirements not identified or insufficient	- Ammonia spill (toxic hazard) - Operational delays (requirements identified late in the process)		REG	2	3	M	- Investigate additional local regulating body requirements associated with ammonia transfer operations, including limitation of toxic release to air or water - Restriction on toxicity (ppm) associated with water ammonia solution that can be disposed to sea	
1.20	All company-specific requirements accounted for	Unsafe operations (by not following company-specific procedures)	Requirements not identified or insufficient	- Ammonia spill (toxic hazard) - Operational delays (requirements identified late in the process)		DEL	2	3	M	- To be addressed in the FEED phase	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
1.21	All stakeholders informed	Lack of information among stakeholders	Stakeholders not identified	- Operational delays - Ammonia spill - Potential for fire/explosion		DEL	2	3	M		
1.22	Approval of operations	Lack of approval may cause increased risk to the public	Lack of regulating body	- Ammonia spill - Potential for fire/explosion		REG	2	3	M	- Approval of operation is required by regulating body - Requirements for vessel-specific STS plan approval by the flag to be verified with the MPA	
2. Exposure of location too, or shelter, prevailing environmental conditions including, where appropriate, met ocean analysis											
2.1	Overall swell height, period and direction Sea characteristics	Large swells	Environmental	- This may cause excessive strain on the transfer hoses - Suspension of operations - Activation of PERC - Mooring line failure	- Environmental assessment has been conducted for prior operations in the bay - The area is rather congested, so no swell is anticipated						Not applicable; thus, no risk rating is provided
2.2	Prevailing wind direction Wind force averages	Strong wind may cause drift-off, separation or drift grounding	Environmental	- This may cause excessive strain on the transfer hoses - Suspension of operations - Activation of PERC - Mooring line failure	- Monsoon season maximum wind speed anticipated around 4-5 and higher - Weather limitations established for the draft and commissioning at the jetty	DEL	2	3	M		
2.3	Tide	Strong tides/currents may cause drift-off, separation or drift grounding	Environmental	- This may cause excessive strain on the transfer hoses - Suspension of operations - Activation of PERC - Mooring line failure	- No tide hazard	DEL	2	3	M		
2.4	Current	Accidental release of Ammonia (loss of containment) due to currents	Strong tides/currents may cause drift-off, separation or drift grounding	- This may cause excessive strain on the transfer hoses - Suspension of operations - Activation of PERC - Mooring line failure	- A protected, sheltered area						Not applicable; thus, no risk rating is provided
2.5	The seabed (holding ground)	Drift grounding due to poor holding ground	- Strong wind, strong currents, and rocky sea bottom may cause drift grounding - The vessel anchor is not holding on to the holding ground. - Failure of anchor chain	- Severe ship damage - Loss of containment - Toxic release - Fire/explosion	- Sea bed (holding ground) clay and sand						- No anchors were used. Not applicable; thus, no risk rating is provided
2.6	Stability of seabed, such as sand waves forming	Grounding due to changes in seabed	- Strong wind, strong currents and harder sea bottom may cause drift grounding - The vessel anchor is not holding on to the holding ground. - Failure of anchor chain	- Severe ship damage - Loss of containment - Toxic release - Fire/explosion							Not applicable; thus, no risk rating is provided

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
2.9	Operational weather limits, including abort criteria	Accidental release of Ammonia (loss of containment) due to insufficient or lack of weather limits	- Incidents due to weather criteria not being followed	Ammonia spill		DEL	2	3	M	- Identify abort criteria for an ammonia transfer operation	
2.10	Visibility (daylight, fog, etc.)	Navigational accident (e.g. grounding, collision or contact) due to lack of visibility	Visibility may hinder navigation	- Ship damage - Operational restrictions or delays	- Permanent full-scale Navigational watch	DEL	2	3	M	- Visibility to be addressed each Vessels SMS and procedures	
2.11	Electrical storms (thunderstorms)	Electrical storms (thunderstorms) may affect cargo transfer operation	Environmental hazards	- Ammonia spill (fire/explosion) - Operational restrictions - Operational delays		DEL	2	3	M	- Identify abort criteria for an ammonia transfer operation	
2.12	Waves	Wave from passing traffic	Passing traffic nearby the anchorage point	- May cause excessive strain on the transfer hoses.		DEL	2	3	M	- Identify abort criteria for wave height generated by passing traffic for the ammonia transfer operation	
2.13	Other environmental hazards (cold fronts, hurricanes, tsunamis, etc.)	Frequent changes in the wind (speed, direction)	Environmental hazards	- Ammonia spill (fire/explosion) - Operational restrictions - Operational delays	-No hurricane, tsunami, or cold fonts	DEL	2	3	M	- Consider the risk of wind gusts for the site location and definition of associated abort criteria. Include vessels' SMS and procedures - Consider stand-by tugs nearby	
3. Navigational hazards in the vicinity of the location											
3.1	Fairway to STS location: - Sufficient water depth and width - Aton sufficient - Critical waypoints or depths - Squat effects	Navigational accident (e.g. grounding, collision or contact) due to narrow waters	Human error	- Experience has shown that the double bottom structure of The Ammonia carrier can accept severe grounding damage without affecting the integrity of the cargo containment system (however, double- the bottom is not required with a C-type Ammonia tank)		SAFE	3	4	M	- During the FEED phase, address required space for maneuvering, turning, etc. given multiple SIMOPS in the area	
3.2	STS location / Space for maneuvering in port/ terminal - Turning circles - Operational water zones Critical depths or coastal areas, rocks	- Ship grounding, collision or contact accident due to lack of maneuvering space	Human error			SAFE	3	4	M	- Per hazard ID 3.1	
3.3	Mooring at location	Mooring LAC	- Technical error - Human error	- Insufficient mooring - Contact damage between ships -Drift away	- Fenders - Established guidelines (STS transfer guide for petroleum SIGTTO) to be followed	SAFE	2	3	M	- Per operations' risk hazard ID 1.2	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
3.4	Mooring at location	Mooring ABV	- Technical error - Human error	- Insufficient mooring - Contact damage between ships - Drift away	- Fenders - Established guidelines (STS transfer guide for petroleum SIGGTO) to be followed	SAFE	2	3	M	- Per operations' risk hazard ID 1.2	
3.5	Emergency unmooring	Unable to unmoor	- Technical error - Human error	- Asset damage/loss - Injuries/fatalities		SAFE	2	3	M	- Consider measures to initiate unmooring if mooring systems become unavailable (Suggestion: quick release of axe)	
4. Ship traffic density in the vicinity of the location, including the presence of other STS activities											
4.1	Close vicinity/nearby traffic lanes Traffic amount and composition	- Collision with ships in the area (passing, crossing, head-on, overtaking, being rammed while STS, etc.)	Technical or human error	- Impact with larger ships will cause increased impact energies and damage potential		SAFE	3	4	M	- Assess the risk of ship collision for the STS location; establish the required Safety Zone - Ensure appropriate communication to the traffic in the area (VTS, NavCharts, Radio, NavWarning etc.)	
4.2	Fishing activities and pleasure crafts interfering with the STS operation	Fishing activities and pleasure crafts interfering with the STS operation	Intentional or lack of awareness of safety zone			SAFE	2	3	M	- Per hazard ID 4.1	
4.3	Distance to other STS locations in the vicinity (SIMOPS)	- SIMOPS should be detailed in 'Operations risk assessment.'				SAFE	2	3	M	- Investigate the QRA potential overlap and escalation risk due to SIMOPS at multiple anchorage points.	
5. Spill and dispersion trajectories and potential impacts											
5.1	Terminals or facilities nearby	Toxic vapour cloud that travels downwind towards the terminal or other operations nearby	Accidental release of Ammonia	Toxic hazard Potential for ignition somewhere within the terminal		SAFE	2	3	M	- Multiple anchorage points - the risk of escalation to be covered by the QRA	
5.2	Terminals or facilities nearby	Fire/explosion or emergency at the terminal or other operation areas nearby	- Flammable cargo handling activities - Bunkering operation/vessel represents an additional source of ignition	Potential for escalation to bunkering operation		SAFE	2	3	M	See hazard ID 5.1	
5.3	Populated areas/private ship traffic	- Potential Ammonia spill may reach shorelines, with population, sensitive areas, etc.	Technical/human error	Toxic hazard	- No populated area in the vicinity	SAFE	2	3	M	- Investigate applicable regulations/restrictions for 3rd party (private) ships crossing the Raffles Reserve Anchorage area.	
6. Requirement for and availability of any additional spill response resources at the location											
6.1	Toxic emergency/ response services and units	- Lack of toxic emergency units nearby may cause incidents to escalate	- Lack of emergency units	Escalation of events		SAFE	1	4	M	- Review existing ERP activities for ammonia spill application. - Investigate the required capacity of emergency/support tugs and firefighting tugs to mitigate toxic gas dispersion. To be discussed with MPA and SCDF on applicable requirements.	

ID	Guideword(s)	Hazard/ hazardous event	Cause	Consequence	Safety Measures	T	P	C	R	Recommendations (and responsibilities)	Notes
6.2	Towing/tug emergency	- Lack of towing emergency units nearby may cause incidents to escalate	- Lack of emergency units	Escalation of events		SAFE	1	4	M	- Per hazard ID 6.1	
6.3	Marine Pollution	- Breach of bunker/ ammonia release due to collision	Collision Impact	Ammonia spill into the water	- Ammonia internal transfer between tanks reviews damage control - Listing and DE ballasting	SAFE	1	4	M	- Perform environmental risk assessment due to ammonia spill caused by a ship collision	
7. Other											
7.1	Shore logistical daily support (tugs, support crafts, etc.)	Lack of shore logistical daily support (tugs, support crafts, etc.)	- Lack of logistical support may affect operations (safety, delays etc.)	- Operational delays	- Shore support required for operations is identified and arranged before vessels arrive at the STS location	SAFE	2	3	M		
7.2	STS Superintendents subcontracted	Lack of experience and competence	- Lack of training and competence (qualification of personnel)	Ammonia spill (toxic hazard)		SAFE	1	4	M	- Per operations' risk hazard ID 4.12	
7.3	Security threats in the area	Security threats	- War, sabotage, and terrorism risks	Ammonia spill (toxic hazard)							- Not Applicable
7.4	Radio/Tele-communication coverage	Lack of radio/ telecommunication coverage	- Lack of tele-communication capacity	Ammonia spill (toxic hazard)							- Not Applicable
7.5	Time	The time window for operation and slot requirements	Multiple activities at the terminal	Stress and potential human failures	- Established operations schemes	SAFE	2	3	M		

6 QUANTITATIVE RISK ASSESSMENT FOR PILOTS

6.1 Overview

DNV was engaged to conduct a Coarse Quantitative Risk Analysis (CQRA) study to identify potential hazards and quantify the risks related to ammonia transfer operations in the pilot phase. DNV has performed the analysis in accordance with the “QRA Technical Guidance” (Revision 9 November 2016).

The scope of the QRA includes the following:

- Identify hazards and quantify risks related to four concepts of ammonia transfer:
  - Cross dock transfer at Terminal A. For this concept, the following cases are modelled:
  - STS bunkering from LAC to ABV at Raffles Reserved Anchorage. The following 3 cases are assessed:
    - Low Flow Case: The low flow case models a transfer of 350 m^3/hr using one hose connection. As part of this operation, one 10,500 m^3 storage tank on the ABV will be filled in 30 hours
    - High Flow Case: The high flow case models a 700 m^3/hr transfer using two hose connections (350 m^3/hr per connection). As part of this operation, two 10,500 m^3 storage tanks on the ABV will be filled in 30 hours
    - Distributed Flow Case: The distributed flow case models a transfer of 350 m^3/hr using two hose connections. As part of this operation, two 10,500 m^3 storage tanks on the ABV will be filled in 60 hours. It is to be noted, the operating conditions and line sizes remain unchanged from the high flow case so the effects of lower flow rates can be assessed
  - STS bunkering from ABV to APS bunkering at Raffles Reserved Anchorage. The following 3 cases are assessed:
    - Low Flow Case: The low flow case models a 350 m^3/hr transfer using one hose connection. As part of this operation, one 3,350 m^3 storage tank on the APS will be filled in 10 hours
    - High Flow Case: The high flow case models a 700 m^3/hr transfer using two hose connections (350 m^3/hr per connection). As part of this operation, one 6,700 m^3 storage tank on the APS will be filled in 10 hours
    - Distributed Flow Case: The distributed flow case models a transfer of 350 m^3/hr using two hose connections. As part of this operation, one 6,700 m^3 storage tank on the APS will be filled in about 19 hours. It is to be noted, the operating conditions and line sizes remain unchanged from the high flow case so the effects of lower flow rates can be assessed
  - Shore to ship, i.e., from ASF to APS at Terminal D
- Determine hazards/risks due to possible toxic dispersion outcomes (only IR Fatality and IR Injury plots are generated)
- Recommend measures to address major hazards/risks and to keep remaining hazards/risks to As Low As Reasonably Practicable (ALARP)
- Qualitatively advise on cumulative risk results in terms of individual risk contours for Terminal A and Terminal D

The QRA is developed with key information as input data. For individual case the specific input data is clearly defined in the Assumptions Register (Appendix C).

6.2 Methodology

The QRA is a well-established methodology to assess the risk acceptance criteria for industrial activity risks. DNV used the QRA methodology presented in Figure 6-1.

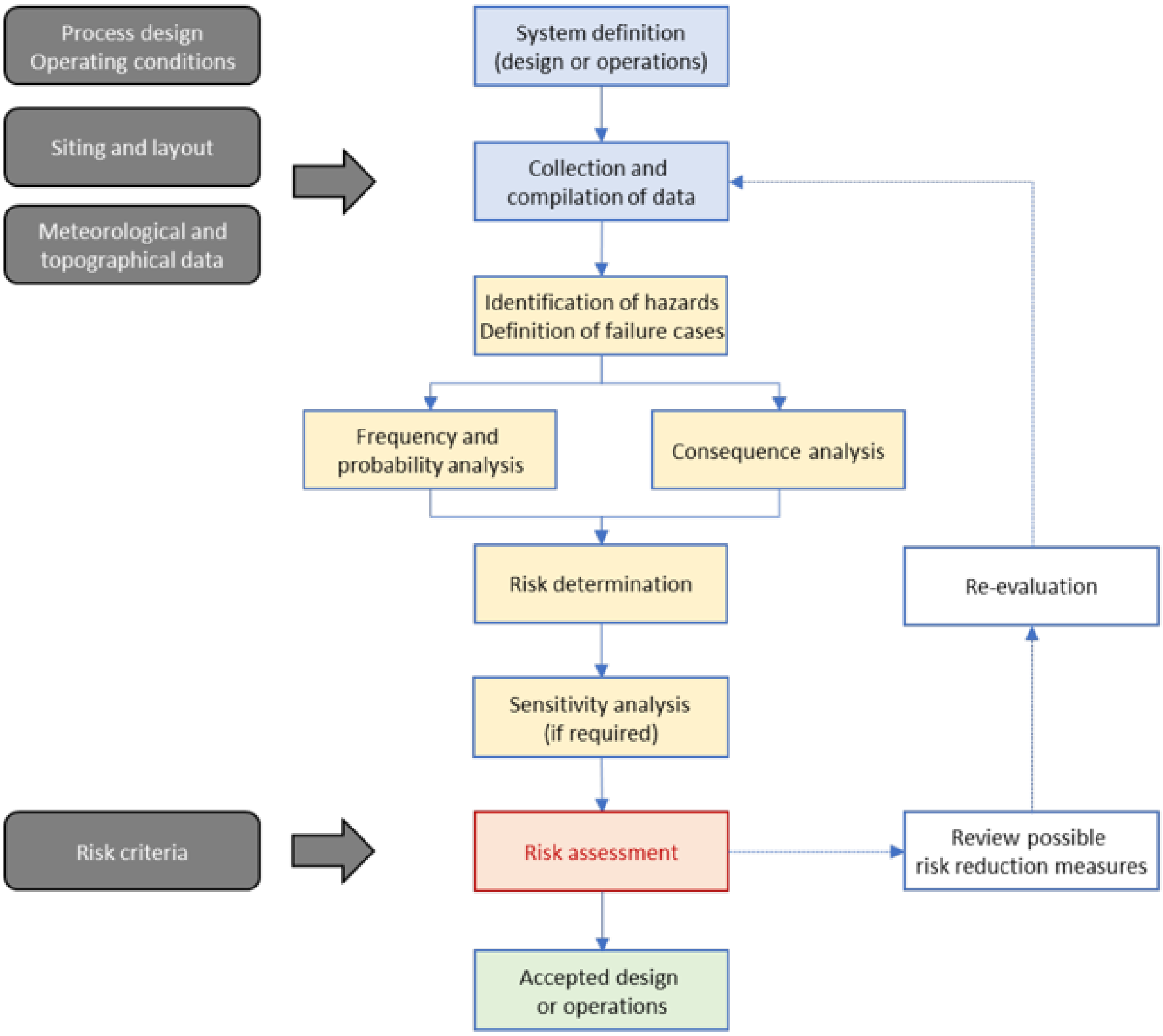

Figure 6-1 QRA methodology

At the time of writing, no known regulatory requirements or guidelines had been developed for risk assessment of the bunkering of toxic fuels in anchorage areas.

6.3 Risk criteria

6.3.1 Nearshore facilities

This section outlines the risk criteria utilised in this study, based on the “QRA Criteria Guidelines” issued by the Ministry of Manpower (MOM), Major Hazards Department (MHD), effective 31 August 2016 [2]. Individual Risk (IR) is defined as the annualised frequency of harm that an individual may experience from all potential hazards at a specific location.

To assess installation QRA (iQRA), the study utilised the acceptance criteria specified in the QRA criteria guidelines, which are listed below:

Table 6-1 IR (fatality) criteria

IR (fatality) (Cumulative risk of fatality/year)	Criteria
5E-05	Confined within boundary
5E-06	Confined to industrial developments only

Table 6-2 IR (injury) criteria

IR (injury) (Cumulative risk of injury/year)	Criteria
3E-07	Confined to industrial and commercial developments only and shall not reach sensitive receptors

Note: Cumulative escalation is only applicable to fire/explosion risks. The cumulative risk criteria are presented only for information.

Table 6-3 Occupied building criteria

IR (Fatality) for On-site Occupied Buildings (Cumulative risk of fatality/year)	Criteria
1E-03	Shall not exceed

Note: Occupied building risk is not assessed in this QRA as onsite manning information is unavailable.

According to the MHD QRA guidelines, the cumulative risk from all operations at a given land site must be evaluated and compared using the acceptance criteria. Therefore, in this study, DNV estimated the cumulative risk by qualitatively combining the risk results from existing operations (excluding ammonia transfer operations) with the proposed ammonia transfer operations.

For the quantitative assessment of the risk, the QRA models for the existing operations and the ammonia transfer operations would need to be modelled as a single combined set. However, DNV does not have access to the native model files for Terminal A; thus, the cumulative modelling was deemed the scope of this study.

The illustrated schematic concept is shown in Figure 6-2.

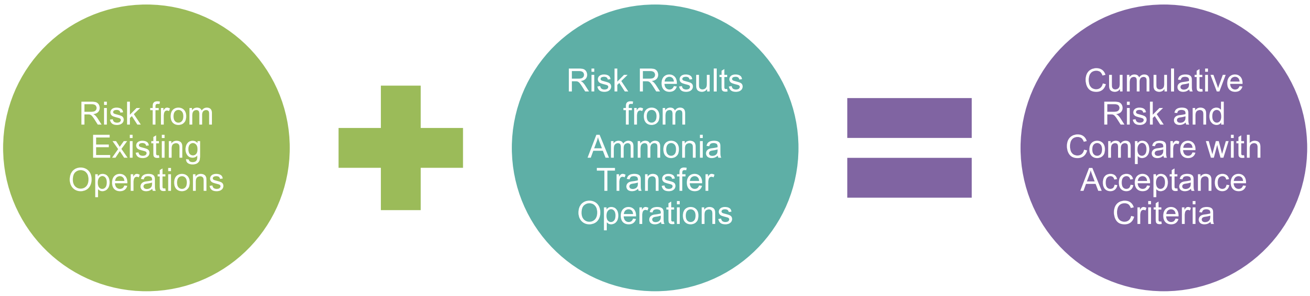

Figure 6-2 Cumulative risk schematic

Estimating cumulative risk is only applicable for Terminal A and Terminal D, as these terminals are located on land.

6.3.2 The anchorage area

Fatality and injury contours are typically generated for land sites and nearshore areas, while offshore areas are assessed on a case-by-case basis in consultation with regulators, as they are typically unoccupied. During ammonia transfer operations in an anchorage area, other ships may be present nearby, thus necessitating the establishment of an exclusion zone to prevent personnel exposure in the event of a loss of containment.

Although Technical Reference (TR) 56 provides guidelines for determining the size of safety zones for LNG bunkering operations, no such guidelines exist for ammonia bunkering operations. Therefore, the principles in TR 56 are used as a proxy for determining safety zones or toxic control zones for ammonia bunkering and breakbulk operations at an anchorage.

To prevent potential ignition sources between the Lower Flammability Limit (LFL) and the Upper Flammability Limit (UFL), a safety zone for LNG operations should be established. Ignition of LNG/ Natural Gas (NG) could result in fires, explosions, personnel injuries, and fatalities.

According to TR 56, the size of the safety zone can be determined by either of the following:

- A deterministic approach: This relies on a recognised and validated dispersion model for the maximum credible release as defined in the HAZID. Examples of maximum credible releases stated in TR 56 are:
    - Release of trapped inventory in the bunkering transfer line
    - Release through a broken instrument connection
- A risk-based approach: A QRA is conducted and compared against established **acceptance criteria** such as the one highlighted in Table 6-4, which refer to IR Fatality contours. The QRA risk contours generated for breakbulk and bunkering operations are compared against these **values.**

Table 6-4 Risk acceptance criteria

Parameter	Acceptance Criteria	Remarks
Individual risk first-party personnel	IR < E-05	This applies to crew and bunkering personnel directly involved in the activity

Individual risk second-party personnel	IR < 5E-05	Port personnel and terminal personnel
Individual risk third-party personnel with intermittent risk exposure	Risk contour for IR < 5E-06	Third-party personnel should not have access for a prolonged period
Individual risk third-party personnel with prolonged risk exposure	Risk contour for IR < E-06	General public without involvement in the activity No residential areas, schools, hospitals, inside this risk contour

6.4 Key findings

6.4.1 Cross dock transfer at Terminal A

This section presents the following information:

- Risk results from existing operations
- Risk results from ammonia transfer operations
- Assessment of the cumulative risk (existing operations + ammonia transfer operations)

Risk results from existing operations

The existing iQRA results (excluding the risk results from ammonia transfer operations) indicate that:

- The IR fatality contours corresponding to the acceptance criteria of 5E-05 per year and 5E-06 per year were not generated as the IR fatality risks calculated are lower than the stated thresholds
- The IR injury contour corresponding to acceptance criteria of 3E-07 per year remains within industrial developments and does not reach any sensitive receptors
- The cumulative escalation does not reach the criteria of 1E-04 per year
- On-site occupied building risk does not reach the criteria of 1E-03 per year
- Overall, the risk results are lower than the criteria stipulated in the MHD QRA guidelines

Risk results from ammonia transfer operations

The IR fatality and IR injury risks from ammonia transfer operations are summarised below:

- The IR fatality contours corresponding to acceptance criteria of 5E-05 per year and 5E-06 per year contours were not generated as the IR fatality risks calculated are lower than these thresholds. This is due to the lower frequency of ammonia transfer operations in the pilot phase of this project (estimated to be one annually). The risk results of the IR fatality and IR injury depend on various factors, such as the flow rate, the number of transfer operations per year, duration per transfer operation, and length of piping and transfer arms
- The IR injury contour corresponding to acceptance criteria of 3E-07 per year was found to remain within industrial developments and did not reach any sensitive receptors
- Overall, the risk results are lower than the criteria stipulated in the MHD QRA Guidelines

Assessment of the cumulative risk (existing operations + ammonia transfer operations)

The cumulative risk (the combined risk from existing operations and ammonia transfer operation) at Terminal A has been assessed qualitatively. To quantitatively assess the risk, the QRA models for existing operations and ammonia transfer operations would need to be modelled as a single combined set. DNV does not have access to Terminal A's native models, and cumulative modelling is beyond the scope of this analysis.

Based on the existing risk and ammonia transfer risk results, it is expected that:

- the cumulative IR fatality risk is likely to remain below the acceptance criteria of 5E-05 per year and 5E-06 per year
- the cumulative IR injury risk is likely to remain below the acceptance criteria of 3E-07 per year and is not expected to reach any sensitive receptors, given that none are present near Terminal A.

6.4.2 LAC to ABV at anchorage: Raffles Reserved Anchorage

The risk results for STS operations between an LAC and an ABV at Raffles Reserve Anchorage are summarised below.

IR Fatality Contour:

- For low flow, high flow and distributed flow cases, contours corresponding to acceptance criteria of 1E-05 and 5E-05 per year were not generated as the IR fatality risks calculated are lower than these thresholds. This is attributable to the lower frequency of ammonia breakbulk operations in the project's pilot phase. The risk results for IR fatality and IR injury depend on the flow rate, number of transfer operations per year, duration per transfer operation, and length of piping and transfer hoses
- For low flow, high flow and distributed flow cases, the contours corresponding to acceptance criteria of 5E-06 per year are confined to LAC and ABV areas and do not reach any third-party personnel
- For low flow, high flow and distributed flow cases, the contours corresponding to acceptance criteria of 1E-06 per year do not reach the general public, residential areas, schools and hospitals

IR Injury Contour:

- IR Injury contours are not assessed for Raffles Reserved Anchorage as there are no known thresholds for IR injury for anchorage areas

Table 6-5 presents the input parameters used to determine the size of the dispersion plot. Two cases were selected for modelling as they have a relatively higher leak frequency and are more credible than other cases. The term "case" refers to a particular failure event.

Table 6-5 Input parameters for deterministic modelling

Case No. and Name	Hole Size (mm)	Pressure (barg)	Temperature (deg C)	Flow rate (m^3/hr)	Inventory Release (kg)
Case 1: This case modelled a release at the manifold location	10	4.0	-33	350	259
Case 2: This case modelled a release at the piping from header to the ABV storage tank	10	4.0	-33	350	590

Note: Release from a 10 mm hole size was modelled because this is assessed to be reflective of a release from a broken instrument connection.

The distance to 1,600 ppm (AEGL 3 for 30 minutes) is presented in Figure 6-5 and Figure 6-6 below for standardisation purposes. The distances presented for the three representative wind conditions and corresponding Pasquill-Gifford Stability class are selected for the purpose of consequence modelling based on Singapore QRA Technical Guidance:

- 1 m/s with stability class F (1F)
- 2 m/s with stability class B (2B)
- 3 m/s with stability class C (3C)

The stability classes are defined as:

- F: Stable
- B: Unstable
- C: Slightly Unstable

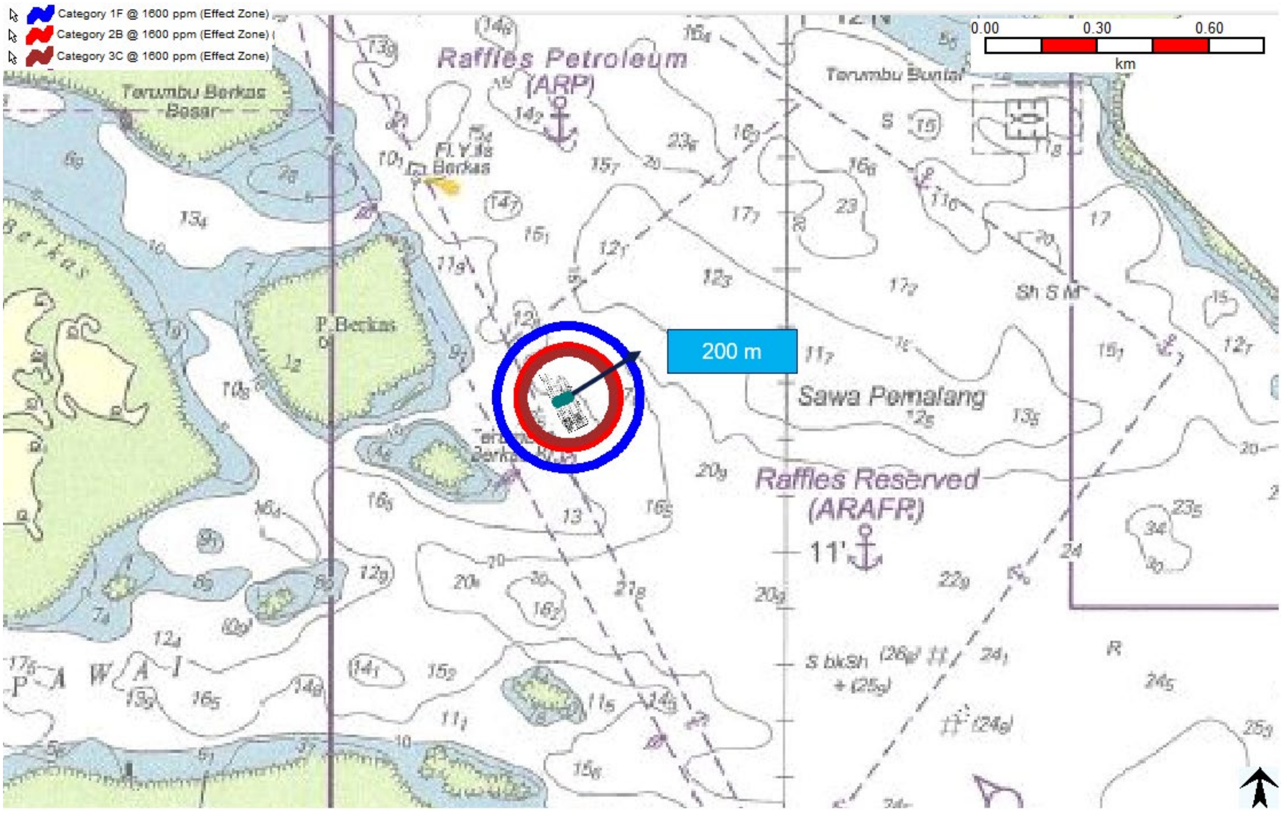

Figure 6-5 Maximum dispersion – case 1

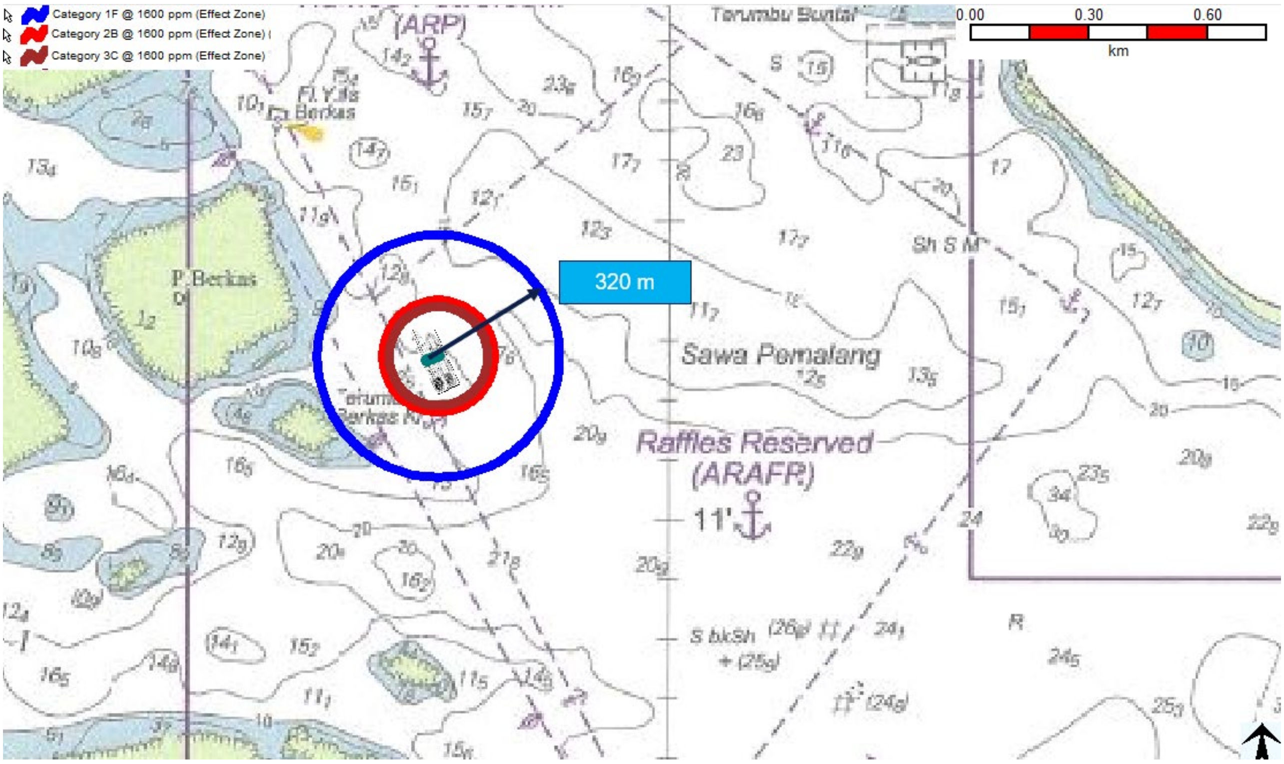

Figure 6-6 Maximum dispersion – case 2

The maximum dispersion distance for cases 1 and 2, is 200 m and 320 m, respectively. The dispersion distance for the distributed flow case will be reduced by about 50% due to lower flow rates. For both the low-flow and high-flow cases, the safety zone size should range from 200 m to 320 m, subject to an ALARP evaluation. For the distributed flow case, it is recommended to utilise the size range estimated for low-flow and high-flow cases to ensure conservatism.

6.4.3 ABV to APS bunkering at anchorage: Raffles Reserved Anchorage

The risk results for STS operation between an ABV and an APS at Raffles Reserve Anchorage are summarised below.

IR Fatality Contour:

- For low flow, high flow and distributed flow cases, the contours corresponding to acceptance criterion of 5E-05 per year was not generated as the IR fatality risks calculated are lower than these thresholds. This is attributable to the lower frequency of ammonia breakbulk operations in the project's pilot phase. The risk results for IR fatality and IR injury depends on the flow rate, number of transfer operations per year, duration per transfer operation and length of piping and transfer hoses
- For low flow, high flow and distributed flow cases, the contours corresponding to acceptance criteria of 1E-05 per year and 5E-06 per year are confined to LAC and ABV areas and do not reach any third-party personnel
- For both low flow and high flow cases, contour corresponding to acceptance criteria of 1E-06 per year do not reach the general public, residential areas, schools and hospitals

IR Injury Contour:

- IR Injury contours are not assessed for the Raffles Reserved Anchorage as there are no known thresholds for IR injury for anchorage areas

Regarding the deterministic modelling, the input parameters used to determine the size of the dispersion plot are presented in Table 6-6 Input parameters for deterministic modelling. It is to be noted the two cases selected for modelling have a relatively higher leak frequency and are, therefore, more credible than other cases. The term “case” refers to a particular failure event.

Table 6-6 Input parameters for deterministic modelling

Case No. and Description	Hole Size (mm)	Pressure (barg)	Temp. (Deg.C)	Flow rate (m^3/hr)	Inventory Released (kg)
Case 1: This case modelled a release at the manifold location	10	4	-33	350	259
Case 2: This case modelled a release at the piping from the tank to the header on the ABV	10	4	-33	350	476

Note: Release from a 10 mm hole size was modelled because this is assessed to be reflective of a release from a broken instrument connection.

The distance to 1600 ppm (AEGL 3 for 30 minutes) is presented in Figure 6-10 Maximum dispersion – case 2 and Figure 6-12 below for standardisation purposes. The distances are presented for the three wind conditions stipulated in the Singapore QRA guideline.

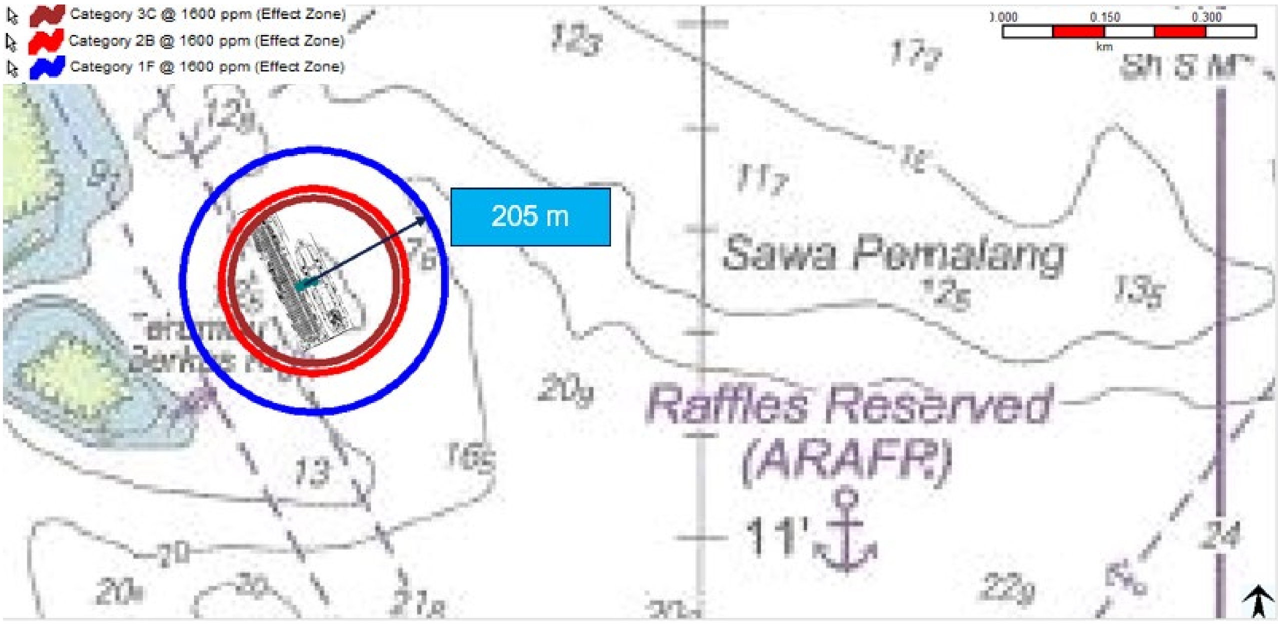

Figure 6-9 Maximum dispersion – case 1

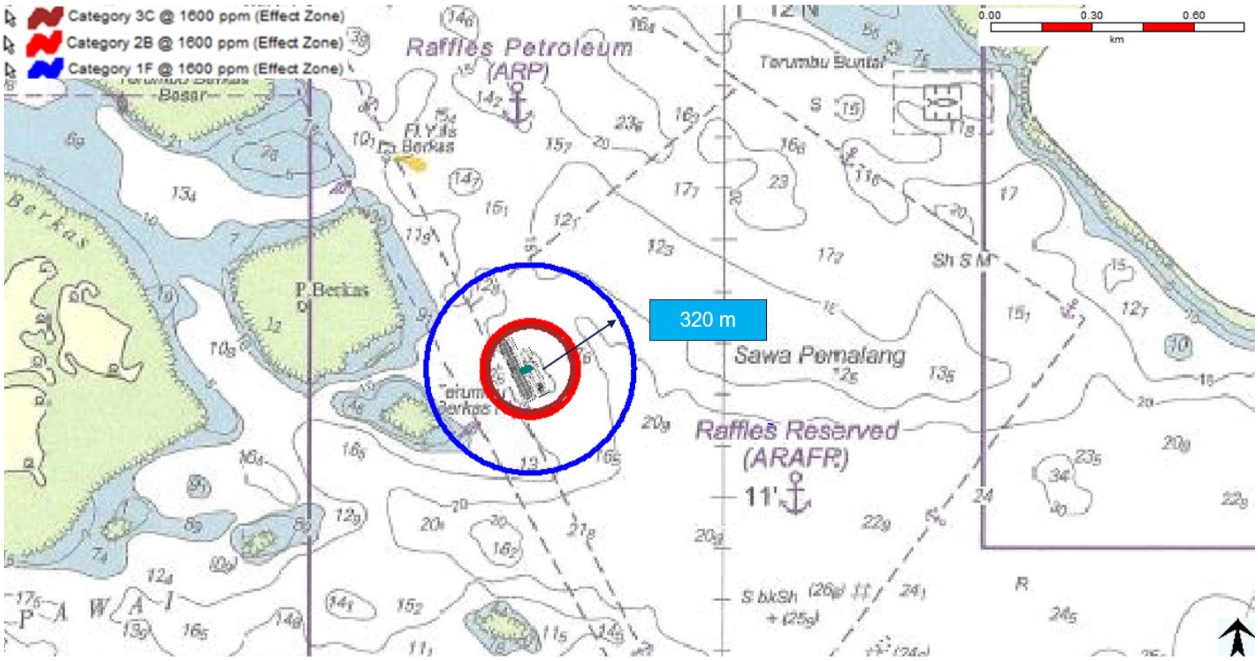

Figure 6-10 Maximum dispersion – case 2

The maximum dispersion distance for Case 1 and 2 is 205 m and 320 m respectively. It should be noted that for the distributed flow case, the dispersion distance will be reduced by about 50% due to the lower flow rates. For both the low flow and high flow cases, the size of the safety zone, should range from 205 m to 320 m, subject to an ALARP evaluation. For the distributed flow case, to ensure conservatism, it is recommended that the size range estimated for low flow and high flow cases be utilised.

6.4.4 SHTS from the ASF to the APS at Terminal D

This section presents the following information:

- Risk results from existing operations
- Risk results from ammonia transfer operations
- Assessment on cumulative risk (existing operations + ammonia transfer operations)

Risk results from existing operations

The risk results of the existing iQRA (excludes risk results from ammonia transfer operations) are summarised below:

- The IR fatality contours corresponding to acceptance criteria of 5E-05 per year and 5E-06 per year generated as part of the existing iQRA. The IR fatality contour is confined to the boundary of the facility, and the IR Injury contour is confined to Jurong Island
- IR injury contours corresponding to acceptance criteria of 3E-07 per year was found to remain within industrial developments and did not reach a sensitive receptor
- Overall, the risk results are lower than the criteria stipulated in MHD QRA Guidelines

Risk results from ammonia transfer operations

IR fatality and IR injury from ammonia transfer operations only are summarised below:

- The IR fatality contours corresponding to acceptance criteria of 5E-06 per year contour was not generated as the IR fatality risks calculated are lower than the stated thresholds. This indicates that IR fatality risks are significantly lower than the acceptance criteria. This is attributable to the lower frequency of ammonia bunkering operations expected in the pilot project. This is because the risk frequency for IR fatality and IR injury depends on the flow rate, number of transfer operations per year, duration per transfer operations and length of piping and transfer arms
- The IR injury contour is confined within industrial developments and does not reach any sensitive receptors
- Overall, the risk results are lower than the criteria stipulated in the MHD QRA Guidelines

Assessment of cumulative risk (existing operations + ammonia bunkering operations)

The combined risk has been assessed qualitatively. This is because to determine the risk quantitatively, the QRA models for existing operation and ammonia transfer operations would need to be modelled as one combined set. Therefore, cumulative modelling is beyond the scope of this analysis.

IR Fatality

- If the IR fatality risk contours for existing operations are combined with those generated for ammonia operations, the criteria for 5E-05 per year and 5E-06 per year are likely to meet the acceptance criteria

IR Injury

- If IR injury risk contours for existing operations are combined with those generated for ammonia operations, the criteria for 3E-07 per year is likely to remain confined within industrial developments and is not assessed to reach any sensitive receptors. It is to be noted that no sensitive receptors are present nearby. Therefore, acceptance criteria of 3E07 per year are likely to be met

6.5 ALARP Process

The ALARP process is a crucial step in ensuring all potential hazards and risks have been identified and that appropriate safeguards put in place to mitigate these risks. The aim is to reduce risks to a desired target level that is “ALARP” based on cost, time and resources. While risks cannot always be eliminated, it is essential to implement all reasonably practicable recommendations to minimise them to a tolerable level.

To achieve this goal, all recommendations made as part of the QRA and other safety studies should undergo an ALARP evaluation to assess “reasonableness”. The facility owner and/or operator are responsible for conducting the ALARP evaluation process.

In addition, the sizes of the safety zones for the LAC to the ABP and the ABV to the APS transfers are at anchorage and are presented as a range. These values are to be taken as indicative and not absolute as there are no known regulatory requirements to determine safety zones for ammonia transfer operation at anchorage. Therefore, before the size of the safety zone is finalised, an ALARP evaluation by the owner/operator of the vessels should be carried out to determine “reasonableness”. As a result, the size of the safety zone could potentially be smaller than the lower bound of the stated range (smallest value) or be set at the value at the upper bound of the stated range (largest value).

6.6 Recommendations

The high-level QRA was performed based on the available information provided by the study partners. The CQRA results show pilot concepts 1 and 4 (transfer at terminals) meet the MHD acceptance criteria. In addition, the safety zones defined in pilot concepts 2 and 3 follow the TR 56 guidelines, subjected to ALARP demonstration.

The study results are solely applied to the determined pilot conditions, and the following recommendations shall be implemented before proceeding with the pilot demonstrations.

- **Updating of design information:** Comprehensive designs of the bunkering / breakbulk concepts have not been fully established at the time of writing due to the limited availability of information. Technical information presented in the process flow diagrams (PFDs) should be reviewed further to identify the number and placement of minor equipment (e.g., valves), validate operating conditions and verify equipment placement and line routing. This can be carried out during the front-end engineering design (FEED) phase of the project.
- **Development of safety zones at anchorage areas:** For the project's pilot phase, the sizes of safety zones or toxic control zones recommended in this report should be implemented subject to ALARP evaluation.
- **Safety and inspection checklists:** Prior to ammonia transfer operations, vessel operators must perform equipment condition checks and safety inspections according to pre-defined checklists. This process helps to assess if the equipment is free from defects and if transfer operations can safely proceed. During the initial years of ammonia transfer operations, it is recommended that completed condition and inspection checklists be submitted to MPA for review and approval before initiating ammonia transfer operations.
- **Development of emergency response plans (ERP):** Terminal A and Terminal D will need to revise their existing ERPs to account for ammonia transfer operations and consult with Singapore Civil Defence Force (SCDF) for integration purposes. The revised ERPs should cover aspects such as (but not limited to):
    - The emergency departure of vessels
    - Response to ammonia release events
    - Alerting facilities nearby following ammonia release events
- **Development of risk assessment guidelines:** MPA should consider developing quantitative and qualitative risk assessment guidelines (similar to MHD's QRA guidelines) to cover ammonia transfer operations offshore and nearshore (areas on water). For alignment purposes, the International Maritime Organization (IMO) Guidelines on Formal Safety Assessment (FSA) can be referenced. This will aid standardisation and provide the ability to benchmark and evaluate risk profiles.

6.7 References

[1] Surbana Jurong (2022). *Concept Selection Report: GABSS-PM-RPT-0001_Surbana Jurong_ GCMD Ammonia Bunkering Safety Study_Concept Selection Report_Rev 1*

[2] National Environment Agency (NEA) Singapore (2016). *"QRA Criteria Guidance", Revision No. 3, 9th November 2016*

[3] Surbana Jurong (2022). *Site Selection Report:GABSS-PM-RPT-0002_SurbanaJurong_GCMD Ammonia Bunkering Safety Study_Concept Selection Report_Rev 1*

[4] UK HSE (2019). *Failure Rate and Event Data for use within Risk Assessments*

[5] RIVM (2009). *Reference Manual Bevi Risk Assessments - version 3.2*

[6] IOGP (2019). *Risk Assessment Data Directory - Ignition probabilities, Report No. 434-6.1*

[7] IOGP (2019). *Risk Assessment Data Directory, Process Release Frequency, Report 434-01*

[8] Singapore Standards Council (2020). *Technical Reference TR 56, Part 3: Procedures and Safety Distance*

[9] DNV (2023). *Quantitative Risk Analysis of Proposed Onshore Ammonia Storage Tank, Client: Confidential*

APPENDIX C: QRA ASSUMPTION REGISTER

C1 INTRODUCTION

C1.1 Definitions

The following terminologies are used in this report:

- Liquid Ammonia Carriers (LAC): Bulk carriers of ammonia used for transporting between two countries/continents
- Ammonia Powered Ships (APS): Any container/cargo/passenger ship with capability to use ammonia as fuel
- Ammonia Bunkering Vessels (ABV): Ship carrying ammonia in cargo tanks for bunkering to ammonia powered ships

C1.2 Brief description of concept for pilot phase

- Concept 2 - Ship to Ship breakbulk operations at Anchorage (LAC to ABV)
- Concept 3 - Ship to Ship bunkering operations at Anchorage (ABV to APS)

C1.3 Scope of work for QRA

The QRA will only cover ammonia transfer operations for the concepts presented in Section A2.1.

C1.4 Objective of the study

The objectives of the study are:

- Identify main accidental hazards (MAHs) to the assessed by QRA
- Perform frequency and consequence analysis for identified MAHs
- Establish Location Specific Individual Risk (LSIR) Contours
- Assess against defined Risk Acceptance Criteria (RAC)
- Recommend measures to address major hazards/risks and to keep hazards/risks to As Low As Reasonably Practicable (ALARP)

The objective of the assumption register is to document operational, technical and analytical assumptions which will form a basis for QRA.

C2 GENERAL ASSUMPTIONS

C2.1 Anchorage locations for breakbulk and ammonia bunkering for concept 2 and 3

The anchorages of the port of Singapore are divided into three (3) sectors:

- Eastern sector
- Western sector
- Jurong sector

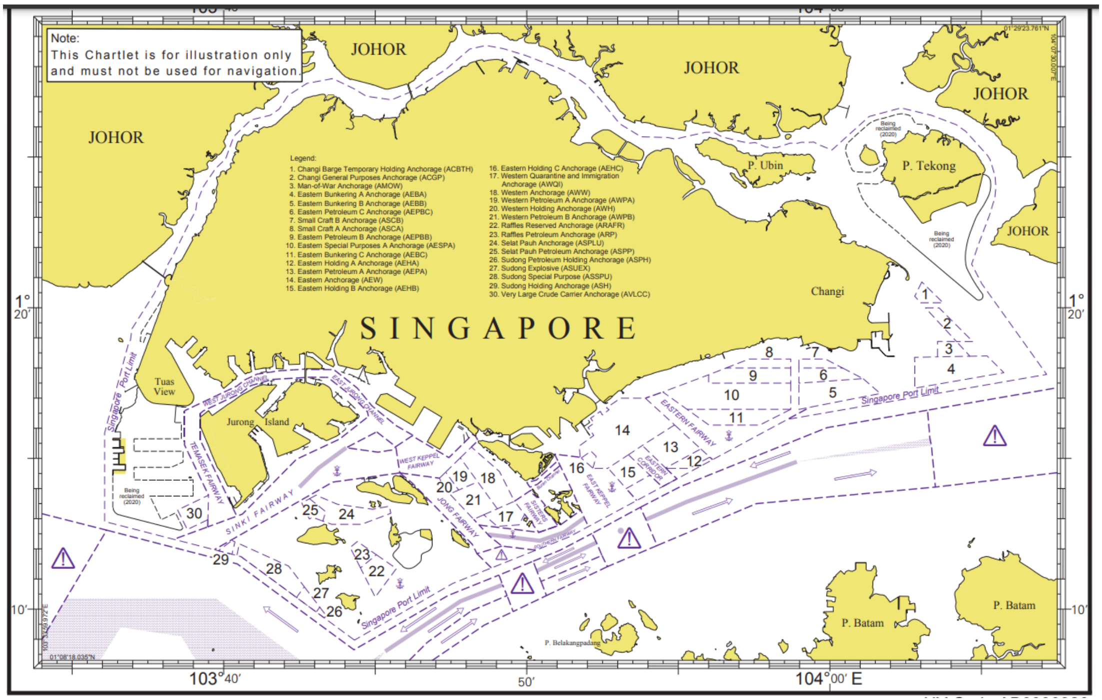

Figure C0-1 Port of Singapore Anchorage Chartlet

With reference to Figure C0-1, ammonia bunkering operations will be carried out at anchorage No. 22 (Raffles Reserved Anchorage).

The following description is to be noted for Raffles Reserved Anchorage:

- **Raffles Reserved Anchorage** - For lash ship operations, vessels requiring emergency repairs, damaged vessels, floating production storage and offloading vessels and other vessels as directed by the Port Master.

The indicative location where the breakbulk and bunkering operations is to be carried out during the Pilot phase is presented in Figure C0-2.

This is a complete but not exhaustive/comprehensive report. The detailed site selection has been removed from the public version.

Figure C0-2 Indicative location of ammonia breakbulk and bunkering for the pilot phase

Effect on Analysis:
The dispersion and risk contours will be overlayed on anchorage location to determine any potentially restriction for passing or stationary marine traffic.

Source:

1. List of Anchorages by MPA, https://www.mpa.gov.sg/port-marine-ops/operations/port-infrastructure/anchorages
2. BA 4040, Tuas View to Pulau Sakijang Bendera, Edition 15, 2nd December 2021

C2.3 Meteorological conditions

The following representative wind speeds and corresponding Pasquill-Gifford Stability class are selected for the purpose of consequence modelling based on the Singapore QRA technical guidance:

- 1 m/s with stability class F (1F)
- 2 m/s with stability class B (2B)
- 3 m/s with stability class C (3C)

The stabilities classes are defined as:

- F: Stable
- B: Unstable
- C: Slightly Unstable

The normalised wind data based on the selected wind conditions is tabulated in Table C0-1.

Table C0-1 Wind rose per QRA technical guidance

Direction	Weather Category			Total
	F1	B2	C3	
N	3.8	6.3	1.3	11.3
NNE	3.7	5.5	3.4	12.5
NE	1.9	2.8	1.1	5.7
ENE	1.3	1.8	0.2	3.2
E	1.6	2.3	0.4	4.2
ESE	1.8	2.5	0.7	4.9
SE	2.3	3.3	1.0	6.5
SSE	2.5	3.6	1.0	7.0
S	3.5	5.4	1.4	10.2
SSW	2.2	3.3	0.6	6.0
SW	1.4	2.1	0.3	3.7
WSW	1.2	1.7	0.1	3.0
W	1.8	2.9	0.2	4.8
WNW	1.8	2.9	0.1	4.8
NW	1.9	3.2	0.1	5.1

The QRA has also assumed:

1. A temperature of 30°C, which is equal to the annual average temperature
2. A relative humidity of 85%, which is equal to the mean annual relative humidity for the facility.

Effect on analysis:
• The wind speed and direction probability distribution determine the direction and length over which an unignited gas cloud will disperse. • A higher air temperature and relative humidity tend to reduce atmospheric transmissivity and therefore the level of thermal radiation to which personnel were exposed. However, the impact of this is normally not significant.
Source:
1. National Environment Agency (NEA) Singapore, "QRA Technical Guidance", Revision No. 3, 9th November 2016. Available at https://www.nea.gov.sg/docs/default-source/our-services/qra-technical-guidance_nov16.pdf.

C3 SUMMARY FROM THE HAZID WORKSHOP

The key points applicable to the QRA are presented in the table below.

Table C0-1 QRA summary from HAZID workshop

Concept No & Name	**Safety philosophy for concepts**
Concept 2 LAC-ABV@ Anchorage	**LAC/ABV per above** 1. Ship collision risk associated with passing ships (busy area) 2. Ammonia spill to water due to hose rupture (6 m middle point of the hose above the sea surface) Post workshop note: Automatic ESD Note: The risk from ship collisions is not directly assessed as it is beyond the scope of this QRA. Furthermore, the risk of ship collision to LAC-ABV is assessed to be the similar to any vessel present in the anchorage area and as a result there is negligible incremental risk to ammonia bunkering operations. In addition, the overall risk of collision with passing vessels is lower as passing vessels are largely assumed to be Piloted (or with Pilot Exemption) and the location of the anchorage area is explicitly marked on navigation charts.
Concept 3 ABV-APS@ Anchorage	**ABV per the above; APS is considered to be fully compliant with IGF, DNV Ammonia Ship Rules; thus** 1. Automatic ESD 2. Liquid detection in a drip tray 3. Gas detection (semi-enclosed bunker station) 4. Single wall fuel piping with welded connections 5. All flanged connections at bunker station have mechanical shielding to protect personnel 6. For semi enclosed bunker station, mechanical ventilation with 30 Air Change Per Hour is provided 7. Storage tank with Tank Connection Space (TCS) 8. Piping design pressure 18 barg 9. Water stray system 10. Fixed and portable dry powered system at the bunker station 11. Passive fire protection at bunkering station A60 insulation adjacent to machinery system **Other** 1. Ship collision risk associated with passing ships (busy area) 2. Ammonia spill to water due to hose rupture (6 m middle point of the hose above the sea surface)

Effect on Analysis:
The aspects captured in the HAZID worksheets will be used to determine applicable preventive and mitigating safeguards for the purposes of the QRA.

Source:

1. HAZID Worksheets

C4 RISK ANALYSIS

C4.1 Operating parameters and parts count for failure cases

The failure cases are summarised in the tables below for each operation type.

- For STS from the LAC to the ABV bunkering at anchorage location 22 (Concept 2): Raffles Reserved Anchorage, the following two cases are assessed:
    - Low-Flow Case: The low-flow case modelled a transfer of 350 m^3/hr using one hose connection. As part of this operation one 10,500 m^3 storage tank on the ABV will be completely filled in 30 hours
    - High-Flow Case: The high-flow case modelled a 700 m^3/hr transfer using two hose connections (350 m^3/hr per connection). As part of this operation, two 10,500 m^3 storage tanks on the ABV will be filled in 30 hours
- For STS from the ABV to the APS bunkering at anchorage location 22 (Concept 3): Raffles Reserved Anchorage, the following two cases are modelled:
    - Low-Flow Case: The low-flow case modelled a 350 m^3/hr transfer using one hose connection. As part of this operation, one 3,350 m^3 storage tank on the APS will be filled in 10 hours
    - High-Flow Case: The high-flow case modelled a 700 m^3/hr transfer using two hose connections (350 m^3/hr per connection). As part of this operation, one 6,700 m^3 storage tank on the APS will be filled in 10 hours

Table C4-1 List of failure cases and parts count - ABV to APS at anchorage-high flow case

ISO-segment	Failure cases	Description	Major Equipment	Minor Equipment	Length of Piping (m)	Pipe Size (inches)	Pipe Size mm	Operating Temperature (°C)	Operating pressure (barg)	Normal Flowrate (m^3/hr)	Volume of vessel/ tank (m^3)
ISO-01C	ABV Tank 1	Ammonia storage	None identified	None identified	0	0	0	-33	Atm.	N/A	10,500
ISO-02C	ABV Tank 2	Ammonia storage	None identified	None identified	0	0	0	-33	Atm.	N/A	10,500
ISO-03C-P1	Piping from Type C Tank 1 to Header on ABV (P101 and P102 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	350	N/A

ISO-03C-P2	Piping from Type C Tank 1 to Header on ABV (P101 and P102 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	None identified	20	8	203	-33	4	350	N/A
ISO-04C-P1	Piping from Type C Tank 2 to Header on ABV (P103 and P104 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	350	N/A
ISO-04C-P2	Piping from Type C Tank 2 to Header on ABV (P103 and P104 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	None identified	20	8	203	-33	4	350	N/A
ISO-05C-P1	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	0.12	700	N/A
ISO-05C-P2	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	0.12	700	N/A
ISO-06C-P1	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-06C-P2	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-07C-P1	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-07C-P2	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A

ISO-08C-P1	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	1) 2 Isolation valves on the pipeline 2) 2 Small Bore Fittings Note: Flange connections are fully welded	25	8	203	23	Atm.	291	N/A
ISO-08C-P2	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	None identified	25	8	203	23	Atm.	291	N/A
ISO-09C	Transfer hose 1 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-10C	Transfer hose 2 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-11C	One Transfer Hose ABV to APS [BOG]	BOG management	None identified	None identified	30	8	203	23	Atm.	291	N/A
ISO-12C-P1	APS Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-12C-P2	APS Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-13C-P1	APS Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-13C-P2	APS Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-14C-P1	APS Manifold - 1 vapour connection [BOG]	BOG management	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-31	0.12	211	N/A
ISO-14C-P2	APS Manifold - 1 vapour connection [BOG]	BOG management	None identified	None identified	5	8	203	-31	0.12	211	N/A
ISO-15C-P1	APS Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	16	406	-33	4	700	N/A
ISO-15C-P2	APS Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	16	406	-33	4	700	N/A

ISO-16C-P1	Piping from Tank 1 (P 201 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	0.12	350	N/A
ISO-16C-P2	Piping from Tank 1 (P 201 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	None identified	20	8	203	-33	0.12	350	N/A
ISO-17C-P1	Piping from Tank 1 (P 202 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	0.12	350	N/A
ISO-17C-P2	Piping from Tank 1 (P 202 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	None identified	20	8	203	-33	0.12	350	N/A
ISO-18C	Ammonia Storage Tank on APS (1 Tank)	Ammonia storage	None identified	None identified- END	N/A	N/A	0	-33	Atm.	N/A	6,700 m^3

Table C0-2 List of failure cases and parts count - ABV to APS at anchorage-low flow case

	ISO-segment	Description	Major Equipment	Minor Equipment	Length of Piping (m)	Pipe Size (inches)	Pipe Size mm	Operating Temperature (°C)	Operating pressure (barg)	Normal Flowrate (m^3/hr)	Volume of vessel/ tank (m^3)
ISO-01C	ABV Tank 1	Ammonia storage	None identified	None identified	0	0	0	-33	Atm.	N/A	10,500
ISO-02C	ABV Tank 2	Ammonia storage	None identified	None identified	0	0	0	-33	Atm.	N/A	10,500
ISO-03C-P1	Piping from Type C Tank 1 to Header on ABV (P101 and P102 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	350	N/A
ISO-03C-P2	Piping from Type C Tank 1 to Header on ABV (P101 and P102 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	None identified	20	8	203	-33	4	350	N/A

ISO-04C-P1	Piping from Type C Tank 2 to Header on ABV (P103 and P104 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 1 Small Bore Fitting Note: Flange connections are fully welded	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-04C-P2	Piping from Type C Tank 2 to Header on ABV (P103 and P104 A/B)	This case is identified to model a release at the piping from tank to header on the ABV	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-05C-P1	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	0.12	350	N/A
ISO-05C-P2	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	0.12	350	N/A
ISO-06C-P1	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-06C-P2	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-07C-P1	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-07C-P2	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-08C-P1	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	1) 2 Isolation valves on the pipeline 2) 2 Small Bore Fittings Note: Flange connections are fully welded	25	8	203	23	Atm.	150	N/A

ISO-08C-P2	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	None identified	25	8	203	23	Atm.	150	N/A
ISO-09C	Transfer hose 1 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-10C	Transfer hose 2 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-11C	One Transfer Hose ABV to APS [BOG]	BOG management	None identified	None identified	30	8	203	23	Atm.	291	N/A
ISO-12C-P1	APS Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-12C-P2	APS Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-13C-P1	APS Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-13C-P2	APS Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-14C-P1	APS Manifold - 1 vapour connection [BOG]	BOG management	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	8	203	-31	0.12	110	N/A
ISO-14C-P2	APS Manifold - 1 vapour connection [BOG]	BOG management	None identified	None identified	5	8	203	-31	0.12	110	N/A
ISO-15C-P1	APS Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flange connections 3) 1 Small Bore Fitting	5	16	406	-33	4	350	N/A
ISO-15C-P2	APS Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	16	406	-33	4	350	N/A
ISO-16C-P1	Piping from Tank 1 (P 201 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	0.12	350	N/A

ISO-16C-P2	Piping from Tank 1 (P 201 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	None identified	20	8	203	-33	0.12	350	N/A
ISO-17C-P1	Piping from Tank 1 (P 202 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-17C-P2	Piping from Tank 1 (P 202 A/B) to Manifold on APS for BOG Transfer	This case is identified to model a release at the piping from tank to manifold at the APS	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-18C	Ammonia Storage Tank on APS (1 Tank)	Ammonia storage	None identified	None identified- END	N/A	N/A	0	-33	Atm.	N/A	6,700 m^3

For transfer operation frequency, the following details are to be noted:

- Number of transfer operations per year: 5
- Duration of each transfer operation: 10 hours (flow rate at 750 m^3/hr and APS tank volume at 6,700 m^3)

Table C0-3 List of failure cases and parts count - LAC to ABV breakbulk at anchorage-high flow case

ISO-segment	Failure cases	Description	Major Equipment	Minor Equipment	Length of Piping (m)	Pipe Size	Pipe Size	Operating Temperature (°C)	Operating pressure (barg)	Normal Flowrate (m^3/hr)	Volume of vessel/ tank (m^3)
						(inches)	(mm)				
ISO-01D	LAC Tank 1	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-02D	LAC Tank 2	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-03D	LAC Tank 3	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-04D	LAC Tank 4	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-05D	Piping from LAC Tank 1 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A

ISO-06D	Piping from LAC Tank 2 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A
ISO-07D	Piping from LAC Tank 3 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A
ISO-08D	Piping from LAC Tank 4 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A
ISO-09D-P1	Piping Header on LAC from Tank 1 (P101 A/B) and Tank 2 (P 102 A/B) to Liquid Manifold Connection 1 **(till Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings Note: Flange connections are fully welded	50	8	203	-33	4	350	N/A
ISO-09D-P2	Piping Header on LAC from Tank 1 (P101 A/B) and Tank 2 (P 102 A/B) to Liquid Manifold Connection 1 **(After Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	None identified	50	8	203	-33	4	350	N/A
ISO-10D-P1	Piping Header on LAC from Tank 3 (P103 A/B) and Tank 4 (P 104 A/B) to Liquid Manifold Connection 2 **(till Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings Note: Flange connections are fully welded	50	8	203	-33	4	350	N/A
ISO-10D-P2	Piping Header on LAC from Tank 3 (P103 A/B) and Tank 4 (P 104 A/B) to Liquid Manifold Connection 2 **(After Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	None identified	50	8	203	-33	4	350	N/A
ISO-11D-P1	Piping from Manifold to Type C Tank on LAC for BOG Management	This case is identified to model a release at the piping connection from manifold to the Type C tank	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings Note: Flange connections are fully welded	50	8	203	-5.2	atm	870	N/A
ISO-11D-P2	Piping from Manifold to Type C Tank on LAC for BOG Management	This case is identified to model a release at the piping connection from	None identified	None identified	50	8	203	-5.2	atm	870	N/A

		manifold to the Type C tank									
ISO-12D-P1	LAC Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	15	8	203	-33	4	350	N/A
ISO-12D-P2	LAC Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	15	8	203	-33	4	350	N/A
ISO-13D-P1	LAC Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	15	8	203	-33	4	350	N/A
ISO-13D-P2	LAC Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	15	8	203	-33	4	350	N/A
ISO-14D-P1	LAC Manifold - One vapour connection [BOG]	BOG management	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	7.5	8	203	-5.2	atm	870	N/A
ISO-14D-P2	LAC Manifold - One vapour connection [BOG]	BOG management	None identified	None identified	7.5	8	203	-5.2	atm	870	N/A
ISO-15D	Transfer hose 1 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-16D	Transfer hose 2 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-17D	One Transfer Hose ABV to APS [BOG]	BOG management	None identified	None identified	30	8	203	-5.2	atm	870	N/A
ISO-18D-P1	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-18D-P2	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-19D-P1	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-19D-P2	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A

ISO-20D-P1	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	1) 2 Isolation valves on the pipeline Note: Flange connections are fully welded	25	8	203	-31	0.12	700	N/A
ISO-20D-P2	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	None identified	25	8	203	-31	0.12	700	N/A
ISO-21D-P1	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	5	8	203	-33	4	700	N/A
ISO-21D-P2	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	700	N/A
ISO-22D-P1	Piping from Header to Type C Tank 1 on ABV (P201 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	350	N/A
ISO-22D-P2	Piping from Header to Type C Tank 1 on ABV (P201 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	None identified	20	8	203	-33	4	350	N/A
ISO-23D-P1	Piping from Header to Type C Tank 2 on ABV (P202 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	350	N/A
ISO-23D-P2	Piping from Header to Type C Tank 2 on ABV (P202 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	None identified	20	8	203	-33	4	350	N/A
ISO-24D	ABV Tank 1	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	10,500
ISO-25D	ABV Tank 2	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	10,500

Table C0-4 List of failure cases and parts count - LAC to ABV breakbulk at anchorage-low flow case

ISO-segment	Failure cases	Description	Major Equipment	Minor Equipment	Length of	Pipe Size	Pipe Size				Volume of

					Piping (m)	(inches)	(mm)	Operating Temperature (°C)	Operating pressure (barg)	Normal Flowrate (m^3/hr)	vessel/ tank (m^3)
ISO-01D	LAC Tank 1	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-02D	LAC Tank 2	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-03D	LAC Tank 3	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-04D	LAC Tank 4	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	5750
ISO-05D	Piping from LAC Tank 1 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A
ISO-06D	Piping from LAC Tank 2 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	5	8	203	-33	4	175	N/A
ISO-07D	Piping from LAC Tank 3 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-08D	Piping from LAC Tank 4 to Header on LAC	This case is identified to model a release at the piping from tank to the header on the LAC	None identified	1) 1 NRV 2) 1 Small Bore Fitting Note: Flange connections are fully welded	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-09D-P1	Piping Header on LAC from Tank 1 (P101 A/B) and Tank 2 (P 102 A/B) to Liquid Manifold Connection 1 **(till Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings Note: Flange connections are fully welded	50	8	203	-33	4	350	N/A
ISO-09D-P2	Piping Header on LAC from Tank 1 (P101 A/B) and Tank 2 (P 102 A/B) to Liquid Manifold Connection 1 **(After Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	None identified	50	8	203	-33	4	350	N/A
ISO-10D-P1	Piping Header on LAC from Tank 3 (P103 A/B) and Tank 4 (P 104 A/B) to Liquid	This case is identified to model a release at the piping header on the LAC	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings	N/A	N/A	N/A	N/A	N/A	N/A	N/A

	Manifold Connection 2 **(till Isolation Valve)**			Note: Flange connections are fully welded						
ISO-10D-P2	Piping Header on LAC from Tank 3 (P103 A/B) and Tank 4 (P 104 A/B) to Liquid Manifold Connection 2 **(After Isolation Valve)**	This case is identified to model a release at the piping header on the LAC	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-11D-P1	Piping from Manifold to Type C Tank on LAC for BOG Management	This case is identified to model a release at the piping connection from manifold to the Type C tank	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 2 Small Bore Fittings Note: Flange connections are fully welded	50	8	203	-5.2	atm	450	N/A
ISO-11D-P2	Piping from Manifold to Type C Tank on LAC for BOG Management	This case is identified to model a release at the piping connection from manifold to the Type C tank	None identified	None identified	50	8	203	-5.2	atm	450	N/A
ISO-12D-P1	LAC Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	15	8	203	-33	4	350	N/A
ISO-12D-P2	LAC Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	15	8	203	-33	4	350	N/A
ISO-13D-P1	LAC Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-13D-P2	LAC Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-14D-P1	LAC Manifold - One vapour connection [BOG]	BOG management	None identified	1) 1 Isolation Valve on the pipeline 2) 1 NRV 3) 4 Flanged connections 4) 2 Small Bore Fittings	7.5	8	203	-5.2	atm	450	N/A
ISO-14D-P2	LAC Manifold - One vapour connection [BOG]	BOG management	None identified	None identified	7.5	8	203	-5.2	atm	450	N/A

ISO-15D	Transfer hose 1 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-16D	Transfer hose 2 ABV to APS [Liquid]	Bunkering of ammonia	None identified	None identified	30	8	203	-33	4	350	N/A
ISO-17D	One Transfer Hose ABV to APS [BOG]	BOG management	None identified	None identified	30	8	203	-5.2	atm	450	N/A
ISO-18D-P1	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-18D-P2	ABV Manifold - Liquid connection No. 1 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-19D-P1	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-19D-P2	ABV Manifold - Liquid connection No. 2 [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ISO-20D-P1	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	1) 2 Isolation valves on the pipeline Note: Flange connections are fully welded	25	8	203	-31	0.12	350	N/A
ISO-20D-P2	Piping from Manifold Location to Type C Tanks on ABV for BOG Management [BOG]	BOG management	None identified	None identified	25	8	203	-31	0.12	350	N/A
ISO-21D-P1	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	1) 1 Isolation Valve 2) 2 Flanged connections 3) 1 Small Bore Fitting	5	8	203	-33	4	350	N/A
ISO-21D-P2	ABV Manifold - Liquid connection Header [Liquid]	This case is identified to model a release at the manifold location	None identified	None identified	5	8	203	-33	4	350	N/A
ISO-22D-P1	Piping from Header to Type C Tank 1 on ABV (P201 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	175	N/A
ISO-22D-P2	Piping from Header to Type C Tank 1 on ABV (P201 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	None identified	20	8	203	-33	4	175	N/A

ISO-23D-P1	Piping from Header to Type C Tank 2 on ABV (P202 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	1) 1 Isolation Valve on the manifold 2) 1 Small Bore Fitting Note: Flange connections are fully welded	20	8	203	-33	4	175	N/A
ISO-23D-P2	Piping from Header to Type C Tank 2 on ABV (P202 A/B)	This case is identified to model a release at the piping on the exposed deck	None identified	None identified	20	8	203	-33	4	175	N/A
ISO-24D	ABV Tank 1	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	10,500
ISO-25D	ABV Tank 2	Ammonia storage	None identified	None identified	N/A	N/A	N/A	-33	atm	N/A	10,500

The following details for the frequency of transfer operations are to be noted:

- Number of transfer operations per year: 1
- Duration of each transfer operation: 30 hours (this duration has been doubled from 15 hours for conservatism, as connection and cooldown times are assessed to be relatively significant during a breakbulk operations)

Note 2: The storage tanks on the LAC are assumed to be of double containment type. This is because the tanks on board LPG carriers are typically of double containment type and design of the LPG carriers is expected to form the basis for the design of ammonia carriers. The likelihood of loss of containment from double containment tanks is negligible and therefore is excluded from the scope of the QRA.

Note 3: For the purposes of the Pilot study, the APS is identified to be a multideck container vessel and the ammonia fuel tank is assumed to be present in the hull. A loss of containment from the ammonia storage tank result in an inbuilding release and is assessed to have a negligible impact on external personnel. Therefore, this event has been excluded from the risk modelling.

Note 4: Based on DNV's experience with LNG projects, the likeihood of release from Type C tanks is also assessed to be negligible and is therefore excluded from the risk modelling.

Note 5: Based on the feedback provided by designers and industry participants, all flange connections on ammonia lines will be welded**.** It is anticipated some flanges will likely be present. At the time of writing, the number of flanges are not known. In addition, the exact number of small bore fittings are not known as the design is preliminary stages. Where flange connections are not welded, the number of flanges are taken to be 2 times the number of valves

Effect on Analysis:
The operating data and presence of equipment have a direct impact on both frequency and severity.

Source:
N/A

C4.2 Leak frequencies for hoses and loading arms

For loading arms, the failure frequency for LNG is utilised from the IOGP database.

Table C0-5 Leak frequency of loading arms – Ship Transfer (Source 1)

Case	Nominal Failure Rate per Year of Operation
Rupture of transfer arm (100% of diameter)	2.0E-05 per transfer arm
Release from a hole in transfer arm with effective diameter of 10% transfer arm diameter with maximum of 50 mm (2”)	2.0E-04 per transfer arm

For loading hoses, the release frequency is maintained the same for small leaks and is increased by one order for rupture events.

Table C0-6 Leak frequency of hoses – Ship Transfer (Assumption)

Case	Nominal Failure Rate per Year of Operation
Rupture of transfer hose (100% of diameter)	2.0E-04 per loading hose
Release from a hole in transfer hose with effective diameter of 10% transfer arm diameter with maximum of 50 mm (2”)	2.0E-04 per loading hose

Effect on Analysis:
The leak frequency affects the size of the LSIR contours.

Source:

1. IOGP, 434-01, Process Release Frequencies, September 2019

C4.3 Toxic modelling

Ammonia is identified as a toxic material and the fatality will be calculated in SAFETI based on the toxic probits,

$$Pr = a + b \ln (C^n \times t)$$

Where:

- Pr = probit associated with the probability
- a, b, n constants for the toxicity of a substance
- C = concentration at time t (ppm)
- t = exposure time (minutes)

The following table shows the toxic probits and AEGL-3 values of ammonia, which will be used for this study. AEGL-3 is assumed to be 30 minutes for the purposes of consequence modelling for presentation of dispersion results.

Table C0-7: Toxic probits and AEGL-3 values

Toxic Component	AEGL-3 @ 30 mins (ppm)	Toxic Probit				Source of Reference
		A (mg/m^3)	A (ppmv)	B	N	
Ammonia	1600	-16	-16	1	2	(Source 1, 2)

Effect on Analysis:
Toxic effects to personnel

Source:

1. Reference Manual Bevi Risk Assessments version 3.2, 01.07.09
2. Ammonia Results - AEGL Program, EPA, https://www.epa.gov/aegl/ammonia-results-aegl-program

C4.4 Failure data for equipment

Leak size

Leak frequencies for the QRA were based upon four (4) representative hole sizes per QRA guidance (Source 1) as defined in the table below.

Table C0-8 Representative hole sizes for equipment

Representative hole size	Hole Size range
10 mm	0 – 15 mm
25 mm	16 – 49 mm
75 mm	50 mm onwards
Catastrophic	Instantaneous release

Leak frequencies

Leak frequency of equipment and pipework are tabulated in the tables below.

Table C0-9 Leak frequency of equipment

Item	Hole size	Leak frequency	Unit	Reference
Valve	Spray release	2.0E-04	per valve per year	UK HSE, Failure Rate and Event Data for use within Risk Assessments (02/02/2019) Item FR 1.2.3
Flange	Spray release	5.0E-06	per flange per year	UK HSE, Failure Rate and Event Data for use within Risk Assessments (02/02/2019) Item FR 1.2.5
Pressure Vessel	10 mm	5.0E-05	per vessel year	UK HSE, Failure Rate and Event Data for use within Risk Assessments (02/02/2019) Item FR 1.1.3
	25 mm	5.0E-06		
	75 mm	5.0E-06		
	Catastrophic	4.0E-06		
	25 mm	-		
	75 mm	-		
	Catastrophic	4.0E-06		
	25 mm	6.8E-04		
	75 mm	-		
	Catastrophic	1.7E-04		
	Rupture	4.0E-02		

Cargo pumps and Fuel/Spray pumps are submerged in the ammonia storage tank; hence, any leaks will be confined within the tank and are not considered further in the QRA study.
Effect on Analysis: Leak frequency estimates have a direct effect on the risk profile associated with each failure case/inventory, and thus, the overall risk profile of the facility.
Source: 1. National Environment Agency (NEA) Singapore, "QRA Technical Guidance", Revision No. 3, 9th November 2016. Available at https://www.nea.gov.sg/docs/default-source/our-services/qra-technical-guidance_nov16.pdf. 2. UK HSE (2019). Failure Rate and Event Data for use within Risk Assessments (02/02/19). Available at http://www.hse.gov.uk/landuseplanning/failure-rates.pdf.

C4.5 Isolation time

For Anchorage Breakbulk and Bunkering Operations The operations for the unloading and loading of ammonia are manned operations; hence, it is assumed that the isolation time (including reaction time) for hoses at the manifold will take approximately 2 minutes to isolate the leak of the hose/arm. This isolation is done by emergency release coupling or manual ESD activation by personnel. This means the dynamic inventory is calculated as release rate (N kg/s) x 2 x 60 seconds.
Effect on Analysis: Required to determine isolation time and thus, release duration and inventory.
Source: 1. National Environment Agency (NEA) Singapore, "QRA Technical Guidance", Revision No. 3, 9th November 2016. Available at https://www.nea.gov.sg/docs/default-source/our-services/qra-technical-guidance_nov16.pdf. 2. DNV LNG QRA Guideline, rev. 01, dated 2012-08-28

C4.6 Receptor height and surface roughness

In SAFETI, the following typical values for the surface roughness are provided:

Table C0-10 Roughness by type of surface

Type of Surface	Roughness Length (mm)
Open water, at least 5 km	0.0002
Mud flats, snow; no vegetation, no obstacles	0.005
Open terrain; grass, few isolated objects	0.03
Low crops; occasional large obstacles, x/h > 20	0.10
High crops; scattered large obstacles, 15 < x/h < 20	0.25
Parkland, bushes; numerous obstacles, x/h < 15	0.5
Regular large obstacle coverage (suburb, forest)	1
City centre with high and low-rise buildings	3

For release on land, a value of 0.03 will be used. For releases on water a value of 0.0002 will be used.

Typically, DNV applies a value of 1 m for the receptor height to reflect the height of a typical human being. The height of release is taken to be 1 m.

Effect on Analysis:
The height of release and height of the receptor directly impacts the individual risk levels. This is because the height at which the receptor comes into contact with ammonia will directly influence the exposure. The surface roughness influences the dispersion distance.

Source:
N/A

C4.7 Ignition probability

According to TNO Purple Book, ammonia is usually modelled as purely toxic (substances with low reactivity are to be modelled as purely toxics). Therefore, flammable aspects will be disregarded as part of this analysis.
Effect on Analysis: Not Applicable
Source: 1. IOGP, "Risk Assessment Data Directory - Ignition probabilities," Report No. 434-06, September 2019 2. National Institute of Public Health and the Environment (RIVM), Reference Manual Bevi Risk Assessments, version 3.2, date: 1 July 2009

C4.8 Effect of water curtain or water spray systems in ammonia release abatement

A paper assessing engineering calculations to estimate jet velocity, diameter & concentration and calculations to evaluate the efficiency of water sprays was presented at the AIChE Spring Meeting and Global Congress on Process Safety.

According to the presentation, water spray curtains are often advertised as means to mitigate the consequences of released chemicals. Spray curtain effectiveness claims by certain vendors are misleading - a curtain placed at the periphery of a tank will only scrub a puff of a release. Studies that demonstrate spray curtains to be effective assume low gas velocities. However, calculations show that pressurised liquid NH_3 when released from an orifice to the atmosphere comes out at a high velocity and momentum in the form of a two-phase jet. The jet must travel quite a distance before the velocity drops enough to be effectively scrubbed by a water curtain. The water curtain therefore needs to be at this large distance and consequently the diameter of the water curtain manifold ring needs to be quite large to be effective. It also needs to be quite high to accommodate the expanding jet angle, the potentially high point of puncture or upward angle of jet. Sprays lose effectiveness after a short distance (5-6 m) due to coalescence of the droplets. Large quantities of water are needed to feed all these nozzles at immediate notice.

Therefore, water spray systems are assumed to absorb released ammonia resulting from a small release. To be conservative, water spray systems are assumed to be ineffective for all other hole sizes.

The water spray system will only be activated upon successful ammonia vapour detection.

The formula for obtaining the failure probability of the detection system is as below:

Unavailability $\approx$ (Failure rate $\times$ Proof test interval)/2

In reliability terminology, failure probability is termed as “unavailability”. The calculation of this involves the failure rate and the proof test interval, i.e. inspection frequency.

The failure rate for Hydrocarbon Gas Detectors is obtained from OREDA 2009 which is 1.2 in 10^6 hours (failure mode: fail to function on demand). It is assumed that inspection (or proof test interval) is carried out once every two years, which is equal to 2 x 365 x 24 hours (17520 hours). It is to be noted that data for ammonia gas detectors is not available, therefore historic failure data for hydrocarbon gas detectors is assumed.

Failure probability = (1.2 per 10^6 hours $\times$ 17520) / 2

= 0.011

The above-mentioned failure probability of 0.011 will be integrated into failure frequencies for small releases for the risk analysis.

Effect on Analysis:
The failure rate directly influences the release frequency.

Source:

1. AIChE Spring Meeting and Global Congress on Process Safety, March 28, 2017
2. OREDA Offshore Reliability Data Handbook, 2009

C4.9 Release direction

Releases within areas with high congestion are modelled as horizontal impinged (reduced momentum) releases, otherwise the releases are modelled as unobstructed, horizontal releases. For this QRA, impinged release is selected as the outflow is likely to be blocked by e.g. ground surface and/or objects in close proximity of the release locations. The terminals are assessed to high congestion due to the presence of manifolds and transfer arms.
Effect on Analysis: In the event of a leak, ammonia can be release in any direction. However, the horizontal direction is known to usually gives the largest impact zone.
Source: N/A

C4.10 Release rates

For pump driven process segments, the maximum release rate will be capped at 120% of the nominal pump flow to account for the sudden pressure loss downstream and the subsequent reaction of (a) centrifugal pump(s) upstream of the rupture. For storage tank events, the release rate and velocity are pressure driven. No capping for this scenario is applied. For gas flow segments, no capping on release rate has been applied.
Effect on Analysis: This aspect will influence the total amount of toxic inventory released and subsequently individual risk.
Source: 1. DNV LNG QRA Guideline, rev. 01, dated 2012-08-28

C4.11 Bund properties

The bund physical size assumed for different area are summarised in Table C0-11.

Table C0-11 Bund dimensions defined in Safeti

Bund area	Height (m)	Length (m)	Width (m)
Terminal A	0.15	6	6
Terminal AD	0.15	10	10

The following scenarios will be assumed to be released on water:

- ABV to APS at anchorage: Release from transfer hose
- LAC to ABV at anchorage: Release from transfer hose

When refrigerated ammonia spilled on water, ammonia becomes very reactive and evaporates at high rates. Half of the spilled ammonia by mass is assumed to be absorbed by water. The remaining ammonia will be assumed to evaporate resulting in a gas cloud.

Effect on Analysis:
Limits size of the pool from the spilled ammonia

Source:

1. HAZID Workshop (supplemented with Engineering Judgement)

C5 INTEGRATION OF RISK RESULTS FOR EXISTING NEARSHORE LOCATIONS

Per Singapore QRA guidelines, the cumulative risk contours generated by the combined operations at a particular land site shall be compared against the acceptance criteria. Based on the pilot study, one of the hazardous operations may include ammonia transfer. The risk from ammonia transfer operations only cannot be compared against the criteria stated in the Singapore QRA guidelines as this would only present a partial picture of risk. Terminals are designated as Major Hazard Installations (MHI) and have carried out QRAs, which have been approved by Major Hazards Department (MHD). The QRAs present the risk contours for the existing operations. To present a cumulative risk picture, the risk contours generated by ammonia transfer operations will be qualitatively assessed with the risk contours for the existing operations to present a cumulative risk (and incremental risk) evaluation. This qualitative assessment of cumulative risk will be compared against the acceptance criteria. This methodology is consistent with recent Technical Memo submissions to MHD.
Effect on Analysis: N/A
Source: N/A

C6 DESIGN AND DIMENSIONS OF VESSELS PROPOSED FOR THE PILOT STUDY

No specific ship design is considered for this assessment and the following aspects are assumed:

- Ammonia carriers or bunker vessels were assumed to be a retrofit of the existing LNG/LPG carriers built in compliance with IGC Code.
- Ammonia fuelled/powered ships were assumed to be built in full compliance with applicable IGF Code in addition to DNV Ship Rules Pt 6 Ch 2 Sec 14 “Gas Fuelled Ammonia” notation.

The dimensions of vessels proposed for this Pilot study are presented in the tables below.

Table C0-1 Dimensions of ABV

Parameter	Value (m)
Length Overall	150
Beam	32

Table C0-2 Dimensions of APS

Parameter	Value (m)
Length Overall	200
Beam	38

Table C0-3 Dimensions of LAC

Parameter	Value (m)
Length Overall	165
Beam	26

Effect on Analysis:
The layout impact the location of release points and the relative size of the LSIR contours.

Source:

1. Design by Surbana Jurong and feedback provided by Study Partners

C7 HARM FOOTPRINTS AND RISK CRITERIA

C7.1 Harm footprints and consequence results

Harm footprints are required to calculate the individual risk and cumulative escalation for checking if the QRA criteria thresholds are met. The tables below per the QRA Technical Guidance (Source 1):

Table C0-1 IR (Fatality) Harm Levels

Hazard	Harm Level	Weightings
Toxic	3% fatality	0.065
	10% fatality	0.24
	50% fatality	0.45

Table C0-2 IR (Injury) Harm Levels

Hazard	Harm Level
Toxic	AEGL-3

Table C0-3 Onsite Occupied Building Harm Levels

Hazard	Harm Level	Weightings
Toxic	3% fatality	0.065
	10% fatality	0.24
	50% fatality	0.45

Consequence distance to the above tabulated vulnerabilities will be provided.

Effect on Analysis:
Required to calculate of the frequency at which personnel become fatalities whilst outside.

Source:

1. National Environment Agency (NEA) Singapore, "QRA Technical Guidance", Revision No. 3, 9th November 2016. Available at https://www.nea.gov.sg/docs/default-source/our-services/qra-technical-guidance_nov16.pdf.

C7.2 Sensitive Receptors

According to Singapore QRA guidelines, the following development types as indicated in the URA Master Plan are defined to be Sensitive Receptors: • Residential • Residential with Commercial at 1st Storey • Commercial and Residential • Hotel • White • Residential / Institution • Health & Medical Care • Educational Institution • Place of Worship • Civic & Community Institution • Park • Beach Area • Sports & Recreation • Transport Facilities • Railway • Mass Rapid Transit • Light Rapid Transit • Port / Airport • Reserve Site • Special Use The following Sensitive Receptors as indicated in the Singapore Land Authority (SLA) OneMap are: • Child Care centers • Workers' Dormitories
Effect on Analysis: The IR Injury contours should be confined to within industrial developments and should not reach sensitive receptors
Source: 1. National Environment Agency (NEA) Singapore, "QRA Criteria Guidance", Revision No. 1, 31st August 2016. Available at https://www.nea.gov.sg/docs/default-source/our-services/qra-criteria-guidelines_final_31aug16.pdf

7 ESTIMATING TOTAL CAPITAL EXPENDITURE

7.1 Introduction

The Concept Selection Report aims to tailor the current industry practice for ammonia transfer to the ammonia bunkering industry in the future. To mitigate the cost risk of the project, this report documents different aspects of the project cost and highlights the methodology for producing an initial budget estimate for an early outlook to support a facility owner's investment decision. This methodology includes analogous estimating, using conceptual information by taking values from past projects with similar scopes and applying them to the current project to produce an order-of-magnitude estimate. It also considers all known assumptions and constraints which pertain to the project's cost.

Estimated costs are not disclosed as they are sensitive to the location of deployment, brownfield modifications, materials cost, procurement strategy, local taxes, and other related parameters.

7.2 Methodology and assumptions

Based on the Concept Selection and Site Selection reports, two concepts have been selected for piloting ammonia transfer:

- Concept 1: STS breakbulk at Terminal A using LAC to ABV
- Concept 4: SHTS bunkering at Terminal D using Ammonia Storage Facility (ASF) to the APS

This report outlines the expected CAPEX investments needed to develop these pilots at a +-40 percent accuracy level and the assumptions used to arrive at the estimate. The estimate does not include costs incurred by other parties and operational expenses.

7.2.1 Basis

The cost estimation has been based on inputs from the previous reports in this study in combination with a set of assumptions based on typical engineering practices and discussions with the facility owner. The following will constitute the BoE for this project:

- Early feasibility study design and developments, including updates in quantities (on an as-of-now basis)
- Project constraints and assumptions, such as procurement supply chain constraints and/or subcontractor constraints
- Project risks and their impact on cost as considered in contingency reserves by the consultant and management reserves by the client

7.2.2 Cost estimation methodology

The preliminary cost estimation is based on an initial material takeoff (MTO) derived from the preliminary process flow diagram (PFD), preliminary plot plan, concept pipe routing sketch and site visit. The price is based on a combination of budgetary quotes from third parties and the Design Consultant's in-house cost data, published rates, project benchmarking and current tender prices.

Engineering services for front-end engineering (FEED) / Engineering, procurement and construction management (EPCM) services are developed based on a percentage of the construction cost of the works and are allowed for management services for the contractor during EPCM, EPCM Scope of Work and EPCM Level 1 Schedule for the project. The percentage is based on the apportionment derived from benchmarking past projects with a similar scale.

The cost of preliminaries is allowed as a percentage of the construction cost of the works. The percentage is based on the apportionment derived from current tenders.

The contingency reserve for known unknowns, which accounts for technical development allowance and construction growth, will be added to all discipline costs to form the project cost baseline. The allowed percentage is based on past project benchmarking of similar project types and scales. The contingency reserve for this preliminary cost estimate has been set to 0%.

The company shall allow the management reserve for unknown unknowns for unrealized/unforeseen project risks in their Final Investment Decision (FID). The management reserve shall consider the following:

(a) Market inflations and escalations

(b) Future client changes to EPC Scope of Work

(c) Discovery work leading to scope changes that cannot be reasonably foreseen

(d) Force majeure events

(e) Post-COVID scenarios and the impact on the cost

(f) Diversion of existing public services and utilities

(g) Diversion, disinvestment of unforeseen/unexpected underground services which are not foreseen within the Contract boundary

(h) Energy efficiency opportunities assessment (EEOA) and any other local or international authority requirements that are not currently known to the project

(i) Client's expenses and those of their appointed contractors and third parties. Items that would fall under the client's costs are typically:

- Project finance costs
- Currency fluctuation cost
- Import duties and customs clearance
- PMC Costs
- Operation and maintenance (O&M) spares
- Company insurance and bonds
- Construction premium/waiting time cost
- Future pre-investment
- Due diligence by third parties
- Client's Project Team
- Client's IT hardware/software/telephone/communication costs
- Cost of land/lease
- Costs arising from shutdowns (flaring, opportunity loss, etc.)
- Client's permitting requirement (license fees)
- Taxation (government service tax)

The management reserve for this preliminary cost estimate has been set to 0%.

7.3 Cost estimation

Based on the assumptions and exclusions outlined in the previous section, both pilot costs have been estimated. The summarised estimated cost results can be found in sections 7.3.1 for concept 1 and section 7.3.2 for concept 4, respectively.

7.3.1 Concept 1: STS breakbulk at Terminal A

The cost estimation for piloting concept 1 has been outlined in Table 7-1. Most of the cost comes from construction at 75.5%, primarily driven by the Instrumentation and Control Works at 15.1% and Mechanical Equipment Installation at 43.5%.

Table 7-1 Summarised cost estimate for Concept 1 (ship-to-ship breakbulk) at Terminal A)

DESCRIPTION	% OF TOTAL
DIRECT COSTS	
Mechanical Equipment Installation	44%
Instrumentation and Control Works	15%
Piping Works including pipe support	7%
Electrical Works	5%
Civil and Structural Steel Works	5%
Painting & Insulation	
Firefighting Works	
Scaffolding	
Site Supervision and Support for Specialist Equipment	
Tie-in Shutdown Supervision	
Commissioning Works (Contractors' support)	
SUB TOTAL OF DIRECT COST	76%
INDIRECT COSTS	
Preliminaries & General Cost	9%
Project Management and Procurement Service	14%
FEED / POST FEED Services	
QA Inspection Services	2%
HAZID, HAZOP and SIL	
Fire & Explosion Risk Assessment	
Blast Impact Assessment	
Noise Study	
Qualified Persons (QP) Authority Submission & Permitting Services	
SUB TOTAL OF INDIRECT COST	24%
TOTAL COSTS	**100%**

7.3.2 Concept 4: SHTS bunkering at Terminal D

The cost estimation for concept 4 has been outlined in Table 7-2. Compared to concept 1, the construction costs for this configuration are significantly lower at 32.0% of total costs compared to 75.5% for concept 1. While Instrumentation and Control Works still are a major cost driver at 25.8%, no mechanical equipment installation is required. Other significant costs include Engineering Services at 17.8% and Project Management and Procurement Services at 35.6% due to the lower construction costs.

Table 7-2 Summarised cost estimate for concept 4 (shore-to-ship bunkering at Terminal D)

DESCRIPTION	% OF TOTAL
DIRECT COSTS	
Instrumentation and Control Works	26%
Tie-in Shutdown Supervision	6%
Piping Works including pipe support	
Commissioning Works (Contractors' support)	
SUB TOTAL OF DIRECT COST	32%
INDIRECT COSTS	
Preliminaries & General Cost	9%
Project Management and Procurement Service	36%
FEED / POST FEED Services	18%
QA Inspection Services	5%
HAZID, HAZOP and SIL	
Fire & Explosion Risk Assessment	
Blast Impact Assessment	
Noise Study	
SUB TOTAL OF INDIRECT COST	68%
TOTAL COSTS	**100%**

8 GUIDEBOOK

The *GABSS Guidebook for Ammonia Bunkering* was prepared through the collective efforts of the consortium partners (DNV, SJ, SMA and GCMD) and the 22 study partners of the GCMD Ammonia Bunkering Safety Study, referencing Singapore's standard for LNG bunkering, Technical Reference 56 (TR 56). Additionally, this guidebook applies to the bunkering of vessels and covers ammonia delivery from ammonia bunkering facilities to receiving vessels through four transfer modes.

This guidebook consists of four parts:

Part 1: General introduction - introduces the properties of ammonia and lists the terms and definitions relevant to the various modes of ammonia bunkering operations.

Part 2: Requirements for custody transfer – provides the requirements for custody transfer during ammonia bunkering operations and determines the energy content loaded from the bunkering facility onto the receiving vessel, including quality and quantity measurements, to ensure consistency and reliability of the energy value transferred.

Part 3: Bunkering procedures and safety requirements – provides guidance on bunker equipment, safety requirements, and general bunkering procedures for different modes of bunkering.

Part 4: Competency requirements for personnel – provides competencies and training required for ammonia bunker personnel at the management, operation, support, and emergency levels.

The reader should familiarise themselves with all sections of the guidebook before focusing on the applicable parts pertaining to their specific requirements.

8.1 Part 1: GENERAL INTRODUCTION

8.1.1 Scope

This guidebook is designed for vessels engaged in ammonia transfers and bunkering pilots. It provides comprehensive guidance on the delivery of ammonia from bunkering facilities to receiving vessels, covering all bunkering scenarios through four transfer modes, as shown in Figure 8-1. Additionally, this section introduces the properties of ammonia, including a list of terms and definitions relevant to the guidelines presented here.

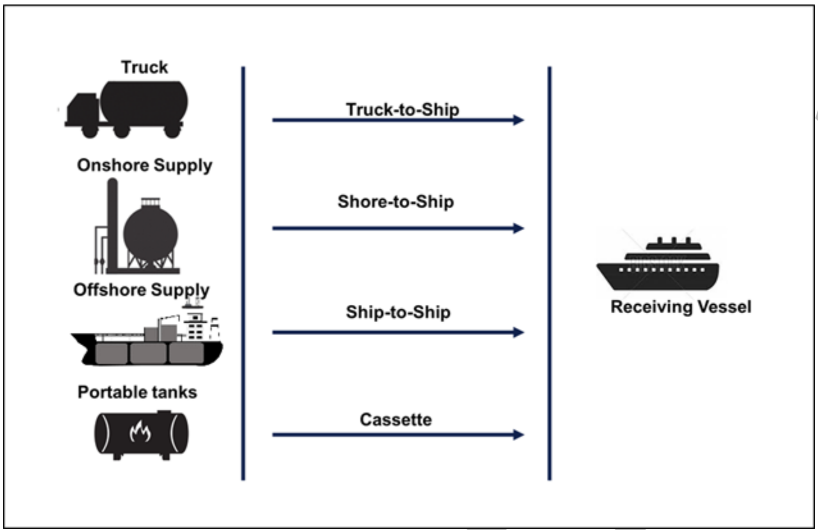

Figure 8-1 Four modes of ammonia bunkering

8.1.2 Properties of ammonia

8.1.2.1 General

Ammonia (NH_3) is a carbon-free fuel comprising nitrogen and hydrogen atoms. Ammonia can be transported and stored in three different states, as shown in Figure 8-2 and Table 8-1.

- Fully refrigerated, typically at -33ºC and close to atmospheric pressure
- Semi-refrigerated, typically at -10ºC to 4ºC, and 4 to 8 bara pressure
- Non-refrigerated or pressurised, typically at 20ºC to 37ºC, and 10 to 15 bar_a pressure

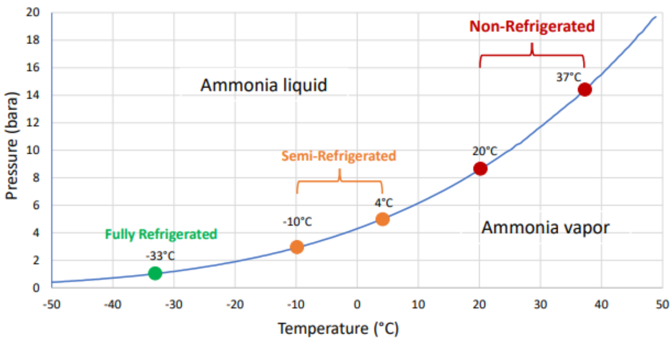

Figure 8-2 Ammonia vapour pressure at gas-liquid equilibrium
[MESD CoE Ammonia bunkering – simulation of hypothetical release scenarios in Singapore]

Table 8-1 Properties of ammonia at different phases

	Refrigerated	Semi-refrigerated	Pressurised
Pressure (bar_a)	1	4 to 8	10 to 15
Temperature (ºC)	-33	-10 to 4	20 to 37

8.1.2.2 Characteristics of ammonia as a bunker fuel

Ammonia is a colourless, toxic gas that emits a pungent odour under ambient conditions. It has a lower density than air and freezes at -78°C. At atmospheric pressure, the boiling point of ammonia is -33°C and has a density of 0.68 t/m^3. The heating value for ammonia on a lower heating value (LHV) basis is 18.6 MJ/kg, and volumetric energy density is 12.7 MJ/L at -33 °C and 1 atmospheric pressure.

Anhydrous ammonia refers to ammonia in its pure form, meaning without water. Ammonia is hygroscopic, indicating that it has a high affinity for water. In gaseous form, it is lighter than air. However, due to its hygroscopic properties, released anhydrous ammonia will rapidly absorb moisture from the air, forming a dense and visible white cloud that may have a higher density than air.

Using ammonia as a bunker fuel presents different challenges than other fuels, such as LNG and LPG, as shown in Table 8-2. Ammonia is more toxic but less flammable than LNG and LPG. The risks associated with ammonia as a bunker fuel are primarily due to the following factors:

- Ammonia is toxic. Exposure to ammonia vapours must always be avoided. The effect of ammonia exposure on the respiratory organs is usually limited to the upper respiratory tract since the gas dissolves well in water and induces strong reflexes that would immediately cause a person to hold their breath. However, the ammonia can reach deeper airways at higher concentrations with longer exposure time. The consequences, such as lung damage (pulmonary edema), are severe, resulting in possible mortality.
- Ammonia is flammable but difficult to ignite. Typically, ammonia has a flashpoint of 132°C. Ammonia has a flammability range from 15% to 28% by volume in the air [DNV Comparison of Alternative Marine Fuels]. Ammonia vapours will generally not constitute a fire hazard in the open atmosphere. In machinery space and fuel preparation rooms, the risk of ignition will be higher, especially if oil and other combustible materials are present.

Table 8-2 Comparison of flammability and toxicity of different marine fuels [DNV Comparison of Alternative Marine Fuels]

	Flashpoint (°C)	Flammability Limits (volume % in air)	Toxicity
LNG	-188	4-15	Not toxic
Hydrogen	Not Defined	4-74	Not toxic
Ammonia	132	15-28	Highly toxic
Methanol	11-12	6.7-36	Low acute toxicity (dangerous for humans)
LPG	-104	1.8-10	Not toxic
HVO	>61	Approx. 0.6-7.5	Not toxic

Additionally, ammonia is also corrosive in nature. It will corrode galvanised metals, cast iron, copper, brass or copper alloys. Hence, careful material selection is required per the IGC code.

8.1.2.3 Hazards associated with ammonia as a bunker fuel

The following hazards are associated with ammonia:

- Severe skin burns due to cold temperature and eye damage from liquid spills [GHS Rev.9 code H314]
- Harmful if inhaled [GHS Rev.9 code H332]
- Severe eye damage upon contact [GHS Rev.9 code H318]
- May cause respiratory irritation [GHS Rev.9 code H335]
- Very toxic to aquatic life upon release to the environment [GHS Rev.9 code H400]
- Flammable gas [GHS Rev.9 code H221]
- A possible explosion of pressurised ammonia gas if heated [GHS Rev.9 code H280]
- Fire, deflagration, or confined explosion from ignited gas evaporating from spilt ammonia in the presence of oil and other combustible materials
- Vapour dispersion and remote flash fire
- Possible BLEVE of a pressurised tank subjected to a fire
- Flashing and expansion of ammonia from pressurised ammonia released into the atmosphere
- Hydraulic shocks
- Corrosion of galvanised metals, cast iron, copper, brass, or copper alloys exposed to ammonia spills
- Stress corrosion in carbon-manganese and nickel steels exposed to ammonia spills
- Brittle fracture of metals exposed to ammonia spills

The hazards associated with ammonia must be considered at the design and operation stages of ammonia bunkering.

8.1.2.4 Toxicity of ammonia

Human exposure limits to ammonia are defined by legislation and can vary slightly from country to country. They are typically a function of concentrations and exposure time.

The information presented in Table 8-3 delineates the recommended exposure guidance for ammonia concentration in air, highlighting the potential impact it may have on individuals.

Table 8-3 Exposure guidance [Karabeyoglu A, Brian E., 2012]

Effect	Ammonia concentration in air (by volume)
Readily detectable odour	20 – 50 ppm
No impairment of health from prolonged exposure	50 – 100 ppm
Severe irritation of the eyes, ears, nose, and throat. No lasting effect on short exposure, aggravation of existing respiratory problems could occur	400 – 700 ppm
Dangerous, more than a ½ hour of exposure can be fatal	2000 – 3000 ppm
Serious edema, strangulation, asphyxia, rapidly fatal	5000 – 10000 ppm

Based on Acute Exposure Guideline Levels (AEGL) for airborne chemicals defined by the US Environmental Protection Agency (EPA), the limits to ammonia exposure can be identified, as shown in Table 8-3.

AEGLs are used by emergency planners and responders worldwide, including Singapore, as guidance in dealing with infrequent, typically accidental, chemical releases into the air. AEGLS specify particular concentrations of airborne chemicals that may result in health effects. Table 8-4 provides the concentration of ammonia for different AEGL levels.

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

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

AEGL 3: Life-threatening health effects or death.

Table 8-4 EPA acute exposure guideline levels [EPA, 2016]

Ammonia (CAS: 7664-41-7) expressed in ppm					
	10 min	**30 min**	**60 min**	**4 hr**	**8 hr**
AEGL 1	30	30	30	30	30
AEGL 2	220	220	160	110	110
AEGL 3	2700	1600	1100	550	390

Per the Workplace Safety and Health Regulations in Singapore, the PEL of toxic substances listed in the First Schedule, applicable to ammonia, is shown in Table 8-5.

Table 8-5 Permissible exposure levels of ammonia [WSH Regulation, Singapore]

Toxic substance	**PEL (Long Term), ppm**	**PEL (Short Term), ppm**
Ammonia	25	35

8.1.3 Terms and definitions

The following terms and definitions apply to this guideline.

8.1.3.1 Aeration

The introduction of fresh air into a tank to remove the inert gases and increase oxygen content to 21% by volume.

8.1.3.2 Ammonia bunker supplier

A company licensed to supply ammonia bunker to vessels.

8.1.3.3 Ammonia bunkering facility

A bunkering facility is an ammonia storage and transfer installation that might be stationary, shore-based, or mobile, including a bunkering vessel (an ammonia bunker tanker or barge), tank truck, or portable tanks used for containerised ammonia bunkering.

8.1.3.4 Ammonia slip

Amount of unreacted ammonia emitted from control equipment such as electrostatic precipitator, selective catalytic reduction (SCR), or selective non-catalytic reduction process or other similar technologies.

8.1.3.5 Apparent density

The weight per unit volume in air.

8.1.3.6 Authorised party

The company or individual authorised by the relevant authorities to perform the task defined in this guideline under local industry practices and regulatory requirements [SS 648].

8.1.3.7 Back pressure

The pressure existing at the outlet of a pump.

8.1.3.8 Boil-off gas (BOG)

The vapour that is produced above the surface of boiling ammonia or evaporation of ammonia. The boiling is caused by heat ingress into the tank or by a drop in pressure inside the tank.

8.1.3.9 Boil-off rate (BOR)

The quantity of evaporated bunker fuel is expressed as a percentage of the total. The quantity of natural BOG vapour generated (i.e., due to heat ingress into the tank) during a single day, expressed as a percentage of total tank capacity.

8.1.3.10 Boiling liquid expanding vapour explosion (BLEVE)

A sudden release of the contents from a vessel containing a pressurised flammable liquid at a temperature well above its standard (atmospheric) boiling point, followed by a fireball.

8.1.3.11 Boiling point

The temperature at which the vapour pressure of a liquid (which includes liquefied gases) is equal to that of the surrounding atmospheric pressure.

8.1.3.12 Breakaway coupling

An emergency release system consists of a coupling that separates at a predetermined section when required, with each section containing a self-closing shut-off valve that seals automatically. This breakaway coupling will be released upon application of excessive force or through mechanical/hydraulic controls.

8.1.3.13 Bunker delivery note (BDN)

A document provided at the time of delivery by the bunker supplier or its representative specifying the quantities and quality per specifications delivered to the receiving vessel.

8.1.3.14 Bunker measurement ticket

A ticket used to highlight the quantity delivered, measured by a mass flow meter after delivery.

8.1.3.15 Bunker tanker

The bunker tanker supplies ammonia bunker as fuel to the vessel.

8.1.3.16 Bunkering

The process of transferring fuel to a ship.

8.1.3.17 Calorific value

The heat energy in kJ/kg released during fuel combustion [Wartsila Encyclopaedia of Marine and Energy Technology].

8.1.3.18 Caustic

Caustic is the ability to burn or corrode organic tissue by chemical action.

8.1.3.19 Communication failure

Any circumstance that comprises less than two functional modes of communication.

8.1.3.20 Competence

The ability to complete a task successfully with understanding and confidence.

8.1.3.21 Container

Portable tank unit [ISO/TS 18683].

8.1.3.22 Controlled zones

Zones must be defined in advance, for which access levels will differ and be controlled. For example, hazardous, safety, toxic and monitoring zones.

Refer to 8.1.3.43 for the definition of a hazardous zone.

Refer to 8.1.3.60 for the definition of a monitoring zone.

Refer to 8.1.3.73 for the definition of a safety zone.

Refer to 8.1.3.81 for the definition of a toxic zone.

8.1.3.23 Cool-down

The operation to reduce the temperature of a tank to an appropriate temperature and specified pressure at which it is safe to commence loading ammonia into the specific tank per the design specifications.

8.1.3.24 Corrosive

Corrosive refers to the ability to damage or destroy other substances with which it comes into contact through a chemical reaction [Wartsila Encyclopaedia of Marine and Energy Technology]

8.1.3.25 Custody transfer

Formal agreements, the associated legal and other documents related to the transfer of ammonia from the supplier to the receiver.

8.1.3.26 Custody transfer measurement

A document containing the quantity and quality of information during a change in ownership or responsibilities.

8.1.3.27 Dew point

The temperature at which condensation will take place within a gas or vapour mixture as temperature decreases.

8.1.3.28 Dry breakaway coupling

A coupling that separates at a predetermined section at a set breaking load, and in which each section contains a self-closing shut-off valve that seals automatically. When activated, a dry breakaway coupling avoids any spill of liquid or vapour or limits it to a minimum [DNVGL-RP-G105].

Functionalities of dry breakaway coupling include:

- A separation function triggered in sufficient time before reaching the load limit on the bunker connection to separate the line between the supply side and the receiving vessel
- A closing function to close the line at both separation points to prevent the spill of liquid or vapour

8.1.3.29 Duty of care

Employers and owners must take all reasonable steps to mitigate risk while performing any acts that could foreseeably harm the health, safety, and well-being of personnel, property, or the environment.

8.1.3.30 Emergency release coupling (ERC)

The ERC is the breakpoint in a transfer system aimed at minimising risk. The valves close, and the ERC splits in the event of an emergency, interrupting the downstream and upstream flows.

8.1.3.31 Emergency release system (ERS)

A system that provides a quick release of the transfer system and safe isolation between the facility or vessel providing the ammonia and the vessel receiving the ammonia in an emergency, with a minimal product release at disconnection time.

8.1.3.32 Emergency Shut down system (ESD)

A manual and automatic system to shut down the bunkering operation quickly and safely by closing the manifold valves essential to ensure safety which is capable of activating remotely or locally.

8.1.3.33 Failure modes and effects analysis (FMEA)

Failure Modes and Effects Analysis (FMEA) is a systematic, proactive strategy for examining a process to discover where and how failure may occur and the relative effect of different failures to identify where improvements are required.

8.1.3.34 Filling limit

The maximum volume of liquid in a bunker tank relative to the total tank volume when the liquid fuel has reached the reference temperature. (Reference temperature means the temperature corresponding to the vapour pressure of the fuel in a fuel tank at the set pressure of the pressure relief valves)

8.1.3.35 Flammable

Capable of being ignited and of burning. This term is often used synonymously with combustible and inflammable.

8.1.3.36 Flashpoint

Flashpoint refers to the lowest temperature (corrected to a standard pressure of 1 bar_a) at which the application of an ignition source causes the vapours of a liquid to ignite under specified test conditions [GHS Rev.9].

8.1.3.37 Formal safety assessment (FSA)

A structured and systematic methodology aimed at enhancing maritime safety, including the protection of life, health, the marine environment, and property, by using risk analysis and cost-benefit assessment.

8.1.3.38 Gas-free

An atmosphere that has been tested and certified as safe to enter and work in for a specific task. This means that the atmosphere is not deficient in oxygen and is sufficiently free of toxic or flammable gases.

8.1.3.39 Gas-freeing

The removal of toxic, flammable and inert gas from a tank or enclosed space, followed by the introduction of fresh air. This process consists of two distinct operations: inerting and aeration.

8.1.3.40 Gassing-up

Replacing an inert atmosphere in a tank or pipeline with gas vapour.

8.1.3.41 Hazard and operability study (HAZOP)

A hazard and operability study (HAZOP) is a planned and systematic analysis of a complicated plan or operation to detect and evaluate problems that might endanger persons or equipment. A HAZOP aims to analyse and identify design and technical flaws that would not have been discovered otherwise.

8.1.3.42 Hazard identification (HAZID)

The process of identifying hazards for a risk assessment. HAZID examines all hazards representing medium or high risks, considers or identifies accidental releases and spills, and technical and operational safeguards that can reduce those risks. In addition, HAZID determines credible release scenarios for determining safety zones.

8.1.3.43 Hazardous zone

The area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment [DNV-RU-SHIP Pt.6 Ch.2].

8.1.3.44 Hold space

The enclosed space within the ship's structure where ammonia fuel is being stored/loaded

8.1.3.45 Hydraulic shock

Hydraulic shock refers to a sudden localised pressure surge in piping or equipment resulting from a rapid change in the velocity of the flowing liquid, with the potential to cause catastrophic failure of piping, valves and other components.

8.1.3.46 Hygroscopic

Hygroscopic refers to the ability to readily absorb moisture [DNV Ammonia as Fuel pilot report].

8.1.3.47 IGC code

The international code for the construction and equipment of ships carrying liquefied gases in bulk.

8.1.3.48 Inert gas

A gas, or a mixture of gases, with insufficient oxygen to support combustion or human life.

8.1.3.49 Inerting

Introducing inert gas into a space to reduce and maintain the oxygen content at a level at which combustion cannot be supported.

8.1.3.50 Insulating flange

A flanged joint incorporating an insulating gasket, sleeves and washers to prevent electrical continuity between pipelines, hose strings or loading arms [Wartsila].

8.1.3.51 Implementing authority

Refer to the national maritime agency and other relevant onshore safety agencies.

8.1.3.52 Knowledge

Possessing information relating to an event or operation for the operation to be conducted safely and effectively.

8.1.3.53 Linked ESD system

A compatible system transmitting ESD signals from ship to shore or vice versa. Various technologies, such as pneumatic, electric, fibre optic and radio telemetry, have been adopted, but vessels trading worldwide may need more than one.

8.1.3.54 Loading limit

The maximum allowable liquid volume relative to a tank's volume at which the tank may be loaded.

8.1.3.55 Lower explosive/flammable limits (LEL/LFL)

The minimum concentration of a particular combustible gas or vapour necessary to support its combustion in the air. Similarly, UEL/UFL are the upper limits of the flammable range [DNV Ammonia as a Marine Fuel Safety Handbook].

8.1.3.56 MARVS

Maximum allowable relief valve setting.

8.1.3.57 Maximum mass flow rate (Q_{max})

The maximum flow rate to which the mass flow meter has been qualified to operate in compliance with the required accuracy [SS 648].

8.1.3.58 Minimum mass flow rate (Q_{min})

The minimum flow rate to which the mass flow meter has been qualified to operate complies with the required accuracy [SS 648].

8.1.3.59 Minimum measured quantity (MMQ)

The smallest amount of liquid for which the measurement is metrologically acceptable for the mass flow meter [SS 648].

8.1.3.60 Monitoring zone

The zone where activities, including shore-side/marine traffic, should be monitored to ensure they do not encroach on the safety zone.

8.1.3.61 Net positive suction head (NPSH)

The absolute pressure at the suction port of a pump [SGMF competency guidelines].

8.1.3.62 Normal temperature and pressure (NTP)

Defined conditions of a temperature of 20°C (293.15 K) and absolute 1 atmospheric pressure.

8.1.3.63 Person-in-charge (PIC)

The designated individual onboard the bunker supply and receiving vessels responsible for the delivery and transfer of bunkers and bunkering documentation for the respective vessels.

8.1.3.64 Presentation flange

The outboard flange of the reducer or spool piece to which the loading transfer line is connected.

8.1.3.65 Pressure relief valve (PRV)

A generic term applying to relief, safety or safety relief valves. They are all devices that automatically open under excessive upstream static pressure and allow the process fluid to flow until normal pressure has been restored. Still, each has its uses and limitations.

8.1.3.66 Purging

Pumping nitrogen (N_2) into hoses and pipes to replace the oxygen content or existing ammonia gas to prevent combustion/emission.

8.1.3.67 Quantitative risk assessment (QRA)

A systematic and formal method to assess the likelihood and consequences of hazardous occurrences induced by the identified hazards.

8.1.3.68 Ramp down

A gradual decrease in the transfer rate of ammonia bunker from the supplying vessel to the receiving vessel. This process ensures that the flow rate is brought down to the minimum safe rate before stopping the flow or while topping up the ammonia tank on the receiving vessel so that no pressure surge occurs when ammonia transfer is stopped on completion of bunkering.

8.1.3.69 Ramp up

A gradual increase in the transfer flow rate of the ammonia bunker from the supplying vessel to the receiving vessel. This is determined by the receiving vessel and depends on the tank's parameters, manifold pressure and limiting flow rates of the ship's piping system.

8.1.3.70 Re-liquefaction

The process of converting boil-off vapours back to a liquid.

8.1.3.71 Risk assessment

A systematic process of assessing the possible hazards associated with a proposed activity or operation.

8.1.3.72 Safety data sheet (SDS)

A document specifying the substance, its constituents and all necessary information for its safe management by the recipient. Formerly known as Materials Safety Data Sheet (MSDS).

8.1.3.73 Safety zone

The area that extends beyond the hazardous zone, where special precautions are required because of the dangers of ammonia during bunkering operations. This is defined by the IR Injury Contour results from the QRA

8.1.3.74 STS

An operation where an ammonia bunker is transferred between ships moored alongside each other. Such operations may take place when one ship is at anchor or alongside at berth.

8.1.3.75 Ship/Shore Interface

All ship and shore operations relate to fuel transfer, access, mooring and communications.

8.1.3.76 SIMOPS

Operations that run concurrently with the bunkering process, either on land, water, or vessels involved.

8.1.3.77 STCW convention

International convention on standards of training, certification and watchkeeping for seafarers.

8.1.3.78 Stress corrosion

Stress corrosion refers to the growth of crack formation in a corrosive environment. It can lead to unexpected and sudden failure of normally ductile metal alloys subjected to tensile stress, especially at elevated temperatures [Wartsila Encyclopaedia of Marine and Energy Technology].

8.1.3.79 Terminal

The cargo terminal or jetty where bunkering operations occur and where the receiving vessel is berthed.

8.1.3.80 Topping up

The final sequence of an ammonia transfer is to ensure the correct filling level in the receiving tank.

8.1.3.81 Toxic zone

Areas have the potential for toxic atmospheres, which can be harmful to personnel in the proximity, where the probability of having health-affecting concentrations of ammonia vapour is high [DNVGL-RU-SHIP Pt.6 Ch.2]. This is defined by the IR Fatality Contour results from the QRA.

8.1.3.82 Toxicity

The degree to which a substance may cause harm to living organisms.

8.1.3.83 Transfer system

The system connects the bunkering facility and the receiving ship to only transfer ammonia or both ammonia and vapours. It consists of all equipment between the bunkering manifold flange on the facility or vessel providing ammonia fuel and the bunkering manifold flange on the receiving ammonia fuelled vessel. It includes transfer arms, articulated rigid piping, hoses, swivels, couplings, a supporting structure handling system and its control/monitoring system.

8.1.3.84 Underpinning knowledge

The bare minimum of technical or other relevant knowledge and expertise is necessary to safely and effectively perform a task without undue danger or delay.

8.1.3.85 Understanding

Possessing sufficient breadth and depth of knowledge and expertise to make suitable judgments regarding the planning and execution of an operation without jeopardising safety or efficiency.

8.1.3.86 Validation

Confirmation that the requirements for a given, intended use or application have been met by providing objective proof.

Note: The objective evidence needed for validation is the result of a test or other form of determination, such as performing alternative calculations or reviewing documents [ISO 9000].

8.1.3.87 Vapour return

An ammonia vapour return line connecting the bunkering facility and the receiving ship.

8.1.3.88 Venting

The release of ammonia vapour or inert gas from ammonia fuel tanks and associated systems.

8.1.3.89 Warm-up

The operation to increase the temperature of a tank to a temperature at which inerting and aeration can be safely commenced without the risk of condensation forming inside the tank.

8.1.3.90 Water spray

A water spray is a form of mitigation used in the event of a leakage. A water spray can dilute ammonia vapour to a safer level [DNV-RU-SHIP Pt.6 Ch.2].

8.1.3.91 Weighbridge measurement ticket

Print out the truck's weight for pre-delivery and post-delivery of the bunkering operation.

8.1.4 Bibliography

[1] DNV Ammonia as a Marine Fuel Safety Handbook

[2] DNV Ammonia as a Marine Fuel Whitepaper

[3] DNV Ammonia as Fuel pilot report

[4] DNV Ammonia Bunkering of Passenger Vessel - Concept Quantitative Risk Assessment

[5] DNV Comparison of Alternative Marine Fuels

[6] DNV-RU-SHIP Pt.6 Ch.2 DNV Rules of Classification for Ships Part 6 Chapter 2

[7] GHS. Rev.9 Globally Harmonised System of Classification and Labelling of Chemicals

[8] IGC Code International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

[9] ISO 9000 Quality Management systems - Fundamentals and vocabulary

[10] ISO/IEC Guide 99 International vocabulary of metrology - Basic and general concepts and associated terms (VIM)

[11] ISO/TS 18683 Guidelines for systems and installations for the supply of LNG as fuel to ships

[12] Linde Safety Datasheet for Ammonia

[13] MESD CoE Ammonia bunkering – simulation of hypothetical release scenarios in Singapore

[14] SS 648 Code of Practice for Bunker Mass Flow Metering

[15] Wartsila Encyclopaedia of Marine and Energy Technology

8.2 PART 2: REQUIREMENTS FOR CUSTODY TRANSFER

8.2.1 Scope

This section addresses the requirements for custody transfer during ammonia bunkering operations. Custody transfer involves ensuring knowledge of the contents, including quality and quantity measurements, that are loaded from the bunkering facility onto the receiving vessel to ensure consistency and reliability of the energy value transferred. These guidelines apply to various transfer modes such as SHTS, truck-to-ship, STS, and cassette bunkering.

8.2.2 Normative standards

The following referenced documents are integral to the application of this guideline.

OIML R76	Non-automatic weighing instruments
OIML R117-1	Dynamic measuring systems for liquids other than water – Part 1: Meteorological and technical requirements
ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories
ISO 22192	Bunkering of marine fuel using the Coriolis mass flow meter (MFM) system
ISO 19230	Gas analysis — Sampling guidelines
ISO 18132-3	Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — General requirements for automatic tank gauges — Part 3: Automatic tank gauges for liquefied petroleum and chemical gases onboard marine carriers and floating storage
ISO 7105	Liquefied anhydrous ammonia for industrial use — Determination of water content — Karl Fischer method
ISO 7106	Liquefied anhydrous ammonia for industrial use — Determination of oil content — Gravimetric and infra-red spectrometric methods
ISO 7066	Assessment of the uncertainty in the calibration and use of flow measurement devices

8.2.3 Terms and definitions

The terms and definitions in Part 1 apply to this guideline.

8.2.4 Properties of ammonia

Refer to Part 1 for ammonia's general properties, characteristics, and hazards.

8.2.5 Ammonia quantity measurements

The amount of ammonia transferred is calculated from measures before and after the transfer. The following elements shall be measured and reported in the Bunker Delivery Note (BDN) to ascertain the energy content of the bunker(s) transferred:

(a) Lower calorific (heating) value, higher calorific (heating) value and density

(b) Mass of bunker(s) transferred

The PIC (refer to Part 3 Section 7.3.8.1 for PIC roles and responsibilities) shall be accountable for the accuracy of the BDN. Refer to Annex B for the BDN.

8.2.5.1 Density and calorific value

The density and calorific value of transferred ammonia can be obtained by conducting gas chromatographic analyses through the continuous or discontinuous sampling of ammonia in the ammonia transfer line(s) between the ship and the terminal. During bunkering, ammonia sampling should be conducted on the ammonia transfer line(s) before possible flashing (vaporisation) in the ship's bunker tanks. The sampling details are explained in Annex C. Some parameters, such as pressure, gas composition and temperature, are constant for custody transfer surveys before and after bunkering.

The calculations will be based on the following:

(a) Its average temperature and density

(b) The characteristics of elementary components (GCV, molar volume, molar weight) are given by reference tables or standards for the gross calorific value. Refer to Annex A for the calorific value calculation procedure

8.2.5.2 Mass of the bunker transferred

Depending on the mode of transfer, the ammonia supplier shall use (but not limited to) any of the following methods to assess the quantity of bunker(s) supplied:

(c) Quantity measurement using a weighbridge

(a) Quantity measurement using a Coriolis Mass Flow Meter (MFM)

(b) Quantity measurement using a Ultrasonic volumetric flow meter (VFM)

(c) Quantity measurement using a Custody transfer measurement system (CTMS)

The bunker calculations shall be performed by the PIC of the bunker vessel and the receiving vessel or their authorised representatives (when engaged), such as bunker surveyors. Otherwise, an automated bunker metering system could calculate the quantity delivered.

The PIC onboard the bunker supply vessel must complete the BDN, and the Chief Engineer or their representative onboard receiving vessel observe and validate all calculations and measurements related to the computation of the supplied quantity in the BDN.

Users of quantity measuring equipment shall guarantee that the equipment and all related devices are correctly operated and maintained to fulfil the specifications outlined in this guideline.

The supplier of the ammonia bunker shall maintain a standard operating procedure that includes, but is not limited to, the following:

(a) Operational procedures to ensure the quantity measurement equipment and all associated devices are correctly operated

(b) Re-calibration criteria for quantity measurement equipment, including re-calibration frequency and intervals and traceability to the International System of Units (SI) via a national primary standard maintained by a National Metrology Institute (NMI). This ensures that the quantity measurement equipment complies with this guideline's maximum permissible error (MPE) requirements

(c) Regular inspections of the quantity measurement system and all associated devices, if applicable, to ensure they are in proper working order

(d) Future ISO standards or internationally accepted guidelines that present new quantity measurement methods and procedures may also be considered

Quantity measurement using a weighbridge (for truck-to-ship)

Weighbridges used for trade measurement must be validated annually and secured with a seal by parties authorised by the national authority for weights and measures. Utilising a weighbridge with a broken or altered verification seal shall be prohibited.

Before commencing quantity measurements with a weighbridge, the following conditions on the field shall be met:

(a) Carry out measurements per standard operating procedures

(b) Refrain from using the weighbridge if its performance is uncertain

(c) Maintain proper housekeeping of the weighbridge platform at all times

(d) The space between the platform and frame shall be always kept clear from obstructions, and

(e) Complete gross and tare measurements within 24 hours (if applicable)

When using a weighbridge, the following procedure shall apply to ascertain the net mass of ammonia transported from truck-to-ship:

(a) Before the commencement of measurement, inspect the weighbridge to guarantee that there are no foreign bodies on the weighing platform

(b) Set the weighbridge to zero

(c) Drive the truck towards the weighbridge gradually and gently advance onto the platform

(d) Make sure that the truck is fully supported by the weighing platform with all its tyres resting within the platform

(e) Turn off the engine and leave the weighing platform

(f) Weigh the loaded truck and mark its gross weight based on the bunker measurement ticket machine (before delivery)

(g) After delivery of the bunker, weigh the truck and mark its gross weight based on the measurement ticket machine (after delivery), and

(h) Two measurements—before and after delivery—are necessary to calculate the net amount of ammonia delivered. The net mass of transferred ammonia is represented by the difference between the two gross masses and will be recorded on the BDN

Quantity measurement using a Coriolis MFM

The Coriolis MFM used for commercial measurement must be validated and sealed by parties authorised by the national authority for weights and measures. A Coriolis MFM with a broken or tampered seal shall be prohibited.

Before installation, the Coriolis MFM shall be calibrated at the required flow rate to verify that the error for ammonia measurement is below 1%, in line with OIML R117-1, before it can be used for ammonia bunkering. The calibration shall be traceable to the SI via national primary standards managed by an NMI. The calibration report shall be issued by an NMI or a laboratory accredited by the Singapore Accreditation Council or its Mutual Recognition Agreement (MRA) partners, according to ISO/IEC 17025.

There shall be a letter/certificate stating that the meter performance achieves the 1% or better meter accuracy requirement for measuring systems that fall under the OIML R117-1 accuracy class of 1.5. The supporting document(s) include, but are not limited to, type evaluation certificates for regional directives (e.g., EC/EU Type examination) and reports undertaken as part of the process to obtain these types of evaluation certificates.

The letter with its relevant supporting documents and test report(s) should be issued by either:

(a) An NMI that has an MRA with Singapore's National Metrology Institute, or

(b) An appointed OIML issuing authority for OIML R117 under the OIML certification system that is accepted by the legal metrology authority

Fast-block valves for zeroing on-site shall be installed on both sides of the Coriolis MFM. Between the fast-block valves, a pressure relief device shall be placed. During the zeroing procedure, the conditions of zero flow and the Coriolis MFM filled with ammonia shall be met.

After verification of the zero verification results, the Coriolis MFM shall be sealed by parties approved by the national weights and measures authority for ammonia bunkering custody transfer measurement.

The Coriolis MFM's zero conditions shall be validated annually to guarantee that the MFM is stable and meets the MPE of 1%.

To prevent or minimise flashing, it is recommended that the difference between the discharge pressure and the vapour pressure (at the fluid temperature) be at least three times the pressure drop across the meter. Considering the meter's minimum flow rate (Q_{min}), increasing the meter size may lower the pressure drop. In addition, increasing static pressure or decreasing process temperature may help compensate for pressure drop and prevent flashing.

A functional field test may be required to determine the optimal process control to prevent boil-off from entering the Coriolis MFM.

The following field conditions shall be met before the beginning of a quantity measurement using a Coriolis MFM:

(a) Conduct measurements following standard operating procedures

(b) Cool the pipework or hydraulic circuit and the Coriolis MFM to reach the liquid temperature. Keep the temperature stable and maintain this sub-cooled temperature for at least 15 minutes before the start of measurement

(c) Ensure a progressive temperature decline to avoid excessive stress on the Coriolis MFM

(d) Verify that the Coriolis MFM has adequate thermal insulation to maintain the operating temperature

(e) Ensure that the Q_{min}, maximum flow rate (Q_{max}) and minimum measured quantity (MMQ) of the Coriolis MFM are fulfilled

The following procedure shall be followed to determine the net mass of ammonia delivered using a Coriolis MFM:

(a) Inspect the Coriolis MFM system to ensure that the pipeline and bypass are secured and that the meter, computer, indicator, pipeline and valves are in good working order and are protected against unauthorised tampering and adjustment before the commencement of measurement

(b) Reset the totaliser of the Coriolis MFM

(c) Minimise stress on the Coriolis MFM caused by the pipeline

(d) Commence ammonia bunker delivery to the receiving vessel

(e) Monitor the discharge pressure and ensure that the delivery is in a single-phase flow condition during the transfer

(f) Make sure the operating flow rate falls within the calibrated Q_{min} and Q_{max} range

(g) Ensure the liquid temperature in the Coriolis MFM falls within the minimum and maximum temperatures recommended by the meter vendor

(h) To prevent flow fluctuations, maintain sufficient and stable back pressure with proper control during the bunkering delivery

(i) After ammonia delivery, read the totaliser of the Coriolis MFM and the reading from the gas flow meter in the vapour line and print out the bunker measurement ticket, and

(j) Indicate the unit of delivery quantity as a mass in a vacuum

Quantity measurement using an ultrasonic VFM

The ultrasonic VFM utilised for trade measurements must be validated and sealed by parties authorised by the national authority for weights and measures. It is prohibited to use an ultrasonic VFM with a broken or tampered seal.

Before installation, the ultrasonic VFM must be calibrated to ensure that the error for measuring ammonia is below 1%, in line with OIML R117-1. The calibration shall be traceable to the SI via the national primary standards managed by an NMI. The calibration report shall be issued by an NMI or laboratory accredited by the Singapore Accreditation Council or its MRA partners according to the ISO/IEC 17025.

Ultrasonic VFMs are used for measuring the velocity of a liquid. For ammonia, it is acceptable to calibrate an ultrasonic VFM using an alternate fluid if the meter vendor can demonstrate the uncertainty of the velocity measurements, geometric parameters, and corrosive resistance of the material and the hydraulic effects are within acceptable limits for the application according to ISO 7066. Timing measurements, time delay corrections, and cross-sectional area are the fundamental inputs of an ultrasonic VFM. Fluid properties do not significantly affect timing measurements if an acceptable signal-to-noise ratio is maintained per the vendor's recommendation. In addition, changes to a meter's geometry caused by operation at colder temperatures may be corrected for ammonia use.

Leak-proof valves for the ultrasonic VFMs should be used to prevent ammonia leaks from the piping system, protecting personnel and the surrounding area.

The ultrasonic VFM's zero conditions shall be validated annually to ensure that it is stable enough to meet the MPE of 1%. However, the influence on zero-offset from changes, including colder conditions or mechanical stress on the meter, is negligible since ultrasonic VFMs utilise time differences for calculations. Similarly, pipe stress and torsion influence are negligible as ultrasonic VFMs have robust metal bodies.

Quantity measurement using a CTMS

Where a CTMS is fitted, references from ISO 10976 or an equivalent shall apply. For most vessels, gauging is automated via the bunker supply vessel's CTMS. The following procedure shall apply to determine the quantities of ammonia transferred during bunkering.

Before such systems are entered into service, an independent ISO/IEC 17025 accredited party should certify the calculation, including corrections and gauge tables programmed into the system, as accurate.

Modern CTMSs typically comprise two parts:

(a) The tank gauging system providing corrected tank levels, temperatures, and pressures, and

(b) Workstation(s) and peripherals, usually located in the ship's bunker control room for volume calculation and report generation

Frequent measurements are recommended, and data can be averaged for improved readings.

The CTMS measures the ammonia levels in each bunker tank and converts them into corresponding volumetric measures while correcting for trim, list and temperature differences. Then, the volumes for all individual bunker tanks are added up.

Modern CTMS produces three printouts:

(a) "Before bunkering" bunker tanks status

(b) "After bunkering" bunker tanks status, and

(c) a "Certificate of Bunkering", a third printout following the "After bunkering" status, containing a summary of the general parameters of the first two statuses and volume transferred (volume difference between the statuses)

Data should only be transmitted to the CTMS from other systems if it is part of the certified arrangement.

Data integrity should be maintained via the following methods:

(a) Instruments are to be connected directly to the system

(b) Computers (PC, process controllers), data communication links (serial, network) and peripherals (screens, keyboards, printers) should not, in general, be shared with other applications

(c) A copy of the calculation software may be hosted on a shared workstation as a backup to the primary system

Summary of requirements for quantity measurement equipment

Table 8-6 below sets out the MPE, type approval and pattern registration for quantity measurement using a weighbridge, Coriolis MFM, ultrasonic VFM and CTMS. It is the user's sole responsibility to determine through verification whether a recalibration must be carried out. To achieve an acceptable level of confidence that the MPE of the system between successive verifications is not exceeded, the user should consider the stability of the measuring system and operational conditions.

Periodic calibration of ammonia quantity measurement equipment by a competent individual is required to assure precision and traceability to the SI via national primary standards maintained by an NMI, with the issuance of a calibration report.

Table 8-6 Summary of requirements for quantity measurement equipment

	Applicability	**Maximum Permissible Error (MPE)**	**Type Approval and/or Pattern Registration**
Weighbridge	Truck-to-ship	Per OIML R76	Instrument type shall be pattern evaluated per OIML R76
Coriolis MFM	SHTS STS	Per OIML R117-1	Instrument type shall be pattern evaluated per OIML R117-1
Ultrasonic VFM	SHTS STS	Per OIML R117-1	Instrument type shall be pattern evaluated per OIML R117-1
CTMS	SHTS STS	Per ISO 18132-3	Instrument type shall be type approved per ISO 18132-3

8.2.5.3 Full discharge for truck-to-ship delivery

When a full discharge of ammonia from the ammonia bunker supplier's truck is conducted, the delivered quantity can be based on the measured amount of ammonia loaded onto the truck at the loading facility.

8.2.6 Ammonia Quality Measurement

Measuring the quality of ammonia requires knowledge of its composition and the sampling and analysis of its components. The composition of ammonia can be determined by way of gas chromatography (GC) utilising a vaporiser while in a gas phase or a Raman analyser while in a liquid phase.

(a) The ammonia bunker supplier and buyer's must provide written consent regarding the bunker parameters. The ammonia bunker supplier must supply bunker(s) of quality according to the specifications agreed upon between the ammonia bunker supplier and buyer

(b) The certificate of quality issued by the ammonia bunker supplier(s) should be representative of the bunker(s) delivered

(c) Retained samples for ammonia bunker operations are unnecessary if a certificate of quality, as stated above, is provided unless otherwise requested by the relevant authorities or between the ammonia bunker supplier and buyer

(d) Information about ammonia sampling and quality measurement can be found in Annex C and D

(e) A competent person must calibrate the ammonia quality measurement equipment periodically to ensure precision and traceability to the SI through national primary standards maintained by the NMI with the issue of a calibration report

(f) Refer to Annex D for details on the validation and calibration of quality measurement equipment

(g) The degree of heel required to ensure ammonia quality for succeeding deliveries and maintaining tank temperature should be considered for truck-to-ship and STS operations

(h) Future ISO standards or internationally accepted guidelines that present new quality measurement methods and procedures may also be considered

8.2.6.1 Ammonia quality measurement in a gas phase

Re-gasified ammonia samples can be analysed using GC to determine their composition, enabling their energy content to be calculated. Direct measurement methods, such as a calorimeter, are less precise and cannot provide the useful compositional information needed to calculate other properties, such as density. The arithmetic average of the online GC analyses or the average composition of the gas chromatographic analyses of the spot samples should determine the molar composition of ammonia.

All classical techniques used to determine the composition of gas mixtures can be directly applied in the case of regasified ammonia. To obtain accurate measurements of the (un)loaded ammonia and the analysis results, the ammonia sample must be vaporised and conditioned properly.

Examples of arrangements that can used include:

(a) A chromatograph with 2 or 3 columns to separate the components selectively, or

(b) Any modern chromatographic equipment that meets the precision statements for all components to be measured in the ISO, ASTM, GPA or IP methods. A typical refinery gas analyser will fulfil these requirements

8.2.6.2 Ammonia quality measurement in a liquid phase

The Raman analyser is a valuable tool to measure ammonia composition during the liquid phase. Raman spectroscopy uses monochromatic light to excite and identify the vibrational modes of molecules and determine the sample's composition by analysing the frequency and intensity of the scattered light. The scattering interaction is so short-lived that the measurement is independent of the flow rate of the sample. The technique is viable for all phases of matter and may be effectively used on mixed-phase samples. Since the intensity of scattered light depends on the number of molecules participating, the best results are achieved with solids, liquids and high-pressure gases. The applicable concentration range for this standard is 200 ppmv to 100 mol%.

The detection module of a Raman analyser incorporates a spectrograph, which detects photons of varying wavelengths to distinct CCD detector pixels. The CCD pixels transform photons into digital signals whose value is proportional to the number of photons. Additionally, a spectrum is produced, representing a histogram charting the number of photons observed at each wavelength and proportionate to the number of molecules with specific vibration frequencies. Finally, the spectra can be mathematically processed to yield the liquid’s molecular composition.

Generally, a laser with a wavelength of 785 nm has been found to work well. Still, other lasers with wavelengths ranging from 500 to 800 nm may also be suitable, provided the detector has been thoroughly validated. The laser should also be compatible with explosive atmosphere safety (see EN 60079-28) and eye safety (see EN 60825-1). This typically includes an interlocking power system with remote capabilities, a redundant power-monitoring system, and a visual operation indicator light system.

By taking spectra of known samples, correlations between spectra and sample species are formed during the development of the analytic method. As long as the Raman spectra are valid, this approach will accurately quantify sample concentrations due to the inherent linearity of the Raman effect. Before the analyser is commissioned, the primary task for ensuring analyser calibration is to calibrate and standardise the spectra. In addition, there needs to be a way to ensure this calibration remains valid over time by using validation approaches.

The Raman spectrums of verified reference materials can be utilised for validation and calibration. Samples of certified reference materials should include gravimetrically established percentages to be measured during the analyser operation.

8.2.6.3 Summary of fuel quality requirement

Table 8-7 summarises the fuel composition limits adopted by a typical ammonia engine maker.

Table 8-7 Sample fuel composition limits by a typical ammonia engine maker

Designation	Unit	Limit	Value	Test Method Reference
Ammonia	% (w/w)	Min.	100	See note [2] below
Water	% (w/w)	Min.	0.1	ISO 7105
		Max.	0.5	
Oil	% (w/w)	Max.	0.4	ISO 7106
Oxygen	ppm (w/w)	Max.	2.5	See note [2] below

Note:
Latest edition to be applied. ISO standard methods are the highest level of international methods and are recommended. Other equivalent standards may apply.
[2] No specific ISO standard is available. Conventional test methods such as gas chromatography and the Raman analyser can be used.

8.2.7 Documentation

8.2.7.1 General

A complete bunkering operation shall include the following documentation:

(a) BDN (refer to Annex B)

(b) Note of protest related to quantity, if applicable, and/or

(c) A written complaint regarding quality, if applicable

Before using any measurement equipment for custody transfer, the ammonia bunker supplier shall provide the following documents to the implementing authority:

(a) Type evaluation certificates/reports per Table 8-6

(b) Registered type/pattern evaluation certification issued by the national weights and measures authority, if applicable, and

(c) Relevant calibration certificate/reports

Appropriate documentation, such as equipment calibration reports/certificates and custody transfer documentation, shall be preserved for at least five years and provided to the implementing authority upon request.

8.2.7.2 BDN

The BDN shall contain the information specified in Annex B. The PIC on board the bunker vessel shall prepare the BDN for the Chief Engineer on board the receiving vessel to sign and acknowledge upon completion of delivery.

The BDN shall include the name and valid ammonia bunker supplier licence number of the licensed ammonia bunker supplier. All relevant and applicable columns of the BDN shall be filled in, and "NA" (or "Not Applicable") shall be placed in that column.

If there are any cancellations or amendments to the BDN, the PIC and Chief Engineer shall endorse and stamp them. The PIC and Chief Engineer shall sign one original and at least two copies of the completed BDN, with their names printed and stamped with the ammonia bunker supplier and vessel stamps.

A copy of the bunker measurement ticket shall be appended to the BDN (see Annex B for a sample BDN). If the certificate of quantity issued by the loading facility is available, it can serve as the bunker measurement ticket for truck-to-ship delivery with full discharge.

8.2.8 Dispute resolution

8.2.8.1 Quality dispute

In case of any dispute regarding the quality of the bunker(s) delivered, the vessel/buyer should submit a written complaint to the ammonia bunker supplier. This shall be done within three days upon completion of bunkering operations.

A copy of the written complaint and a copy of the BDN shall be simultaneously lodged with the "Executive Director, Singapore Shipping Association" and the implementing authority.

8.2.8.2 Quantity dispute

In case of any dispute regarding the quantity of bunker(s) delivered, the vessel/buyer should submit a Note of Protest to the ammonia bunker supplier. This shall be done within three days upon completion of bunkering operations.

A copy of the Note of Protest and a copy of the BDN shall be simultaneously lodged with the "Executive Director, Singapore Shipping Association" and the implementing authority.

8.2.8.3 Dispute resolution procedures

The Singapore Bunker Claims (SBC) terms shall apply to all disputes arising out of or in connection with any contract for the sale and/or supply of bunkers where the parties involved expressly provide for or submit their dispute for arbitration under the SBC terms.

Annex A: ENERGY VALUE CALCULATION

Ammonia quality measurements are needed to obtain the ammonia composition for calorific value computation. The lower and higher calorific value (LCV, HCV) and the density can be computed based on the composition of the gas and the reference data. The use of lower or higher calorific values for energy content calculation shall be agreed upon between the ammonia bunker supplier and buyer.

The LCV and HCV can be calculated in several ways. For example, the LCV and HCV can be calculated using the formula:

$$LCV = \frac{\sum X_i M_i LCV_i}{\sum X_i M_i}$$

$$HCV = \frac{\sum X_i M_i HCV_i}{\sum X_i M_i}$$

The energy of the transferred ammonia can be calculated as such:

$$E_H = M\ X\ HCV_i$$
$$E_L = M\ X\ LCV_i$$

The density of the ammonia loaded shall be calculated as

$$d = \frac{\sum (X_i \times M_i)}{\sum (X_i \times V_i)}$$

where,

X_i	=	molar fraction of component i
M_i	=	molecular mass of component i, expressed in g/mol
V_i	=	molecular volume of component i, expressed in m^3/mol
d	=	total density, expressed in g/ m^3
E	=	energy, expressed in kJ
M	=	measured mass of the delivered ammonia in a vacuum, expressed in kg
LCV_i	=	mass lower calorific value of component i, expressed in kJ/kg
HCV_i	=	mass higher calorific value of component i, expressed in kJ/kg

ASTM 3588: The standard practice for calculating heat value, compressibility factor, and relative density of gaseous fuels may be used to provide tables of physical constants and methods of calculating factors necessary to determine the LCV, HCV and density.

The physical constants HCV_i, LCV_i and M_i are specified in coherent standards.

Annex B: AMMONIA BUNKER DELIVERY NOTE

(BUNKER SUPPLIER'S NAME) BDN NO. ____________

(BUNKER SUPPLIER'S ADDRESS AND TELEPHONE NUMBER)

(LICENCE NO.: ___________)

BUNKER DELIVERY NOTE

Port : ______________
Delivery location : ______________
Bunker tanker IMO no./
Truck no. : ______________
Alongside vessel : ______________
Commenced pumping : ______________
Completed pumping : ______________

PRODUCT SUPPLIED

Ammonia properties			Ammonia Composition		
Lower calorific (heating) value	MJ/kg		Ammonia	%(wt/wt)	
Higher calorific (heating) value	MJ/kg		Water	%(wt/wt)	
Density at ammonia temperature delivered*	kg/m^3		Oil	%(wt/wt)	
Vapour pressure after delivery*	$mbar_a$		Oxygen	%(wt/wt)	
Vapour temperature after delivery*	ºC				
Ammonia temperature delivered*	ºC				

* Write "NA" if not applicable.

QUANTITY

Net total delivered

____________MT ____________m^3

SUPPLIER'S CONFIRMATION	**MASTER'S/CHIEF ENGINEER'S ACKNOWLEDGEMENT**
We declare that the bunker fuel supplied confirms the quantities stated For ____________ Company's name and stamp ____________ Signature of PIC ____________ Full name in block letters ____________ Bunker tanker's/truck's stamp	We acknowledge receipt of the above product in the quantities stated. I confirm having received a copy of the IMO Safety Data Sheet. ____________ Signature of Master/Chief Engineer/Time ____________ Full name in block letters ____________ Vessel's stamp

REMARKS____

Was any note of protest issued? Yes/No For MPA's purposes The following rating is our satisfaction level with the bunkering operations (Please circle) 1_______2_______3_______4_______5 ________________________ Very Very Signature of Master/Chief Engineer Unsatisfied Satisfied

Annex C: SAMPLING OF AMMONIA

Ammonia can be sampled in a gaseous phase with a vaporiser and measured by the GC system. Ammonia can also be measured in liquid form via an inline analyser. The choice of sampling or measurement method should be agreed upon between the ammonia bunker supplier and the buyer. The operating parameters of the sampling device (pressure, temperature, flow rates) should be kept as constant as possible throughout the sampling period to allow for representative and repeatable sampling. It is necessary to condition the fluid sampled from its initial state, liquid at low temperature, to a final state, gas at ambient temperature, without partial vaporisation or loss of product.

A sampling of ammonia includes three successive operations:

(a) taking a representative sample of ammonia

(b) complete and instant vaporisation, and

(c) conditioning the gaseous sample (e.g., ensuring a constant temperature and pressure) before transporting it to the analyser and/or sampler

Sampling is the most critical point of the ammonia measurement chain. The process must be carefully taken to ensure the sample composition is not altered. The sampling system is not changeable during bunkering. Some operators have a backup sampling system to ensure sample collection in the event of failure of the main system.

Note that spot sampling described below has become almost obsolete for Custody Transfer System (CTS) measurements. It is therefore recommended to use this only as a backup in case of failure of the primary device. The sampling processes currently used in the ammonia industry comprise mainly continuous and intermittent sampling, as defined in ISO 8943. The terms continuous and discontinuous sampling is related to the analysis of gaseous ammonia, that is, after evaporation of the sampled liquid stream. Ammonia sampling systems sample ammonia continuously.

For GC analysis, it is recommended that ammonia should be sampled when the transfer flow rate is sufficiently stabilised. It is necessary to exclude the final period when the ammonia flow rate begins to decrease before stopping completely. When significant changes in pressure or flow rate occur in the transfer line, it is imperative to temporarily suspend sampling. Sampling should only be conducted with a stable bunkering flow rate.

It is recommended to install the sampling/testing point as close as possible to the custody transfer point to ensure that the characteristics of ammonia are not altered before the actual transfer due to potential heat input. In general, the influence of heat is limited when the flow does not vary too much in a properly insulated main bunkering line.

The sampling point is generally located on the main bunkering line after the ammonia is pumped out.

In addition, it is recommended that sample condition equipment (lines, containers, etc.) are purged.

Before sampling starts,

(a) Introduce ammonia by vaporising and circulating the ammonia in the vaporiser and pipework

(b) Subsequently, purge the gas into the atmosphere (small gas flow rate) or to the boil-off gas handling system of the plant

Before filling the gas sampling container,

(a) Connect the container(s),

(b) Successively fill and empty each container (3 times or more) before any gas sample is collected

(c) Isolate and remove of the container(s)

The sampling system should be in service between operations to ensure that the equipment is continuously purged and ready for a new sampling with the same operating parameters.

C.1 Sampling of ammonia (Vaporisation)

For the composition analysis, a sample of ammonia is extracted from a gaseous state and subsequently vaporised. The sampling of ammonia for analysis should be performed in accordance with the procedures in ISO 19230 (Gas analysis – Sampling guidelines) or an equivalent national standard.

The conditions of the system (flow temperature and pressure) must be stable during sampling, and the sampling point should be as close to the custody transfer point as possible. Sudden changes in gas offtake affecting the gas flow should be avoided as they can cause the gas to fractionate, leading to improper sampling and fluctuations in the measured heating value.

A large gas holder (usually between 0.5 and 1 m^3) may store a representative portion of vaporised ammonia during the transfer operation. The gas characteristics contained after completion and mixing represent the un(loaded) characteristics of ammonia. These gas holders can be of two types:

(a) water-sealed, the sealed water is saturated with gas by bubbling regasified ammonia through it before filling the holder, or

(b) waterless, with a bladder in the gas holder and a vacuum pump

Some common sampling methods include:

(a) <u>Direct piping to a gas analyser</u>

During the bunkering process, a GC is directly connected to the vaporiser outlet to perform subsequent analyses. In this instance, a pipe (compatible with ammonia) with a small diameter directly connects the vaporiser outlet to a manifold at the inlet of the gas analyser. Fittings, regulators, valves, and flow meters ensure consistent flow and pressure. The pressure drop in the gas line may necessitate using a gas compressor.

(b) <u>Spot sampling</u>

During the bunkering process, gas sample containers are directly connected to the outlet of the vaporiser unit, and regasified ammonia is periodically pumped into a properly purged sample container. Each gas sample container should be at least 500 cm^3 in volume. When gas samples are retrieved during the ammonia transfer, it should be done at regular intervals, depending on the characteristics of the transfer lines and equipment, the organisation of operation in the plant, and the duration of gas sample analysis, etc. For example, the standard practice for spot sampling is to take samples at only three events - 25%, 50% and 75% of bunkering operations.

(c) <u>Continuous sampling</u>

This sampling process involves a continuous collection of ammonia from the ammonia flow line during bunkering operations, possibly through a booster or vacuum pump. After that, the regasified ammonia from the vaporiser is continuously fed into the gas sample holder. Finally, gas sample containers are filled with the mixed gas from this gasholder after completion of the sampling process for offline analysis.

(d) <u>Discontinuous sampling (referred to as intermittent by ISO 8943)</u>

This sampling process also involves a continuous collection of ammonia from the ammonia flow line during (un)loading (bunkering) operations. However, the regasified ammonia from the vaporiser is partly directed to an online GC and partly into a constant pressure floating piston (CP/FP) sample container (definition according to ISO 8943). The total amount of such portions depends on the transfer flow and the amount of ammonia cargo transferred. In this case, the sample holder generally has a volume between 500 and 1000 cm^3. A CP/FP sample container can maintain constant pressure from the process line into the gas cylinder during gas sampling. The gas sample collected in the CP/FP sample container is for offline analysis.

(e) <u>CP/FP sample container</u>

CP/FP sample containers are directly connected to the outlet of the vaporiser unit. Re-gasified ammonia is fed at specified intervals into a CP/FP sample container during the bunkering process with a piston sampler. Each CP/FP sample container should have a minimum volume of 500 cm^3.

C.2 Measurement in the liquid phase (Raman spectroscopy)

Ammonia can also be measured directly in a liquid state and analysed inline using spectroscopic techniques such as Raman spectroscopy. Eliminating the vaporisation steps significantly improves the analysis of ammonia quality, as the incorrect operation of ammonia vaporisers can lead to inaccuracy.

The most basic Raman analyser consists of a laser and spectrograph, and a processor to operate them. The laser must be sufficiently stable to allow the shift in light to be consistently measured, and powerful enough to deliver close to the maximum allowable optical power to the probe tip. The spectrograph must also be capable of measuring the frequency and intensity of light to great precision. Since Raman scattering is a non-contact and non-destructive technique, calibration may be accomplished without custom gas or liquid samples. An instrument is calibrated by characterising the laser's wavelength and intensity and the spectrograph's sensitivity. This can be accomplished with stable physical references such as neon gas or diamond crystals. The potential of Raman scattering as an analytical technique for ammonia is in its ability to measure a liquid directly without a change into a gas. Therefore, this technique is unsuitable for trace analysis of components such as sulphur.

Measuring the volume of fractions of individual molecular species contained in a liquid stream of interest, such as ammonia, is accomplished by obtaining and analysing a Raman spectrum observed through an optical probe inserted into a product stream. The sample probe interfaces with the fibre cable to the sample stream. It should be made of materials compatible with the sample stream and capable of maintaining stable optical performance in cooler temperatures. The probe contains a hermetically sealed window separating the optics from the sample stream. The probe has a small sapphire window at the tip to allow the incident laser light and scattered light to pass to the analyser. The primary functions of the probe are removing the Raman signal generated by the laser light travelling through the excitation fibre (which would contaminate the sample spectra), imaging the laser light into the sample, superimposing an image of the collection fibre onto the illuminated sample volume, removing the majority of the unshifted laser light before leaving the probe, and efficiently delivering the excitation light into and collecting the Raman signal out of the stream to be measured.

The characteristics of the probe are as follows:

(a) The probe must be designed to operate at low temperatures with no loss of function to the enclosed optics

(b) The probe tip should be mounted on the pipe or vessel carrying the liquid to be measured and positioned into the flow for at least two inches or 10% of the pipe diameter from the pipe wall or container to ensure representative sampling

(c) The probe should be mounted according to the manufacturer’s recommendation. The temperature and pressure conditions should be such to ensure that the sample is in a liquid state

(d) The probe should be engineered to be within fatigue limits of expected vortex shedding, included vibrations. The probe window and housing structure should be designed to withstand the expected pressure and temperature of the sample being measured with a reasonable margin of safety

(e) The probe should be installed to eliminate explosion hazards if an explosive sample mixture is present. This is accomplished either by limiting the laser’s power to a level below that which can cause ignition or by employing an interlock, in which a physical switch turns off the laser when it detects that the liquid level will fall below the probe

Monochromatic light from a laser is directed down a fibre-optic cable via a sample-compatible probe and into the liquid to be measured. By interacting with the molecules of the liquid via the Raman effect, monochromatic photons produce new photons whose wavelengths have been shifted following the vibration frequencies of the molecule. These new, shifted photons are collected and directed down a separate fibre connected to a detection module. The liquid sample should not contain any vapour or bubbles. While the instrument should tolerate some bubbles, an excessive number will decrease the signal to the point where precision would be compromised, and the instrument software should send an alert.

Annex D: EQUIPMENT CALIBRATION FOR QUALITY MEASUREMENTS

D.1 Gas chromatography (gas phase)

The GC analyser system should be calibrated or validated before and after each bunkering operation. If validation fails, a recalibration is required. There are two possibilities:

(a) Type 1 analysis: The analysis first determines the response functions through a multi-point calibration using several calibration standards, followed by a regression analysis. These response functions are then used to calculate component mole fractions. Type 1 analyses do not have non-linearity errors

(b) Type 2 analysis: The analysis assumes a linear response function, and the subsequent sample analysis is carried out against routine calibrations using a single calibration standard. Because the assumed response function could differ from the true one, type 2 analyses can have non-linearity errors, which should be evaluated using a multi-point performance evaluation per ISO 10723

Calibration is carried out with the following:

(a) Certified reference gas mixtures (CRMs) – a reference gas mixture characterised by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty and a statement of metrological traceability. Such CRMs should be traceable to a primary ammonia mixture standard prepared by an NMI using the gravimetric method

(b) Working measurement standard (WMS) – a measurement standard that is used routinely to calibrate or verify measuring systems

The preparation and certification of the CRM and WMS should be performed according to standards such as ISO 6142 and ISO 6143, respectively.

The calibration gas mixture should include all the components in the regasified ammonia to be analysed within close percentages. Therefore, it is crucial that all components in the calibration gas are certified and that this is reported in the certificate.

GC is recommended to be calibrated annually with a measurement uncertainty according to OIML R140.

D.2 Raman analyser (liquid phase)

The Raman analyser should be validated periodically. If it fails, a re-calibration is required.

Traceable ammonia composition standards in the liquid phase may also be used to calibrate the commercial Raman analysers. Using the gravimetric method, such standards should be traceable to a primary ammonia mixture standard.

8.2.9 Bibliography

[1] ASTM 3588 Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels

[2] EN 60079-28 Explosive atmospheres – Part 28: Protection of equipment and transmission systems using optical radiation

[3] EN 60825-1 Safety of laser products – Part 1: Equipment classification, requirements and user's guide

[4] OIML R117-1 Dynamic measuring systems for liquids other than water – Part 1 Meteorological and technical requirements

[5] OIML R117-2 Dynamic measuring systems for liquids other than water– Part 1 Meteorological controls and performance tests

[6] OIML R140 Measuring systems for gaseous fuel

[7] OIML R76 Non-automatic weighing instruments

[8] ISO 6142 Gas analysis — Preparation of calibration gas mixtures — Part 1: Gravimetric method for Class I mixtures

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[13] ISO 19230 Gas analysis — Sampling guidelines

[14] ISO 18132-3 Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — General requirements for automatic tank gauges — Part 3: Automatic tank gauges for liquefied petroleum and chemical gases onboard marine carriers and floating storage

[15] ISO 7105 Liquefied anhydrous ammonia for industrial use — Determination of water content — Karl Fischer method

[16] ISO 7106 Liquefied anhydrous ammonia for industrial use — Determination of oil content — Gravimetric and infra-red spectrometric methods

[17] CGA G-2.2: Guideline Method for Determining Minimum of 0.2% Water in Anhydrous Ammonia

[18] SS 648 Code of Practice for Bunker Mass Flow Metering

[19] ISO 7103Liquefied anhydrous ammonia for industrial use – Sampling – Taking a laboratory sample

8.3 PART 3: BUNKERING PROCEDURES AND SAFETY REQUIREMENTS

8.3.1 Scope

This section addresses the bunker equipment and safety requirements and general bunkering procedures for different modes of bunkering: Shore-to-Ship (SHTS), Truck-to-Ship (TTS), STS, and cassette.

8.3.2 Terms and definitions

Refer to Part 1 of this guideline for the detailed terms and definitions.

8.3.3 Properties of ammonia

Refer to Part 1 of this guideline for the properties of ammonia under various storage modes.

8.3.4 Transfer configurations

Ammonia can be stored and transported in three different states, as shown in Table 8-8, fully refrigerated (FR), semi-refrigerated (SR), and pressurised (PR). Ideally, this provides nine transfer configurations for the bunkering operations, broadly classified as transfers across the same storage conditions, colder to warmer storage conditions, and warmer to colder storage conditions. Refer to Part 1 for FR, SR, and PR operating ranges.

Table 8-8 Economic viability of various ammonia transfer configurations

		Receiver Vessel		
		Fully Refrigerated -33°C, 1 bar$_a$	Semi Refrigerated -10 to 4°C, 4 to 8 bar$_a$	Pressurised 20 to 37°C, 10 to 15 bar$_a$
Supplier Vessel	Fully Refrigerated -33°C, 1 bar$_a$	**Viable**	**Viable**	**Less viable**
	Semi Refrigerated -10 to 4°C, 4 to 8 bar$_a$	**Not viable**	**Viable**	**Less viable**
	Pressurised 20 to 37°C, 10 to 15 bar$_a$	**Not viable**	**Not viable**	**Viable**

**This table represents the relative economic viability of the various transfer configurations based on the required CAPEX and OPEX for operations.*

8.3.4.1 Transfers across the same storage conditions

Ammonia transfer across the same storage conditions is highly viable (FR to FR, SR to SR, or PR to PR). While the operational principle for FR and SR transfers are the same, the latter requires a storage tank designed to withstand higher pressure. For PR transfers, ammonia is stored at ambient conditions, eliminating the low-temperature operations.

8.3.4.2 Transfers from colder to warmer storage conditions

Ammonia transfer from FR to SR is deemed economically viable, provided the pumps in a fully refrigerated system will have the sufficient discharge pressure needed to achieve semi-refrigerated storage conditions.

Ammonia transfer from FR/SR storage systems to PR systems will require booster pumps with much higher discharge pressure to meet the pressure requirements. This is technically feasible. There is also the possibility that the receiving vessel's transfer and storage system will be incompatible with low-temperature liquid ammonia.

8.3.4.3 Transfers from warmer to colder storage conditions

Transfer of ammonia from hotter to colder storage conditions is commercially not viable considering the requirements for additional cooling mechanisms to meet the receiving tank conditions. Therefore, transfers from PR to FR/SR are considered economically unviable.

Therefore, based on the above discussions, the economically viable transfer configurations are identified to be the following:

(a) Fully refrigerated to Fully refrigerated

(b) Semi-refrigerated to Semi-refrigerated

(c) Pressurised to Pressurised

(d) Fully refrigerated to Semi-refrigerated

(e) Fully refrigerated to Pressurised

(f) Semi-refrigerated to Pressurised

8.3.5 Modes of bunkering

Bunkering refers to the process of delivering fuel to vessels for their propulsion. Transfer of ammonia can be carried out via four different modes: TTS, SHTS, STS, and cassette.

8.3.5.1 Truck-to-Ship (TTS)

TTS bunkering is the process of transferring ammonia from an ISO tank truck to a receiving vessel using ammonia as fuel. Typically, the ISO tanks on the truck are pressurised and store ammonia at ambient temperature. Therefore, the most suitable transfer mode for TTS is PR to PR, which is the most used method for delivering small quantities of bunker transfers to small receiving vessels such as tugboats, inland vessels, and coastal ships.

8.3.5.2 Shore-to-Ship (SHTS)

SHTS refers to transferring ammonia from an ammonia storage terminal connected to receiving vessels via a pipeline or loading arm. Most terminals store ammonia under FR conditions. Hence, the most suitable configuration will be FR to FR. However, FR to SR/PR operations can be executed by deploying pumps with higher head pressure.

8.3.5.3 Ship-to-Ship (STS)

STS bunkering is the most popular mode for transferring fuel to ocean-going vessels such as container ships, tankers, and bulk carriers. It involves the transfer of ammonia from bunker vessels to receiving ones. However, for ocean-going vessels, PR may not be the ideal state of fuel storage. Therefore, more practical bunker configurations for STS mode will be from FR/SR to FR/SR and FR to SR.

Typically, these operations are carried out via SIMOPS, where an operation or activity runs in parallel to the bunkering process. Examples of SIMOPS activities include (but not limited) to the following:

(a) Cargo handling

(b) Passenger and crew embarking/ disembarking

(c) Dangerous goods loading/unloading and any other goods loading or unloading (i.e., stores, provisions, and waste)

(d) Chemical products and other low flash point product handling

(e) Bunkering of fuels other than ammonia and lubricants

(f) Maintenance, construction, testing, and inspection activities

(g) Port and terminal activities

(h) Unexpected events (e.g., Breakdown)

8.3.5.4 Cassette bunkering

Ammonia can be transferred as a “cassette” type cell system. This mode of bunkering involves a portable tank delivered by a truck or bunker vessel, which can be lifted or driven onboard and connected to the fuel system of the receiving vessel. The cassette can be a FR/SR/PR tank, but it does not offer the flexibility to adjust the temperature and pressure of the fuel during the transfer operation.

8.3.6 Bunkering equipment

Bunkering operations require a set of critical equipment required to function. All the equipment maintenance and testing shall be performed per the respective manufacturers’ guidelines and recommendations. In addition, requirements from relevant authorities must be taken into consideration. The equipment are as follows:

8.3.6.1 Bunker hose (Supplier)

Two types of flexible hoses (one for liquid and the other for vapour) connect the supplying and receiving tanks. The ammonia liquid/vapour transfer hoses must be specially designed and constructed to prevent corrosion and sustain low temperatures (-33°C). The bunker hoses are to be identified according to a defined system, so there will be no risk of using an incorrect hose type. The hoses must have a suitable size and length, be in good condition, be visually checked, and be within the last replacement date before all transfer operations, following local and class rules. Preferably the number of different hoses is to be kept to a minimum. In some TTS operations, multiple trucks can bunker ammonia simultaneously.

8.3.6.2 Rigid/mechanical arm (Supplier and receiver)

For large-diameter hoses, cranes assist in connecting hoses with the receiving vessels. Full rigid arms are provided with rigid insulated pipe sections to transfer ammonia to the receiving vessel. These arms are typically installed on fixed bunkering stations or bunker vessels. In addition to the support, the use of mechanical rigid bunkering arms helps to:

(a) Ensure the safety of the bunkering operation

(b) Allow precise connection/disconnection of hoses

(c) Optimise the overall bunkering duration

(d) Increase the possibility of delivering bunker connections at different heights

8.3.6.3 Mooring equipment (Supplier and receiver)

The supplier ships must have good-quality mooring lines and winches. Fairleads must be a closed type, class approved, and complies with recognised standards. For safety reasons, soft mooring lines (or tails) should be used.

8.3.6.4 Portable tanks (Supplier)

The standard container tank for ammonia transport should not be used as a portable tank for cassette bunkering. The portable tanks used for cassette ammonia bunkering should follow the IGF Code and bear a certificate of approval. In addition, the ISO tanks must be corrosive-resistant and capable of tolerating low temperatures (-33°C).

8.3.6.5 Coupling

A break-away coupling should be placed on each hose in the receiving ship’s manifold to prevent hose breakage under extreme movements. In an emergency, the two quick-closing shut-off valves in the coupling will close immediately and stop any leakage. Therefore, this coupling will act as the chain’s weakest part and break off if any force exceeds the limit.

8.3.6.6 Purging system

To ensure the vessel meets safety requirements, it is necessary to perform nitrogen purging to eliminate any moisture and oxygen content in the hoses or pipes, thus preventing stress corrosion cracking (SCC). To achieve this, installation of a nitrogen generator is highly recommended for purging operations. However, if one is not available, stored nitrogen in pressure cylinders may be accepted as an alternative.

8.3.7 Ammonia bunkering plan

An ammonia bunkering plan shall be developed to ensure the safe and effective operation of ammonia bunkering processes. This plan shall demonstrate and document all proof of compliance with the regulations of all relevant authorities, industry practices, and vessel Safety Management System (SMS) requirements.

The ammonia bunkering plan should include but not be limited to, the following:

(a) Purpose, objective, and safety policies

(b) Compatibility assessment

(c) Risk management

(d) Organisation planning

(e) Communication

(f) Management of change

(g) Emergency procedure

(h) Training

(i) Operations, procedures, and checklists (include SIMOPS if applicable)

8.3.8 Risk and safety of bunker operations

8.3.8.1 Role and responsibility

Each party in the bunkering operation should be fully aware of their role and responsibilities in the process.

(a) Port authorities

- Ensure the bunker supplier meets all criteria before, during, and after bunkering that includes, but is but not limited to:
    - Bunkering operations adhere to local requirements, international rules, and best practices
    - Risk analysis and risk assessment have been completed
    - Control zones are defined
- Approval of all bunkering operations and their locations
- Validation of credentials of person-in-charge
- Validation of the bunker supplier according to the requirements
- Approval of SIMOPS
- Setting the criteria for ammonia bunkering operations: weather conditions, sea state, wind speed, and visibility

Refer to the Annex F for further details.

(b) Person-in-charge (PIC)

The PIC is the individual designated by the bunker supplier responsible for the bunker delivery, transfer, and bunkering documentation. The port, bunkering facility, and receiving ship agree with the selection of the PIC. The PIC's role and responsibilities shall include the following:

- Commencing and ending the bunkering operation
- Ensuring that all required communications are made with the implementing authority
- Ensuring declaration of inspection forms and checklists are completed
- Confirming with the master(s), or their representatives, the correct relative location of vessels, mooring and placement of fenders
- Conducting a pre-operations meeting with the receiver's designated personnel
- Evaluating present and forecasted meteorological conditions for the duration of the operations
- Monitoring communications throughout the operations
- Verifying and ensuring that site-specific risk mitigations measures, including monitoring and safety zones, are in place
- Ensuring that the transfer system is in good working condition and the ESD system is connected correctly and tested
- Ensuring the transfer system and associated emergency release systems are capable of safe connection/disconnection
- Confirming that the SIMOPS assessment has been carried out, if applicable
- Monitoring fuel transfer rates and vapour management
- Advising the Master or their representatives when bunkering is completed
- Ensuring that, when necessary, all incidents are reported without delay and by the most direct means to the implementing authority and port master, and a detailed report of the circumstances of the incident or occurrence is submitted to the port master as required.

(c) Master (receiving vessel)

The master is responsible for his ship, personnel, bunker's safety and all matters related to the complete operation. The master shall appoint a bunker-in-charge officer to liaise with the PIC for ammonia bunker operations. All bunker operations must be agreed upon between the bunker and the receiving ships before commencing any activities.

8.3.8.2 Communication

All communication systems, electrical equipment, and other equipment must be safe and reliable, including those in hazardous regions. During bunkering activities, at least two reliable and independent communication channels must always be available - a main and another – as part of contingency communications. Transfer procedures are to commence only after all parties have confirmed clear communications between each other.

A communication plan should be agreed by all parties before commencing operations, including the communications equipment used within hazardous zones which will need to be appropriately classified, if required.

(a) Verbal communications

Before operations begin, all stakeholders should agree upon a language that can be understood by all parties during the bunkering process.

(b) Non-verbal communications

Before bunkering begins, it is essential for all parties involved to establish and agree upon hand signals for communication, as outlined in Annex G. Communications must always be maintained between the supplier and the receiving ship during the bunkering operation. If communication is lost, bunkering should immediately cease, and the emergency signal should be activated. Operations should remain suspended until communication is fully restored.

During bunkering, the PIC must communicate directly and immediately with all personnel involved in the bunkering operation. Communication devices used in bunkering should comply with recognised standards acceptable to the administration.

If applicable, the ship-shore link (SSL), equivalent to a bunkering source provided for automatic ESD communications, must be compatible with the receiving ship and the delivering facility's ESD system. The SSL should be compatible with all systems.

8.3.8.3 Risk assessment

A team of suitably skilled and knowledgeable personnel representing several different disciplines, with experience in risk assessment procedures for ammonia applications, should conduct the risk assessments. A risk assessment shall cover the bunkering operation, including the risk to employees and the environment. Representatives from the supply and receiving vessels are held accountable for completing risk assessments.

- The objectives of the bunkering operations risk assessment are to:
  - (a) Demonstrate that risks to people and the environment have been eliminated wherever possible, and if not, to mitigate them as necessary
  - (b) Provide insight and information to help set the required safety and security zones around the bunkering operation depending on the transfer configurations and bunker modes
- The bunkering operations risk assessment must include the following operations:
  - (a) Preparations before and during the ship's arrival, approach, and mooring
  - (b) Preparation, testing, and connection of equipment
  - (c) Ammonia transfer
  - (d) Boil-off gas (BOG) management, if applicable
  - (e) Completion of bunker transfer and disconnection of equipment
  - (f) SIMOPS, if applicable
- Examples of SIMOPS activities include, but not limited to, the following:
  - (a) Cargo handling
  - (b) Passenger and crew embarking/disembarking
  - (c) Dangerous goods loading/unloading and any other goods loading or unloading of any other goods (such as stores, provisions, and waste)
  - (d) Handling of chemical products and other low flash point products
  - (e) Bunkering of fuels other than ammonia and lubricants
  - (f) Maintenance, construction, testing and inspection activities
  - (g) Port and terminal activities

(h) Unexpected events, such as breakdowns

A Risk Assessment (RA) should be undertaken before introducing a new bunkering operation procedure. The RA is sufficient to meet the objectives of the bunkering operation risk assessment given that the bunkering operation is one of the four standard bunkering modes below:

(a) SHTS

(b) TTS

(c) STS

(d) Cassette transfer

The RA activities can be divided into two main parts: a high-level HAZID activity and a more detailed HAZOP activity.

A HAZID study is a complex identification process that provides sufficient details for operators to understand the hazard nature and identify the controls necessary for hazard management

A HAZOP study is a structured and systematic examination of a planned process or operation to ensure the equipment can perform according to the design intent and to identify the causes and consequences of all possible deviations from normal conditions

A supplement to the RA may be required in the event of the following:

(a) Bunkering is not of a standard type

(b) Design, arrangements, and operations differ from the guidance given in this document; and

(c) Bunkering is undertaken alongside other transfer operations (SIMOPS)

The need for a RA addition is determined by the administration or port authority based on the conclusions and outcomes of the RA and accepted by the concerned parties. An RA is mandatory.

RA reviews shall be conducted periodically to identify previously unlisted hazards. RAs will be reconducted when there is a:

(a) Change of receiving ships

(b) Modification of receiving systems

(c) Change of location

(d) Modification of operating procedures

(e) Introduction of SIMOPS

(f) Modification to bunkering equipment

8.3.8.4 Controlled zones

Controlled zones, including hazardous, safety, toxic, and monitoring zones for both the receiving ship and bunker facility, shall be proposed based on the QRA and RA results and relevant international requirements (e.g., ISPS), and determined by the local authorities.

Determination of hazardous, safety, toxic, and monitoring zones:

(a) A hazardous area must be established where only appropriately rated electrical fixed/portable equipment shall be used. Repairs should be undertaken outside of this area

(b) A safety zone shall be established within which ignition sources are adequately controlled. Only essential personnel and activities approved for exposure to flammable gas in case of an accidental release are allowed in this zone

(c) A toxic zone perimeter shall be established per local requirements, where toxic fumes could be harmful to personnel in the proximity during activities such as bunkering connections and disconnections

(d) A monitoring zone shall be established around the ammonia bunkering activity area to reduce external interference based on the risk assessment

8.3.8.5 Emergency Procedures

Developing effective emergency procedures is crucial for ensuring the safety and security of personnel and the environment during ammonia bunkering operations. These procedures should clearly define the duties, roles, and actions of all personnel and organisations involved in the ammonia bunkering operation, and must be tailored to the specific site and activity. Joint exercises should be conducted regularly to validate and familiarise staff with the procedures. It is important to note that the emergency protocols must be relevant to each bunkering model, and the response strategy must be developed based on the risk assessment.

To ensure that the emergency procedures are effective, risk assessment techniques should be used to identify all potential hazards and their consequences. Optimum response strategies should be developed to mitigate these risks. The emergency procedures should cover the following aspects, but not limited to:

(a) Ammonia leakage

(b) Hose failure

(c) Hose quick-release arrangements

(d) Mooring line failure

(e) Communication failure

(f) Personnel injuries (frost burns, suffocation, overexposure, etc.)

(g) Fire

(h) Blackout

(i) Ship collision

(j) Fender burst

Situations must be analysed to determine which risk scenarios are more likely to occur and addressed in the emergency procedures.

Before the bunker operation, an emergency procedure shall be agreed upon between the receiving vessel and the bunker supplier. During an emergency, both parties should evaluate the situation and act accordingly. A sample emergency procedure is presented below:

(a) Sound the agreed emergency signal

(b) Activate ESD-system, and firefighting, where appropriate

(c) Alert all crew and staff of both parties

(d) Notify port and authorities

(e) Activate HazMat monitoring, control and rescue procedure

(f) Send mooring personnel to stations

(g) Purge bunker hoses with nitrogen

(h) Disconnect bunker hoses

(i) Confirm that engines are ready for immediate use

(j) The ship master(s) or relevant terminal authorities (if bunkering alongside the jetty) is to make the final decision whether the vessel shall remain positioned or leave the berth or the terminal

8.3.8.6 Preventive measure

Controlled zone

Refer to Section 8.3.8.4 for the determination of various control zones.

Monitoring, control and safety system/alarm

Local and remote control, alarm, and safety functions should be provided to maintain operations within pre-set parameters for all ammonia bunkering operations. Operations not within the boundaries of the pre-set parameters or activation of safety functions are to be equipped with audible and visual alarms in the bunkering control location.

The temperatures, pressures, flow rates, and functions of the ammonia bunkering system are to be controlled as follows:

(a) A control and monitoring system should be provided in the bunkering control location

(b) The control and monitoring systems are to be able to identify faults in the equipment and process system

(c) Indications of parameters necessary for safe and effective operations are to be provided

Tank pressure and levels should be monitored at the bunkering control location. In addition, an overfill alarm and automatic shutdown should be installed and marked at the site.

Remote reading manifold pressure gauges and transmitters with isolation valves are to be fitted to indicate the pressure between stop valves and hose connections.

8.3.8.7 Mitigation measure

Personal protection equipment (PPE)

As ammonia is hazardous, personnel must wear the appropriate PPE and personal ammonia gas detector during ammonia bunkering activities to minimise injury in the event of an accident. Four levels of PPE apply to different handling conditions of ammonia, as outlined in Table 8-9, which include examples. The appropriate PPE level depends on the AEGL or equivalent measure of exposure to the operators/crew.

Table 8-9 - PPE to be used for different levels of ammonia exposure

PPE Level	PPE to be worn
Level A – when the greatest level of skin, respiratory, and eye protection is required. This is the maximum protection for workers in danger of exposure to unknown chemical hazards or levels above the IDLH or greater than the AEGL-2.	(a) NIOSH-certified Chemical, Biological, Radiological, and Nuclear (CBRN) full-face-piece SCBA (b) A totally Encapsulating Chemical Protective (TECP) suit (c) Chemical-resistant gloves (outer & inner) (d) Chemical-resistant hard-toe boots

	(e) Coveralls and a hard hat
Level B - when the highest level of respiratory protection is necessary, but a lesser level of skin protection is required. This is the minimum protection for workers in danger of exposure to unknown chemical hazards or levels above the IDLH or greater than AEGL-2	(a) NIOSH-certified CBRN full-face-piece SCBA (b) A hooded chemical-resistant suit (c) Chemical-resistant gloves (outer & inner) (d) Chemical-resistant hard-toe boots (e) Coveralls and a hard hat
Level C – When contaminant and concentration are known, and criteria for Air Purifying Respirators are met or equivalent.	(a) NIOSH-certified CBRN tight-fitting air-purifying respirators (APR) with canister-type gas mask suited for levels greater than AEGL-2 (b) A NIOSH-certified CBRN Powered Air Purifying Respirator (PAPR) with a loose-fitting face-piece, hood, or helmet, a filter, a combination of organic vapour, acid gas, and particulate cartridge/filter combination or a continuous flow respirator for air levels greater than AEGL-1 (c) A hooded chemical-resistant suit that protects CBRN agents. (d) Chemical-resistant gloves (outer) (e) Chemical-resistant gloves (inner) (f) Chemical-resistant boots with a steel toe and shank (g) Escape mask, face shield, coveralls, long underwear, a hard hat worn under the chemical-resistant suit, and chemical-resistant disposable boot covers worn over the chemical-resistant suit are optional
Level D – When contaminant and concentration are known and below AEGL-1 or its equivalent.	(a) Coveralls, boots, and gloves

Accommodation openings

All openings to safe spaces such as accommodation, storerooms, machinery, and cargo where ammonia vapour could enter should be closed during bunkering. In addition, designated doors are to be defined for personnel transit, which should be closed after use.

Firefighting equipment

The following firefighting equipment shall be readily accessible to the crew and be available throughout the bunker operation:

(a) Fire Main: Water spray system

(b) Suitable Extinguishing Media: Carbon dioxide, dry chemical powder, appropriate foam, water or fog spray

(c) Dry chemical powder fire extinguishers provided to cover all possible leak points

Firefighting system monitors that use foam and water should be pointed towards the bunker manifolds. The maintenance of firefighting equipment should adhere to classification requirements. Personnel involved in bunker operations should be trained on actions to take in the event of a fire.

Leakage detection systems

Gas detectors shall be installed per the receiving vessel's class requirements. During a leak, detectors should be connected to the bunker control location, emitting audio and visual signals. The bunker operation shall be terminated and resumed only after it is safe to proceed.

Water spray

In the event of gas dispersion, a water spray can be used to reduce the rate of gas dispersion. Ammonia is highly soluble in water. Therefore, the spray will dilute or remove any ammonia. A water or fog spray should only be used and directed at an ammonia cloud forming above the liquid ammonia pool. Water spray systems should be capable of remote activation and located in an accessible area.

ESD system

During an emergency, an ESD system can safely and effectively stop the transfer of ammonia (and vapour, where applicable) between the ammonia bunkering facility and the receiving ship. The ESD control systems is a linked system that can be triggered automatically or manually by either party (on board the receiving ship and the bunkering facility) to shut down the transfer during an emergency. The goal is to prevent ammonia exposure to personnel onboard or nearby and reduce the amount of explosive air/gas mixture forming that could cause an explosion. The ESD systems' activation design requirements must comply with the class rules. ESD must be activated when the threshold pressure is reached, and the coupling must be compatible.

Some examples of events that could initiate an ESD system, include:

(a) High tank pressure

(b) Excessive ship movement

(c) Abnormal pressure in the transfer system

(d) Loss of instrument pressure

(e) Loss of electricity

(f) Gas detection

(g) Manually initiated shutdown

(h) Fire detection

The ESD process may consist of two stages:

- ESD-stage 1

  A system that regulates the shutdown of the ammonia transfer process in a controlled manner when it receives input from one or more of the following sources:

  (a) Transfer personnel

  (b) Tank alarms detecting high levels of ammonia

  (c) Cables or other means designed to detect excessive movement between vessels or vessels and an ammonia port facility, or other alarms, where applicable

- ESD-stage 2

  A system including an ERC that activates between transfer vessels or between a ship and an ammonia port facility. The decoupling mechanism contains quick-acting valves designed to contain the contents during a breach of the ammonia transfer line (dry-break).

The ERC is in the ammonia transfer system at the receiving end of the ship, the bunker facility end, or in the middle of the transfer system. When activated, it separates at a predetermined section. Each separated section contains a self-closing shut-off valve, which seals automatically.

Grounding

- Terminal-to-ship bunkering

  The loading arm for terminal-to-ship bunkering is metallic, an excellent electrical conductor with a very low resistance to electricity flow. There is a danger of electric arcing at the manifold during the connection and disconnection of the shore hose and loading arm due to changes in electrical potential between the ship and the terminal.

- TTS bunkering

  The truck must be electrically grounded, and the wheels have to be secured to prevent unintended drive away.

- STS bunkering

  An electric isolation flange is required to break the continuous electrical path between the ship and the bunker vessel.

Gas Shelter

The gas shelter is an optional requirement.

Training

Refer to Part 4 of the guideline for the training and competency requirements.

8.3.9 Conditions and requirements for operations

8.3.9.1 Approval

Before commencing any bunker operations, approval from the authorities and checks with the local regulations are required before the transfer is planned to be carried out.

8.3.9.2 Ship compatibility

Mooring and bunker equipment should be compatible in design so the bunker operation can be conducted safely.

At a minimum, the compatibility of the following equipment and installation should be assessed and confirmed:

(a) Communication/ESD systems

(b) Bunker connection and bunker station location

(c) The relative freeboard difference

(d) Transfer system specifications (e.g., type and size of hose connections), locations and loading on manifolds, and connection order

(e) Pumping system specifications (pumping rate, pressure, etc.)

(f) Vapour return line, if applicable

(g) Nitrogen line, if applicable

(h) Mooring arrangement/equipment

8.3.9.3 Transfer area

The transfer area is determined and approved by authorities. The approaching bunker ship checks and evaluates if the area is suitable for bunkering operations. The operation should be aborted if there are issues that can compromise a safe transfer. Points to be considered are:

(a) Manoeuvring space

(b) Tidal conditions

(c) Traffic density

(d) Waves, swell, and weather conditions

8.3.9.4 Weather conditions

Before commencing bunkering operations, it is crucial to predict the weather and current forecast for the area. Each master is responsible for his ship, and both masters must agree that ambient conditions, such as wind and weather are acceptable before bunkering can commence. The master is also responsible for identifying any restrictions and taking immediate action in the event of sudden changes in the ambient conditions during a bunker transfer, such as an unfavourable shift in wind direction.

8.3.9.5 Light conditions

The bunkering operation is best conducted in daylight. Adequate lighting is necessary for mooring and bunkering operations after daylight.

The minimum lighting requirements include the bunker ship deck, the receiving ship bunker station, and the mooring bollards.

8.3.10 Bunkering operations procedure

The bunkering operation is divided into four stages: Planning, pre-transfer, transfer, and post-transfer. Below is a brief outline of the various steps involved in each stage. Refer to the checklist in Annex E to verify which modes of bunkering are applicable.

8.3.10.1 Planning

The planning stage involves a comprehensive risk assessment to identify potential hazards and risks associated with the bunkering operation. It includes:

(a) Bunkering operations risk assessment: Before confirming the bunkering operation, a bunkering operations risk assessment shall be performed.

(b) Compatibility assessment: Before confirming the bunkering operation, the compatibility of the bunkering facility and receiving ship must be assessed. The assessment shall be undertaken with an appropriate checklist to be agreed upon by the master(s) and PIC.

(c) Regulatory approval: The validity of the ammonia bunker supplier license shall be verified.

(d) Schedule and location confirmation, manoeuvring/berthing: After the schedule and location are confirmed and the berth is granted, the manoeuvring approach can commence.

(e) SIMOPS assessment (if applicable): All SIMOPS within the safety zone shall be permitted only after the necessary risk assessment has been conducted and environmental conditions and the type of SIMOPS activity (Annex H) have been considered.

The SIMOPS activities to be executed must be agreed upon during the pre-transfer meeting. Any activity not permitted shall not be carried out without the knowledge of the entities involved.

Refer to the checklist in Annex H to mark at which stage of bunkering SIMOPS is intended to be carried out.

8.3.10.2 Pre-transfer

In the pre-transfer stage, several steps must be taken to ensure a safe and successful bunkering operation. Here is an overview of the different measures involved:

(a) Safety precautions: Before commencing the bunker operation, all personnel should know the location and function of all safety and firefighting equipment as laid down in the vessel's safety plans.

(b) Major bunker system check:

- Ammonia tank system - Both ships must check the ammonia tanks' temperature and pressure before bunkering and note this on the pre-transfer bunker checklist. The bunker ship master is to confirm that both ships combined temperature and pressure range are within the safety limits before commencing transfer.
- Mooring equipment - Lines, fenders, winches, and other mooring equipment are to be visually checked for wear or damage. Equipment should be replaced or mooring aborted if there are doubts about equipment quality and safety.
- Bunker hoses – These are to be visually checked for wear or damage and that the hose markings are correct for the actual transfer operation. Bunker hoses should be replaced if there are doubts about equipment quality and safety.

(c) Mooring: The mooring system must ensure that the receiving vessel is well secured throughout the bunkering operation such that there is no damage to the transfer system. This considers the prevalent and prognostic weather, tidal conditions, passing traffic, and changes during the bunkering.

(d) Personnel transfer access: Safe access points acceptable to marine standards shall be provided if personnel transfer between the bunkering facility and the receiving vessel is required.

Upon confirmation of the personnel transfer plan, personnel transfer equipment, e.g., gangways, baskets, wharf ladders, etc., shall be deployed and secured according to the agreed procedures.

(e) Pre-transfer meeting and documentation: Before ammonia transfer, the PIC of the bunker facility and receiving vessel shall complete the pre-bunkering safety checklist to confirm that all points are addressed. The PIC should inform all ammonia bunkering operation participants, including third-party surveyors, of the safety protocol to be followed during the bunkering operation.

Before the commencement of ammonia bunkering operations, some critical actions must be undertaken by the identified representatives, such as the PIC, terminal/bunker station operator, truck operator, ship master, and cassette equipment operator, depending on the mode of transfer, including:

- Agreeing in writing on the transfer procedures, including the maximum loading or unloading rates
- Agreeing in writing on the action to be taken in the event of an emergency
- Completing and sign the ammonia bunker checklist accordingly, and
- Meeting the port authority (e.g., port marine notices/circulars) and terminal requirements/regulations.

(f) Truck preparation for TTS transfer (if applicable): The truck shall be correctly positioned (e.g. wheel chocks are in place), engines turned off, and keys removed to ensure truck stability during the transfer. Contingency plans should be discussed if multiple loading trucks can be accommodated in the bunkering facility.

(g) Connecting transfer systems: Two type of hoses (vapour and liquid) and couplings shall be connected across the two systems to enable vapour and liquid transfer systems. ESD links/communication cables shall be established across the receiving vessel and bunkering facility.

(h) Nitrogen purge and leak test: After connection, the transfer systems shall be purged with nitrogen to eliminate moisture and oxygen. Purging continues until the oxygen content in vapour and liquid manifolds are less than 1% by volume, and moisture content as agreed between supplier and receiver sides. Then, the transfer system shall be pressurised suitably with nitrogen to ensure no leaks at the flange connections and then depressurised.

(i) Transfer data: Ammonia bunker transfer data, such as temperature, pressure, density, volume, transfer rate, and quantity, shall be exchanged and agreed upon by the parties.

(j) ESD test: The ESD link shall be tested from both the bunkering facility and the receiving vessel before the commencement of the bunkering operation.

(k) Line cool down (if applicable): The bunker lines of both parties shall be cooled down at an agreed rate to prevent hose rupture from cold shock.

8.3.10.3 Transfer

Here is an overview of the steps involved in the transfer stage.

(a) Periodic checks: Periodic checks on the bunker quantity shall be communicated between the bunkering facility and the receiving vessel.

Mooring and vessel positions are to be monitored/checked.

Periodic checks per the transfer checklist are to be carried out at agreed intervals.

(b) Vapour management: No venting of ammonia gas is allowed during bunkering (except in emergencies). Therefore, the tank pressures of both tanks shall be continuously monitored to avoid tank pressurisation and subsequent release of vapour through the tank pressure relief valve and ARMS. The vapour management procedure discussed in the pre-bunkering stage shall be strictly followed.

During emergency scenarios where a release from overpressure in the fuel tank is made, the release should be directed to the vent mast to prevent ammonia from being trapped.

(c) Ramp-up and ramp-down procedures: Ammonia flow during bunkering shall be ramped up and down per the procedure discussed in the exchange of ammonia bunker transfer data.

(d) Topping off procedures: Notice shall be given to the bunkering facility to commence the flow rate reduction and ramp-down process.

The transfer process shall be ramped down with an appropriate flow rate reduction when the bunker level approaches the agreed loading limit.

The bunker level shall be monitored to avoid overfilling.

(e) Ballasting/de-ballasting: The stability of the vessel(s) involved shall be maintained through ballasting/de-ballasting to avoid any stress exerted on the manifold connection and transfer systems.

8.3.10.4 Post-transfer

The final stage is post-transfer.

(a) Draining and purging liquid lines: Upon completion of bunkering or in the event of overfilling, the liquid lines shall be drained and purged with nitrogen. The lines should not be disconnected without purging and releasing vapour through ARMS. Due consideration should be given to de-icing (if applicable) the transfer system. Consider a gravity liquid draining system for draining. Release of vapour through the tank pressure relief valve and ARMS.

(b) Purge and disconnect vapour return transfer system: Like the liquid line, the vapour lines shall also be purged with nitrogen and releasing vapour through ARMS to ensure no vapours are trapped in the hose.

(c) Disconnect transfer system: Before disconnecting the system, the valves on both sides (bunkering facility and receiving system) shall be checked for complete closure. A final check shall be performed to ensure the ammonia level in the transfer system is less than 1% by volume. After this, the transfer system can be disconnected.

(d) Disconnect all cables: All additional cables provided for communication and ESD can be disconnected.

(e) Post-transfer meeting: The post-transfer checklist shall be completed and exchanged across parties.

(f) Personnel transfer access: Personnel transfer equipment, e.g., gangways, baskets, wharf ladders, etc., shall be dismounted, lifted, and stored according to the agreed procedures.

(g) Unmooring and departure: The receiving vessel can be unmoored for departure.

Annex E: POSSIBLE CHECKLIST FOR BUNKERING

This section presents the general ammonia bunkering checklist applicable to the different modes of bunkering. The bunkering facility and the receiving vessel should jointly complete all checks.

- The letters A, R, or P in the code column indicate the following:
  (a) A (Agreement) – Indicates an agreement or procedure that should be identified in the remarks column of the checklist or communicated in some other mutually acceptable form
  (b) R (Re-check) – Indicates items to be re-checked at appropriate intervals, as agreed between both parties, at periods stated in the declaration
  (c) P (Permission) – Indicates that permission is to be granted by authorities
- For the checks that are not applicable, the boxes are shaded in grey. The “if applicable” marked checks are not mandatory; users can skip these checks by indicating “N.A.” in the “Remarks” column. The bunkering facility and the receiving vessel should retain a copy of the completed checklist.
- The joint declaration should not be signed until both parties have checked and accepted their assigned responsibilities and accountabilities. When duly signed, copies of these documents will be kept for at least one year with the bunkering facility and receiving vessel.

Part A: Planning

Mode of Bunkering: ____

Ammonia Supply (Terminal/Port/Truck/Ship): ____

Bunker Facility Name/IMO Number: ____

Bunker Facility Location: ____

Ammonia Receiving Vessel's Name & IMO Number: ____

Ammonia Receiving Vessel's Location: ____

Date and Time: ____

S. No	Check	Ship	Terminal	Truck	Code	Remarks
1	Local authorities have granted permission for ammonia transfer operations for the specific location.				P	
2	Planned SIMOPS during ammonia bunkering are per receiving vessel's approved operational documentation.					
3	Local authorities were notified one hour before the start of ammonia bunker operations.					Time notified: _____hrs
4	Local authority's requirements are being observed.					
5a	The terminal/bunker barge has been notified one hour before the start of ammonia bunker operations.					Time notified: _____hrs
5b	The terminal/bunker barge has been notified of the simultaneous bunker or cargo or other operations during ammonia bunkering.				P	
6	Local terminal/bunker barge requirements are being observed.					
7	The ammonia bunker vessel has obtained the necessary permissions to go alongside the receiving vessel.				P	
8	The receiving vessel and bunker facility have agreed upon the mooring and fendering arrangement.				A, R	
9	Vessels in the direct vicinity of the transfer location are informed of the transfer operation.					
10	All personnel involved in the bunker operation have the appropriate training and				A	

	have been instructed on the bunker equipment and procedures.					
11	Inclement weather conditions e.g., thunderstorms, maximum wind and swell criteria for operations, have been agreed upon.				A	
12	The receiving ship is securely moored and sufficient fendering is in place.				R	Metal-to-metal contact must be avoided at all times.
13	There is a safe means of access between the ship and the shore.				R	
14	The bunker location is accessible for the supply tank truck, and the total truck weight does not exceed the maximum permitted load of the quay or jetty.					
15	The ship / truck is both ready to move under their own power.					
16	The bunker location is sufficiently illuminated.					
17	All ammonia transfer and gas detection equipment are certified, in good condition and appropriate for the service intended.				A	
18	An effective means of communication between the responsible operators and supervisors at the ship and truck has been established and tested.				A, R	VHF / UHF Channel: ________ Primary System: ________ Backup System: ________ Emergency Stop Signal: ________
19	The safety/security zone has been designated and activated. Appropriate signs mark this area.				A	
20	Regulations with regard to ignition sources are observed both on the ship and on the shore. The transfer safety zone is free of ignition sources. These include but are not limited to smoking restrictions and regulations with regards to naked light, mobile phones, pagers, VHF and UHF equipment, radar and AIS equipment.				A, R	Including vehicles other than the tank truck. The radars are switched off. Fixed radio (VHF / UHF / AIS) transceivers are on the correct power mode or are switched off.

21	All firefighting equipment is ready for immediate use.				A	
22	Personnel involved have adequately rested per applicable work and rest hour regulations (e.g., MLC2006 / STCW).				A	
23	Safety procedures and mitigation measures for simultaneous activities, as mentioned in the receiving vessel's approved operational documentation, are agreed upon and are being observed by all parties involved.				A, R	

Declaration

We, the undersigned, have jointly covered all items on this section (Part A) and have satisfied ourselves that the entries we have made are correct to the best of our knowledge.

Receiver	Supplier
Name	Name
Signature	Signature
Date & Time	Date & Time

Part B: Pre-transfer

Mode of Bunkering: ____

Ammonia Supply (Terminal/Port/Truck/Ship): ____

Bunker Facility Name/IMO Number: ____

Bunker Facility Location: ____

Ammonia Receiving Vessel's Name & IMO Number: ____

Ammonia Receiving Vessel's Location: ____

Date and Time: ____

S. No	Check	Ship	Terminal	Truck	Code	Remarks
1	Both Part A has been completed and approved.					
2	Port/ terminals have been informed of ammonia transfer operations and nearby vessels have been instructed to keep clear from the specified location.					Time notified: _____hrs
3	Sufficient supervision is provided for the bunker operation. An officer must be placed in both the receiving vessel and bunker facility to oversee the operation.					
4	Local authorities' requirements are being observed.					Time notified: _____hrs
5	All roles of personnel, bunkering plan and other vessel specifications are briefed and posted for personnel awareness.				A	
6	Current weather and wave conditions are within the agreed limits.				A R	Cease bunkering transfer operations at: __________ Disconnect at: ____________ Unmoor at: ___________ *In the event of bad weather conditions, all bunkering operations are to cease and be suspended.*
7	All external doors, portholes and accommodation ventilation inlets are closed.				R	
8	Ship and bunkering ship (if applicable) are securely moored under the mooring arrangements set prior. Sufficient fendering is in place.				R	.

9	A safe means of access is secured for the ship and the bunkering facility.				R	
10	All essential firefighting equipment is readily available for urgent use.					
11	All areas are adequately illuminated.				A, R	
12	The receiving vessel and bunker facility can operate independently under their own power in a reliable and non-obstructed direction.				R	Not applicable for Shore Bunker Stations
13	An effective means of communication between the responsible operators and supervisors at the ship and truck has been established and tested.				A, R	VHF / UHF Channel: ________ Primary System: _______ Backup System: _______ Emergency Stop Signal: ________
14	Sufficient supervision is in place during Ammonia transfer.				A	
15	Emergency stop signal and shutdown procedures are agreed upon, tested, and all personnel are to be familiar with the procedures.				A	
16	Controlled zones have been defined and marked with signage.				A	
17	The ESDs on both the receiving vessel and bunker facility, including automatic valves or similar devices, have been tested, found to be in goodworking order, and are ready foruse. Both ESD systems are linked, and the closing rates of the ESDs have been exchanged.				A	ESD receiving vessel: __________seconds. ESD bunker facility: __________seconds.
18	The safety/monitoring zone is currently in place. Other ships, unauthorised individuals, items, and ignition sources are not permitted within the safety zone. Where applicable, appropriate signage denotes this location.				A R	
19	All parties are to observe measures made to prevent falling objects.				R	
20	Gas detection equipment has been tested and is in excellent condition.					
21	Safety Data Sheets (SDS) for the delivered ammonia fuel are available.				A	

22	All safety requirements regarding ignition sources are met.				R	
23	Personnel involved in the connection and disconnection of the bunker hoses and personnel in the direct vicinity of these operations use sufficient and appropriate protective clothing and equipment.					
24	An [powered] emergency release coupling ([P]ERC) is installed and is ready for immediate use.					
25	The water spray system has been tested and is readily available.					If applicable.
26	Spill containment arrangements meet the material, volume, and position requirements.					
27	All bunker transfer equipment is in good working condition.				A	
28	Bunkering vessel tanks are protected against accidental overfilling. The tank's content is to be monitored, and alarms are correctly set.				R	
29	All safety and control devices on the ammonia installations are inspected, tested and in good working condition.					
30	Pressure control equipment and Boil off or re-liquefaction equipment are in good working condition.					If applicable.
31	The ammonia transfer system is in good condition, leak-tested, certified, properly rigged and supported.					
32	Ammonia bunker connection has compatible and safe connection couplings. ERS are in place and inspected for functionality and in good working condition.				A	
33	Proper grounding is in place for the ammonia bunker connection.					
34	The ammonia transfer system has been connected per regulations and purged with nitrogen.					Oxygen content after purging: ___________________ Dew point temperature: ___________________
35	Ensure the cooling down process follows the recommendations listed by the manufacturer.					

36	The truck engine is not running while the connection and disconnection of the ammonia transfer system and purging are occurring.					If applicable
37	Emergency fire control plans are located and available for use.					Location fire plan: ________________ Location international shore connection: ________________
38	Smoking is not allowed unless done in allocated rooms for smoking.				A	On receiving vessel: ________________ On bunker facility: ________________
39	The truck is grounded, and the wheels are locked to prevent unintended movement.					If applicable
40	Appropriate protective equipment and clothing are ready for immediate use.					
41	All personnel are in the appropriate protective equipment and clothing.					
42	Portable communication equipment, portable gas instruments and Flashlights are intrinsically safe.					

Declaration

We, the undersigned, have jointly covered all items on this section (Part B) and have satisfied ourselves that the entries we have made are correct to the best of our knowledge.

Receiver	Supplier
Name	Name
Signature	Signature
Date & Time	Date & Time

Part C: Bunker transfer

Mode of Bunkering: ______________________________

Ammonia Supply (Terminal/Port/Truck/Ship): ______________________________

Bunker Facility Name/IMO Number: ______________________________

Bunker Facility Location: ______________________________

Ammonia Receiving Vessel’s Name & IMO Number: ______________________________

Ammonia Receiving Vessel’s Location: ______________________________

Date and Time: ______________________________

	Receiving vessel		**Bunker supply**	**Unit**
	Tank 1	**Tank 2**		
Ammonia tank temperature				ºC
Ammonia tank pressure				bar/ MPa* (gauge)
Ammonia tank available capacity				PQU
Agreed quantity to be transferred				PQU
Starting pressure at the manifold				bar/MPa* (gauge)
Starting rate				PQU per hour
Max. transfer rate				PQU per hour
Topping off rate				PQU per hour

Agreed maximums and minimums	**Maximum**	**Minimum**	**Units**
Pressures during bunkering at manifold:			bar/MPa* (gauge)
Pressures in the ammonia bunker tanks:			bar/MPa* (gauge)
Temperatures of the Ammonia:			°C
Filling limit of the ammonia bunker tanks:			%

Declaration

We, the undersigned, have checked the above items in Parts C in accordance with the instructions and have satisfied ourselves that the entries we have made are correct.

We have also made arrangements to carry out repetitive checks as necessary and agreed that those items coded ‘R’ in the checklist should be re-checked at intervals not exceeding ____ hours.

If, to our knowledge, the status of any item changes, we will immediately inform the other party.

Receiver	Supplier
Name	Name
Signature	Signature
Date & Time	Date & Time

Record of repetitive checks								
Date/Time								
Initials for receiver								
Initials for supplier								

Post-bunkering

(To be used after the transfer has been completed and before disconnecting the hoses)

Mode of Bunkering: ________________________________

Ammonia Supply (Terminal/Port/Truck/Ship): ________________________________

Bunker Facility Name/IMO Number: ________________________________

Bunker Facility Location: ________________________________

Ammonia Receiving Vessel's Name & IMO Number: ________________________________

Ammonia Receiving Vessel's Location: ________________________________

Date and Time: ________________________________

S. No	Check	Ship	Terminal	Truck	Code	Remarks
1	Ammonia bunker hoses, fixed pipelines and manifolds and the entire transfer system are purged with nitrogen and properly drained for disconnection.				A	
2	Ammonia vapour concentration has been checked before disconnection of the transfer system. All control valves are to be closed and ready for disconnection.				A	Ammonia vapour concentration is to be below 1% by volume.
3	All signage used for annotating controlled zones is to be removed after disconnection.				A	

4	Local authorities are informed about the completion of the ammonia bunker transfer.				P	Time notified: ____________hrs.
5	Local authorities are to be informed of any near miss or incidents.					Report number: ______________
6	Local authorities are to be informed in the event of any accidents.					Report number: ______________

Declaration

We, the undersigned, have jointly covered all items on this section and have satisfied that the entries we have made are correct to the best of our knowledge.

Receiver	Supplier
Name	Name
Signature	Signature
Date & Time	Date & Time

Annex F: RESPONSIBILITY ASSIGNMENT MATRIX (RACI)

Phases	Tasks	Implementing authority	Terminal	Ammonia bunker supplier	Ammonia bunkering facility PIC	Receiving vessel
Planning						
1	Risk assessment per section 7.1.8.3	C	C	A/R	I	A/R
2	Ammonia system and transfer equipment specifications per requirements			A/R	A/R	A/R
3	Determining the safety and monitoring zones for the intended operations	C	C	A/R	I	A/R
4	Ammonia Bunkering plan prepared	C		A/R	A/R	A/R
5	Notify implementing authority/terminal for ammonia bunkering operations	C	C	A/R	R	R
6	Compatibility assessment; equipment and mooring arrangement for intended operations per requirements	I	C	A/R	C	A/R
Pre-Transfer						
1	Pre-transfer meeting and documentation (including contingency plan, communication, loading limits, boil-off gas management)		A	I	A/R	A/R
2	Ensure all conditions are met, such as weather conditions, sea state, wind speed, and visibility			A/R	A/R	A/R
3	Ensure PPE requirements are followed				A/R	A/R
4	Ammonia transfer data (pressure, temperature, flowrate, quantity)			I	R	R
5	Both vessels/trucks are safely moored and secured				A/R	A/R
6	Transfer system, connectors and ESD			I	A/R	A/R
7	Grounding, water spray, fire protection and gas detection				A/R	A/R
8	Nitrogen purge, leak test, ESD test and cooling down				A/R	A/R
Bunkering						
1	Periodic checks of surroundings (weather, tide, passing traffic, safe mooring)				R	A/R
2	Periodic check of the transfer parameters, including vapour management				A/R	A/R
3	Stoppage requirement based on pressure built-up in the receiver tank				R	A/R
4	Ramp up, ramp down and topping up procedure/requirement				A/R	R

5	Notice the requirement before completion of the transfer				A/R	A/R
Post Bunkering						
1	Drain, and purge liquid lines and gas-free before disconnecting the transfer system				A/R	A/R
2	Purge and disconnect vapour return transfer system where fitted				A/R	A/R
3	Caution on disconnecting all cables (STS communication system, grounding cable) with regard to static electricity hazard		A/R		A/R	A/R
4	Post-transfer meeting		R	I	A/R	A/R
5	Issuance of bunker delivery note			I	A/R	A/R
6	The parties acknowledge bunkering checklists		R	I	A/R	A/R
7	Ammonia supplier (truck/vessel) readiness to depart		I	I	A/R	A/R
SIMOPS						
1	SIMOPS assessment		C	A/R	C	A/R
2	SIMOPS approval		A	I	I	A/R
3	SIMOPS planning		R	I	A/R	A/R
4	SIMOPS monitoring to ensure no breach of condition		R		A/R	A/R

Legend

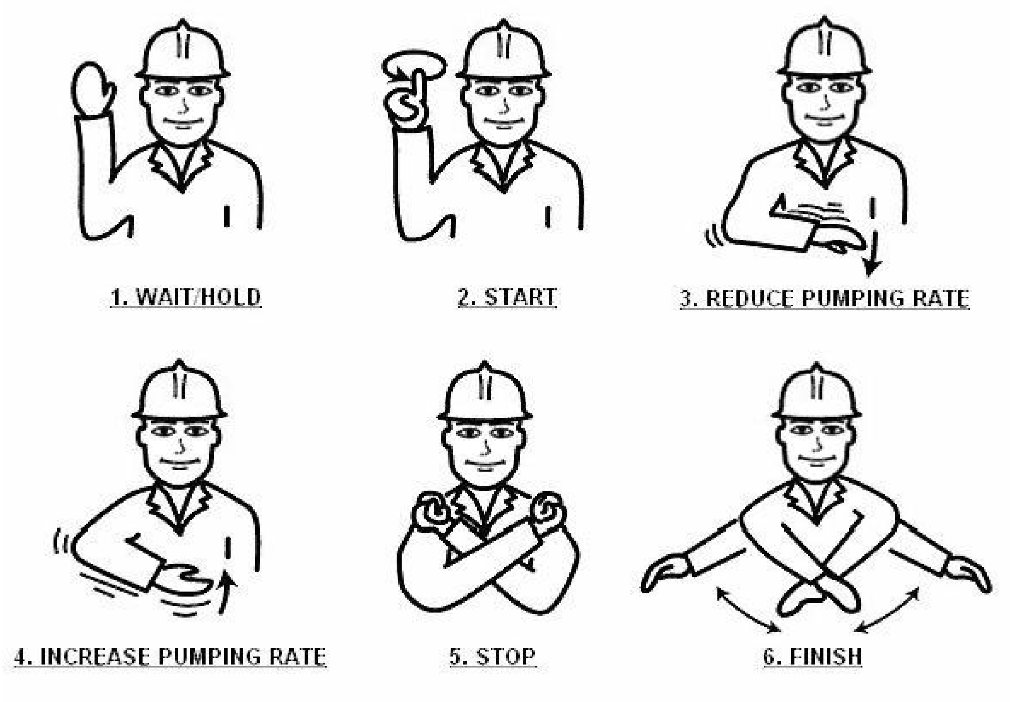
R = Responsible: The party is responsible for completing a task.

A = Accountable: The party accountable for major tasks and the result.

C = Consulted: The party/parties to be consulted before deciding or completing tasks. These parties are not responsible or accountable for the outcome.

I = Informed: The party/parties are to be informed of the task's progress. These parties do not need to provide input during the process but must be aware of the decisions made.

Annex G: HAND SIGNALS FOR BUNKERING OPERATION



Annex H: ACTIVITY CHECKLIST FOR POSSIBLE SIMOPS

Activity	Description	Pre-transfer	Bunker transfer	Post-transfer	Remarks
Cargo handling					
Passenger and crew embarking/ disembarking					
Dangerous goods loading/unloading (stores, provisions and waste)					
Chemical products and other low flash point products handling					
Bunkering of fuels other than ammonia and lubricants					
Maintenance, construction, testing and inspection activities					
Port and terminal activities					
Maintenance of dual fuel system					
Loading or unloading general containers					

Loading or unloading the IMDG container					
Loading or unloading reefer container					
Quay crane operations					
Ballasting					
Gangway & mooring line operation					
Regulatory inspections					
Hot work (onshore & onboard)					
Any type of drills on board					
Discharge or oil waste/slop					

8.3.11 Bibliography

[1] IGF Code - MSC.391(95) International code of safety for ships using gases or other low-flashpoint fuels

[2] IEC 31010 Risk Management – Risk assessment techniques

[3] IEC 60079-10-1: Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres

[4] OCIMF - MEG4: Mooring Equipment Guidelines, 4th edition (2018)

[5] OCIMF Ship to Ship transfer guide

[6] SIGTTO ESD Arrangements & Linked Ship/Shore Systems for Liquefied Gas Carriers (2009)

[7] SIGTTO Recommendations liquid gas carrier manifolds (2018)

[8] DNV-RU-SHIP Pt. 6 Ch. 2 (2021)

[9] European Maritime Safety Agency, Guidance on LNG Bunkering to Port Authorities and Administrations (2018)

[10] Maritime Energy & Sustainable Development, Ammonia as a Marine Fuel .(2022)

[11] IACS LNG Bunkering Guidelines (2016)

[12] UK P&I Risk Focus: Safe LNG Bunkering Operations (2019)

[13] Port of Helsinki, Safety manual on LNG bunkering procedures for the Port of Helsinki (2017)

[14] Technical Reference, TR 56: LNG bunkering (2020) (In chapter 7 GUIDEBOOK)

[15] IGC Code – MSC.5(48) International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

[16] CDC, NIOSH – Ammonia Solution (UN 3318); Ammonia, Anhydrous (UN 1005) (2011)

[17] Rotterdam LNG Bunker Checklist (2021)

8.4 Part 4: COMPETENCY REQUIREMENTS FOR SHIPBOARD AND SHORE PERSONNEL

8.4.1 Scope

To supply ammonia fuel safely and efficiently to ships, this guidebook covers competencies and knowledge required by ammonia bunker personnel, shore side, and ship staff (Management, Operation, Support and Emergency) for four modes of ammonia bunkering (shore-to-ship, truck-to-ship, STS and cassette bunkering). This part specifies the appropriate training required to fulfil the requirements set out in this guidebook.

8.4.2 Terms and definitions

For this guideline, the terms and definitions in Part 1 apply.

8.4.3 Properties of ammonia

For the general properties, characteristics and hazards associated with ammonia, refer to Part 1.

8.4.4 Training and competency framework for ammonia bunkering operations

8.4.4.1 Training requirements

A combination of both training and operational experience is key to developing the required competencies for ammonia bunkering operations. The level of competency needed for each task depends on the role and responsibilities of the individual. Therefore, the training may vary from person to person.

The following should be considered in developing the training programme:

(a) Specific role in the bunkering operation, shore side or on-board ship

(b) Experience with ammonia or other gaseous fuels ashore or on board

(c) Whether the individual will be directly involved in the transfer or the handling of the ammonia, and

(d) Exposure of the individual to potentially hazardous areas

Personnel involved in ammonia bunkering operations performs four roles: Management, Operation, Support and Emergency. The roles of the four different ammonia bunker transfer modes are specified in Table 8-10.

Table 8-10 Specific roles of personnel for the four modes of ammonia bunkering

Roles	Truck-to-Ship	Shore-to-Ship	STS	Cassette Bunkering
Management	A person who oversees and coordinates the truck bunkering operation, a person to whom the operator directly reports.	A person who oversees the bunkering operation at the bunkering facility (e.g., terminal) and coordinates the bunkering operation, a person to whom the person-in-charge of operation directly reports.	A crewmember serving as the master, chief mate, chief engineer, and second engineer onboard the ammonia-supplying ship.	A person who oversees and coordinates the ISO tank truck bunkering operation, a person to whom the operator directly reports.
Operation	A person in charge of the operation at the location of ammonia bunkering transfer.	A person in charge of the operation at the location of ammonia bunkering transfer (Loading Master).	A crewmember serving as a deck or engineer officer onboard the ammonia-supplying ship.	A person in charge of the operation at the location where the ISO tanks are transferred to the receiving ship.

Support	A person who performs the manifold watch, connection/disconnection of hoses, etc.	A person who performs the manifold watch, connection/disconnection of hoses, etc.	A crewmember serving as ratings on board the ammonia-receiving ship.	A person who performs the lifting operation from the ISO truck to the receiving ship.
Emergency	Person-in-charge of responding to ammonia tank related emergencies.	Person-in-charge of responding to emergencies related to transfer of ammonia as fuel.	Person-in-charge of responding to emergencies related to ammonia as fuel.	Person-in-charge of responding to ISO ammonia emergencies.

8.4.4.2 Modular approach

A modular approach is adopted to develop the competency for ammonia bunkering operations. Modules can be added to the training portfolio of the individual until the desired level of competency for the intended role is met. The modules are laid out in the same order as the bunkering process. For the details of the safety requirements and bunkering procedures, refer to Part 3 of this guideline.

The trainee will acquire the prerequisites and competencies in each module. The respective modules identify the prerequisites and competencies for each role. For each role involved in the ammonia bunkering operations, refer to the matrix in Annex K for the training modules.

The summary of prerequisites for all the roles involved in the ammonia bunkering operations is outlined in Annex I. The details of the prerequisites in Annex J are outlined in Annex I.

For shipboard personnel undergoing training for these competencies, there may be overlap with competencies required to operate ships subject to IGF code or personnel engaged in handling liquefied gases, under STCW convention.

8.4.4.3 Safety

Safety is of utmost importance during ammonia bunkering operations.

(a) Safety management system (SMS)/ammonia bunkering plan

- Objective

  To provide the management, operation, support and emergency personnel with an understanding of the corporate SMS and how the corporate-level policies are translated into the ammonia bunkering plan and ship/operating unit-specific documentation.

- Module summary

  Trainees will understand the shipboard SMS and the ammonia bunkering plan and how the policies are implemented through specific instructions after completing the module. Trainees will understand the importance of implementing and maintaining the ammonia bunkering procedures to ensure the integrity of the bunkering equipment. Trainees will understand the importance of recording information on safety incidents and near-misses to promote understanding, learning and improved performance in the future.

- Prerequisites

  - Shipboard SMS and related procedures
  - Ammonia bunkering plan.

- Learning outcomes

- Reinforce knowledge of operations conducted according to all applicable national and international maritime legislation, local regulations, and industry best practices
- Be familiar with ammonia vessels, operations, and ammonia equipment
- Understand STS transfer equipment, design, maintenance, and STS training methods
- Maintain safe staffing levels for the tasks to be undertaken
- Understand the properties and hazards of ammonia, including toxicity

- Training methodology
  - Theory and discussions
  - Practical (during OJT)
  - Alternative methods – manufacturer's manuals/instructions/video

(b) Risk assessment

- Objective

  To expose the management and operation personnel to ammonia's properties and characteristics as a liquid and vapour.

- Module summary

  After completing the module, trainees will understand risk assessment frameworks, methodologies, how and when they should be practically applied to the ammonia bunkering operation.

- Prerequisites
  - Physics and chemistry of ammonia
  - Hazards of ammonia, including toxicity
  - Impact of ammonia on equipment and construction materials
  - Methods of risk assessment
  - SMS and procedures
  - Communication and teamwork

- Learning outcomes
  - Understand the risk assessment framework (such as the code of practice on Workplace Safety and Health (WSH), Risk Management, etc.)
  - Understand the principles and methodologies of risk assessment
  - Identify situations relating to an ammonia bunkering operation where risk assessment needs to be undertaken or revisited, including SIMOPS, change in receiving systems, etc.
  - Be able to perform a hazard identification and risk assessment and develop and implement mitigating measures
  - Understand how to plan and monitor work carried out under a risk assessment to ensure its effectiveness and the management of all risks

- Understand the necessity to view risk assessments relating to commonly performed operations regularly
- Understand the importance of following a risk-assessed procedure

- <u>Training methodology</u>
  - Theory
  - Practical exercises
  - Practical (during OJT)
  - Alternative methods – manufacturer's manuals/instructions/video

(c) Roles and responsibilities of bunkering stakeholders

- <u>Objective</u>

  To let the management, operation, support, and emergency personnel understand the roles and responsibilities of the various stakeholders and organisations that may be involved in the ammonia transfer operations.

- <u>Module summary</u>

  After completing the module, trainees will understand the operational and safety roles of themselves and other parties, including the lines of responsibility and reporting. In addition, trainees will understand their role in ensuring the safe and environmentally responsible transfer of ammonia.

- <u>Prerequisites</u>
  - Roles and responsibilities of bunkering stakeholders
  - Communication and team working
  - Hazards of ammonia, including toxicity
  - Impact of ammonia liquid and vapour on the environment
  - Administrative processes and stakeholder interactions
  - Compatibility assessment

- <u>Learning outcomes</u>
  - Understand the need to verify risk assessments and mitigation measures, and whether they continue to be valid
  - Understand the need to report and record safety/environmental incidents
  - Understand the roles and responsibilities of various stakeholders and organisations involved in the ammonia transfer operation
  - Understand their roles throughout the bunkering process
  - Understand the importance of a contingency or emergency procedures and how to follow it

- <u>Training methodology</u>
  - Theory and discussions
  - Practical (during OJT)

- Alternative methods – manufacturer’s manuals/instructions/video

(d) Communication

- Objective

  To let the management, operation, support, and emergency personnel understand effective communication methods and how to receive feedback confirming that the communication has been understood.

- Module summary

  Trainees will be able to implement effective communications to allow the bunkering operation to take place safely and efficiently after completing the module. Trainees will be able to understand the specific information that should be exchanged, including when and with whom it should be exchanged.

- Prerequisites
  - Communication and teamwork
  - Pre-bunkering activities
  - Ammonia bunkering management plan
  - Roles and responsibilities of bunkering stakeholders
- Learning outcomes
  - Understand what information should be exchanged, when and with whom
  - Understand effective communication methods and how to receive feedback confirming that the communication has been understood
  - Be able to record appropriate information for governance accurately
  - Understand the different methods of communication
  - Communication and teamwork
- Training methodology
  - Theory and discussions
  - Practical (during OJT)
  - Alternative methods – manufacturer’s manuals/instructions/video

(e) Controlled zones

- Objective

  To let the management, operation, support*, and emergency personnel understand the definitions and uses of the safe and monitoring zones.

  Note: the (*) indicates the competencies and pre-requisites knowledge to be acquired for the support role.

- Module summary

  Trainees will be able to identify the hazardous areas, safety and monitoring zones defined by the relevant authorities and understand the applications of the zones after completing the module. In addition, trainees will be able to understand how to assess surrounding areas.

- Prerequisites

- Safety and monitoring zones*
- The importance of assessing the surrounding areas
- Classifications of hazardous areas
- Electrical equipment in hazardous areas
- How static and electrical equipment can cause sparks and ignitions
- Equipment manufacturers' operating manuals

- Learning outcomes
  - Understand the definitions of the toxic zone and monitoring zone*
  - Understand the use of toxic and monitoring zone*
  - Understand how to conduct an assessment of the surrounding areas
  - Understand the application of safety and monitoring zones as depicted by the relevant authority*
  - Understand the application of recommended maritime literature dedicated to safety and monitoring zones (i.e., SIGTTO, SGMF, local rules and regulations, etc.)
  - Understand the hazards associated with electrical current and static electricity during transfers of ammonia liquid and/or vapour
  - Understand how and why land-based equipment and road tankers need to be earthed
  - Understand the purpose of an insulating flange in ammonia transfer hose
  - Understand the reason for maintaining electrical continuity of bunkering lines
  - Understand the requirements for the use of electrical equipment in hazardous areas
  - Understand how to examine the physical condition of electrical equipment in hazardous areas for safe function before use
  - Understand the requirements for competent personnel to inspect, maintain, repair, overhaul and reclaim electrical installations within hazardous areas (refer to IEC 60079-17 & 60079-19)

- Training methodology
  - Theory and discussions
  - Practical (during OJT)
  - Alternative methods – manufacturer's manuals/instructions/video

(f) Low-temperature protection and safety equipment

- Objective

  To let the management, operation, support, and emergency personnel understand the calibration and maintenance procedures of the hazard detection equipment and how environmental conditions may affect their performance.

- Module summary

  After completing the module, trainees will know about the low-temperature protection systems, such as insulating blankets and safety equipment required to support the ammonia transfer operation, including their purpose(s), operating procedures, and maintenance. In addition, trainees will have the knowledge to carry out relevant safety device test(s) before the bunkering operation.

- Prerequisites
    - Fire and gas detection systems
    - Safety-related (leak/spill) equipment
    - Impact of ammonia on equipment and construction materials
    - Firefighting techniques and equipment that may be used with ammonia
    - Equipment manufacturers' operating manuals (Note: Basics for emergency personnel)
- Learning outcomes
    - Understand the purpose of drip trays and water sprays and how they are used to protect the vessels(s)/bunkering transfer areas
    - Understand the operation of hazard detection equipment, such as gas and fire detectors, and how environmental conditions may affect their performance
    - Understand the calibration and maintenance procedures of the hazard detection equipment
    - Understand where safety equipment is installed and/or where it needs to be installed
    - Understand and carry out relevant safety device test(s) before the bunkering operation
- Training methodology
    - Theory and discussions
    - Practical (during OJT)
    - Alternative methods – manufacturer's manuals/instructions/video

(g) ERS and ESD systems

- Objective

  To let the management, operation, support, and emergency personnel understand the working principle of ESD/ERS systems and the different means and levels of activation and the effects for all modes of transfer except cassette bunkering.

- Module summary

  Trainees will be able to understand the purpose and function of the ESD system and ERS after completing the module. In addition, trainees will have the knowledge to carry out the required procedures and checks in the case of an unavailable linked ESD/ERS system.

- Prerequisites
    - ESD system
    - ERS
    - Fire and gas detection systems
- Learning outcomes

- Understand how ESD/ERS systems work and the different means and levels of activation, and the effects
- Understand the procedure(s) to follow in the event of an ESD/ ERS activation to find and correct the underlying cause before restarting a transfer
- Understand why and how to link/connect and test an ESD/ ERS system from an ammonia supplier to an ammonia receiver
- Understand the additional procedures and checks required should a linked ESD/ ERS system not be available
- Understand how warm and cold ESD/ERS tests should be conducted

- Training methodology
  - Theory and discussions
  - Practical (drills and exercises - during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

(h) Firefighting

- Objective

  To let the management, operation, support*, and Emergency personnel understand the correct procedures to isolate potential ignition sources safely.

  Note: The (*) indicates the competencies and pre-requisites knowledge to be acquired for the support role.

- Module summary

  Trainees can respond to any ammonia fire and contain it after completing the module. Trainees will be able to understand the various emergency procedures related to ammonia fires.

- Prerequisites
  - Physics and chemistry of ammonia*
  - The impact of ammonia liquid and vapour on the environment*
  - Hazards of ammonia, including toxicity*
  - Leak behaviour*
  - The impact of ammonia on equipment and construction materials*
  - How static and electrical equipment can cause sparks and ignition*
  - Personal protective equipment (PPE)*
  - The firefighting techniques and equipment that may be used with ammonia*

- Learning outcomes
  - How to safely isolate potential ignition sources
  - Understanding emergency procedures

- How and when to fight an ammonia fire*
- How and when to start firefighting equipment*

- Training methodology
    - Theory and simulator training
    - Practical (drills and exercises)

(i) Emergency Procedures

- Objective

  To let management personnel, understand the emergency responses to potentially hazardous events during bunkering operations.

- Module summary

  After completing the module, trainees will be able to demonstrate a detailed understanding of the potential hazards that may result from a bunkering operation involving ammonia and how such hazards should be dealt with, including contingency planning. In addition, the different roles and limitations of the local immediate responders will be made clear to trainees, along with the correct procedures for coordination during emergency services.

- Prerequisites
    - Hazards of ammonia, including toxicity
    - Physics and chemistry of ammonia
    - Impact of ammonia on equipment and construction materials
    - Contingency planning
    - Emergency procedures
    - SMS and procedures
    - Ammonia bunkering plan

- Learning outcomes
    - Understand how to effectively respond to a variety of potentially hazardous events that may occur during bunkering operations
    - Understand the principles of escalation, in which one hazardous event may lead to others
    - Understand the principles of an emergency evacuation, and where appropriate, the role of temporary refuges, and how plans may need to be modified for different weather, damage scenarios and bunkering processes
    - Understand when to evacuate to a muster point (or temporary refuge)
    - Understand the roles and limitations of local immediate responders and how to coordinate with, and when to handover to emergency services
    - Understand the need for realistic emergency drills and the process for incorporating lessons learnt into the emergency procedures

    - Understand how contingency and emergency procedures should be prepared, implemented and reviewed

- Training methodology
    - Theory
    - Practical (drills and exercises – during OJT)
    - Simulator
    - Alternative methods – manufacturer's manuals/instructions/video

(j) Responding to emergencies (emergency organisation)

- Objective

  To let the management, operation, support and emergency personnel understand the basic structure of the emergency organisation.

- Module summary

  Trainees can identify and respond to emergencies through alarms after completing the module.

- Prerequisites
    - Hazards of ammonia, including toxicity
    - Physics and chemistry of ammonia
    - Impact of ammonia on equipment and construction materials
    - Contingency planning
    - SMS and procedures
    - Ammonia bunkering plan

- Learning outcomes
    - Describe the four commonly known elements of the basic structure of the emergency organisation, namely command centre, emergency party, backup emergency party and technical party
    - Understand the roles on board in the emergency organisation and the required duties in the scenario of an emergency procedure initiation
    - Identify the senior officer in charge and serving as a deputy during the emergency
    - Understand the general composition and the tasks of the command centre, emergency party, backup emergency party and the engineers' group
    - Describe the general and fire alarm signals
    - Be familiar with the emergency plan and act accordingly when the emergency alarm is raised

- Training methodology
    - Theory
    - Practical (drills and exercises – during OJT)
    - Alternative methods – manufacturer's manuals/instructions/video

(k) Responding to Emergencies (emergency procedures)

- Objective

  To let the management, operation, support and emergency personnel understand the activation procedures of the ESD systems and the emergency notifications.

- Module summary

  Trainees can identify and respond to emergencies after completing the module. In addition, the knowledge to activate ESD systems and execute specific emergency procedures will be provided to trainees.

- Prerequisites

  - Physics and chemistry of ammonia
  - Hazards of ammonia, including toxicity
  - Properties of inert gases (including nitrogen)
  - Emergency procedures
  - Firefighting techniques and equipment that may be used
  - Contingency plans
  - Leak behaviour
  - Instrumentation and monitoring devices
  - First aid action is to be taken when someone comes into contact with ammonia

- Learning outcomes

  - Describe how ammonia liquid or vapour could be released into the atmosphere during the bunkering process
  - Understand ESD systems and how they are activated
  - Know how and when to activate the ESD system
  - Know the emergency notifications
  - Demonstrate knowledge and skills needed to execute the emergency procedures
  - Know the location and access route to the muster point (or temporary refuge)

- Training methodology

  - Theory and simulator training
  - Practical (drills and exercises – during OJT)
  - Alternative methods – manufacturer's manuals/instructions/video

(l) Personal protective equipment (PPE)

- Objective

  Let the management, operation, support and emergency personnel understand the various types of PPE required for ammonia handling.

- Module summary

After completing the module, trainees will know the types of PPE to use when working with ammonia, how to use it correctly and how to check that the equipment is fit for its purpose.

- Prerequisites
  - Hazards of ammonia, including toxicity, and
  - PPE
- Learning outcomes
  - Understand what PPE should be used when working with ammonia and how to use them
- Training methodology
  - Theory
  - Practical (during OJT)
  - Alternative methods – manufacturer's manuals/instructions/video

8.4.4.4 Bunker transfer

When it comes to bunker transfer, several critical procedures must be followed.

(a) Periodic checks

- Objective

  To ensure management, operation, and support are well informed on the requirements to monitor ammonia transfer and record the outcomes of periodic checks.

- Module summary

  Trainees will be able to understand the importance of monitoring the ammonia transfer process by re-checking the items after completing the module.

- Prerequisites
  - Codes used in checklists
  - The fundamentals of control systems,
  - The proper course of action is to be followed in case of deviation from standard conditions
- Learning outcomes
  - Fully comprehend the checklist elements and know how to use them effectively,
  - Document the outcomes of routine checks
- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

(b) Vapour Management

- Objective

  To ensure management, operation, and support are well informed on the properties and characteristics of ammonia and gases.

- Module summary

  After completing this module, trainees can maintain tank pressure within the safe operating limit independently or with assistance. When difficulties in maintaining tank pressures arise, pressure readings should be regularly monitored, and relief valves should never be raised. If a ship's tank pressure rose during the early stages of bunkering, it could be controlled by activating the top sprays and condensing some vapour, assuming such equipment has been installed.

- Prerequisites
  - Instrumentation and monitoring devices
  - Storage tank operations
  - Pressure relief mechanisms

- Learning outcomes
  - Know how to control the liquid level and pressure in an ammonia tank when transferring ammonia
  - Recognise the pressure and vacuum protection systems in ammonia tanks
  - Recognise the several kinds of level and pressure gauges used in ammonia tanks, and their shortcomings
  - Recognise the safe tank filling limit and how to compute it
  - Know how to manage the vapour return line and the operating procedures for the vapour return
  - Have accurate reading skills for level and pressure gauges

- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

(c) Control and monitoring

- Objective

  To ensure management, operation, and support are well informed on the systems for operating and monitoring bunkering.

- Module summary

  After completing this module, trainees will be able to explain the systems used to monitor and operate the bunker system and be able to use them appropriately and effectively.

- Prerequisites
  - Valves

    - Fire and gas detection systems
    - Instrumentation and monitoring devices
- Learning outcomes
    - Recognise major alerts, understand their most likely triggers, and be aware of any future implications
    - Understand the functions of fire and gas monitoring systems
    - Demonstrate the ability to respond to alarms and take action in an emergency
    - Understand the operation of bunkering control systems
    - Know how, by whom, and with what equipment the ammonia transfer process can be monitored
    - Understand the various activation methods and levels used by the ESD system, its underlying philosophy
    - Understand how to interpret the level, pressure, and temperature readings of instruments
- Training methodology
    - Theory
    - Practical (during OJT)
    - Simulator
    - Alternative methods – manufacturer's manuals/instructions/video

(d) Ramp-up and ramp-down procedures

- Objective

  To ensure management, operation and support are well informed on how to assist in transferring ammonia safely.
- Module summary

  Trainees can help safely and effectively transfer ammonia after completing the module.
- Prerequisites
    - Operation of storage tanks
    - Equipment for monitoring and instrumentation
    - Ammonia pumps
    - Ammonia transfer systems
    - Tanks for storing ammonia
    - Valves
    - Communication and teamwork
- Learning outcomes
    - Know the steps to take to complete the transfer

- Be aware of the documents that must be maintained during the transfer process and complete them
- Realise the significance of having a transfer strategy in place
- Manage and monitor ammonia flows during all phases of the ammonia transfer process
- Understand the data to be monitored and the appropriate settings to demonstrate safe functioning
- Know and understand the steps that must be taken to regulate the temperature and pressure inside the ammonia storage tanks and related systems
- Be aware of the necessity to lower the loading rate
- Be aware of the significance of communication to give notice before reducing the rate at which tanks are topped off

- Training Methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

(e) SIMOPS

- Objective

  To ensure that management, operation, and support personnel are well informed on the potential hazards due to SIMOPS and how to make decisions for that specific bunkering operation.

- Module summary

  After completing this module, trainees will understand the dangers posed by SIMOPS and make appropriate decisions for a specific bunkering operation set-up.

- Prerequisites
  - SIMOPS scenarios
  - Precautions for SIMOPS and planning
  - Techniques for assessing risk
- Learning outcomes
  - Compare and contrast the various SIMOPS with ammonia bunkering
  - Recognise the potential hazards SIMOPS may present
  - Know how to assess whether SIMOPS are appropriate for a specific bunkering operation set-up
  - Understand the SIMOPS approval process(es) and list of precautions, and
  - Understand the necessity of monitoring of SIMOPS conditions and actions to be taken in the event SIMOPS requirements are breached or cannot be met
- Training methodology
  - Theory

- Practical (during OJT)
- Simulator
- Alternative methods – manufacturer’s manuals/instructions/video

8.4.4.5 Post bunkering

Post-bunkering procedures are essential for the safe and efficient handling of ammonia.

(a) Draining liquid lines

- Objective

  Ensure management, operation, and support personnel are well-informed on the safe methods of draining the ammonia transfer system upon the completion of bunkering.

- Module summary

  After completing this module, trainees can drain the ammonia transfer system safely and help after completing a transfer.

- Prerequisites
  - Valves
  - Isolation operations
  - Ammonia transfer systems
  - Instrumentation and monitoring devices
  - Mechanical handling
  - PPE
  - Operational instructions from equipment manufacturers
  - Draining procedures
  - Pressurisation and depressurisation
- Learning outcomes
  - Understand the various techniques for draining transfer lines safely and effectively without letting ammonia or its vapour leak into the environment
  - Be able to demonstrate steps to prevent ammonia from becoming trapped within any part of the transfer system
  - Show how to ensure/test that transfer lines are gas-free before disconnecting
- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer’s manuals/instructions/video

(b) Purging liquid and vapour lines after draining

- Objective

  To ensure management, operation, and support personnel are well-informed on the safe methods of purging the ammonia transfer system upon the completion of bunkering.

- Module summary

  After completing this module, trainees can safely purge the ammonia transfer system and help after the transfer completion.

- Prerequisites
  - Valves
  - Isolation operations
  - Ammonia transfer systems
  - Properties of inert gases (including nitrogen)
  - Instrumentation and monitoring devices
  - Mechanical handling
  - PPE
  - Operational instructions from equipment manufacturers
  - Purging procedures
  - Pressurisation and depressurisation

- Learning outcomes
  - Understand the various techniques for draining and clearing transfer lines safely and effectively without letting ammonia or its vapour leak into the environment
  - Be able to demonstrate steps to prevent ammonia from becoming trapped within any part of the transfer system
  - Show how to ensure/test that transfer lines are gas-free before disconnecting

- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

(c) Disconnect transfer systems

- Objective

  To ensure management, operation, and support personnel are well-informed on the requirements and procedures of disconnecting the ammonia transfer system after a bunkering operation.

- Module summary

After completing this module, trainees can disconnect the ammonia transfer system after completing a bunkering operation independently or with assistance.

- Prerequisites
    - Valves
    - Isolation procedures
    - Ammonia transfer systems
    - Properties of inert gases (including nitrogen)
    - Instrumentation and monitoring tools
    - Mechanical handling
    - Personal protective equipment (PPE)
    - Equipment manufacturer operating manuals
    - Purging operations
    - Pressurisation and depressurisation
    - Draining operations
- Learning outcomes
    - Understand how to isolate and detach the ammonia transfer equipment safely
    - Properly position and park the ammonia transfer equipment
- Training methodology
    - Theory
    - Practical (during OJT)
    - Simulator
    - Alternative methods – manufacturer's manuals/instructions/video

(d) Disconnect all cables

- Objective

  Ensure management, operation, and support personnel are well informed on disconnecting all cables after the bunkering process.
- Module summary

  After completing this module, trainees can disengage all electrical bonding connections, the emergency shutdown systems, and the ammonia transfer communication systems once the bunkering process is completed.
- Prerequisites
    - Electrical equipment in hazardous areas
    - Ammonia transfer system
    - How static and electrical equipment can cause sparks and ignition

- Operating manuals for equipment manufacturers

- Learning outcomes
  - Understand how to isolate and safely disconnect the ammonia transfer equipment
  - Communication and teamwork
  - Store/park ammonia transfer equipment correctly
  - Understand the philosophy of how ESD systems work
  - Understand the different means and levels of activation
  - Understand the impact of actuating the ESD system
  - Understand the procedure to follow in the event of an ESD situation occurring

- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative method – manufacturer's manuals/instructions/video

(e) Post transfer meeting

- Objective

  To ensure management, operation and support personnel are ready to participate in the post-transfer meeting.

- Module summary

  After completing this module, trainees will be well-prepared to participate in the post-bunkering meeting.

- Prerequisites
  - The management of ammonia quality and quantity
  - Instrumentation and monitoring devices
  - Ammonia transfer procedure (such as the transfer measurement process)

- Learning outcomes
  - Understand the composition and energy quality phrases in the ammonia quality certification that was supplied before the ammonia transfer, assess whether the ammonia is within specifications, and any impact it might have
  - Recognise the calculations and accuracy required to verify the quantity and quality of the ammonia transferred
  - Recognise the results of the ammonia quality and quantity measurement apparatus
  - Realise the importance of a Bunker Delivery Note (BDN)

- Training methodology
  - Practical (during OJT)

- Alternative method – manufacturer’s manuals/instructions

8.4.4.6 Operating and regulatory framework

Compliance with the operating and regulatory framework by personnel is important.

(a) Compliance with regulations

- Objective

  To expose trainees to the international and local rules and regulations governing ammonia bunkering operations and to familiarise them with SMSs and procedures.

- Module summary

  After completing the module, trainees will comprehend the significance of international and local regulations, the safety reasons for the operational procedures, and the consequences of global and local regulations.

- Prerequisites
  - Ammonia bunkering operations
  - International rules and regulations and guidance covering ammonia bunkering
  - Local rules and regulations covering ammonia bunkering
  - SMSs and procedures
- Learning outcomes
  - Understand international and local rules and regulations governing ammonia bunkering, and potential ramifications for the license to operate if they are not followed
  - Understand the implications that modifications to an asset can have on safety operations
  - Understand the role of the safety, environmental, and operating manuals, including the ammonia bunkering plan, in compliance with international and local rules and regulations, along with identifying gaps in compliance
  - Understand the ammonia bunkering delivery process and the procedures that must be followed
  - Understand the importance of complying with an appropriate change management process to ensure that any modifications to the asset maintain compliance with applicable rules and regulations
- Training methodology
  - Theory

(b) Organisation and management

- Objective

  To expose trainees to the roles and responsibilities of the organisation and management of ammonia bunkering operations.

- Module summary

  After completing the module, trainees can efficiently organise and manage the ammonia bunkering operation.

- Prerequisites
    - Ammonia bunkering activities
    - The impact of ammonia liquid and vapour on the environment
    - Effective communication and teamwork
    - Safety management procedures and systems
    - Roles and responsibilities of bunkering stakeholders
    - Learning outcomes
    - Understand the roles and responsibilities of the ammonia buyer/receiver and ammonia bunker supplier
    - Understand the roles and responsibilities and the appropriate training and competency required for personnel undertaking ammonia bunkering activities
    - Understand the significance and need to develop appropriate operating procedures for ammonia bunkering activities aligned with industry regulations and guidelines. Typical operating procedures can cover but not be limited to:
        - Manning
        - Communications
        - Roles and responsibilities
        - Emergencies
        - Compatibility checks, and
        - Ammonia bunkering operations etc
- Training methodology
    - Theory

(c) Safety and operating procedures

- Objective

  To expose trainees to the safety and operating procedures and the role and scope of safety procedures during ammonia bunkering operations.

- Module summary

  After completing the module, trainees can identify the proper safety and operational procedures (including those indicated in manuals), when they should be implemented, and how they should be controlled.

- Prerequisites
    - Operational procedures
    - SMSs and procedures
- Learning outcomes
    - Understand the role and scope of the operating and safety procedures concerning ammonia bunkering operations

- Understand which safety and operating procedures are suitable for an ammonia bunkering operation
- Understand how to manage change processes properly to improve safety, or operating procedures

- Training methodology
  - Theory

8.4.4.7 Planning phase

Training modules also include elements critical in the planning for ammonia bunkering operations.

(a) Preparation for ammonia transfer

- Objective

  Ensure all trainees are aware of the prerequisite conditions, pre-transfer check requirements, and the purpose and consequences of failing to meet the safety conditions.

- Module summary

  After completing the module, trainees will be capable of verifying that the conditions are safe before starting an ammonia transfer and being aware of the hazardous and safety zones and how they should be implemented.

- Prerequisites
  - Hazards of ammonia, including toxicity
  - Impact of ammonia on equipment and construction materials
  - Leak behaviour
  - Physical and chemical properties of ammonia
  - Risk assessment and its communication
  - How static and electrical equipment can cause sparks and ignition
  - Safety-related (leak/spill) equipment
  - Pre-bunkering activities
- Learning outcomes
  - Understand the objective and requirements of pre-transfer checks and how they should be carried out
  - Understand how to prepare the area where ammonia transfer occurs
  - Understand the effects of environmental conditions and the implications they may have with the bunkering process and personnel performance
  - Understand the necessary safety equipment
  - Understand the purpose and requirements of safe access for personnel involved in the bunker operation in the case of an emergency
- Training methodology
  - Theory

- Practical (during OJT)
- Alternative method – Manufacturer's manuals/instructions/video

(b) Pre-transfer Meeting and Documentation

- Objective

  To expose trainees to the importance of pre-bunkering meetings, the items that may hinder the safety of the bunkering operations, and what is to be covered during the meeting.

- Module summary

  After completing the module, trainees will understand the importance of holding a pre-bunkering meeting that covers subjects such as planning, safety inspections, and communication throughout operations.

- Prerequisites
  - Code used in the checklists
  - Communication and teamwork
  - Pre-bunkering activities
  - SIMOPS scenarios
  - Precautions for SIMOPS

- Learning outcomes
  - Understanding how important to share the knowledge and agreements on safety items during the planning stage
  - Understanding the additions risk(s) during concurrent bunker, cargo or other operations

- Training methodology
  - Theory
  - Alternative method – Manufacturer's manuals/instructions/video

(c) Ammonia Transfer Quality and Quantity

- Objective

  To ensure trainees are adept in identifying the quality and quantity of ammonia transferred along with the certifications and procedures for the BDN.

- Module summary

  After completing this module, trainees will be able to assess the quality and quantity of ammonia transferred for commercial and governance reasons.

- Prerequisites
  - Instrumentation and monitoring devices
  - Ammonia transfer process (e.g., transfer measurement process)
  - Ammonia quality management

- Learning outcomes
    - Understand the principles of the transfer measurement process
    - Understand the certification of ammonia quality before the transfer, including the composition and energy quality terms, evaluate the quality of ammonia to be within specifications, and know the implications if quality was not up to standards
    - Understand the units of measurement, calculations and the accuracies required to confirm the quality and quantity of the ammonia transferred
    - Understand the principle of operation and operating procedures of the various types of equipment specific to the mode of transfer (e.g., flow, level, temperature, pressure and weight measuring equipment) and appreciating potential sources of inaccuracies from such measuring equipment
    - Understanding how quality and quantity measurement output is used within the BDN
- Training methodology
    - Theory
    - Practical (during OJT)
    - Simulator
    - Alternative method – Manufacturer's manuals/instructions/video

(d) Ammonia Transfer Technical Data

- Objective

  To ensure trainees understand the transfer measurement process and how to generate a supporting record of the ammonia transfer process.

- Module summary

  After completing this module, trainees will understand the transfer measurement method and how to keep a supporting record.

- Prerequisites
    - Instrumentation and monitoring devices
    - Ammonia transfer process (e.g., transfer measurement process)
    - Ammonia quality and quantity management
- Learning outcomes
    - Understand the principles of the transfer measurement process
    - Understand the information required to be recorded for quality and quantity purposes
    - Understand the principles of operation and operating procedures of the various types of flow, level and weight measuring equipment that may be encountered
    - Understand the different types of temperature instruments, pressure gauges and level instruments installed, potential sources of inaccuracy, and how to read them accurately
    - Understand the various types of ammonia quality measurement equipment

- Understand the distinction between calibration and validation for quantity and quality measurement equipment

- Training methodology
    - Theory
    - Practical (during OJT)
    - Simulator
    - Alternative method – Manufacturer’s manuals/instructions/video

(e) Ammonia Bunker Transfer and Associated Equipment

- Objective

  To expose trainees to the equipment and items maintenance, certifications and how to assess the safety of the equipment.

- Module summary

  After completing the module,

    - the trainee will be able to ensure that any transfer and safety equipment and supporting systems, whether owned or rented, are appropriate for their intended purpose
    - the trainee will recognise the necessity for and proper application of mechanical handling equipment
    - the trainee will comprehend the ammonia transfer system

- Prerequisites
    - Physics and chemistry of ammonia
    - Responsibilities surrounding owned and leased equipment
    - Ammonia transfer system
    - Mechanical handling
    - Equipment manufacturer’s operating manuals
    - Ammonia storage tanks
    - Ammonia transfer systems
    - Impact of ammonia on equipment and construction materials

- Learning outcomes
    - Understand which items of equipment need to be certified and the necessity to confirm that the certification(s) are up to date
    - Understand what maintenance and test records are needed for both owned and rented equipment
    - Comprehend the concept of duty of care, including how this protects both persons and assets and how to decide which precautions/actions are necessary
    - Correctly handle a transfer hose, bunker boom or loading arm

- Understand why the ammonia transfer system must be supported to prevent excessive stresses and for the hose to be able to bend, breakaway in the form of a coupling, connector and manifolds
- Understand why and which items of mechanical handling equipment are covered by certification systems and the need to confirm that the certifications are up to date
- Understand how to examine the mechanical handling system for safe function before usage
- Understand which mechanical handling systems must remain in place during the transferring of ammonia
- Understand the various connection methods that may be utilised
- Understand how to assemble the ammonia transfer system in the correct order
- Understand how components within a transfer system should be appropriately connected so that the possibility of leaks is minimised and what checks are needed to verify that the system is free from leaks across the operating temperature range
- Understand the checks needed to guarantee that electrical community and insulation devices are correctly maintained and installed
- Understand the various types of ammonia storage systems that may be used by a supplied and the resulting implications relating to the transfer of ammonia may need to be considered

- <u>Training methodology</u>
    - Theory
    - Practical (during OJT)
    - Alternative method – Manufacturer's manuals/instructions/video

(f) Inspection of Bunkering Equipment

- <u>Objective</u>

  To expose trainees to the importance of equipment certification and how to assess the components of the equipment if it is safe to use and well maintained.

- <u>Module summary</u>

  Trainees will be able to ensure that no damage or wear may lead to dangerous situations after completing this module.

- <u>Prerequisites</u>
    - Impact of ammonia on equipment and construction material
    - Ammonia transfer system
    - Equipment manufacturer's operating manuals

- <u>Learning outcomes</u>
    - Understand the importance of certification of equipment
    - Understand how to examine all the components of the ammonia transfer system for physical damage and wear

- Understand how to follow up if physical damage and wear are found on equipment, ensure the equipment is well maintained and calibrated for accurate ammonia custody transfers

- Training methodology
    - Theory
    - Practical (during OJT)
    - Alternative methods – manufacturer's manuals/instructions/video

(g) Connection of Transfer Systems

- Objective

  To ensure trainees can correctly perform the connections for the ammonia transfer systems with hands-on experience during the simulator training.

- Module summary

  After completing this module, trainees will be competent in correctly connecting the ammonia transfer system.

- Prerequisites
    - Mechanical handling
    - Impact of ammonia on equipment and construction materials
    - Equipment manufacturers' operating manuals
    - Physics and chemistry of ammonia

- Learning outcomes
    - Identify the various connection and methods that may be utilised
    - connect the ammonia transfer system correctly
    - Undertake the checks needed to verify that the system is free from leaks across the operating temperature range

- Training methodology
    - Theory
    - Practical (during OJT)
    - Simulator
    - Alternative method – Manufacturer's manuals/instructions/video

(h) Nitrogen Purge and Leak Test

- Objective

  To expose trainees to the methods used for purging as well as the potential risks that may hinder the safety of the procedure.

- Module summary

After completing this module, trainees will understand the need to ensure the transfer system is clear of air and moisture, and free from leaks before commencing bunkering operations.

- Prerequisites
  - Properties of inert gases (including nitrogen)
  - Pressurisation and depressurisation
  - Leak behaviour
  - Safety-related (leak/spill) equipment
  - Purging operations
  - Hazards of ammonia, including toxicity
  - Impact of ammonia on equipment and construction materials
- Learning outcomes
  - Understand the risks that may arise if moisture is not removed from the ammonia transfer system before the introduction of ammonia vapour or liquid
  - Understand the methods that may be employed to purge the ammonia transfer system before use and the indications for satisfactory completion
  - Understand the methods used to purge ammonia safely into the environment
  - Understand the emergency procedure for accidental release or purging of large ammonia volume into the atmosphere
  - Understand the potential physical and environmental harm an ammonia leak may cause
  - Able to test for leaks in the ammonia transfer system
  - Understand the implications of a leak of liquid or vapour and how to take the proper corrective measures
- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative method – Manufacturer's manuals/instructions/video

(i) Line Cool Down

- Objective

  To expose trainees to the methods of cooling down an ammonia system and the procedures for vapour return.

- Module summary

  After completing the module, trainees can explain why and how to cool down the ammonia transfer system.

- Prerequisites

- Impact of ammonia on equipment and construction materials
- Pressure protection devices
- Storage tank operations
- Equipment manufacturers' operating manuals
- Leak behaviour
- Safety-related (leak/spill) equipment
- Purging operations
- Physics and chemistry of ammonia
- Ammonia transfer systems
- Ammonia storage tanks

- Learning outcomes
  - Understand the necessity of cooling down ammonia systems and the possibility of leakage
  - Understand the techniques for cooling down an ammonia transfer system and how it should be monitored, and
  - Understand the procedures for vapour return, disposal or pressure management related to various ammonia storage systems
- Training methodology
  - Theory
  - Practical (during OJT)
  - Simulator
  - Alternative methods – manufacturer's manuals/instructions/video

8.4.5 Assessment of ammonia bunkering operation competency

Assessment is a method to determine whether a trainee has attained the prescribed standard or level of competence. Competence refers to what a trainee requires to perform the role during normal ammonia bunkering operations and in emergencies.

Section 8.4.4 provides the prerequisites and competencies to be acquired for ammonia bunkering. They shall be assessed in the following ways:

(a) Written examination and simulation exercise at an approved test centre of the implementing authority, and
(b) On-the-job experience under supervision and aligned with the company's safety and training management system

Note: The on-the-job trainer should be qualified and experienced in liquefied gas handling and bunkering operations.

After completing activity (a), a training completion certificate shall be issued to the candidates.

Upon satisfactory completion of (b), a certificate of proficiency shall be issued by or under the authority of the implementing authority to the candidate.

A proficiency certificate will be valid for five years after it is issued. The validity of the certificate of proficiency can be extended for a further five years if the candidate can maintain the required standards of competence to undertake the tasks, duties and responsibilities in ammonia bunkering operations as determined by the implementing authority.

8.4.6 Requirements for trainers and assessors

Trainers and assessors should be qualified in the modules for which the training or assessment is being conducted and have appropriate training in instructional techniques and evaluation methods. The term “qualified” refers to proficiency in the subject matter and relevant operational experience.

A qualified trainer or assessor shall assess trainees who oversee ammonia bunkering. The trainer or assessor shall:

(a) Have the appropriate level of knowledge (including prerequisites) and understanding of the required level of competence needed for the trainee for his role in the ammonia bunkering operations
(b) Know of or have received guidance in the assessment methods and practice
(c) Be qualified for the task for which the assessment is being made
(d) Ensure that the assessment is consistent
(e) Have practical assessment experience

8.4.7 Simulation exercise requirements

8.4.7.1 Exercise using simulators

Where the exercise is carried out using simulators, the trainer should have completed necessary simulator training, particularly on the limitations of a simulator, and should have practical experience under the guidance of an experienced simulator trainer.

8.4.7.2 Requirements for simulators

The simulator should replicate the operational capabilities of ammonia operations as realistically appropriate to the assessment objectives. This includes capabilities, limitations and possible errors of associated equipment. The simulator shall comply with the minimum requirements prescribed by the implementing authority. The type of simulator utilised may depend on the training requirements and should be designed to provide the trainee with a realistic operational experience.

In addition, cargo handling simulators used for training and assessment shall include, but are not limited to, the following:

(a) Air and inert gas driers
(b) Inert gas generator
(c) Nitrogen generator
(d) Ammonia vaporiser
(e) BOG compressor(s)
(f) Gas heaters, glycol water/thermal oil (GW/TO) heaters
(g) Forcing vaporiser
(h) Cargo pumps
(i) Spray pumps
(j) Cargo tank relief valves
(k) Real-time switching
(l) Control and operation equipment
(m) Hose connection and disconnection, including draining and nitrogen (N_2) purging
(n) Blanking/de-blanking of manifold, including strainers
(o) Bonding cable connection/disconnection

(p) Gas detection equipment
(q) Safety equipment (e.g., Self-contained breathing apparatus)
(r) An ESD system
(s) Quantity and quality measurement equipment

8.4.8 Assessment criteria

The assessment aims to gather evidence to judge the effectiveness of training and confirm that the trainee has achieved the desired learning outcomes and appropriate level of competency.

When developing assessment criteria, the training centre should ensure the following:

(a) Clarity in the instructions given to a trainee
(b) Coverage of all relevant topics
(c) Appropriate weightage of marks are given to the topics
(d) Varied methods of assessment are used
(e) Security and confidentiality of developing question papers, conducting examinations and simulated exercises are maintained

The assessment should test a trainee's ability to:

(a) Identify the physical and chemical properties and characteristics of ammonia and their impact on safety and environmental protection by making good use of information resources
(b) Follow the correct procedures before, during and after bunkering
(c) Monitor gas detection and pressure, and other monitoring equipment consistent with safe operating procedures
(d) Identify emergencies and file appropriate reports and operate emergency systems

When evaluating the prerequisites, the assessment should test knowledge, comprehension and application of fundamental principles.

A trainee's ability to perform a task competently should be tested by performance-based assessments as part of on-the-job training or using simulators.

ANNEX I: SUMMARY OF PREREQUISITES (NORMATIVE)

Category	Prerequisites	Management	Operation	Support	Safety / Emergency
1 Fundamental knowledge for common ammonia bunkering operations	1.1 The physics and chemistry of ammonia	x	x	x	
	1.2 The impact of ammonia liquid and vapour on the environment	x	x	x	
	1.3 Hazards of ammonia, including toxicity	x	x	x	x
	1.4 Leak behaviour	x	x	x	x
	1.5 The impact of ammonia on equipment and construction materials	x	x	x	x
	1.6 How static and electrical equipment can cause sparks and ignition	x	x	x	x
	1.7 The properties of inert gases (including nitrogen)	x	x	x	x
2 Corporate governance and management systems	2.1 International rules, regulations and guidance covering ammonia bunkering	x	x		
	2.2 Local rules and regulations covering ammonia bunkering	x	x		
	2.3 Methods of risk assessment	x	x	x	
	2.4 The responsibilities surrounding	x	x		

	owned and leased equipment				
	2.5 Safety management system (SMS) and procedures	x	x	x	
	2.6 Ammonia bunkering plan	x	x	x	
	2.7 Operational procedures	x	x		
3 Organisation and management	3.1 Communication and teamwork	x	x	x	
	3.2 Roles and responsibilities of bunkering stakeholders	x	x	x	x
	3.3 Administrative processes	x	x	x	
	3.4 Stakeholder interactions	x	x	x	
4 Familiarity with the operation, calibration and maintenance of equipment and instrumentation	4.1 Mechanical handling	x	x	x	
	4.2 The ammonia transfer system	x	x	x	
	4.3 Ammonia storage tanks	x	x		
	4.4 Ammonia pumps	x	x		
	4.5 Valves	x	x	x	
	4.6 Pressure protection devices	x	x	x	
	4.7 Electrical equipment in hazardous areas	x	x	x	x
	4.8 Safety-related (leak/spill) equipment	x	x	x	x
	4.9 Personal protective equipment (PPE)	x	x	x	x

	4.10 Equipment manufacturers' operating manuals	x	x	x	
5 Bunkering operations	5.1 Pre-bunkering activities	x	x	x	
	5.2 Purging operations	x	x	x	
	5.3 Pressurisation and depressurisation	x	x	x	
	5.4 Storage tank operations	x	x		
	5.5 Draining operations	x	x	x	
	5.6 Isolation operations	x	x		
	5.7 Codes used in the checklists	x	x	x	
	5.8 Compatibility assessment	x	x		
6 Control and monitoring	6.1 Fire and gas detection systems	x	x	x	
	6.2 ESD systems	x	x	x	
	6.3 ERS	x	x	x	
	6.4 Basic concepts of control systems	x	x	x	
	6.5 Instrumentation and monitoring devices	x	x	x	
	6.6 Classification of hazardous areas	x	x	x	x
7 Non-standard and emergency operations	7.1 Emergency procedures	x	x	x	x
	7.2 The firefighting techniques and equipment that	x	x	x	x

	may be used with ammonia				
	7.3 Contingency planning	x			
	7.4 The first aid action to be taken in the event of a person coming into contact with ammonia	x	x	x	x
8 Commercial considerations	8.1 Ammonia transfer process (e.g., transfer measurement process)	x	x		
	8.2 Ammonia quality and quantity management	x	x		
9 Additional safety aspects	9.1 Safety and monitoring zones	x	x	x	x
	9.2 The importance of assessing the surrounding areas	x	x		x
	9.3 Simultaneous operation (SIMOPS) scenarios	x	x	x	
	9.4 Precautions when planning and during SIMOPS	x	x	x	

NOTE – See Annex K, which outlines the subject matter of the prerequisites.

ANNEX J: DETAILS OF THE PREREQUISITES (NORMATIVE)

J.1 Fundamental knowledge for common ammonia bunkering operations

J.1.1 The physics and chemistry of ammonia

- The gas laws and how they apply to ammonia operations
- The physics related to the change of state of liquids
  - (a) Latent heat
  - (b) Heat and energy transfer
  - (c) Refrigeration and liquefaction of gases
  - (d) Critical temperature
  - (e) Diffusion and mixing gases
  - (f) The meaning of dew point
  - (g) The behaviour of cold gas clouds

J.1.2 Impact of ammonia liquid and vapour on the environment

- Performance of gas-fuelled engines vs oil concerning emissions
- Toxic release

J.1.3 Hazards of ammonia

- Toxicity
- Low temperature, such as Cold burns
- Flammability
  - (a) Explosive and Flammable limits (UEL, UFL, LEL & LFL)
  - (b) Flash point
  - (c) Auto ignition temperature
- Safety data sheets

J.1.4 Leak behaviour

- Toxic clouds
- Wind direction

J.1.5 Impact of ammonia on equipment and construction materials

- Impact of low-temperature conditions and corrosiveness on (construction) materials, including selection and failure modes
- How materials contract when their temperature reduces and the meaning of the term “coefficient of expansion.”
- Location of materials used
- Repair methods, including the importance of using the correct replacement materials
- How ammonia and water interact

J.1.6 How static electricity and electrical equipment can cause sparks and ignition

- How electrical equipment causes sparks
- Causes of static electricity
- Definition of hazardous areas

J.1.7 Properties of inert gases (including nitrogen)

- Definition of an inert gas
- Gaseous nature
- Moisture content

J.2 Corporate governance and management systems

J.2.1 International rules, regulations and guidance covering ammonia bunkering

- IGF code
- Ammonia transfer compliance with port regulations and safety management systems under ISM code
- Ammonia supply from road tankers and containers, bunker vessels, and bunkering at ammonia terminals
- Guidance about ammonia operations provided by shipyards, flag states, class societies and equipment suppliers
- Guidance from relevant industry bodies such as the Society for Gas as a Marine Fuel (SGMF), International Organization for Standardisation (ISO), Oil Companies International Marine Forum (OCIMF) and the Society of International Gas Tanker and Terminal Operators (SIGTTO)

J.2.2 Local rules and regulations covering ammonia bunkering

- Applicable Singapore regulations and their use
- Knowledge of where to access local rules and regulations relevant to different roles
- Understanding of how to interpret and apply regulations

J.2.3 Methods of risk assessment

- Elements of an assessment
- How to identify hazards
- How to determine risk
- How to establish the likelihood and severity
- How to decide if the risk is tolerable
- How to prepare a risk control action plan

J.2.4 Responsibilities surrounding owned and leased equipment

- Knowledge of the responsibilities resulting from the legal principle of duty of care regarding safeguarding others from harm
- Knowledge of regulatory and procurement processes for owned/rented equipment
- Knowledge of equipment manufacturers' operating manuals

- Knowledge of the principles of mechanical handling and the associated dangers of performing this without mechanical support
- Knowledge of how the ammonia transfer system must be supported to avoid excessive stresses in the hose, breakaway coupling, connector and manifolds
- Knowledge of appropriate response/reaction if defects are noted in equipment or documentation
- Knowledge of how the various safety detection devices work and are calibrated

J.2.5 Safety management system (SMS) and procedures

- Overview of corporate safety management systems and how corporate-level policies are translated into ship/operating unit-specific documentation.
  - (a) Techniques and methodologies to ensure effective risk management
  - (b) Need to manage any change to ensure continued safety requirements are met and changes are implemented in a controlled manner
  - (c) Importance of recording information on safety incidents and near-misses to promote understanding, learning, and improved future performance.
  - (d) Safe manning levels for the task to be undertaken

J.2.6 Operational procedures

- The roles of operational procedures and the legal framework that they represent
- The content of the various operational procedures and where they may be located
- The need to follow operational procedures
- The need to manage any change to the operational procedures in a controlled manner

J.2.7 Ammonia bunkering plan

- Purpose of the ammonia bunkering plan
- Knowledge of information found in the plan
- Ability to evaluate and apply safety instructions

J.3 Organisation and management

J.3.1 Communication and teamwork

- Chain of command
- Importance of internal team communication methodologies and practices
- Pre-transfer meetings
  - (a) Purpose
  - (b) Content
- Checklists and how they should be used to be effective
- Ship shore safety checklist (or similar)

J.3.2 Roles and responsibilities of bunkering stakeholders

- Ammonia supplier
- Bunker delivery company
- Ammonia receiver
- Port Authority
- Independent surveyors

J.3.3 Administrative processes

- Completion of forms and checklists
- Accessing and interpreting checklists, process descriptions and procedures
- Archiving documents, including the understanding of retention periods
- Use of electronic and paper-based management systems

J.3.4 Stakeholder interactions

- Able to identify relevant stakeholders in different scenarios
- Understand stakeholder perspective and information requirements relevant to own role
- Ability to apply relevant communication techniques. e.g., walkie-talkie, handphone
- Aware of safety implications of stakeholder interactions, e.g., message filtering and misunderstanding

J.4 Familiarity with the operation, calibration and maintenance of equipment and instrumentation

J.4.1 Mechanical handling

- Knowledge of mechanical handling devices that might be used in ammonia bunkering.
- Knowledge of the principles of mechanical handling and the dangers associated with operating transfer equipment without adequate mechanical support.

J.4.3 Ammonia transfer system

- Knowledge of the components and their principles of operation that make up an ammonia transfer system:
    (a) Flexible hoses
    (b) Articulated hard arms
    (c) Fixed pipework on the vessel or ashore
    (d) Breakaway and emergency relief couplings
    (e) Transfer system/manifold connectors
    (f) Manifold arrangements
- An understanding of the failure modes that may lead to equipment failure.

J.4.3 Ammonia storage tanks

- Types of liquefied gas storage tanks used for bunkering
- Construction and installation for each type
    (a) Classification of tanks

(b) Details of Type C and examples

(c) Details of Type B and examples

(d) Details of Type A and examples

(e) Details of Membrane tanks and examples

- Operating requirements for each type
- Operating restrictions for each type

J.4.4 Ammonia pumps

- Pump operation

(a) Head versus flow characteristics

(b) NPSH requirements

(c) Specific issues around pumping such as (e.g., cavitation, starting, restarting etc.)

- Types of ammonia pumps used for bunkering:

(a) Construction and installation for each type

(b) Operating requirements for each type

(c) Operating restrictions for each type

J.4.5 Ammonia valves

- Types of valves used in ammonia and gas systems for:

(a) Isolation

(b) Control

- Design features
- Operating requirements

(a) Prevention of surge pressures

(b) Maintenance requirements

- Problems that can occur – leakage

J.4.6 Pressure-protection devices

- Pressure release valves and systems

(a) Types

(b) Design features

(c) Operating requirements

(d) How they are operated

(e) Limitations

- Problems that can occur

J.4.7 Electrical equipment in hazardous areas

- Hazardous area classification (zones and different gases):
  (a) The various categories of safe type electrical equipment
  (b) The role of standards in regulating the safe use of electrical equipment
  (c) How to identify that an electrical item is safe for use in a hazardous area

J.4.8 Safety-related (leak/spill/moisture) equipment

- Drip trays
  (a) Recommended practice
  (b) Draining procedures
- CCTV/monitoring equipment
- Overfill protection methods
- Firefighting equipment for common fire incidents and fires from leaks/spills due to a pipe burst
- Positive air pressure room (safe room) for escaping
- Dew point monitoring equipment for moisture control in tanks and pipe lines

J.4.9 Personal protective equipment (PPE)

- Clothing
- Personal gas monitors
- Escape hoods
- Respirators
- SCBA

J.4.10 Equipment manufacturers' operating manuals

- Content of equipment manufacturers' operating and maintenance manuals for each item of equipment
- Importance of referring to specific equipment rather than generic information

J.5 Bunkering operations

J.5.1 Pre-bunkering activities

- Compatibility of the receiving vessel's manifold with the ammonia transfer system
- Compatibility of the ammonia supplier's equipment with the ammonia transfer system
- Completion of appropriate pre-bunkering checklists
- Purpose of the pre-transfer meeting and the need for both the receiver and ammonia bunker supplier to sign off each other's checklists

J.5.2 Purging operations

- Purpose and importance of the purging operation before and after ammonia transfer
- Potential safety, operational and fiscal outcomes of incorrect or ineffective purging processes

J.5.3 Pressurisation and depressurisation

- Pressurisation processes
  - (a) Reasons for controlling the pressurisation rate
  - (b) Pressurisation processes and related testing
  - (c) Pressure protection
- Depressurisation processes
  - (a) Joule-Thomson cooling effect and how equipment temperatures may reduce significantly
  - (b) Vacuum

J.5.4 Storage tank operations

- Operating requirements
- Tank temperature management
- Tank pressure management
- Depressurisation processes
  - (a) Joule - Thomson cooling effect and how equipment temperatures may reduce significantly
  - (b) Vapour return
  - (c) Use of onboard consumers
  - (d) Spraying ammonia within the tank
- Level management
- Protection devices
- Alarm set points and actions

J.5.5 Draining operations

- Methods of draining lines before disconnection
  - (a) Methods and precautions related to safe liquid freeing of lines and connections
  - (b) Methods and precautions related to safe gas freeing of lines and connections before disconnection
  - (c) Safety issues arising from ineffective draining or gas-freeing processes

J.5.6 Isolation operations

- Methods of safely isolating lines and equipment regarding:
  - (a) Avoiding trapping of liquid
  - (b) Ensuring safe disconnection
  - (c) Ensuring safe conditions on completion of the transfer operation

J.5.7 Codes used in the checklists

- How to complete ammonia bunkering checklists (part 2)

(a) Meaning of codes (e.g. A –Agreement, R –Re-check and P –Permission)

J.5.8 Compatibility assessment

- How to undertake a compatibility assessment
  - (a) Understand the various transfer systems
  - (b) Review physical compatibility, i.e., moorings arrangement
  - (c) Review operational compatibility
  - (d) Understand customer and bunker vessel ammonia system
  - (e) Review bunkering operations and procedures, including vapour management
  - (f) Understand the ESD system and emergency procedures

J.6 Control and monitoring

J.6.1 Fire and gas detection systems

- Operating principles
  - (a) The suitability of different types of fire and gas detectors for various environmental applications
- The purpose, operating procedures, limitations, and calibration requirements of each type of leak detector
  - (a) PPM detector for ammonia vapour leakage
  - (b) Chemical tubes

J.6.2 ESD systems

- Purpose
- Operating principles
- Connection arrangements
- Operational considerations related to both linked and standalone systems
- Actions when triggered

J.6.3 ERS

- Purpose
- Operating principles
- Connection arrangements
- Actions when triggered

J.6.4 Basic concepts of control systems

- An overview of how control systems for bunkering work
- An overview of how different control systems interact
- Control functions
- Control elements

- Alarms and trips

J.6.5 Instrumentation and monitoring devices

- Temperature measurement
  - (a) Types
  - (b) Limitations
  - (c) Alarm set points
- Pressure measurement
  - (a) Types
  - (b) Limitations
  - (c) Alarm set points and actions
- Level measurement, including over-flow protection
  - (a) The principles of operation for each type
    - Float gauge
    - Radar gauge
  - (b) The operating requirements for each type
  - (c) The limitations for each type
  - (d) The maintenance requirements for each type
  - (e) Alarm set points and actions

J.6.6 Classification of hazardous areas

- Understanding of hazardous areas and their determination
- Define zones used in bunkering operations, e.g. hazardous areas, toxic, safety and other zones
- Able to determine operational requirements and special precautions applicable for each zone

J.7 Non-standard and emergency operations

J.7.1 Emergency procedures

- Effective use of emergency procedures
- Importance of effective drills and post - drill discussion
- Knowledge of the location of the muster point for temporary refuge

J.7.2 Firefighting techniques and equipment that may be used with ammonia

- Use of high-expansion foam
- Use of dry powder
- Use of CO_2, inert gas and fire hydrant systems
- Danger of re-ignition

- Heat intensity of ammonia fires
- Potential dangers of extinguishing the fire before stopping the leak
- Process isolation and draining
- Water spray protection for firefighting

J.7.3 Contingency planning

- Role of contingency planning in standard and non‐standard and emergency operations

J.7.4 First aid

- Skin contact
- Inhalation
- Ingestion

J.8 Commercial considerations

J.8.1 Ammonia transfer process

- Fuel transfer procedures, including accurate record keeping

J.8.2 Ammonia quantity and quality management

- The importance of ammonia quantity and quality management systems and how they work:
  - (a) How to operate ammonia quantity and quality measurement equipment
  - (b) Achievable levels of accuracy of ammonia quantity and quality measurement equipment and how to maintain these through calibration and testing
- Ammonia quality certification and contractual documents and calculations

J.9 Additional aspects of safety

J.9.1 Safety and monitoring zones

- Implement safety distances as identified in the HAZID, hazardous plan, other documents or study carried out in consultation with the stakeholders and relevant authorities - Monitoring zone
- Established based on the findings from the risk assessment or determined by the relevant authorities
  - (a) Toxic zone
  - (b) Hazardous area
  - (c) Safety zone

J.9.2 Importance of assessing surrounding areas

- How to check the surrounding areas for any possible ignition sources during normal ammonia bunkering operations
- How to check the surrounding areas for any possible toxic gas releases during normal ammonia bunkering operations
- How to check the surrounding areas for any other external factors that could have an impact on the safety of ammonia bunkering operations
- How to assess the risk posed to the surrounding areas during normal ammonia bunkering operations

J.9.3 SIMOPS Scenarios

- Assessment of the impact of the various operations carried out on the vessels(s) or in the vicinity of the ammonia bunkering operation, such as:
  (a) Receiving stores and spares
  (b) Passenger boarding and disembarking
  (c) Cargo operation
  (d) Ballast and de-ballast
  (e) Ship repair
  (f) MGO fuel bunkering operation for the vessel with dual fuel engine

J.9.4 SIMOPS precautions and planning

- How to check the impact of SIMOPS on overall safety
- Understand the regulatory requirements on the type of SIMOPS allowed and the safety precautions to be taken
- Understand the special procedures for each SIMOP

Annex K: TRAINING MODULES MATRIX (NORMATIVE)

The matrix below shall be read in conjunction with Table 8-10.

Training Requirement	Modules	Management	Operation	Support	Safety / Emergency
7.4.4.3 Safety Ammonia may be transported at low temperatures and thus has safety risks associated with carriage and transfer operation. It is highly toxic, presenting a potential danger to lives and damage to properties. Any ammonia leak is a hazard to people and surrounding environment	Safety management system (SMS)/Ammonia bunkering plan	x	x	x	
	Risk assessment	x	x		
	Roles and responsibilities of bunkering stakeholders	x	x	x	x
	Communication	x	x	x	
	Controlled zones	x	x	x	x
	Low-temperature protection and safety equipment	x	x	x	x
	ESD and ERS Systems	x	x	x	x
	Firefighting	x	x	x	x
	Emergency procedures	x			
	Responding to emergencies (emergency organisation)	x	x	x	x
	Responding to emergencies (emergency procedures)	x	x	x	x
	Personal protective equipment (PPE)	x	x	x	x
7.4.4.4 Bunker transfer During the bunker transfer, periodic checks of transferred	Periodic checks	x	x	x	
	Vapour management	x	x	x	
	Control and monitoring	x	x	x	

quantities shall be communicated between the supplying and receiving entities for verification	Ramp up and ramp down procedures	x	x	x	
	SIMOPS	x	x	x	
7.4.4.5 Post bunkering After the ammonia transfer, the vessel's representative(s) shall be informed. Appropriate valves shall be closed, and the lines purged before disconnection. Documentation required for the custody transfer shall be completed	Drain and purge liquid lines	x	x	x	
	Purge of liquid and vapour lines	x	x	x	
	Disconnect transfer systems	x	x		
	Disconnect all cables	x	x	x	
	Post-transfer meeting	x	x		
7.4.4.6 Operating and regulatory framework All ammonia bunkering activities shall comply with the regulatory framework of the relevant national authorities	Compliance with regulations	x	x		
	Organisation and management	x			
	Safety and operating procedures	x	x		
7.4.4.7 Planning phase Before any fixture for ammonia transfer, a compatibility assessment shall be done, considering the	Preparation for ammonia transfer	x	x	x	
	Pre-transfer meeting and documentation	x	x		
	Ammonia transfer quality and quantity	x			

compatibility of the physical connections, bunker control, and safety systems	Ammonia transfer technical data	x	x		
	Ammonia bunker transfer system and associated equipment	x	x		
	Inspection of equipment	x	x	x	
	Connection of transfer systems		x	x	
	Nitrogen purge and leak test	x	x	x	
	Line cool down	x	x		

8.4.9 Bibliography

[1] IGC Code International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

[2] IGF Code International Code of Safety for Ships using Gases or other Low-flashpoint Fuels

[3] ISM code International management code for the safe operation of ships and for pollution prevention

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

[5] Code of Practice on Workplace Safety and Health (WSH) Risk Management

[6] IEC 60079-17 Explosive atmospheres - Part 17: Electrical installations inspection and maintenance

[7] IEC 60079-19 Explosive atmospheres - Part 19: Equipment repair, overhaul and reclamation

About DNV

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