University of Strathclyde Glasgow

# Port Infrastructure and Safety Requirements for Ammonia Bunkering of Ocean-Going Vessels: A Comparative, Enhanced, and Replicable Framework

**Maritime Industry Decarbonisation Symposium 2025**

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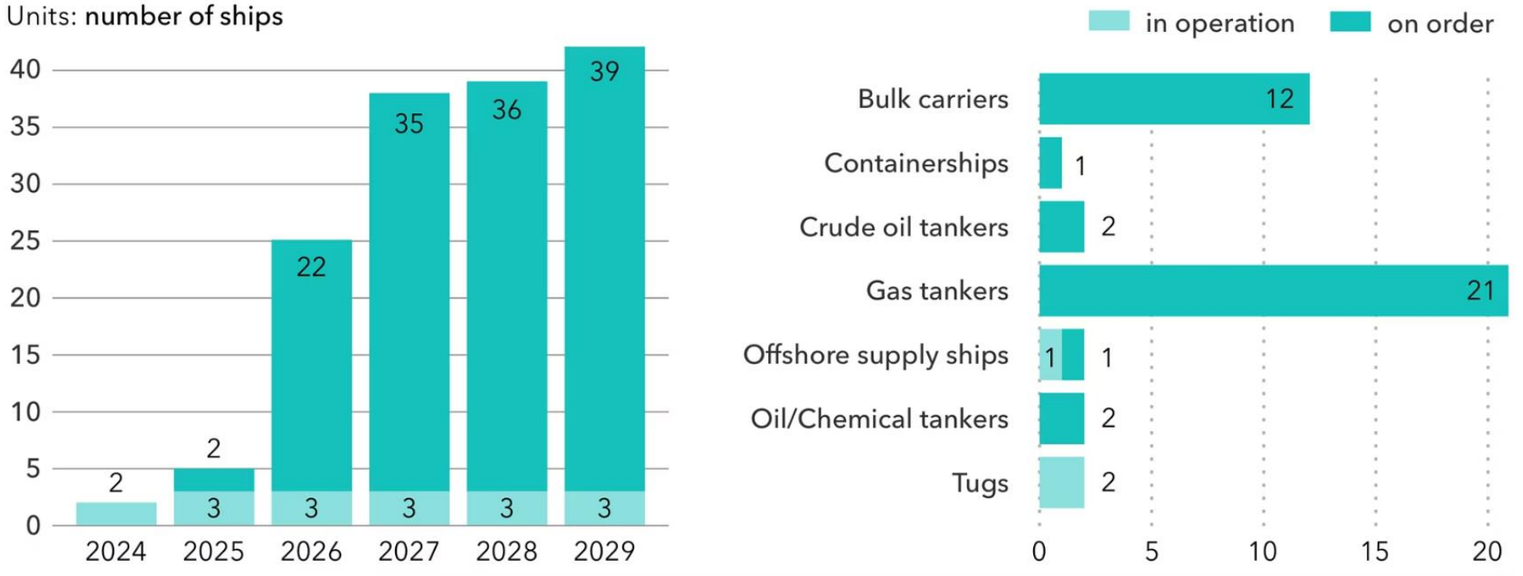
# Why Ammonia?

Ammonia is emerging as a leading contender for decarbonizing the maritime industry due to several strategic advantages:

- **Regulatory Alignment:** Directly supports IMO MEPC 80 strategies and benefits from the IMO Net-Zero Framework's approval, which includes pricing and rewarding mechanisms for sustainable fuels.
- **Established Logistics:** Boasts a mature global production and transport chain. Approximately 18-20 million tonnes of ammonia are traded annually (DNV, 2025), making it suitable for long-distance shipping compared to other low-flashpoint alternatives like LNG, methanol, and hydrogen.
- **Operational Efficiency:** Offers easier storage solutions than hydrogen, requiring only pressurization or refrigeration rather than ultra-cryogenic conditions.
- **Market Momentum:** Significant investment is underway, evidenced by 39 ammonia-fuel capable newbuilds ordered as of August 2025.
- **Versatile Application:** Currently under extensive investigation as a fuel for both internal combustion engines (ICE) and advanced fuel cells.




*Growth of ammonia fuel uptake by number of ships (left) and by ship type (right) as of August 2025, Source: DNV Maritime Forecast to 2050 (2025)*

# Regulatory Framework & Obligations

Understanding the evolving international regulatory landscape is crucial for the decarbonization of ocean-going vessels. Key initiatives and milestones from the International Maritime Organization (IMO) shape the path forward for ammonia bunkering, particularly concerning port infrastructure and safety requirements.

## Key Regulatory Developments

- **Approval of IMO Net-Zero Framework:** A comprehensive approach towards decarbonization, including:
  - Development of a **global fuel standard** for marine fuels.
  - Implementation of a **global economic measure** to incentivize sustainable practices (IMO, 2025).

## Timeline of Ammonia Bunkering Regulations

**February 2025** — 1

IMO MSC.1/Circ.1687 (Interim Guidelines adopted) for the safety of ships using ammonia as fuel.

**April 2025 (MEPC 83)** — 2

Approval of amendments to the IGF Code and SOLAS Convention, specifically marine fuel.

**July 2026** — 3

IGC Code (para. 16.9.2) lifting the prohibition on using ammonia cargo as fuel officially enters into enters into force, paving the way for wider adoption.

*The World's First Use of Ammonia as a Marine Fuel in a Dual-Fuelled Ammonia-Powered Vessel in the Port of Singapore, Source: MPAS, 2024.*

# Research Aim

- **Primary Aim:**
  - **To identify the port infrastructure** and **operational requirements** needed to ensure the **safe and practical bunkering** of ammonia-fuelled ocean-going vessels.
- **Scope:**
  - Covers **all stages of the bunkering process** from **pre-arrival** to **post-departure** of the vessel.
- **Additional Objective:**
  - **To develop structured safety checklists** for **each stage** of the ***proposed bunkering methods*** to enhance consistency and safety compliance.

# Ammonia Safety Precautions & Controls

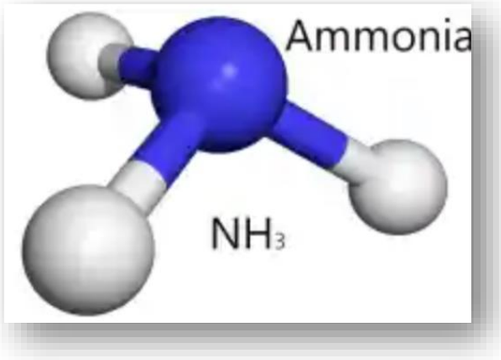
Understanding and mitigating potential hazards is crucial for safe operations. Key risks associated with the materials and processes involved include:

- Toxicity
- Corrosiveness
- Vapour dispersion
- Flammability

## Occupational Exposure Limits

As defined by the UK Health and Safety Executive:

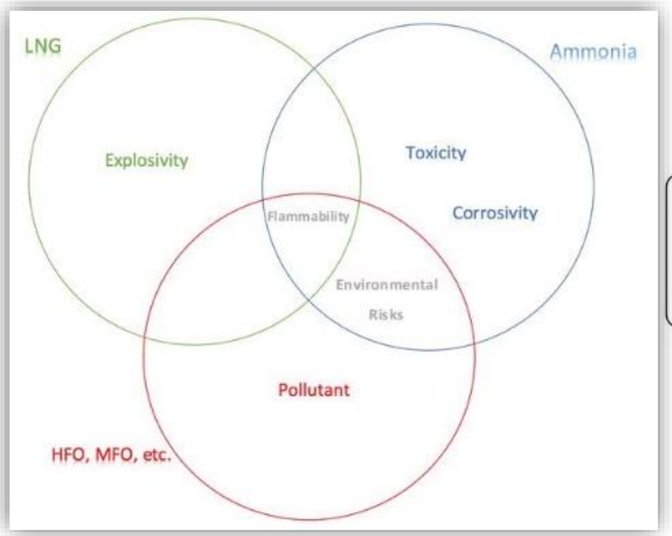
- Time-Weighted Average (TWA): 25 ppm
- Short-Term Exposure Limit (STEL): 35 ppm, (UK HSE, 20



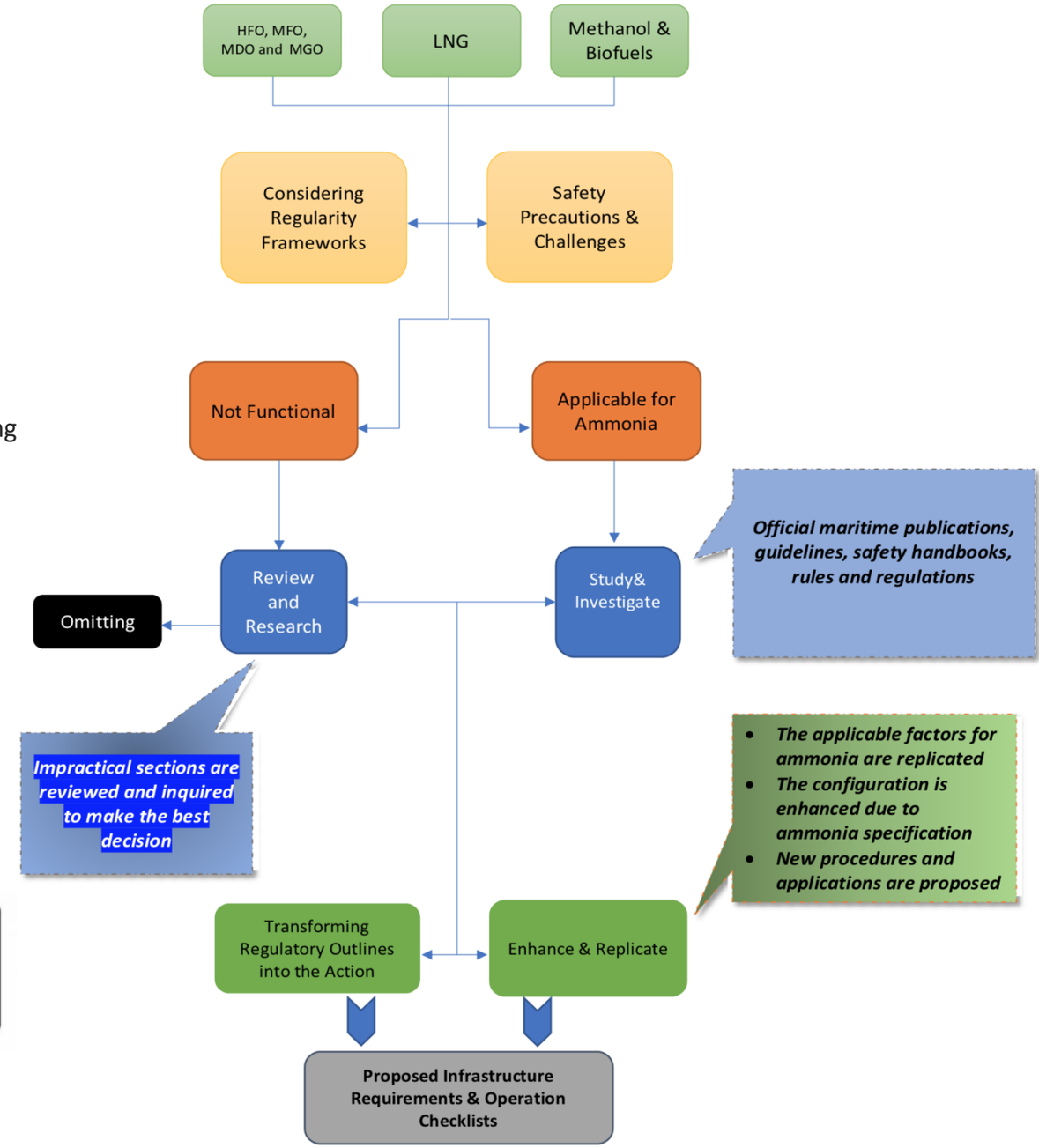

*The world's first ship-to-ship transfer of ammonia using vessels at anchorage, Source: www.yara.com, 2024.*

# Methodology

- **Comparative analysis** of existing bunkering procedures for marine fuels, biofuels, LNG, and methanol.
- **Identification of operational challenges and best practices**
- **Literature review and regulatory study**
- **Reference to LNG bunkering procedures** as the closest low-flashpoint analogue, adapting key elements for ammonia's specific properties
- **Integration of policy, operational, and technical perspectives** through structured analysis of existing standards and IMO guidelines.
- **Transformation of regulatory insights into actionable infrastructure requirements**,
- **Qualitative and quantitative data synthesis** from academic literature, industry reports, and recognised maritime organisations to ensure technical robustness and applicability.
- **Introduced suggestions on the requirements and safety checklists for bunkering**







# Source Selection and Document Review

A critical first step in defining robust safety precautions for ammonia-fuelled vessels involves a thorough and systematic review of existing literature and regulatory frameworks. This process ensures that all proposed port infrastructure and operational requirements are informed by the latest research, best practices, and established safety guidelines.

| Reference | Extention | Title |
|---|---|---|
| (Amini, 2009) | - | *Mooring and Anchoring Ships: Inspection and Maintenance* |
| (BV, 2022) | Bureau Veritas | *Ammonia-Fuelled Ships - Tentative Rules* |
| (CCS, 2022) | China Classification Society | *Guideline for Ships Using Ammonia Fuel* |
| (CDI, 2013) | Chemical Distribution Institute | *Ship to Ship Transfer Guide: For Petroleum, Chemicals and Liquefied Gases* |
| (CDI, 2014) | Chemical Distribution Institute | *Guidelines for Liquid Chemical Hose Management* |
| (Clark, 2009) | Nautical Institute | *Mooring and Anchoring Ships: Principles and Practice* |
| (EMSA, 2022) | European Maritime Safety Agency | *Potential of Ammonia as Fuel in Shipping, American Bureau of Shipping, CE Delft and Arcsilea* |
| (IACS, 2016) | International Association of Classification Societies | *LNG Bunkering Guidelines* |
| (IMO, 2020) | International Maritime Organisation | *International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code)* |
| (IMPA, 2022) | International Maritime Pilots' Association | *Guidance on the Master - Pilot Exchange* |
| (ISGOTT, 2020) | International Safety Guide for Oil Tankers and Terminals | *International Safety Guide for Oil Tankers and Terminals* |
| (KR, 2022) | Korean Register | *Rules and Guidlines for the Classification of Ships Using Low-flashpoint Fuels, Guidelines for Ships Using Ammonia as Fuels* |
| (LR, 2023) | Lloyds Register | *Recommendations for Design and Operation of Ammonia-Fuelled Vessels Based on Multi-disciplinary Risk Analysis* |
| (NK, 2024) | Nippon Kaiji Kyokai | *Guidelines for Ships Using Alternative Fuels - Methyl/Ethyl Alcohol/LPG/Ammonia* |
| (OCIMF, 2018) | The Oil Companies International Marine Forum | *Mooring Equipment Guidelines* |
| (PIANC, 2016) | Permanent International Association of Navigation Congresses | *Design of Small to Mid-scale LNG Marine Terminals Including Bunkering* |
| (SIGTTO, 2021) | The Society of International Gas Tanker and Terminal Operators | *Liquefied Gas Handling Principles on Ships and in Terminals* |

| Reference | Acronym Expansion | Title |
|---|---|---|
| ABS (2023) | American Bureau of Shipping | *Requirements for ammonia fueled vessels* |
| BV (2024) | Bureau Veritas | *Ammonia-Fuelled Ships - Tentative Rules* |
| CCS (2022) | China Classification Society | *Guideline for Ships Using Ammonia Fuel* |
| CDI (2013) | Chemical Distribution Institute | *Ship to Ship Transfer Guide: For Petroleum, Chemicals and Liquefied Gases* |
| DNV (2019a) | Det Norske Veritas | *Ammonia Bunkering of Passenger Vessel* |
| EMSA (2018) | European Maritime Safety Agency | *Guidance on LNG Bunkering to Port Authorities and Administrations, Potential of Ammonia as Fuel in Shipping- American Bureau of Shipping, CE Delft and Arcsilea* |
| IACS (2016) | International Association of Classification Societies | *LNG Bunkering Guidelines* |
| IAPH (2022) | The International Association of Ports and Harbors | *Bunker Checklist - Liquefied Gas Series - Ship to Ship bunker operations* |
| IMO (2025a) | International Maritime Organisation | *MSC.1/Circ.1687 – Interim Guidelines for the Safety of Ships Using Ammonia as Fuel* |
| IMO (2025b) | International Maritime Organisation | *Amendments to SOLAS and IGC Code for the Use of Ammonia Cargo as Fuel – MSC 109 Outcomes* |
| IRS (2022) | Indian Register of Shipping | *Guidelines on Ammonia Fuelled Vessels* |
| ISGOTT (2020) | International Safety Guide for Oil Tankers and Terminals | *International Safety Guide for Oil Tankers and Terminals* |
| KR (2022) | Korean Register | *Rules and Guidelines for the Classification of Ships Using Low-flashpoint Fuels, Guidelines for Ships Using Ammonia as Fuels* |
| LR (2023) | Lloyd's Register | *Quantitative Risk Assessment of Ammonia-fuelled Vessels, Recommendations for Design and Operation of Ammonia-Fuelled Vessels Based on Multi-disciplinary Risk Analysis.* |
| NK (2024) | Nippon Kaiji Kyokai | *Guidelines for Ships Using Alternative Fuels - Methyl/Ethyl Alcohol/LPG/Ammonia* |
| PIANC (2016) | Permanent International Association of Navigation Congresses | *Design of Small to Mid-scale LNG Marine Terminals Including Bunkering* |
| PRS (2017) | Polish Register of Shipping | *Bunkering Guidelines for LNG as Marine Fuel* |
| SIGTTO (2021) | The Society of International Gas Tanker and Terminal Operators | *Liquefied Gas Handling Principles on Ships and in Terminals* |

# Proposed Bunkering Method Categories for Ammonia

Based on a synthesis of current practices and projected infrastructure constraints, three core bunkering methods are proposed for ammonia-fuelled ocean-going vessels:

## Unfixed Bunkering

*Ship-to-Ship, Bunker Barge-to-Ship, and Offshore Construction-to-Construction-to-Ship*

- Port of Rotterdam STS pilot (Apr 2025)
- Port of Singapore pilot with Fortescue Green Pioneer
- Future off-shore self-driven bunkering stations

## Shore-to-Ship

This method involves transferring ammonia directly from a shore-a shore-based facility to the vessel, typically through MLAs and MLAs and composite hoses.

## Capsule Transfer

An innovative approach where ammonia is transported using using pressurised ISO tank containers transferred via shore-based shore-based lifting equipment. This method offers high flexibility, flexibility, containment integrity, and independence from pipeline pipeline systems.

*Ammonia bunkering pilot between two vessels at a terminal in the port of Rotterdam on 12 April, 2025, Source: https://www.portofrotterdam.com*


*Proposed Capsule Transfer Method, Writer*

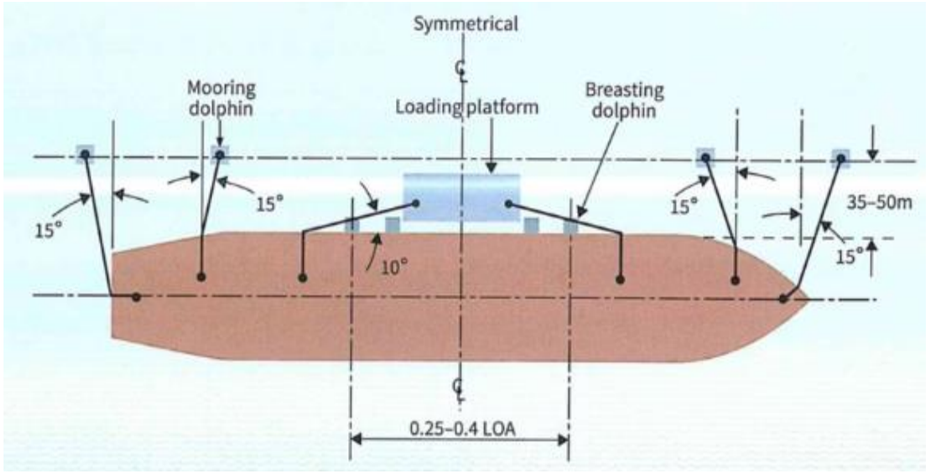
# Safe Navigation Requirements for Ammonia Ammonia Bunkering

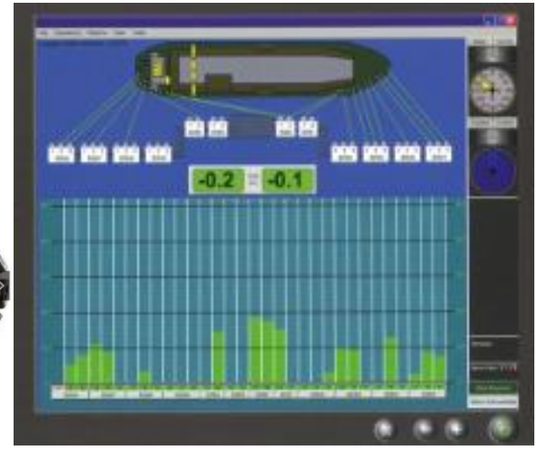
Ensuring safe ammonia bunkering operations requires careful attention to several navigational and infrastructural aspects. Key considerations include:

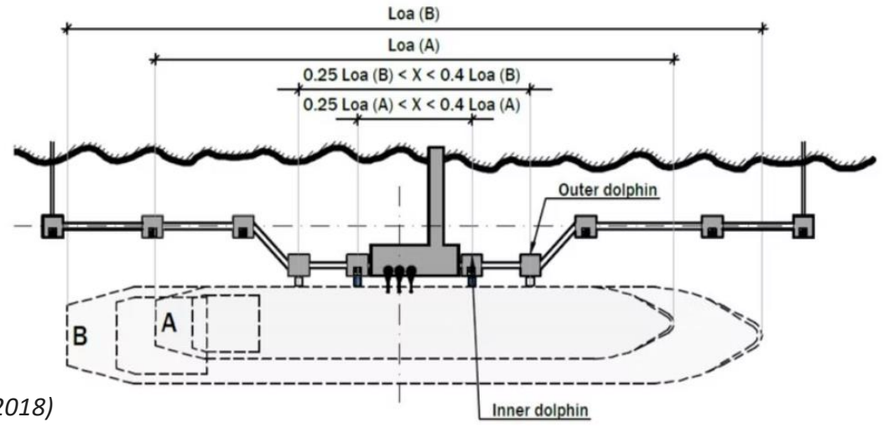
- I**MO STCW.7/Circ.25 (2025)** : Establishes mandatory **basic and advanced training** for seafarers as well as port sector as port sector personnel on alternative fuels.
- **Pilotage and Information Exchange** Detailed planning and communication are crucial for safe vessel movements.

- **Approach Channel and Manoeuvring Conditions** Assessing channel suitability and managing vessel manoeuvring are manoeuvring are critical for incident prevention.
- **Tug Assistance and Support Operations** Appropriate tug support ensures precise vessel positioning and safety during critical phases.
- **Berthing and Mooring Infrastructure** Robust infrastructure is paramount for securing vessels safely.
    - Energy-absorbing fendering: Essential for mitigating impact during berthing.
    - Quick Release Hooks (QRHs): Facilitate rapid unmooring in emergencies.
    - Corrosion-resistant mooring points: Ensure long-term integrity and reliability.
- **Fendering Systems: Primary & Secondary Fenders** The selection and deployment of fendering systems are crucial for vessel protection.
    - **Discrete fenders**:
    - **Continuous fenders**
- **Longitudinal Space of Fendering Systems** Proper spacing is crucial for effective energy absorption and protection.

- **Continuous Tension Monitoring and Emergency Alert Systems** Real-time monitoring enhances safety and enables rapid response to mooring stress.
- **Advanced Mooring Technologies** Consideration of vacuum mooring or electrically earthed bollards can significantly enhance mooring safety and stability during transfer operations.




*PIANC(2016), SIGTTO (2021), OCIMF (2018)*

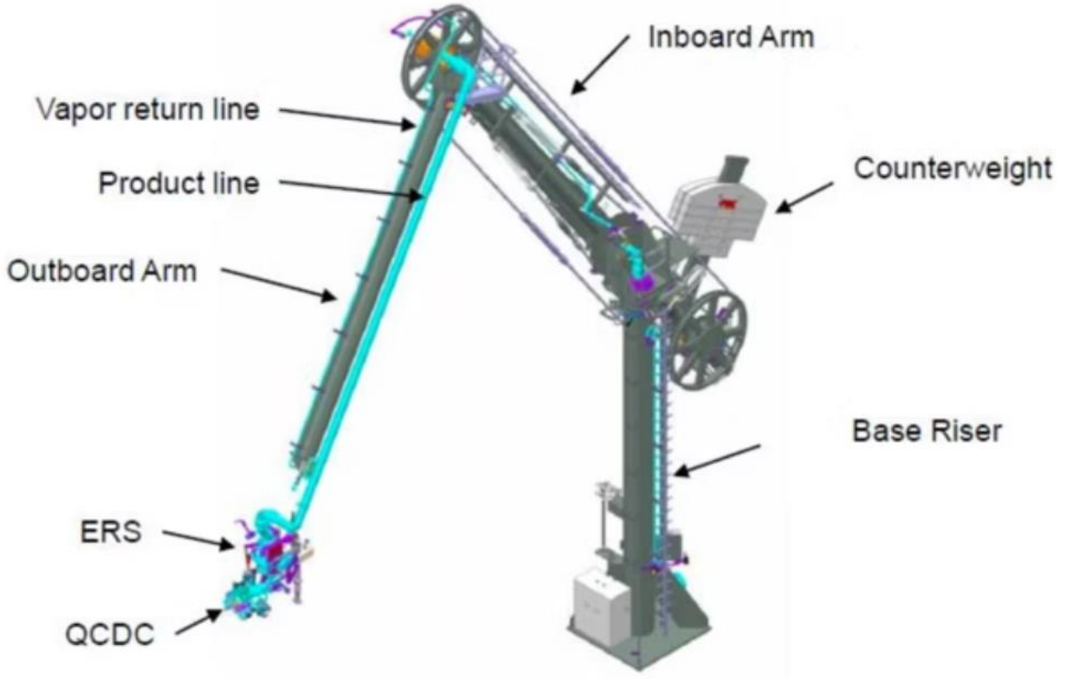
# Bunkering Systems and Operation

Efficient and safe ammonia bunkering relies on robust systems and precise operational protocols. Key components and features include:

## Marine Loading Arms (MLAs)

- **Equipped with Emergency Release Systems (**ERS) and drip-free Quick Connect/Disconnect Couplings (QCDC) for secure and efficient transfer.

- **Corrosion-resistant Internal Linings**: Essential for handling ammonia and preventing material degradation.
- **Vapour Return Lines**: Designed to control overpressure during bunkering operations.
- **Double-Block-and-Bleed Isolation Valves**: Ensures enhanced safety by preventing leakage and ensuring complete isolation.
- **Purging and Inerting Connections**: Critical for maintaining a safe atmosphere within the system during and after operations.
- **Automated Diagnostics and Emergency Override Systems**: Provides real-time monitoring and immediate response capabilities to ensure to ensure operational safety.




*Example of a bunkering system diagram., PIANC (2026)*

## Composite Hoses

For operations requiring greater flexibility, composite hoses offer distinct advantages:

- **Lightweight**: Facilitates easier handling and maneuverability.
- **High Flexibility**: Adaptable to various bunkering configurations and movements.
- **Broad Chemical Compatibility**: Suitable for safe ammonia transfer, resisting degradation from the chemical properties.

### Hoses must meet strict criteria for:

- **Chemical resistance** (to ammonia's toxicity and corrosivity)
- **Burst pressure and fatigue resistance**
- **Permeation and static dissipation**

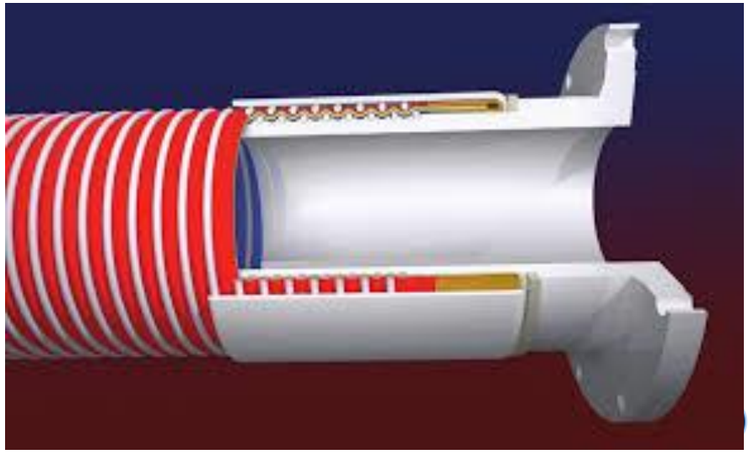


*Illustration of a composite hose., https://titeflex.com/, (2025)*

## Emergency Systems & Mitigation

Understanding and implementing robust emergency systems are crucial for safe maritime operations, particularly when transporting novel fuels like ammonia.

**Emergency Navigation Scenarios**

| Scenario | Safety Actions |
|---|---|
| 1. Channel Approach | • Call Master<br>• Log the time and relevant event<br>• Activate Emergency Shut Down (ESD)<br>• Call VTS/Control Centre<br>• Consider Anchoring<br>• Bridge team and crew actions |
| 2. Alongside / Bunkering Operation | • Call Master<br>• Log the time and relevant event<br>• Activate ESD<br>• Call VTS/Control Centre<br>• Request ambulance if needed<br>• Crew emergency response |
| 3. Emergency Unberthing | • Call Master<br>• Log the time and relevant event<br>• Activate ESD<br>• Call VTS/Control Centre and request Pilot<br>• Unberth using Quick Release or axe<br>• Anchor at a safe location/place of refuge |
| 4. Berthing / Unberthing (Ammonia Leak) | • Call VTS/Control Centre<br>• Log the time and relevant event<br>• Bridge team and crew actions<br>• Monitor toxic gas zones and trigger alarm systems |

*https://www.oshaoutreachcourses.com,(2025)*


To effectively manage potential incidents, several key emergency response components are being developed and integrated:

- Emergency Response Systems (ERS) & Quick Release mechanisms are integrated with Vessel Traffic Services (VTS).
- New water curtain and water circulation jackets are being developed, with KR 2025 approval expected.
- Systems for run-off collection and neutralisation are essential for containing spills.
- Clear alarms and designated muster zones ensure crew and personnel safety during emergencies.

Here, the **Unfixed Bunkering Safety Checklist** is illustrated as an example of the important outcomes of this research.

Stage A – Preparation stage

Stage B – Pre-bunkering operation stage

Stage C – Alignment and accord stage

Stage D – Connection testing stage

Stage E – Transfer stage

Stage F – Post-bunkering operation stage

**For instance: Stage A1 - Unfixed**

*Preparation - Compatibility check topics*

The list of topics is an unlimited open guidance and can be expanded with other topics.

| Local and Site specifications | Manifold | People |
|---|---|---|
| - Local laws and authorisations<br>- Install electrical equipment in the hazardous zone<br>- Control zones and safetymeasures<br>- Controlled access to safety and hazardous zones<br>- Approved public safety separation distance | - Separation<br>- Direction<br>- Height and strength<br>- Formation<br>- Instrumentation<br>- Size and kind of connections<br>- Toxicity and corrosivity protection<br>- containment | - Instruction of members<br>- Training for incident response<br>- Safety zones and bunkering safety precautions familiarisation<br>- Shutting down methods and emergency stop signal<br>- Organising<br>- Positions and duties<br>- Appointment for PICs |
| **Mooring** | **Connection** | **Incident reaction** |
| - Mooring arrangement and points<br>- Mooring loads<br>- Mooring lines<br>- Mooring equipment working load such as bitts, rollers, etc.<br>- Fenders<br>- Flat area of ship's hull<br>- Vessel type, dimension and obstacles<br>- Freeboard<br>- Fire wire | - Lifting configuration<br>- Bunker hose arrangements<br>- Height and length between manifold and bunker terminal<br>- ESD / (P)ERC | - Plan to contain spill<br>- Emergency Response techniques<br>- Contingency planning |
| **Equipment** | **Bunkering and safety measures** | **Communication** |
| - Approved transfer tools<br>- Electricity insulation<br>- International shore connection<br>- Crane and crane reach<br>- Loading arm and arm reach<br>- Boom<br>- Hoses<br>- Hose support tools<br>- Manifold<br>- Deluge System<br>- Drip trays, gutters | - Differences in freeboard, draught, waves and tide<br>- Weather conditions<br>- ESD feature for vessel separation detection<br>- Bunkering techniques such as testing, cooling down and purging<br>- Information transmitting<br>- Maximum permitted variables<br>- BOG / vapour management tools and return connections<br>- Classification and regulation of hazardous areas<br>- PIC and manifold in charge persons' duties<br>- Monitoring and inspection | - Joint Plan of Bunker Operations(JPBO)<br>- Communication tools, methods and contact<br>- Information about the parties involved<br>- Language<br>- Communication of PICs<br>Information exchange between ESD and safety systems |

| Stage E1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Check | Status | | | | Remarks | | |
| - | Time of check | | | | | | | |
| 1 | Wave and weather conditions and limitations | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 2 | Practical mooring arrangement | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 3 | There is secure access between the ship and the bunker centre | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 4 | Working communication is available | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 5 | Enough lightening | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 6 | Bunker centre is able to sail on its own | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 7 | There are no open doors or ports of bunkering centre | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 8 | The standards for the safety and exclusion zones as well as restricted areas are followed | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 9 | limitations on spills and gas detection are followed | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 10 | Backfill prevention is working | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |
| 11 | SIMOPS limitations are followed | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | ☐ Yes | |

# Research Limitations & Future Directions

This section outlines key limitations encountered during our research and proposes opportunities for further investigation to advance maritime decarbonisation efforts.

| Limitations | Future Research Opportunities |
| --- | --- |
| Focused on bunkering interface only | End-to-end supply chain analysis |
| | Rotterdam & Singapore pilots can be modelled |
| National regulations not analysed | Regulatory alignment with IMO guidelines |
| | Evaluate role of small-scale/remote port bunkering |
| Truck-to-ship excluded | CFD dispersion & risk zone modelling |

# Conclusion

The journey towards sustainable maritime operations is gaining momentum, with ammonia bunkering emerging as a viable solution. We've seen significant progress in moving this critical technology from theoretical discussions to practical implementation.

- Ammonia bunkering has successfully transitioned from a conceptual framework to an operational reality within the maritime industry.
- This advancement is underpinned by three crucial developments that together forge a structured path for safe and widespread deployment:
  - The initiation and successful execution of real-world pilot projects.
  - The establishment of comprehensive international guidelines and regulatory regulatory frameworks.
  - The development and implementation of advanced port readiness tools and infrastructure.

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# Thank You for Your Attention

We hope our insights into Maritime Decarbonisation have been informative and thought-provoking.

## Questions & Discussion

I welcome your questions, comments, and perspectives on this critical topic.

## Contact

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Feel free to connect for further discussion.