MARITIME TECHNOLOGIES FORUM

LEADING THE MARITIME WORLD FORWARD

# SAFETY CONSIDERATIONS FOR ESTABLISHING GREEN SHIPPING CORRIDORS

## Executive Summary

At COP26 the Clydebank Declaration was signed by 22 governments, pledging to "identify and explore actions to address barriers to the formation of green shipping corridors. This could cover, for example, regulatory frameworks, incentives, information sharing or infrastructure." The Maritime Technologies Forum (MTF) identified that multiple reports are published focusing on feasibility for realization, barriers, costs, and fuel supply. However, safety had not yet been considered in detail for green corridors.

MTF have therefore conducted this study to facilitate information sharing on green corridor safety considerations, with a focus on ship owners and port authorities planning to establish and operate green corridors.

**Proposed green corridor safety checklist will facilitate necessary safety considerations:** The safety considerations cover approval basis and regulatory framework, operation of vessels in international trade, risk to third-parties, port operations and bunkering, training and competence, as well as fuel specific considerations. All recommendations are summarized in the safety checklist.

In addition to the safety checklist, and based on the work done, the following six recommendations can be given:

**Early planning for safety assessments:** Arranging introductory design and planning meetings between ship owners, ship flag, port authorities and other relevant stakeholders is key to provide efficient knowledge sharing and plan for safety assessments.

**Risk assessment of port operations and bunkering:** Zone analysis and safe bunkering risk assessment are recommended to be conducted as tabletop exercises where stakeholders and technical experts are gathered to discuss the operations prior to the first bunkering and depending on the circumstances, as necessary by the local authorities.

**Use available standards to ease future port acceptance:** Recognized safety standards detailed in IMO guidelines, class rules, and local authority requirements, as applicable, should be used as basis for the ship design as far as practicable. This will ease the potential safety vetting by a port authority and will limit the need for extensive vetting prior to port calls or other operations.

**Understanding the risk to third parties in ports** not regulated for dangerous cargoes is essential to facilitate acceptance from port authorities to enter ports, develop emergency response plans, and establish safety procedures for port-operation and bunkering.

**Sharing of information and invitation to emergency planning** is recommended when the green corridor is adjacent to the waters of intermediate States. While no formal agreement is required, accidents can occur underway and emergency plans should be prepared for possible scenarios.

**Develop and implement SMS fit for alternative fuels:** The ship management company has the overarching responsibility to ensure that the safety management system (SMS) is fit for purpose in addressing the elevated operational risk of alternative fuels. Senior management should understand that managing the elevated operational risks requires them to systematically address changes needed throughout the organization and ensure adequate resources are provided to maintain safe operation.

## Introduction and Objective

The Maritime Technologies Forum is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process. This report provides recommendations to industry stakeholders towards safe adoption of alternative fuels on board ships in green corridors.

Alternative fuels will be one of the key measures to reduce GHG emissions from shipping, and their importance will increase with the new net-zero emission target for shipping by 2050. The industrywide introduction and use of alternative fuels in shipping, with some of them more hazardous than conventional fuels, will lead to new safety hazards and associated risks. These risks must be addressed and controlled before operating a vessel with alternative fuels in a green corridor.

The establishment of green corridors allows for the multitude of barriers hindering the global uptake of zero or near-zero carbon emission fuels (such as risks, costs, and supply) to be addressed and resolved on a manageable scale. As identified in this report, the majority of safety considerations for establishing green corridors are linked to the interface between the ship and the port. To manage the additional safety hazards of alternative fuels, together with the lack of industry experience and detailed guidelines, specific risk assessments should be conducted for bunkering and port operations. Limiting the number of involved parties and establishing early collaboration through green corridors is key to manage the stakeholder complexity and provide efficient knowledge sharing and safety assessments.

Even though currently discussed alternative fuels, such as, e.g., methanol, ammonia and hydrogen have differing physical and chemical properties from LNG, they require quite similar system designs and safety standards. The safety procedures, experience and guidelines developed based on 20 years of operating LNG vessels will therefore provide a solid foundation to assess the additional measures needed to address the new fuel specific risks such as toxicity, third party risk and explosions. As regulations and procedures for LNG exist, this fuel is not explicitly discussed in the report, but applying the LNG knowledge forms the basis for most recommendations.

This report highlights the safety concerns and considerations for the operation of ships sailing with alternative fuels in green corridors and provides suitable recommendations in a checklist to ship owners and port authorities for adoption of alternative fuel when establishing green corridors. The checklist is intended to be used as a reference in the planning and assessment of the green corridor to ensure that important topics are identified and covered.

MTF's recent work and other reports can be found on our website: www.maritimetechnologiesforum.com.

## Disclaimer

While the advice given in this report has been developed using the best currently available information, it is intended to be used solely as guidance. No responsibility is accepted by MTF or its members for any consequences resulting directly or indirectly from the adoption of any of the recommendations in this report.

## Green Corridors and the Clydebank Declaration

At COP26, the Clydebank Declaration was signed by 22 governments "recognising that a rapid transition in the coming decade to clean maritime fuels, zero-emission vessels, alternative propulsion systems, and the global availability of landside infrastructure to support these, is imperative for the transition to clean shipping." The goal of the declaration was to establish at least six green corridors by 2025, and scale activity the following years.

While there are several definitions of green shipping corridors, the Clydebank Declaration states that they are simply 'zero-emission maritime routes between two (or more) ports. The interpretation in this report is that 'zero-emission' means that any carbon-neutral fuel can be used in a green shipping corridor, such as carbon-neutral methanol, methane, biodiesel, ammonia, and hydrogen, as well as battery-electric propulsion, onboard carbon capture and nuclear propulsion.[1]

To support the declaration the signatories pledged to "identify and explore actions to address barriers to the formation of green corridors. This could cover, for example, regulatory frameworks, incentives, information sharing or infrastructure." MTF's work in this report is to explore the regulatory framework and facilitate information sharing on the safety considerations for establishing green corridors. This supports other green corridor projects undertaken by MTF members, such as the four green and digital shipping corridor initiatives led by Singapore and the Port of Rotterdam, Port of LA/Long Beach, Tianjin Port and Japan.

There are no fixed standards or procedures for governments on how to initiate and develop green corridors. Either the industry can define the scope and the placement of the initiatives, or governments take a more active role in defining the placement of future corridors through bilateral partnerships with other countries, or any collaboration initiative in between.[2]

Independent of the initiative, the government's responsibility for ensuring safety and enforcing existing regulations will be the same. The benefit of involving and committing governments to green corridors is ensuring early involvement in the permitting process for handling alternative fuels.

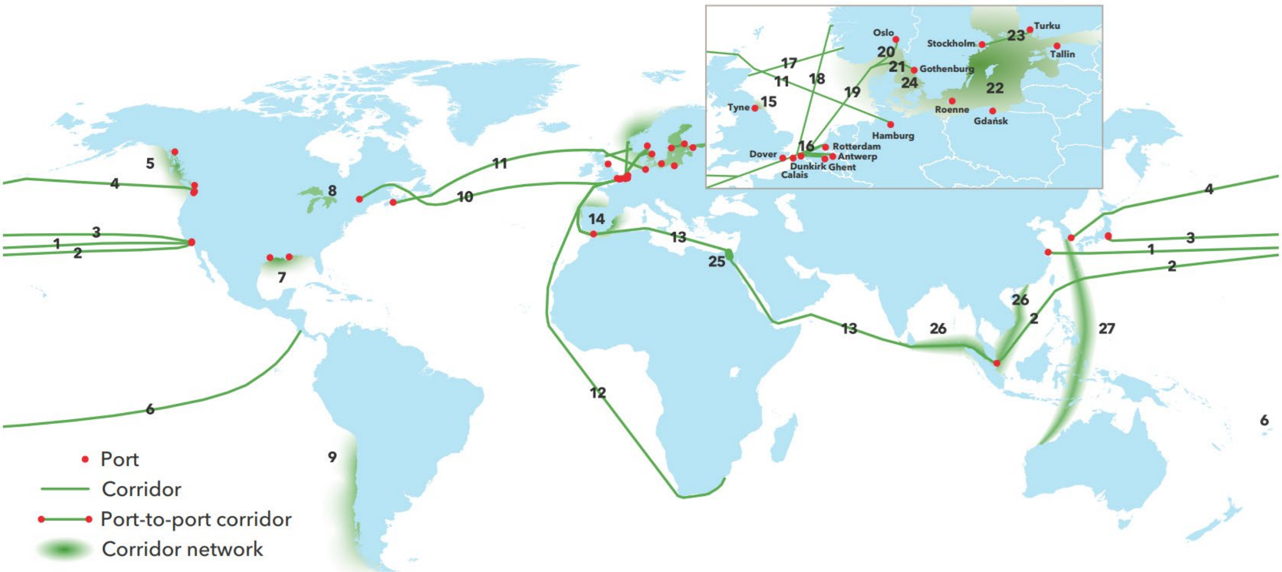
As of January 2024, 44 green corridors have been announced and in planning worldwide, however none are currently in operation internationally.[3] As shown in figure 1 the announced corridors are covering a large span of routes and shipping lanes, from domestic ferries to local feeder lines and deep-sea shipping lanes. The focus of this report will be on international green corridors between two or more port States as the regulatory framework and relevant safety considerations are more complex and universal than

[1] The signatory countries of the Clydebank Declaration are: Australia, Belgium, Canada, Chile, Costa Rica, Denmark, Fiji, Finland, France, Germany, Ireland, Italy, Japan, Lithuania, Republic of Korea, Republic of the Marshall Islands, Morocco, Netherlands, New Zealand, Norway, Palau, Singapore, Spain, Sweden, the United Arab Emirates, the United Kingdom of Great Britain and Northern Ireland, and the United States of America.

for domestic routes. Further, the detailed safety considerations are presented for limited alternative fuels –ammonia, methanol and hydrogen – as these fuels are identified to be most relevant and have the highest number of safety considerations to address. Nevertheless, the general findings in this report would be relevant for all green corridors where use of alternative fuels is planned.

A green shipping corridor involves an ecosystem of many actors such as cargo owners and charterers, ports, shipowners and operators, energy suppliers, financial institutions, and authorities [4]. Multiple studies have been undertaken to explore topics such as feasibility for realization, barriers, costs, and fuel supply. One of these is the extensive feasibility studies in the blueprint from Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. [5] However little has been published on the topic of safety governance and regulatory framework to enable the safe bunkering of zero – and near-zero carbon emission fuels at scale along corridors.

**Thirty announced green shipping corridor initiatives as of June 2023, mapped as ports, corridors, port-to-port corridors, and corridor networks**




1 Shanghai – Los Angeles (LA)
2 LA-Long Beach – Singapore
3 LA – Tokyo -Yokohama
4 Busan – Seattle/Tacoma
5 Pacific Northwest – Alaska
6 US – Fiji – Panama
7 Gulf of Mexico
8 Great Lakes – St. Lawrence
9 Chilean Green Corridor Network
10 Antwerp – Montreal
11 Halifax – Hamburg
12 South Africa – Europe Iron Ore Corridor
13 Singapore – Rotterdam
14 Green Corridors Spain
15 Clean Tyne Corridor
16 Dover – Calais and Dover – Dunkirk
17 $H_2$ powered North Sea Crossing
18 Rotterdam – West-Coast Norway
19 Gothenburg – North Sea Port
20 Oslo Fjord – Rotterdam
21 Gothenburg – Rotterdam
22 European Green Corridor Network
23 Turku – Stockholm (Decatrip)
24 Nordic Regional Corridors
25 Suez Canal
26 SILK Alliance
27 Australia – East Asia Iron Ore
28 Rotterdam – Algeciras*
29 QUAD Shipping Taskforce*
30 G7 Corridors*

*not shown in map Source: DNV, 2023

Figure 1. Map of announced green corridors. Source: DNV – Maritime Forecast to 2050

# Safety Considerations for Establishing Green Corridors

Green corridors enable technologies relevant to zero-emission shipping to be launched and tested within a coordinated and limited scope. With industry and governments joining efforts to establish green corridors they can reduce regulatory barriers and uncertainty, as well as providing early port preparedness. This should facilitate advancement and learning while experience is still low, thereby paving the way for new vessel designs, fuels and infrastructure. In this chapter, we present the identified safety considerations and relevant regulatory framework for establishing safe green corridors.

## Approval Basis and Regulatory Framework

As with all international shipping, it is a requirement that vessels with alternative fuel are approved by the flag State and classification society according to the applicable IMO Codes and Conventions, national/regional regulations, and class rules and local authority requirements, as applicable and/or guidelines.

IMO provides an international mandatory regulatory framework for alternative fuels through the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) which puts internationally recognized safety standards in place to ensure safe use of natural gas as a fuel. However, neither methanol, ammonia nor hydrogen are currently covered by detailed technical requirements in the IGF Code.

In order to obtain approval by flag State and classification society for ships with alternative fuels, the ship designer and ship builder will have to demonstrate through extensive risk evaluations that the chosen fuel system design solution meets the intent of the goal and functional requirements of the IGF Code. They will also need to demonstrate that the design provides the same level of safety as having a new and conventional fuel oil system for propulsion and power generation. This risk-based approval process is detailed in the IMO guidelines for the approval of alternatives and equivalents (MSC.1/Circ. 1455.) known as the alternative design process.[6]

Unlike conventional designs based on detailed technical requirements in IMO Codes, the final design and arrangement of a vessel based on the alternative design process will vary determined by findings in the risk assessment and safety analysis. Parties not directly involved in the approval process, e.g. port authorities, Port State Control (PSC), or operators, must therefore reference the vessel specific approval report submitted by the flag State to IMO GISIS to get details on the scope of the approval and the ship specific system design solutions. Compared to referencing a set of standard technical requirements, such individual vetting will require more resources and higher competence from the party desiring to understand the system design and risk associated with the vessel. For green corridors where vessels are planned to sail a fixed route, introductory design meetings and tabletop exercise meetings between ship owners, ship flag, class, port authorities and other stakeholders can provide efficient knowledge sharing.

The IMO is working in amendments to the IGF Code for methanol, and interim guidelines for hydrogen and ammonia are expected to be finalized and published early 2025. Further, class rules or guidelines from a number of IACS Classification Societies are in place for methanol, ammonia, and hydrogen (even though not all have published their hydrogen rules to this date). Using the recognized safety standards detailed in these guidelines and class rules/guidelines as basis for the ship design is recommended as far as practicable to limit extensive vetting prior to port calls or other operations.

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| 1 | Vessel is designed according to recognized safety standards in relevant IMO guidelines, class rules/ guidelinesand local authority requirements, as applicable | | |
| 2 | Vessel is approved by flag State according to MSC.1/Circ. 1455 and the approval is submitted to IMO GISIS | | |
| 15 | Tabletop exercise conducted between ship owner and port to identify and understand potential hazards | | |

## Transit in International Waters, Territorial Seas and Internal Waters

International green corridors calling at two or more ports will inherently pass through the waters of the States involved in the green corridor. A goal of the green corridor should be facilitating the acceptance of vessels entering internal waters and establishing potential restrictions or provisions for such operations.

In addition, a green corridor might pass through international waters and the territorial seas (12 nm of the baseline) of intermediate States not part of the green corridor agreement. While a green corridor agreement does not need to be signed by intermediate States whose waters are adjacent to the corridor, approaching such States to share information is regarded as good practice. This is particularly relevant considering that ships with alternative fuels might encounter problems underway and be in need of assistance and a safe harbour. IMO res. A.949(23) provide guidelines on places of refuge for ships in need of assistance. This guideline outlines the dilemma "What to do when a ship finds itself in serious difficulty or in need of assistance without, however, presenting a direct risk to the safety of life of persons involved. Should the ship be brought into shelter near the coast or into a port or, conversely, should it be taken out to sea?" A vessel with ammonia as fuel, and a damage to the fuel system jeopardizing the integrity of its safety systems will pose a higher risk to its surrounding. Some port States might be hesitant accepting a vessel with a damage. To facilitate the Master's decision-making process if the ship is in difficulty and provide information to the port State, emergency plans should be prepared for possible scenarios.

Nuclear powered ships also have the right for innocent passage through the territorial sea but must follow special precautionary measures established for such ships by international agreements. Conventional nuclear technology (pressurized water reactor) results in an exclusion zone around the ship where access is restricted, this increases the complexity of operation. Due to an inherently safer design, coming generations of nuclear reactors (often referenced as 3rd and 4th generation) are envisioned to not require an exclusion zone. However, there are no regulations in place for such reactors yet and the technology has a low maturity. This report will therefore not go into more detail on safety considerations for nuclear green corridors.

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| 3 | Emergency plans are developed for emergencies when the ship is under way (ref. IMO res. A.949(23)) | | |

## Understanding Third-party Risk

One key safety consideration that distinguishes alternative fuelled vessels from conventional fuelled vessels is the risk to third parties. Where a fire onboard a conventionally fuelled vessel normally is contained within the ships' sides and extinguished by on board crew. An accident on board a vessel with alternative fuels can pose an immediate danger to people in the nearby vicinity of the vessel. Examples of this are release of toxic ammonia gas or an explosion from an uncontrolled leak of hydrogen.

The concept of third party risk is well known in the shipping industry and is relevant for all ships carrying dangerous goods, gases, or chemicals as cargo. Vessels carrying such dangerous cargoes are normally required to notify the harbour master prior to arrival, and normally have restrictions on where they can berth. Gas carriers and chemical tankers berth at designated tank terminals to load and unload. These terminals have specific provisions, local approvals, and emergency plans for handling large quantities of these dangerous cargos. To grant local approval and to develop emergency plans for these tank terminals, a common requirement is to perform quantitative risk assessments (QRA) and dispersion analysis for the area. These analyses often result in risk contours that describes the frequency (e.g. 1.0 x 10-6/year) of a pre-defined consequence (e.g., fatality) in the specific area.

A difference between a ship carrying dangerous cargoes and a ship with alternative fuels is that the alternative fuelled vessel might be carrying cargoes or performing operations that requires berthing at ports not regulated for dangerous cargoes.

Alternative fuel systems designed according to the gas safe principle prescribed by class rules/guidelines and the upcoming IMO interim guidelines should most likely have a low risk of uncontrolled releases. A series of passive and active safety requirements are designed to protect, contain and detect release, and shut down the fuel system, to minimize potential consequences from system failures. Some of these safety principles are secondary physical barriers containing leaks, requirements for detection and automatic safety actions such as emergency shut down (ESD), ventilation of flammable gas to dedicated vent masts, release mitigation systems for toxic gas and available personal protective equipment. Other risk reducing requirements for bunkering are dry disconnect couplings, breakaway coupling, and emergency shut-down systems with ship-shore communication enabling automatic safety actions on both land or bunker tanker and ship side.

Regardless of the number of technical safety systems in place, experience has shown that primary barriers and safety systems can fail resulting in unintentional releases. The cause of such releases can be operational human error, lack of maintenance or component failure. To reduce the consequence of unintentional releases and to understand the actual risk to crew and passengers, a gas dispersion analysis of credible leak scenario will be required. The primary goal of such gas dispersion analysis is to determine ship arrangements and the safest locations for ventilation, bunker stations, mustering, and other systems on board.

In addition, the gas dispersion analysis can also be used as an effective tool for developing an understanding of and illustrate the extent of potential hazards to areas outside the ship's side. A far field analysis can produce ship specific dispersion contours. Examples for such dispersion contours are illustrated in figure 2 and figure 3 with ammonia concentrations in parts per million [ppm]. Normally such contours will not be perfectly round, as the true dispersion is affected by ship geometry, nearby infrastructure, wind and direction of release. However, the generalized information may effectively provide information about the potential hazard, and can be applied across different ports and areas along the pier. This may reduce the need for detailed analysis for all possible locations and sailing routes and provide valuable information to emergency response teams on land.

Transfer of fuel through flexible, non-permanent bunker hoses are inherently more prone to high flow leaks than the permanent fuel system installed on board. This is reflected in the larger extent of the contours for bunkering in figure 2 than what is expected for normal operation shown in figure 3. As a possible outcome, the port authorities could allow normal loading and unloading of cargo with minor provisions, while bunkering operations must take place at a designated area.

The same principle with risk contours for identifying control zones is applied as an industry standard for LNG bunkering. The Society for Gas as a Marine Fuel (SGMF) has developed a guide and program, BASiL, for calculating the extent of LNG zones during bunkering. [7] Similar detailed analysis should be made for alternative fuel bunkering operations in green corridor ports.

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| 5 | Gas dispersion analysis preformed and ship specific dispersion contours are available | | |
| 6 | Risk to third parties is quantified according to the chosen fuel, storage method and design solutions | | |

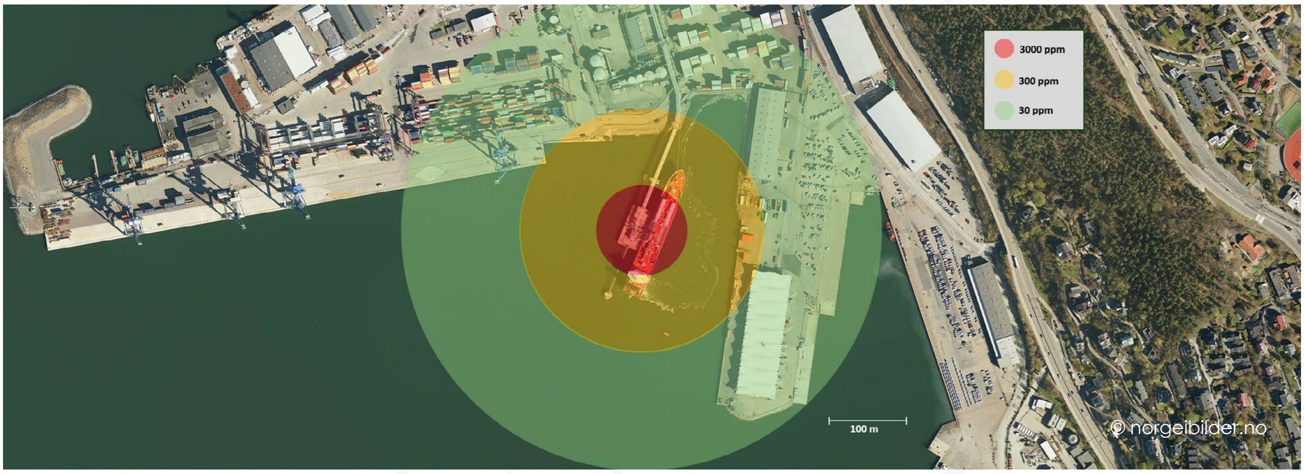



Figure 2 – Illustration for a worst-case dispersion contour for ammonia bunkering.


Figure 3 – Illustration for a dispersion contour for ammonia operation.

## Port Specific Safety Considerations

The majority of safety considerations for establishing green corridors are linked to the interface between the ship and the port. The scope of the maritime rules and regulations for ships' fuel are generally limited to the installation on board and stops at the bunkering connection of the ship, while the port and shore side bunker installation pertain to different regulatory regimes.

One challenge in developing green corridors is that the shore side regulatory framework is local. This implies that there will be differences in the regulations for each new port state and individual ports in the green corridor. The regulations are for instance related to approval of bunkering infrastructure and handling of dangerous goods and are in addition enforced by multiple agencies. A study by the Maritime & Coastguard Agency identified that 47 pieces of legislation relating to port governance and the handling of hazardous good within the port environment exist in the UK.[8] For the stakeholders developing green corridors this results in a complex regulatory landscape to navigate across different states. To limit the scope of this report, shore side regulations for approval of infrastructure and local zoning requirements has not been considered. For successful implementation of green corridors, strong communication between ports and relevant government agencies is essential.

Port bylaws are local laws that specifies the powers of the harbour master and provide for the orderly control of such matters as navigation, mooring, bunkering, and handling of goods and cargo. Among the provisions in bylaws are limitations to where a ship with dangerous goods can navigate and offload cargo, requirements for gas fueled ships and bunkering procedures. For the ship owner it is important to identify if there are any provisions in the bylaws prohibiting operations with toxic gas such as ammonia. The port authority must ensure that the bylaws are updated with specific provisions for alternative fuels. One example is that the Port of Gothenburg bylaw states that vessels with methanol fuel shall be designed and approved according to the IMO methanol guideline, but has no reference to requirements for hydrogen or ammonia. Port authorities establishing green corridors should revise the port bylaws to facilitate for cargo operations and bunkering. And if necessary, provide specific restrictions for ships with alternative fuels. Restrictions should be based on the findings from a risk assessment and could include limitations on bunkering parameters (pressure, flow rate, hose diameter), weather or local traffic. Ports should strive to develop safe bunkering operations together with the ship owner and bunker provider to limit the extent of restrictions.

Another issue identified is that a ship is required to report its dangerous cargo to the harbour master typically 12 hours prior to entering the port. However, as no such reporting is normally required for fuel, the harbour master could be unaware that a ship with ammonia as fuel is arriving since the vessel likely is listed as a dual-fuel engine with MGO as the primary fuel. The harbour master should make sure detailed reporting of fuel on board or tracking of relevant ships with alternative fuel is established.

Four different modes of bunkering are envisaged for alternative fuels. Ship-to-ship bunkering, shore-based terminal-to-ship, truck-to-ship bunkering and swapping of portable fuel containers. While the report will not go in detail on the specific hazards for the different modes, some key differences to consider is the location of the bunker operation and the different safety systems. A common consideration is to ensure compatibility between the ship and bunker manifolds, safety system and accompanying procedures.

The shore-based terminal-to-ship will be in a fixed designated location in the port with specific provisions, local approvals, and existing emergency plans. As long as the vessel dispersion contours and safety zone are within the approved terminal area, bunkering should be acceptable. The other three modes are not fixed in location and bunker operations should be analysed individually for each location. Ship-to-ship bunkering can be both alongside in the port or further out at the mooring. At mooring third parties at risk could also include neighbouring ships moored downwind. Truck-to-ship introduces risk as the emergency shut down system is that of the individual truck and this system can be different from truck to truck. For swapping, portable fuel containers are lifted or rolled on board. Lifting operations introduces the additional risk of a dropped container with full rupture of the tank and full release of the content.

For analysing and managing the risk when bunkering at non-permanent locations, the industry standards for zoning should be identified and applied. SGMF defines the following five zones for control measures: [7]

- **Hazardous Zone** is a three-dimensional space in which a highly toxic or explosive atmosphere can be expected frequently enough to require special precautions. Generally, no persons should be within this zone when bunkering.
- **Safety Zone** can be defined as the three-dimensional envelope of distances inside which the majority of leak events occur and where, in exceptional circumstances, there is a recognised potential to harm life. Non-essential people should be excluded from this zone and essential staff should be protected through the use of appropriate PPE and emergency covers.
- **Marine Exclusion Zone** is to protect the bunkering vessel from other marine traffic, primarily by defining minimum distances and speeds for passing vessels.
- **Monitoring Zone** is defined as the three-dimensional space inside which activities (including people and vehicle movements) need to be identified and monitored to ensure that they do not affect the safety of the bunkering operation. People in this zone should also be aware of the ongoing bunkering, and evacuation procedures should be clearly defined.
- **External Zone** is defined by the level of risk general members of the public can be exposed to, based on local regulatory requirements. Port cannot influence how the general public behaves outside the port area so the risk level outside must be kept low.

To facilitate the zone analysis and safe bunkering risk assessment, it is recommended to conduct tabletop exercises where relevant stakeholders and technical experts are gathered to discuss the operations prior to the first bunkering and depending on the circumstances, as necessary by the local authorities. Further analysis could also include safety critical task analysis (SCTA) to assess human error opportunities, working environment health risk assessment (WEHRA), and SIMOP reviews to analyse simultaneous port activities.

Stakeholders should also reference the available guidance for LNG operation and bunkering as basis for bunkering other alternative fuels. Even though methanol, ammonia and hydrogen have differing physical and chemical properties from LNG, they require quite similar system designs and safety barriers. The learnings and safety approaches from LNG bunkering will therefore provide a solid foundation to assess the additional measures needed to address the new fuel specific risks. Industry organizations are currently working on updating and developing new guidelines for alternative fuels based on the existing experience from LNG. Before these new guidelines are published, the following LNG guidelines can be recommended:

- EMSA – Guidance on LNG Bunkering to Port Authorities and Administrations [9]
- IACS – LNG Bunkering Guidelines Rec. No. 142. [10]
- IAPH – LNG Bunker Checklists [11]
- SGMF – Safety and operational guidelines – bunkering [12]
- MPA – Technical Reference: LNG Bunkering (TR 56) [13]

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| 7 | The ship's bunker plan and operational manual should be specific to the fuel | | |
| 9 | Port Bylaws and local regulations are updated to accommodate vessels with alternative fuels | | |
| 10 | Restrictions and limitations on bunkering (pressure, flow rate, hose diameter), weather or local traffic are identified | | |
| 13 | Bunker crew have available suitable PPE for handling, responding, and escaping from a release of fuel. | | |
| 14 | A designated escape plan is developed, and safe havens established if identified necessary | | |
| 17 | Safety zones and control measures for bunkering are analysed and specified | | |
| 18 | Specific emergency plans are developed and agreed for when vessel is in port | | |
| 19 | SIMOP review conducted to analyse acceptable simultaneous port activities is preformed | | |
| 20 | Safety critical task analysis (SCTA) and working environment health risk assessment (WEHRA) preformed | | |

## Training and Competence

Equally as important to the technical safety barriers installed are the crew and personnel operating the fuel and bunker system. New and modified technical skills will be required for those directly involved in managing the transfer or handling of alternative fuels. All personnel will need to be aware of the fuel specific properties and hazards. [14] It is stated that Seafarers on vessels operating with conventional fuels will have to adopt the safety mindset of the tanker/gas fleet when working on ships with new fuel types. [15]

According to the requirements in the IGF Code, the ship owner or operator shall ensure that seafarers on board ships using gases or other low-flashpoint fuels shall have completed training to attain the abilities that are appropriate to the capacity to be filled and duties and responsibilities to be taken up STCW Code Part A / Section AV/3 (IGF Basic and IGF Advanced). Further the ship owner or operator is responsible for providing appropriate ship and equipment specific training as specified in regulation I/14 of the STCW Convention.

Currently no IMO model courses or official training from training providers are available for hydrogen, ammonia, and methanol as fuel. As a consequence of the non-existent STCW approved training and responsibility on ship owners to provide appropriate ship and equipment specific training, it is anticipated that there will be inconsistent implementation of training across different vessels. The flag State should follow up the crew training as part of the alternative approval and following ISM revisions. However, such revision cannot guarantee consistent training. These gaps are further elaborated in the MTF report on safe operation of alternative fuels [16]. To mitigate these gaps flag states such as Singapore, and the UN Maritime Just Transition Task Force, are developing training programs. [17] MPA is also looking at developing a Training Facility which would be equipped to train seafarers working on board ships running on alternative fuels and prepare them for the future.

For the safe operation of green corridors, and especially bunkering of alternative fuels, it is crucial that both the crew on board and the onshore bunker personnel have undergone similar basic training and have the same understanding of the fuel properties and safety barriers. Specifically, they need to have the same situational awareness, communicate clearly, and make coordinated correct actions to mitigate potential hazards. Crew and bunker personnel should therefore also be involved in the tabletop exercise as far as practicable to familiarize them with the fuel and bunker systems and related hazards.

Emergency personnel such as paramedics and firefighters responsible for the local area around ports establishing green corridors should be informed about the plan to accept ships with alternative fuels, and ideally be included in the tabletop exercise. This is especially important for ports without prior experience with handling dangerous goods. If not prepared and trained, emergency response team might not be able to respond correctly and swiftly to the hazard to save life and minimize the consequences. In a worst-case scenario, the emergency response team could even escalate the accident by performing wrong actions.

Training and competence are also relevant for personnel working in the land organization of companies operating vessels on alternative fuels. The managing company has the overarching responsibility to ensure that the safety management system (SMS) is fit for purpose in addressing the elevated operational risk of alternative fuels. Senior management should understand that managing the elevated operational risks requires them to systematically address changes needed throughout the organization and ensure adequate resources are provided to maintain safe operation. Findings and identified hazards should be reflected in the vessel's safety management system (SMS). Communication, learning, crew engagement, and work practice adherence will be key to successfully maintaining a high level of safety. [14] The MTF report on "Guidelines to develop and implement Safety Management System for alternative fuels on board ships" elaborates this topic in further detail. [18]

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| 4 | Ship owner has updated the SMS and relevant ship certificate to reflect the additional risk from alternative fuel | | |
| 8 | The ship's crew are trained for responding to and limiting potential releases. | | |
| 11 | Emergency personnel on land are trained and familiar with the relevant fuel | | |
| 12 | Port bunker crew are trained for responding to and limiting potential releases. | | |
| 16 | Ship's crew and bunker personnel are invited to the tabletop exercise to familiarize them with the fuel and bunker systems and related hazards. | | |

# Fuel Specific Safety Considerations

This chapter will provide an overview of the specific properties for ammonia, methanol and hydrogen related to safety. With an additional overview of the relevant storage methods and related safety considerations. These considerations are relevant for all vessels with alternative fuels and not exclusively green corridors. Further, the list of safety considerations is indicative and should not be regarded as an exhaustive list for hazard identification.

## Ammonia

Ammonia ($NH_3$) is a gas at ambient temperature. It can be stored as a refrigerated liquid at or near its boiling point (-33.4 °C) or at ambient temperature at pressure (8.6 bar at 20 °C). Ammonia is corrosive in water solutions and has a characteristic odour that most people can smell already at 5 ppm.

The main risk with ammonia is toxicity. Ammonia is a hygroscopic compound, which means it seeks water from the nearest source, including the human body. Mucous membranes, like the eyes, respiratory system and skin, have high moisture contents and are especially at risk when put into contact with ammonia. [19] Several global standards have assessed the toxic impact on humans during an ammonia release. One of the most well-established is AEGL (Acute Exposure Guideline Level), dividing the exposure [ppm] into time and three consequence levels, as seen in table 1. These limits can be applied when assessing zoning as discussed in the chapter on port specific safety considerations.

Table 1 – AEGL table for ammonia – Source: National Academies [20]

| Acute Exposure Guideline Level | | 10 min [ppm] | 30 min [ppm] | 60 min [ppm] |
|---|---|---|---|---|
| AEGL 1 | Notable discomfort | 30 | 30 | 30 |
| AEGL 2 | Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape | 220 | 220 | 160 |
| AEGL 3 | Life-threatening health effects or death | 2700 | 1600 | 1100 |

The gas phase ammonia is generally buoyant with a density around 0.70 relative to ambient air. This results in gas clouds rising and thus limiting dispersion concentration at ground level relatively rapidly. However, for certain situations ammonia vapour may form clouds denser than air. The situation which is of most concern is releases of pressurised warm liquid ammonia. In case of release of pressurized warm ammonia, the gas will become two-phased after atmospheric expansion, forming a fine aerosol mist that is heavier than air and travels along the ground for long distances. Multiple studies have identified the increased risk with warm pressurized ammonia and increased resulting risk contours. [21,22,23] In the current development of IMO guidelines for the safety of ships using ammonia as fuel, the recommendation is to store and bunker ammonia as a refrigerated liquid at or near its boiling point.

Water spray systems can be used to dilute and reduce spreading of ammonia vapour clouds. However, water should not be added to liquid pools of ammonia as this will cause instant evaporation of large amounts of gas. Personal protective equipment such as gas masks, protective clothing and face shields should as a minimum be available for people or crew in areas where leaks can occur.

The combustion properties of ammonia are considerably different from those of other low flashpoint fuels like methane and hydrogen. Because the lower explosion limit and minimum ignition energy of ammonia are high, ammonia is more difficult to ignite, and thus there is a comparatively low probability of fires caused by ammonia. [24] Fire and explosion risk for ammonia in open air may therefore be considered as almost negligible.

The industry has experience with handling ammonia, as around 20 million tons are carried on gas tankers as cargo yearly. However, using ammonia as a fuel comes with many additional considerations, such as bunkering, fuel preparation, piping, and ventilation, which lead to increased risks of leaks and exposure compared with carriage as cargo. As a result, safety, including crew safety, is a key hurdle for the use of ammonia as a fuel in the maritime industry. Due to the similar physical properties, operational experiences on LPG bunkering will provide additional useful guidance in creating ammonia bunkering procedures. However, being chemically far from LPG, the safety aspect of ammonia will deserve a separate study that may benefit from the established chemical industry, where safety precautions, material compatibility and machinery are meticulously addressed. [22,25]

## Methanol

Methanol ($CH_3OH$) is a clear liquid at ambient temperature and pressure. As it does not require pressurization or cooling, the liquid can be stored in standard tanks on board with only minor additional requirements compared to MGO. Methanol is a toxic and highly flammable chemical. It is more flammable than ammonia and burns with a flame that can be hard to see in daylight, creating a risk of undetected fires. Methanol has a low flashpoint (12 °C), this is the temperature at which vapours evaporate to form an ignitable air mixture. The vapour is slightly heavier than air causing vapour to accumulate close to the ground. Specific safety measures that prevent methanol vapours from forming and the installation of appropriate ventilation, leak detection, heat detection and fire extinguishing equipment are recommended.[19] Its toxicity means safety protocols must be in place to protect seafarers and port operatives from coming into contact with the fuel.

Following the first methanol-powered ship which came into operation ten years ago, experience in handling methanol as a marine fuel has grown. Truck-to-ship bunkering of methanol was successfully demonstrated in 2015, then shore-to-ship bunkering in 2016, barge-to-ship bunkering in 2021, and ship to container ship bunkering in 2023. Methanol bunkering has since been validated in several different locations and types of conditions, with 10 global ports now offering methanol bunkering and a further 11 planning to establish capability in the near term. [26, 27]

## Hydrogen

Hydrogen ($H_2$) is a gas at ambient temperature. It can be stored as a refrigerated cryogenic liquid at its very low boiling point (-253 °C), or as a gas under high pressure (200 – 700 bar) at ambient temperature. The two storage systems are substantially different and should be approached as two distinct "fuels". The main risk with hydrogen is the wide flammability, low ignition energy and higher explosive potential than other fuels. Hydrogen burns with an almost colourless flame almost impossible to identify in daylight. Ignition can be initiated by static electricity, and if hydrogen gas is allowed to accumulate to concentrations ranging from 4% (LEL) to 75% ignition can result in an explosion. Compared to other fuels, hydrogen has higher explosion pressures and can cause substantial damage to nearby structures. [28]

Hydrogen is much lighter than air and will rise and disperse quickly out in open air if not obstructed. One key safety barrier is to ensure that possible leakage points for hydrogen are either enclosed and inerted or have an unobstructed path of release. Hydrogen should not be able to accumulate under roof structures or similar. For compressed hydrogen the initial jet vector from a potential leak will give momentum in the respective direction, causing hydrogen to spread over a potential larger area before rising due to buoyancy.

Liquid hydrogen will be stored in vacuum insulated type C tanks. Double wall piping must also be insulated with a vacuum, or helium where a vacuum is not possible. Since the temperature of liquid hydrogen (-253 °C) is lower than the liquefaction temperature of oxygen (-183 °C) and nitrogen (-196 °C), air will become liquid if exposed to uninsulated surfaces. Nitrogen, as is normally used as inert gas for LNG, cannot be used for liquid hydrogen systems as it will solidify in the pipes. If nitrogen gas is used for purging liquid systems, the pipes must be cleared with warm hydrogen gas before introducing liquid hydrogen.

Some vessel projects are also exploring swapping fuel containers as the method of bunkering hydrogen. If the fuel containers are to be lifted on board, the additional risk of a dropped fuel container must be assessed in detail, as the consequence can be full loss of containment.

# A Green Corridor Safety Checklist

This checklist summarizes the key findings of this report. It is intended to be used by the ship owner and port authorities as a reference in the planning and assessment of the green corridor to ensure that important topics are identified and covered.

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| | Vessel Specific Considerations | | |
| 1 | Vessel is designed according to recognized safety standards in relevant IMO guidelines, class rules/guidelines and local authority requirements, as applicable. | | |
| 2 | Vessel is approved by Flag State according to MSC.1/Circ. 1455 and the approval is submitted to IMO GISIS | | |
| 3 | Emergency plans are developed for emergencies when the ship is under way (ref. IMO res. A.949(23)) | | |
| 4 | Ship owner has updated the SMS and relevant ship certificate to reflect the additional risk from alternative fuel | | |
| 5 | Gas dispersion analysis preformed and ship specific dispersion contours are available | | |
| 6 | Risk to third parties is quantified according to the chosen fuel, storage method and design solutions | | |
| 7 | The ship's bunker plan and operational manual should be specific to the fuel | | |
| 8 | The ship's crew are trained to respond to and limit potential releases. | | |
| | Port Specific Considerations | | |
| 9 | Port Bylaws and local regulations are updated to accommodate vessels with alternative fuels | | |
| 10 | Restrictions and limitations on bunkering (pressure, flow rate, hose diameter), weather or local traffic are identified | | |
| 11 | Emergency personnel on land are trained and familiar with the relevant fuel | | |
| 12 | Port bunker crew are trained for responding to and limiting potential releases. | | |
| 13 | Bunker crew have available suitable PPE for handling, responding, and escaping from a release of fuel. | | |
| 14 | A designated escape plan is developed, and safe havens established if identified necessary | | |

Non-applicability

| # | Checklist | Ship Owner | Port Authority |
|---|---|---|---|
| | Collaborative Considerations | | |
| 15 | Tabletop exercise conducted between ship owner and port to identify and understand potential hazards | | |
| 16 | Ship's crew and bunker personnel are invited in the tabletop exercise to familiarize them with the fuel and bunker systems and related hazards. | | |
| 17 | Safety zones and control measures for bunkering is analysed and specified | | |
| 18 | Specific emergency plans are developed and agreed for when vessel is in port | | |
| 19 | SIMOP review conducted to analyse acceptable simultaneous port activities is preformed | | |
| 20 | Safety critical task analysis (SCTA) and working environment health risk assessment (WEHRA) preformed | | |
| | Technical Considerations | | |
| 21 | Sensors for leak detection installed in port, e.g., gas detection, thermal camera, or ultrasonic monitors | | |
| 22 | Bunker hoses, fixed piping, valves and manifolds are certified for relevant fuel | | |
| 23 | The bunker system is equipped with a safety break away dry-disconnect coupling | | |
| 24 | The ship shore link (SSL) and emergency shutdown (ESD) communication is compatible between port and ship | | |

Non-applicability

# Conclusions

MTF identified that multiple reports on green corridors are published focusing on feasibility for realization, barriers, costs, and fuel supply. However, safety had not yet been considered in detail for green corridors. Therefore, MTF conducted this study to explore the regulatory framework and provide knowledge and recommendations to ship owners and port authorities planning to establish and operate green corridors.

From the recommendations identified it can be concluded that green corridors enable zero emission shipping to be launched and tested more effectively. As green corridors limit the scope of operation to a finite number of ports, this allows the ship owner to initiate the recommended, resource intensive, collaboration activities such as tabletop exercises. Through collaborative efforts between the industry and governments, there is potential to reduce regulatory barriers and provide early port preparedness. However, this also requires additional effort by stakeholder, which may not be typically required in normal operations.

The main high-level findings of the report can be summarized in the following six recommendations:

- **Early planning for safety assessments:** Arranging introductory design and planning meetings between ship owners, ship flag, port authorities and other relevant stakeholders is key to provide efficient knowledge sharing and plan for safety assessments.
- **Risk assessment of port operations and bunkering:** Zone analysis and safe bunkering risk assessment are recommended to be conducted as tabletop exercises where stakeholders and technical experts are gathered to discuss the operations prior to the first bunkering and depending on the circumstances, as necessary by the local authorities.
- **Use available standards to ease future port acceptance:** Recognized safety standards detailed in IMO guidelines, class rules, and local authority requirements, as applicable, should be used as basis for the ship design as far as practicable. This will ease the potential safety vetting by a port authority and will limit the need for extensive vetting prior to port calls or other operations.
- **Understanding the risk to third parties in ports** not regulated for dangerous cargoes is essential to facilitate acceptance from port authorities to enter ports, develop emergency response plans, and establish safety procedures for port-operation and bunkering
- **Sharing of information and invitation to emergency planning** is recommended when the green corridor is adjacent to the waters of intermediate States. While no formal agreement is required, accidents can occur underway and emergency plans should be prepared for possible scenarios.
- **Develop and implement SMS fit for alternative fuels:** The ship management company has the overarching responsibility to ensure that the safety management system (SMS) is fit for purpose in addressing the elevated operational risk of alternative fuels. Senior management should understand that managing the elevated operational risks requires them to systematically address changes needed throughout the organization and ensure adequate resources are provided to maintain safe operation.

The **recommendations summarized in the safety checklist for establishing green corridors** are intended to be used by the ship owner and port authorities as a reference in the planning and assessment of the green corridor to ensure that important topics are identified and analysed. The checklist is not intended to be a comprehensive list of all operational and technical aspects concerning the safe uptake of alternative fuels, and most of the recommendations listed will require detailed work and new specific checklists.

MTF knows that other industry organizations are working on updating and developing new guidelines and specific checklists for alternative fuels based on the existing experience from LNG. Going forward these guidelines and specific checklists can be used in conjunction with the safety checklist and the high-level recommendations identified in this report.

# References:

1. DNV, Energy Transition Outlook Maritime Forecast to 2050, 2023 edition
2. Global Maritime Forum, National and regional policy for green shipping corridors 2023
3. Global Maritime Forum, ANNUAL PROGRESS REPORT ON GREEN SHIPPING CORRIDORS 2023
4. ABS, GREEN SHIPPING CORRIDORS: LEVERAGING SYNERGIES, 2022
5. Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Green Corridors: Feasibility phase blueprint, 2022
6. DNV, State of play – status on regulatory development for zero-carbon fuels – Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping
7. SGMF, FP02-01 Recommendation of Controlled Zones during LNG bunkering
8. Maritime & Coastal Agency, Supporting the ports ecosystem in decarbonisation, 2022
9. EMSA, Guidance on LNG Bunkering to Port Authorities and Administrations, 2018
10. IACS, LNG Bunkering Guidelines No. 142., 2017
11. IAPH, LNG Bunker Checklists, 2019
12. SGMF, Safety and operational guidelines – bunkering FP07-01 rev. 3, 2022
13. MPA, Technical Reference: LNG Bunkering (TR 56)
14. LR and Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Human Factors Considerations: Ammonia Fuel End-of-Stage Report, 2023
15. DNV, INSIGHTS INTO SEAFARER TRAINING AND SKILLS NEEDED TO SUPPORT A DECARBONIZED SHIPPING INDUSTRY - Report no.: 2022-0814, rev. 0
16. MTF, OPERATIONAL MANAGEMENT TO ACCELERATE SAFE MARITIME DECARBONISATION
17. UN Maritime Just Transition Task Force, Mapping a Maritime Just Transition for Seafarers, 2022
18. MTF, Guidelines to develop and implement Safety Management System for alternative fuels onboard ships, 2024
19. DNV, Ammonia as a Marine Fuel Safety Handbook Rev.02, 2023
20. National Academies, Acute Exposure Guideline Levels for Selected Airborne Chemicals Volume 6
21. Green Shipping Programme – Report for pilot "Ammonia as Fuel", 2021
22. LR and MMMCZCS, Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis, 2023
23. Nanyang Technological University, AMMONIA AS A MARINE FUEL – Bunkering, Safety and Release Simulations, 2022
24. ClassNK, "Part C "Guidelines for the Safety of Ships Using Ammonia as Fuel" of Guidelines for Ships Using Alternative Fuels", ClassNK Technical Journal No.5 2022
25. ABS, SUSTAINABILITY WHITEPAPER AMMONIA AS MARINE FUEL, 2020
26. Nanyang Technological University, METHANOL AS A MARINE FUEL – Availability and Sea Trial Considerations
27. Methanol institute, MARINE METHANOL Future-Proof Shipping Fuel
28. SGMF, Hydrogen as a marine fuel – an introduction, 2023

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