Human Factors Considerations: Ammonia Fuel End-of-Stage Report

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Acknowledgements

This end of stage report serves as project document supporting the publication "*Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis*".

The findings of this project document are built on extensive cross-sector collaboration between organizations in the maritime industry and beyond. Initially, the project team comprised the Lloyd's Register Maritime Decarbonisation Hub (MDH), the Mærsk McKinney Møller Center for Zero Carbon Shipping (MMMCZCS), Maersk, Mitsubishi Heavy Industries (MHI), NYK Line, TotalEnergies, and MAN Energy Solutions. The American Bureau of Shipping (ABS), BP, Cargill, CF Industries, Stolt Tankers, and V.Group were subsequently added to the team.

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For special and detailed contributors, we refer to the *"Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis"* report.

(*): Seconded to MMMCZCS.

List of abbreviations

Abbreviation	Description
ABS	American Bureau of Shipping
CCTV	Closed Circuit Television
DCS	Distributed Control System
DNV	Det Norske Veritas
ECR	Engine Control Room
EHFA	Early Human Factors Analysis
EI	Energy Institute
ESD	Emergency Shutdown
FO	Fuel Oil
FPR	Fuel Preparation Room
HSE	Health & Safety Executive
IAPH	International Association of Ports and Harbours
IGF	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IGC	International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organisation
IOGP	International Association of Oil & Gas Producers
ISM	International Safety Management
LEL	Lower Explosive Limit
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LR	Lloyd's Register
MDH	Maritime Decarbonisation Hub
MMM	Maersk McKinney Moeller
MoC	Management of Change
NIOSH	National Institute for Occupational Safety and Health
OCIMF	Oil Companies International Marine Forum
OGP	Oil Gas Producers
PPE	Personal Protective Equipment
PSF	Performance Shaping Factors
RINA	Royal Institution of Naval Architects
SCTA	Safety Critical Task Analysis
SCR	Selective Catalytic Reduction
SCTA	Safety Critical Task Analysis

SCTW	Standards of Training, Certification and Watchkeeping for Seafarers
SIGTTO	Society of International Gas Tanker and Terminal Operators
SIMOP	Simultaneous Operations
SGMF	Society for Gas as a Marine Fuel
SMS	Safety Management System
TCS	Tank Connection Space
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
WEHRA	Working Environment Health Risk Assessment

Executive summary

Overview

Lloyd's Register Maritime Decarbonisation Hub (LRMDH) and the Maersk McKinney Moeller (MMM) Zero Carbon Shipping Centre commissioned Lloyd's Register's Human Factors advisory department to assist with the identification of human factors considerations related to the use of ammonia as fuel for reference designs of tanker, container and bulk carrier vessels. The objective was to provide a preliminary account of the factors that should be addressed to prepare for ammonia fuel use within the context of safe, efficient and environmentally sound operations.

As with conventional fuel, using ammonia as fuel is associated with hazards. Ammonia hazards include toxicity to humans, corrosion, and to a lesser extent, fires and explosions. Due to its novelty as a fuel in the maritime industry, it is critical that the various ammonia risks including those associated with human factors are understood so that appropriate operational and design safeguards, including engineering and administrative controls, can be put in place to address risk potentials.

Method

Lloyd's Register's Human Factors team led and contributed to various risk assessment work packages within the Mærsk McKinney Møller (MMM) Zero Carbon Shipping and LRMDH Ammonia Fuel's Risk Analysis programme of work. They included the following:

- Early Human Factors Analysis (EHFA): To identify human factors safety challenges associated with industry preparedness of using ammonia fuel to establish further risk assessment approaches
- Risk reduction workshop participation: Participation in safety workshops to explore human factors considerations and challenge assumptions of risk associated with various design risk nodes.
- Safety Critical Task Analysis (SCTA): Qualitative Risk Assessment method to assess human error opportunities contributing to process safety for various scenarios.
- Working Environment Health Risk Assessment (WEHRA): Assessment of conceptual designs of vessel to address the health and safety of persons for bunkering, maintenance and fuel preparation activities.
- Competency needs analysis: Identification of key areas of upskilling based upon a high-level concept of new operations.

Findings

The results of these analyses point to the need for companies and the marine industry to apply human factors engineering principles, such as ergonomics, within the design of ammonia fuelled vessels as well ensuring enhancements to a company's safety (and environmental) management system and approach. For example, procedures must outline any new or modified planning, communication, competency / training and emergency response requirements related to ammonia. Other areas where modification, changes or new enhancement would be needed include but are not limited to, managing changes to operational and maintenance procedures and practices, personnel related matters including roles, responsibilities, staffing and interfaces with other organizations. An overview of rating of human factors impacts for ammonia fuel use as compared to conventional fuel use is provided in the table below.

Table 1– Human Factors Considerations

Stages	Description	Impact	Ammonia-fuel vessels are anticipated to impact the following areas:
Ergonomics design	Workspace arrangements and Human Machine Interface	Medium	• Deck & bunker stations • Local engine and tank spaces (e.g., FPR, TCS) • Systems process command, control and remote monitoring
Roles & Responsibilities	Organisational structure and assigned roles	Low	• Changes to organisational structure with new accountabilities • Updated responsibilities related to risk assessment, safe work practices and emergency response • Contractor interfaces, tasks and actions
Competence	Technical and non-technical skills, knowledge, understanding and application	High	• New technical skills for specific operations/ maintenance • General ammonia risk awareness across crew • Emergency response • Raised importance of non-technical skills
Resourcing and Personnel	Workload distribution and number of personnel	Low	• Maintaining the structural integrity of fuel machinery and spaces through safe systems of working • Tasks associated with overseeing process control; • Preparedness for onboard emergencies.
Process and Procedures	Documented processes and work practices	High	• New ammonia specific policies, procedures and processes • Updates to operational and maintenance work practices, procedures and plans • Increase in requirements for risk assessment and employment of formal safe work practices • Review and, where necessary, change to emergency response processes
Occupational Health hazards	Exposure to toxicity, fire, noise, musculoskeletal risks, trips and falls etc.,	High	• Mechanical • Thermal • Materials / substance exposure (e.g., toxicity) • Fatigue
Process Safety Hazards	Human involvement in the contribution, exacerbation and recovery of a major accident	High	• Changes to and management of ammonia system parameters such as those associated with tanks and the system including level, temperature and pressure. • New skills related to ammonia leak detection, isolation and repair • New explosivity and flammability atmospheric conditions • Corrosivity potential • Updates to gas and chemical management • New maintenance precautions with metals and materials • New supply and maintenance precautions with metals and materials
Management of Change	Organisational, operational and technical changes that must be managed to achieve final ammonia preparedness and the process of change itself	Medium	• Change management program to address ammonia operations and risks at Company level • Modified approaches to vessel operations and maintenance • Increased awareness of when vessel management of change processes may be required. • Potential changes to planning and communications involving entities outside the vessel and Company

Using the information provided in this report, it is believed that if the marine industry addresses the human factors considerations, builds upon existing marine industry experience with low flash point fuels / cargo and ensures sufficient safeguards are provided for the various ammonia risks then ammonia can provide an acceptable alternative to conventional fuel use. Such guidance would help the industry to move forward with its goal for using low carbon fuel alternatives.

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Human Factors Ammonia Fuel: End-of-Stage Report

1. Introduction

1.1 Background

As with conventional fuels, the use of ammonia presents hazards to seafarers. These include toxicity, causticity, and flammability as well as other hazards associated with its compressed containment, such as pressure release and cold temperatures.

Due to its novelty as a fuel, it is critical that the human factors' risks associated with operations & maintenance are understood so that appropriate guidance can be developed to support industry preparedness. This guidance includes human factors engineering principles, as well as proposed enhancements to a company's safety management system including but not limited to; change to operational practices, workload staffing, competence and training, emergency preparedness, etc.

1.2 Aim

The aim of this report is to detail the principal human factors considerations to guide industry in its preparedness for ammonia-fuel operations and maintenance.

1.3 Scope

The study primarily focuses upon the operations and maintenance activities undertaken by crew members on new build, ammonia-fuel reference vessels. The basis of the study was to identify changes or enhancements that would be needed to move from operating solely with convention fuel oil to employing dual fuelled engines utilizing conventional fuel oil and ammonia fuel. This report makes mention of parallels to the practices of other gas fuelled or gas cargo vessels (e.g., LNG, LPG) but the focus this work was to highlight ammonia fuel requirements for moving beyond the sole use of conventional fuel oil.

The following themes have been assessed:

- Ergonomics design (Workspace arrangements and Human Machine Interface (HMI)).
- Roles & Responsibilities (Organisational structure and assigned roles).
- Competence (Technical and non-technical skills, knowledge, understanding and application).
- Resourcing and Personnel (Workload distribution and number of personnel).
- Processes and Procedures (Documented processes and work practices).
- Occupational Health hazards (Exposure to toxicity, fire, noise, musculoskeletal risks, trips and falls etc.,).
- Process Safety Hazards (Human involvement in the prevention of, as well as contribution, exacerbation and recovery related to a major accident).
- Management of Change (Organisational, operational and technical changes that must be managed to achieve final ammonia preparedness).

Many of these themes align and address Safety Management System (SMS) sections as defined by ISM code.

1.4 Method

The following report findings have been achieved through collaboration with risk, technical and operations expertise within the Mærsk McKinney Møller Center for Zero Carbon Shipping and Lloyd's Register Decarbonisation Hub.

Human Factors methods have been used to detail particular risks and challenges. These include proportionate application of the following:

- Early Human Factors Analysis (EHFA): Identify human factors safety challenges associated with industry preparedness of using ammonia fuel to establish further risk assessment approaches (International Association of Oil & Gas Producers, IOGP – 454 Human Factors Engineering in Projects).
- Risk reduction workshop participation: Participation in safety workshops to explore human factors considerations and challenge assumptions of risk at various design risk nodes.
- Safety Critical Task Analysis (SCTA): Application of Qualitative Risk Assessment method for addressing human error traps for bunkering, maintenance and fuel preparation safety critical activities (Energy Institute Guidance on 'safety critical task analysis').
- Working Environment Health Risk Assessment (WEHRA): Assess conceptual designs of vessel to address the health and safety of persons for bunkering, maintenance and fuel preparation activities. This assessment was based on factors such as noise, vibration, illumination, musculoskeletal, exposure to chemicals or harmful substances.
- Competency needs analysis: Approach to identify key areas of upskilling based upon a high-level concept of new operations.

Outputs from these work activities are referenced within Table 5.4 (Section 5).

1.5 Limitations and Assumptions

It is clear that industry has good awareness of managing high hazard chemicals / gases either as a fuel or through cargo.

This report details the areas of vessel operations and maintenance where ammonia-fuel systems may introduce new, distinct or modified challenges to seafarer activities when compared to conventional fuelled vessels and / or gas-fuelled or gas cargo vessels.

These challenges may be novel, or they may represent circumstances where the operational context of an ammonia-fuelled vessel presents a different impact on safe working conditions and how an accident may arise or is recovered from.

The study findings are limited to the assessment of the project's reference vessels only and the proposed concepts for the engine areas and deck bunker stations.

Future studies would be expected to mature the understanding of findings within this report.

2. Ammonia Fuel Vessel Features

2.1 Overview

An ammonia-fuelled vessel will present a different work environment for seafarers when compared to conventional fuel oil powered vessels. This is principally driven by vessel arrangements to address the chemical properties of ammonia with regards to its combustion, storage, handling and hazardous properties.

Key features of ammonia-fuelled vessel include:

- New systems associated with the processing of ammonia as a fuel e.g., bunker arrangements, sampling, fuel preparation and transfer, reliquification, venting, etc. This also includes the addition of support systems to facilitate the operations of these functions.
- Special safety design concepts such as double barriers, area segregation, isolation methods, detoxification scrubbing, ammonia detection systems, water systems such as curtains etc. will be incorporated. Selective catalytic reduction systems (SCRs) will be added to enhance environmental performance.
- New safe methods of crew working with ammonia e.g., specific Personal Protection Equipment (PPE), remote monitoring of hazardous areas, ammonia exposure level limitations, mustering in toxic conditions, ammonia decontamination showers, modified emergency response procedures, rescue operations, etc.
- Constraints on vessel practices e.g., vessel-to-vessel fuel transfer, extended time required for fuel transfer (including preparatory activities), voyage planning for port entry, safe coordination with other vessels or with ports, limitations related to simultaneous ammonia bunkering and cargo operations, etc.
- Integration with other onboard systems e.g., dual fuel systems, engine operations, process control and command systems (including alarms), fire and gas detection, refrigeration.
- Maintenance regimes etc. e.g., modernisation and possible restrictions of maintenance practices; special ammonia corrosive properties; use of special techniques, tools, materials, metals; classification of fuel areas, such as the tank connection spaces (TCS) and Fuel Preparation Room (FPR), as enclosed spaces.

Although it should be noted that many ammonia operations will have parallels to those practiced on gas fuelled or cargo vessel, the consequence of these key features, in their entirety, is that the seafarer will not only interact with novel systems and situations but also encounter an operational environment which presents different challenges to seafarer's performance compared to that conventionally experienced.

For example, the rapid dispersal of ammonia as a leak will present pressure upon timely responses and decision-making; donning additional PPE for occupation health reasons may contribute to a seafarer's fatigue and physical capability, whilst use of new systems, such as remote monitoring CCTV systems for inspection, will impact new ways of working and reliance on imagery in decision-making and fault-finding. These examples present areas which should be addressed through further controls and safeguards.

The table below provides a synopsis of the anticipated impact on various human factors themes. Impact is measured through criteria affecting seafarer performance such as task novelty, frequency of human interaction, criticality and known issues.

Table 2– Human Factors Considerations

Stages	Description	Impact	Ammonia-fuel vessels are anticipated to impact the following areas:
Ergonomics design	Workspace arrangements and Human Machine Interface	Medium	• Deck & bunker stations • Local engine and tank spaces (e.g., FPR, TCS) • Systems process command, control and remote monitoring
Roles & Responsibilities	Organisational structure and assigned roles	Low	• Changes to organisational structure with new accountabilities • Updated responsibilities related to risk assessment, safe work practices and emergency response • Contractor interfaces, tasks and actions
Competence	Technical and non-technical skills, knowledge, understanding and application	High	• New technical skills for specific operations/ maintenance • General ammonia risk awareness across crew • Emergency response • Raised importance of non-technical skills
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Management of Change	Organisational, operational and technical changes that must be managed to achieve final ammonia preparedness and the process of change itself	Medium	• Change management program to address ammonia operations and risks at Company level • Modified approaches to vessel operations and maintenance • Increased awareness of when vessel management of change processes may be required. • Potential changes to planning and communications involving entities outside the vessel and Company

Impact	Criteria Description
Low	Small changes to seafarer tasks where vessel design/operational practices addressed through industry practiced guidance and requirements.
Medium	Changes to seafarer tasks through additional complexity, time-consuming, increased reliance on human reliability. Vessel design/operational practices addressed through further application of human factors principles.
High	Significant changes to seafarer tasks through additional complexity, time-consuming, increased reliance on human reliability. Specific HF studies required to address implication and involvement of human actions on accidents.

3. Human Factors Considerations

3.1 Ergonomics Design

3.1.1 Overview

Ergonomics relates to ensuring the design of a vessel and its components addresses the intended users' capabilities and limitations given the operating circumstances and conditions. Companies should be prepared to incorporate user-centred, ergonomics design practices to the design and procurement of ammonia related systems, equipment or components including any proposed changes to conventional items to accommodate the presence of ammonia.

Regulation and class notation currently detail certain ergonomics requirements associated with ensuring safe design, such as those related to ship motions, design arrangement, layout and location of operation, berthing and maintenance spaces, access routes, display design, valve operation etc. However, a significant element of designing a vessel and its systems to operate safely and effectively is through risk-based guidance, where knowledge of the crew capabilities, skills and operating environment should be considered to determine and support design decisions.

This will not only address designing to positively exploit human capabilities but to reduce limitations including eliminating human involvement or intervention, where appropriate. This approach will reduce opportunities for physical discomfort and injury as well as minimising errors interacting with equipment that could have process or personal safety consequences.

3.1.2 Ergonomics considerations

The principal vessel areas where ammonia-fuel represents a challenge to ergonomics include:

Deck and Bunker Stations

- Bunker station interfaces and access arrangements such as connections, hose, sampling points, will present manual handling, chemical exposure risks to the crew. Hoses with breakaway devices and reinforced pipe material will be heavy and present challenges for manoeuvrability and occupational health consideration through proximity to crane operations. There will be a need for further protection measures e.g., some mechanical shielding in place to guard against exposure to leakage. Lessons learned from fuelling approaches such as LNG can help to inform requirements for ammonia.

- Reappraisal of human physical capabilities related to safe working practices i.e., donning chemical protective suits will incumber crew, affecting strength for strenuous tasks, such as hose coupling, and contributing to general fatigue for tasks over a long duration. Procurement of equipment should address this in the form of revised user requirements and design specifications.

- Restrictions to working in areas due to crew ammonia exposure times and general hazard mitigation will promote remote working during scenarios such as bunkering. Design should enable crew to remotely oversee the bunkering operation through facilitating remote situational awareness and effective working. This would include increased levels of remote surveillance and/or ensuring uninterrupted sightlines from control point locations.

- Safe zones of deck working. Ship-to-ship mooring is likely to accompany the bunkering activity. This will affect deck design and bunker station areas with regards to circulation routes, denoting safe deck zones, and the physical access to allow dynamic risk mooring activities.

Local Spaces (i.e., engine and tank spaces)

The design of local spaces should facilitate maintainability and operability, including activities such as periodic inspection, testing, running maintenance, replacement activities and emergency work associated with new process and alert systems.

- Safe access: Provision of local information either at and/or near equipment itself and local panels (for equipment and systems in enclosed spaces but also for air quality in "safe" areas).
- The type and number of entrances to engine and other areas should consider control of access to high-hazard workspaces e.g., air-lock access as opposed to bolt lock.
- The method of door closure and opening should also consider assisting seafarers with door access and closure to a room whilst retaining the physical barrier integrity (e.g., for room pressure control, controlling gas leak dispersal etc.). For example, seafarers may have a propensity to leave doors open when repeatedly having to access areas or take equipment to and from the room. This should be addressed through the design of the door operation assisting the seafarers with access, egress and door closure.
- The potential for ammonia leaks will require rooms and interconnecting areas to maintain an acceptable atmosphere as well as promote safe and timely escape and abandonment if required e.g., ventilation, venting, enclosed stairwells, water curtains, clearance spaces, air locks etc. In addition, safe havens, including citadels, muster spaces and escape routes, will need to be established and well-marked.
- Audible or visual alarms for ammonia detection ensuring these can be seen and heard from various locations in a space and on deck.
- Readily accessible Emergency Shutdown Devices (ESD) devices especially within ammonia spaces including bunkering stations.
- The quantity, type and storage requirements of PPE such as chemical / gas tight suits, respirators, breathing apparatuses (e.g., SCBAs) and air supply etc., must take account of the needs and access required for all crew members. Design should promote access and safe storage of items so as not to invalidate PPE, ensure dry storage and assure readily accessible and usable for emergency support equipment (e.g., escape PPE including Emergency Escape Breathing Devices, stretchers, rescue equipment).
- Preventative, planned, corrective and replacement maintenance could be expected to be undertaken in workshop areas rather than in situ when appropriate. This would require room design space to address accessibility, lifting requirements and clearances to allow maintenance staff to handle system parts for removal e.g., trolley access, load management, etc.
- A dual-fuel vessel may present opportunities for maintenance error through not only increasing the number of systems but also the likelihood of mistakes and incorrect application on ammonia specific components e.g., incorrect wrench application, preparatory work for isolation, valve operation etc. Design should seek to minimise these error traps in maintenance through considering opportunities for slips, lapses and mistakes particularly with regards to the conduct of safety critical tasks. Consideration should also be given to providing written / manufacturer's instructions to outline any special features, requirements or restrictions. Lessons learned from other dual fuel applications could prove beneficial to consider.

- Fugitive ammonia leaks can occur and thus ammonia odour can be present during start-up, operation, and shutdown, due to leaks from pumps seals, valve seals, flanges, heat exchangers, etc., and due to the permeation of liquid, vapour, or gas through solids, such as gaskets. Such odours are likely to be present in ammonia spaces though small leaks are also possible in the engine room. Attention, such as to ventilation design and ammonia detector allocation, must be given to addressing this potential since exposure to ammonia in small does could be potentially unpleasant and affect the overall work environment as well as task performance. Long term exposure could impact seafarer wellbeing.

Systems Command and Control

The additional processes associated with overseeing ammonia as a fuel will present new levels of complexity to vessel command and control. This will be compounded through processes associated with the pilot fuel as well as alternative dual fuel and other safety measures, e.g., detoxification scrubbers, vents, detectors, reliquefication etc.

A vessel engineer's oversight and intervention options for this process could be implemented through automated control systems and possible network connectivity to present a unified way of understanding of system state on the vessel. It could also be that the control of ammonia-fuel process remains distinct from the process control of other systems onboard.

Furthermore, systems to allow remote maintenance and inspection of engine areas would be developed as an engineering safeguard to reduce the need for crew to enter hazardous areas e.g., this would be expected to be achieved through augmented CCTV systems within the Engine Control room.

3.2 Roles & Responsibilities

3.2.1 Overview

Regardless of the type of fuel used, the vessel operator / owner is required to demonstrate that the responsibilities of those on board have been clearly defined and that personnel can safely perform activities such as navigating, mooring, ship integrity, emergency response etc. with the resources provided. In addition, relevant shoreside and shipboard personnel are responsible for ensuring that personnel, whether shipboard or with other organizations that would interface with the company and its vessels are aware of potential hazards. In this case, this would include the relevant information about the presence of ammonia, and any adjustments that would need to be taken by them. This would include shipboard crew as well as suppliers, contractors, vendors port authorities and visitors.

The organisational structure onboard an ammonia fuelled vessel would not be expected to change significantly compared to comparable existing high-hazard vessel types. However, within the organisational structure, it could be expected that roles and responsibilities associated with ensuring safe methods of working and emergency response would need to be developed to account for the new emerging technical tasks, health hazards, and ensuring appropriate accountability for emergency response decision-making and implementation of plans.

3.2.2 Roles & Responsibilities Considerations

Safe methods of working

With the use of ammonia as fuel on various vessels, the responsibilities for ensuring safe, efficient and environmentally sound operations will increase. While it is unlikely that traditional roles ranks would change onboard, there is a potential for the addition of personnel, some of whom might have specialized knowledge. Most likely, such personnel could be fit within the existing organisational structure. Organizations will need to conduct their own evaluations to determine the sufficient number of personnel and required competencies needed to ensure safe, efficient and environmentally sound operations while operating with ammonia as fuel. This evaluation is particularly important since the addition of ammonia onboard is not limited to operating and maintaining the ammonia fuel systems, equipment and components but would also include needed support systems as well the traditional ship's systems and equipment. This would include the retention of conventional fuel oil systems for supplying conventional fuel oil to dual fuel engines as well as those used for navigation, manoeuvring, power production, habitability, ballast, cargo operations and environmental equipment.

Since ammonia presents unique hazards when compared to the use of conventional fuel oil, senior officers, such as the Master and Chief Engineer, will see their responsibilities expand to ensure that those under their command understand the potential impacts of ammonia hazards and conduct their tasks in a manner to reduce risk potentials. Both will need to gain new knowledge, technical and non-technical, to lead the activities in their departments and on the ship. This new knowledge will assist with decision making to ensure effective risk management. In particular, both Masters and Chief Engineers will need to be cognizant of new relevant ammonia regulations, rules and reporting requirements including changes related to port visits.

Other officers will also need to understand the potential influence of ammonia on board in terms of managing risk potentially affecting the completion of their tasks and their supervision of others. For example, deck officers will need to understand how the presence of ammonia on board might affect port approaches; mooring including ship-to-ship mooring for ammonia bunker transfers; bunkering; cargo operations, deck / cargo equipment maintenance as well as working and living conditions.

Engineering officers may see the greatest impacts to their responsibilities since the majority of the ammonia fuel and support systems will be operated and maintained by their department personnel. Engineers will be monitoring and controlling many of the ammonia related operations from the Engine Control Room. This role will involve a digital and technological shift as increased automation and computerized display / control systems are more likely to be integrated onboard. This would require new skill sets if personnel are not already familiar with the use of such technology. Under these circumstances, development of non-technical skills such as critically appraising a situation, decision-making and intervention as needed would also be crucial.

Engineers have a crucial role related to fuel storage, handling and use so they will be responsible for ensuring system parameters are maintained within limits including level, pressure and temperature requirements. They are the most likely persons, along with their staff, to enter spaces containing ammonia systems such as fuel preparation rooms and tank connection spaces. Their attention will be needed to ensure operations and maintenance activities take place safely and efficiently. These officers will be responsible for supervising personnel conducting operational and maintenance tasks including those with less understanding and knowledge of ammonia such as ratings.

All Officers, both deck and engine, must be familiar with their relevant actions with regards to emergency response. Their understanding of the intricacies of ammonia and its behaviours will be crucial to reducing the consequences of any emergency situations and in keeping shipboard and potentially shoreside personnel safe.

Other personnel, such as ratings, will also need to have basic understandings of the potential hazards of ammonia and how to respond to exposures in a manner appropriate to their role. Such personnel should also understand that there is likely to be an increased need for risk assessments and that could result in the need for them to employ formal safe work practices and permits such as confined space and lock out – tag out more frequently.

Emergency Response

Officers would also need to ensure that all ship's personnel, including ratings, understand how, when and where to use PPE, as well as the locations of any PPE lockers or devices like shelters and decontamination showers. They will need to ensure everyone understands what actions they can take to minimize exposures. Personnel will need updated training with regards to their emergency roles in cases where the potential presence of ammonia would change what actions they would take. For example, if firefighting regimes or PPE change due to ammonia, these personnel would need to receive training about new routines. All personnel would need to understand what response is needed from them in the case of an ammonia alarm. They would need to understand any new processes for escape, mustering, evacuation, or abandonment, as it would affect them where ammonia a factor in the emergency.

3.3 Competency and Training

3.3.1 Overview

Competence and skill development for seafarers are currently supported through SCTW, IGF, IGC, ISM regulations and other guidance publications. The onus is upon the operating company to demonstrate that its crew have appropriate training and certification for ammonia-fuel.

The addition and novelty of ammonia as a fuel and any associated new systems / equipment (e.g., vents, detox scrubbers, SCR) will not only introduce new technical skills for those directly involved in managing the transfer or handling of the ammonia but also further emphasize the need for non-technical skills for all crew such as maintaining situation awareness and recognizing potential hazards which will affect decision-making and communication under various circumstances.

3.3.2 Competence and Training Considerations

With modification to shipboard personnel's roles and responsibilities, new competencies will be needed to ensure ammonia fuelled ships operate safely, efficiently and in an environmentally sensitive manner.

Competence refers to the ability to undertake responsibilities and to perform activities to a recognised standard on a regular basis. Competence is a combination of practical and thinking skills, experience and knowledge, and may also include a willingness to undertake work activities in accordance with standards, rules and procedures.

Competence depends on the working environment and context and will be a significant factor in the effectiveness of seafarers in controlling and responding to health and safety risks on an ammonia fuelled vessel.

Competence Regulations

Currently IMO's Standards of Training and Watchkeeping (STCW) details knowledge, skill and competency requirements for seafarers on vessels operating with conventional fuels. It also outlines further requirements for specific ship types, like tankers, as well as for ships using low flashpoint fuels, like LNG / LPG (see IGF Code). Additionally, the marine industry, has competency guidelines (e.g., SGMF and SIGTTO) for low flashpoint gases and some seafarers have experience with carrying and handling ammonia as cargo.

Low flashpoint gas competencies that are outlined in regulations, industry guidelines as well as marine cargo experience, can serve as the basis for establishing many of the ammonia as fuel competency requirements. Further competencies will need to be established to address ammonia's unique characteristics and properties as well as new skills and technical knowledge for ammonia related / ammonia support systems, equipment and components as well as for using complex systems and increased automation.

Specific Competence Development

Key areas of ammonia as fuel areas where new or modified knowledge or skills would be required include:

- Ammonia hazards awareness and risk management
- Emergency response
- Vessel operations

- Maintenance
- Simultaneous Operations.

Ammonia hazard awareness and risk management

As discussed above, understanding of ammonia hazards / risks as well as ammonia's characteristics and properties, as appropriate to a job function is critical. This would include toxicity, corrosivity, explosivity and flammability aspects. Relevant personnel need a basic understanding of ammonia's unique behaviours, dispersion, and ignition characteristics.

For officers this would extend to updating their knowledge related to ammonia hazards and risk management based on both engineering controls, such as automation and administrative controls, like safe work practices. They would need to be aware of how the presence of ammonia could affect day-to-day, routine, off normal and emergency operations, as well as maintenance, and lead those activities appropriately. They would need to understand the technical aspects of operating ammonia systems as well as update their non-technical skills related to data analysis, decision-making and communications. As appropriate, officers would need to have knowledge of ammonia regulations, requirements and guidelines at the international, national, regional, local and port levels. This would include required planning, communications, recordkeeping and record submissions.

Ratings, at a minimum, would need to understand the potential impacts of ammonia, how to avoid exposure and what to do in the event of such an exposure. They would also need to be knowledgeable about their role during emergencies. Such personnel would need to understand how and when to use PPE and locations of any such devices.

The Company would also need to ensure that contractors, visitors, and marine pilots, as well as various port personnel, have relevant information about the potential hazards associated with ammonia and how to protect themselves. Processes would need to be in place, and personnel will need to be cognizant of these, to ensure that planning of any operations or interfaces with other organizations appropriately addresses the presence of ammonia on board.

Emergency response

The presence of ammonia onboard will change the emergency response actions related to personnel onboard and ashore as well as actions that may be undertaken in concert with other organizations. Ship officers will need to have an understanding the potential impacts of catastrophic events such as toxic vapor clouds or explosions as well as the potential impacts of external events such as collisions and allusions. In particular, relevant personnel would need to understand the potential impacts to persons onboard or in adjacent areas. This could include potential impact to other ships, ports or communities. Appropriate understanding of ammonia's characteristics, properties and impacts would also be needed for shoreside personnel supporting emergency response efforts.

All procedures related to emergencies would need to be reviewed, and where needed, new procedures created, to ensure that emergency actions are conducted in a manner that protects people and assets from ammonia hazards or that any consequences are reduced as low as reasonably possible. Relevant personnel would need to be aware of these changes as well as understand what safeguards are available for use and how these might be employed. This might extend to the use of automatic operational shutdowns including fuel switchovers, emergency shutdown devices, water mist / curtains, ventilation systems, and vents.

The Incident Commander / Response Leader would need an understanding of how to ensure communications, coordination and reporting relays relevant information related to the impact of ammonia for the accident scenario would be effectively delivered.

All personnel would need to understand their role related to emergency response including what actions to take upon a general ammonia alarm and how to ensure that they are effectively protected. This could be as simple as understanding how and when to use PPE, to understanding any new actions or duties required to assist with firefighting or leak detection. Those in supervisory roles would need to maintain a broader perspective and direct response actions including any new regimes directed at ammonia.

As a part of emergency response planning, people's knowledge related to first aid would be updated for understanding potential actions for ammonia exposure and rescue of personnel affected by exposure. To accomplish this, personnel would need to be aware of where any ammonia related emergency response equipment and items were located and how to use them.

Lastly, relevant personnel would need to understand the potential interactions of ammonia leaks with other fuels, cargo, ship's infrastructure, systems / equipment and chemicals on board the vessel. This would extend to ammonia releases as gas or any types of liquid spills. They would also need to be well versed in the various response actions for these scenarios and able to inform any organizations aiding with response of necessary precautions.

Vessel operations

With adding ammonia as fuel, technical complexity on board will increase. For example, dual fuel engines will be employed and so personnel must be knowledgeable about ammonia storage, tank management, fuel preparation, transfer and use in the engines. Also, there will be a number of functions such as system start-ups and shutdowns that will be automated. To assist with control of various ammonia systems and equipment, including the engines, new or updated display / control system knowledge would be needed including any related hardwired and computerized systems. Such knowledge would need to extend to how to address partial or full automation failures. To ensure personnel are proficient, any new training must take into consideration the previous familiarity of personnel with process control and computerized / automated systems. This could affect personnel more greatly whose experience with automation is limited.

With the addition of ammonia onboard, new operational sequences will be required. In addition, old sequences, like port approaches and mooring, may need to be amended to ensure that any potential impacts of ammonia are addressed.

Maintenance

With the potential presence of ammonia, especially in ammonia fuel systems equipment and in support systems, like vent masts, new or amended maintenance routines and practices will be needed. Relevant personnel will need to understand the implication of potentially interacting with, replacing or repairing such systems, equipment or components. Relevant personnel will need to be aware of ammonia incompatibilities such as to particular metals and materials. In some cases, this may lead to the need for the use of specialized tools or work methods. Based on the properties of ammonia, an increased employment of risk assessments prior to tasks and use of safe work practices such as confined space, lock-out tag-out, hot work, etc as well as PPE during tasks is likely. It is also possible that updated chemical management knowledge would be required with the introduction of new chemicals, like glycol and methanol, to support ammonia operations. It is also possible that new approaches to maintenance and data analysis could occur where tasks intervals become based more frequently on conditions or variables like vibration rather than time windows in an effort to reduce potential exposures for personnel and increase overall efficiency.

Simultaneous Operations

Understanding of potential Simultaneous Operations (SIMOPS) and the impact of such activities on increasing risk potentials, will be required for senior officers. Where appropriate, familiarity with risk analysis and the decision-making process and analysis for determining what operations are permitted together will be needed. It will also be necessary that the allowances for SIMOPS are outlined in the Company's SMS as well as in agreements with other organizations involved such as ports, terminals, supplies, contractors and other stakeholders. Ship personnel, as appropriate, would need to understand these requirements.

Industry Preparedness for Competency Changes with Ammonia as Fuel

It should be noted that for seafarers to use ammonia as fuel, increased training or upskilling will be needed. The impact is expected to be different based on the vessel type, past experience with low flashpoint gases and use of computerized systems or automation. Currently, regulations require tanker vessels personnel to undertake additional training and certification. The same is true for vessel crews interfacing with low flashpoint gases. As a result, it likely that the amount of additional training or upskilling needed for tanker personnel will be less. This would be particularly true for those with gas fuel or cargo experience. Container ships or bulk carriers' personnel without such experience would need higher levels of upskilling, training and certification.

Another factor influencing the amount of additional training will be seafarer's experience with chemistry, new technologies, digital systems, computer-based display / control systems and automation. Bridge and engineering officers may need higher levels of both technical, managerial, and organizational competencies especially when compared to ratings. Regardless, all marine segments and personnel will require additional training and familiarization to ensure new or amended competencies support safe, efficient and environmentally sensitive operations while using ammonia as fuel.

3.4 Resourcing and Personnel

3.4.1 Overview

The principles of safe manning on board vessels requires the operator to demonstrate that the crew can safely perform activities such as navigating, mooring, ship integrity, emergency response etc.

Broadly, resourcing levels would be based around assessment of the time required (duration and frequency), complexity (including importance) and any conflicting circumstances which cause constraints on how work can be done.

The following ammonia-fuel activities present circumstances which impact resourcing levels:

- Maintaining the structural integrity of fuel machinery and spaces through safe systems of working
- Tasks associated with overseeing process control; and
- Preparedness for onboard emergencies.

3.4.2 Resourcing and Personnel Considerations

Safe Systems of Working

When considering ammonia-fuel, it is clear that the hazardous working environment would impact changes to managing safety functions and onboard safety arrangements. This is predominantly associated with precautions around operations, maintenance and repair to the machinery.

- The number of risk assessments and the use of formal safe work practices including permitting could increase time required, scheduling restrictions and workload.
- The design of ammonia related equipment and systems in terms of the accessibility and workplace ergonomic design, as well as environmental conditions, could affect time and number of personnel needed to complete tasks.
- In some cases, workload could be affected by the need to use PPE to respond to situations. At a minimum, this need could slow response time (time to dress out).
- The actual PPE itself could prove cumbersome, slowing physical movement. Personnel may also have to limit time while conducting a task depending on the environmental conditions (like humidity, ambient temperature) that could be present).
- The need to ensure crew members adhere to more intensive, safe systems of working may require additional, on-site supervision.
- The duration of bunkering may extend to beyond 6 hours. Consequently, the number of personnel required to undertake this process would need to be evaluated.

Process Control, Monitoring and Intervention

The additional complexity associated with new systems / equipment (e.g., vents, detox scrubbers, SCR) will contribute to the level of monitoring and general complexity under normal operational conditions. It is anticipated that most parameters and functions will be automated, alleviating workload for crew under stable state / normal operations. Other automated support activities may include remote inspection methods through CCTV, automated testing methods, methods to support mustering and disembarkation of persons on board etc.

However, the following contributors to workload should be noted:

- A particular operational concern is the increase in efforts needed for equipment / system monitoring and alarm management and response. This would be related to additional (ammonia and support) systems being added to the ship alongside existing ship's systems and equipment.
- Under other conditions, like operational upsets, bunkering or if automated functions are lost, the workload will be high. Also under emergency situations, the increased potential for toxicity, fires or explosions, would strain resources.
- There could be a temporary increase in workload where leak detection and isolation are needed. It is assumed under these circumstances, other activities would be postponed or stopped thus making personnel / resources available for this task.
- The level of and methods for maintenance and repair to the ship and its machinery, equipment and systems is to be determined and will have a direct impact upon the workload levels of staff. Factors such as needing to purge fuel systems prior to works may also contribute to general time-pressure requirements.

Emergency preparedness and response

It is assumed that under emergency scenarios, most tasks would cease thus providing personnel to concentrate and react. As with any emergency, workload will be high but similar to emergencies on fuel oil or gas fuelled vessels though with additional hazards such as toxicity. One exception, further increasing workload, would be if personnel are needed for local operations for ammonia specific tasks.

- Maintenance and administration of additional occupational health and lifesaving safeguards on board the vessel (including specialist PPE, appropriate firefighting and other safety systems) would increase.

3.5 Procedures and Processes

3.5.1 Overview

A human factors' approach to procedures and process development would be to identify where these serve as an appropriate control measure (given the occupation health limitations of working around ammonia) and if so, how they should be developed to address the criticality of the risk, and how their delivery is managed in an integrated manner to promote adherence from the crew.

Ammonia presents numerous changes to work practices, procedures and plans. Onboard, there will be a more frequent need to use safe work practices including risk control methods such as job safety analysis, permits, confined space, lock-out tag-out, toolbox talk etc. to manage fuel risks as well as revision to processes which accompany the safe transit of ammonia-fuelled vessels, relating to flag State, port State, ports, pilots, vendors and contractors.

3.5.2 Procedures and Process Considerations

Risk assessment should establish whether the procedures and processes remain an appropriate control measure given the changes to operations.

Some of the procedures and processes that will need to be created or modified are expected to include:

- Voyage plans
- Arrival / departure
- Mooring arrangements
- Ship-to-ship transfers for bunkering, including associated mooring arrangements, if applicable
- Bunkering for ammonia and all associated plans – may mimic LNG processes
- Ammonia sampling procedures
- Changes to FO bunkering plans due to ammonia presence onboard
- Port plans
- Recordkeeping and reporting onboard, as well as to Company, flag, port State, Class
- Communication plans for various activities especially with other entities
- Periodic rounds / inspections for deck officers and engineers
- Method statements, work instructions, permits, job aids etc. which operators may find useful when conducting their own procedure review
- Processes and procedures associated with various operational modes including start-up, shutdowns, fuel transfers
- Processes and procedures related to any SIMOPS
- Specific procedures and practices e.g., risk of vapor pocket caused by excessive trim & list
- Processes and procedures for off-normal and emergency conditions such as leak detection and isolation, manual / emergency shutdowns, failures of automation

- Maintenance regimes, processes, procedures, practices and recordkeeping including within associated data bases (PMS)
- Changes to official logs and records to accommodate reporting for ammonia fuel or operations
- Updates to emergency response plans including spill plans and requirements for periodic ammonia-related drills
- New requirements for to CCTV monitoring for new spaces and increase in maintenance for the cameras. This may also change the Security plans including restricted spaces aspects
- New requirements for type / use / storage of PPE
- Additional written processes for rescue operations and / or first aid support for those exposed to ammonia. These should address the required actions for various locations including any use of shelters, eye wash and decontamination showers
- Changes to familiarization, training, On-the-job training (OJT) materials and processes. Potential requirements for gas certifications
- Changes to processes for allowing visitors and contractors including marine pilots on board including ammonia risk awareness and PPE needs
- Changes in planning, communications and actions for organizations coordinating operations or providing services to the vessel. This could be port authorities, marine pilots, contractors, vendors or suppliers
- Changes in planning, communication and response processes for the organization aiding in an emergency

3.6 Occupational Health

3.6.1 Overview

There are a range of occupational health effects of ammonia due to the nature and exposure levels and duration of the chemical when in contact with a person (e.g., acute & chronic toxic effects), the method of storage (e.g., high-pressure, explosive, low temperature, working at height), its combination with other vessel chemicals (e.g., low-flash point with oil) and any accompanying high hazard systems in its processing (e.g., caustic acid for detoxification scrubbers) or support (e.g., chemicals for SCRs, use of methanol).

Although the onshore industry and ammonia gas carriers have experience in dealing with ammonia storage, transfer and use, much of the maritime industry presents additional human factors considerations with regards to specific new activities, the appropriate level and stowage of PPE that should be worn (given the physical nature of maritime work), new specialist systems and personal safety tools, and a general seafarer awareness of the acute and chronic effects of ammonia contact.

The vessel operator will be responsible for the specific care measures employed to address occupational health on their vessels and decisions on which PPE, practices and design measures area appropriate given the hazards and operating context. The following provides a description of some of the considerations.

3.6.2 Occupational Health Considerations

The initial intent would be to eliminate or reduce the need for crew to access hazardous areas. This would primarily be through adopting maintenance and operational practices where automated or remote working would be possible (e.g., remote CCTV inspection, exposure detection, maintenance activities in workshops where possible).

The following opportunities for occupational health hazards have been identified for circumstances when crew will work in hazardous areas. Further assessment of appropriate safeguards would assist in the development of task-specific PPE requirements.

Mechanical e.g., crushing, falling, stability

During bunkering activity, it is assumed that bunker lines would be raised and fitted using lifting appliance / cranes but assisted locally by bunker team members. The ammonia lines connection is assumed to be quick-release system with relatively heavy, rigid hoses. The location and design of vessel bunker station would need to consider access of personnel and safe methods of working to assist with this process as opportunity for range of occupational health hazards e.g., crushing, musculoskeletal etc. While the bunkering process manoeuvres and associated hazards to accommodate ammonia fuel will be different from those currently employed for conventional fuel, the experience from LNG would be applicable and serve as a guide for establishing safe bunkering operations.

Thermal e.g., hot surface, flames, cold stress

To reduce the potential for hot and cold conditions, most maintenance activities are expected to be conducted after equipment has been purged / inerted and equipment is closer to ambient temperatures. In addition, job planning including safe work practices and use of PPE would reduce the potential for exposures and provisions to treat ammonia burns would include decontamination showers and other treatment aids.

Materials and substances e.g., caustic, toxic

The method for controlling personal exposure to ammonia levels in ambient surroundings will be undertaken through weighted average record ratings (gas levels over period of time). This will have implications to working arrangements including rostering and resultant actions on detection. This may have greater implications for bulkers or containers versus tankers which have less familiarity with the carriage of hazardous material.

Liquid spills are possible, including during the bunkering process due to potential drain off from the pipe after disconnection. This could result in burns to personnel. Bunker stations would have drip trays to capture spills and there may also l be water curtains / mist system that could dilute spills. Emergency response procedures must outline response steps for spills including any that go overboard including to the sea.

New portable equipment etc will require appropriate stowage. These items will have manual and chemical handling considerations. PPE would provide some safeguard against hazards, but action would need to be defined to safeguard crew against opportunities for toxic and burn exposure and minimise quantity of residual ammonia.

The method of sampling is to be determined. However, if intrusive sampling is to be undertaken where crew members are required to access fuel connections directly, there is an opportunity for NH3 release and exposure. A favoured process would be to design out human intervention and undertake sampling through automated systems.

Access and occupancy to hazardous areas would need to be controlled and sufficient information should be provided to support safe decision to entry e.g., indication of ammonia gas presence, safety labelling, communications process. Furthermore, due to the rapidity with which a leak may cause unsafe conditions, methods to provide a timely awareness of the health of crew within a space should be reviewed.

Regular maintenance of parts such as filter cleaning, their replacement and storage prior to disposal present opportunities for exposure which needs to be addressed through new practices and PPE provisions.

There are a number of other substances, including chemicals, that would be added to the ammonia-fuelled vessel. These include nitrogen, sulfuric acid, glycol, methanol. With ammonia as fuel, the vessel may need to carry and store methanol on board for unfreezing lines or pumps in cases where condensation has formed and mixed with ammonia. For vessel where methanol is not currently carried on board the vessel, personnel will need to be trained about the operational use of methanol as well as the hazards it can present. Personnel must also be aware of how to treat personnel with negative impacts from methanol exposures thus further requiring updates to first aid procedures and personnel's knowledge about these.

Fatigue

During bunkering, the type of PPE needed could influence the potential for personal fatigue or endurance of crew members attending the area. For example, personnel may only be able to attend the bunker station for limited time periods if wearing a gas tight suit, gloves and an SCBA during certain weather conditions.

In the pre-planning phase for bunkering, it may be necessary to determine a personnel rotation scheme to ensure personnel remain fit for duty. The need for personnel attending the bunker station could be influenced by allowing the use of CCTV for monitoring while personnel are at a distance from the bunker station. It should also be noted that if vessels were conducting FO bunkering simultaneously with ammonia bunkering, the conventional FO methods would need to be revised to take account of the potential presence of ammonia.

Similar planning may be needed for any extended operation or maintenance activities that would need personnel to be fully outfitted in PPE for long periods of time. These could be undertaken in locations like FPRs, TCS or tanks themselves under particular circumstances.

Other

Class rules and the LNG industry recognize the TCS and FPR as enclosed spaces. There is a potential for ammonia to be present in these spaces resulting in personnel exposure (e.g., in the event of an ammonia release, the person would have very limited time to don additional respirator). It should be noted that donning additional PPE in preparation for maintenance tasks may be seemed as excessive by crew members given the small amount of time needed within an area for inspection purposes (current practice includes routine inspection to fuel spaces twice per day, approximately), their risk perception and the potential impedance it offers when using smell, sight & sound to inspect machinery integrity. In addition, PPE may also be deemed excessive given the restrictive movements for physical activities required for manual handling maintenance tasks e.g., it could be determined that a light-weight suit and breathing assistance would be sufficient for short periods of time

Further opportunities to ensure adherence to appropriate PPE rules should be considered to ensure safe and effective maintenance regimes. This would ideally be achieved through incorporating these user constraints in the design for maintainability. Practices on tankers carrying ammonia cargo could also serve as input to work practice and PPE decision-making.

3.7 Process Safety Hazards and Management

3.7.1 Overview

The introduction of ammonia fuel presents new circumstances where human activities may contribute to, exacerbate or prevent recovery from a hazard. At the same time, early recognition of and prompt reaction to off normal conditions could also prevent situations from escalating. These human activities may be associated with the ammonia fuel process directly or other, accompanying safety-critical processes i.e., scrubbers, purging etc.

3.7.2 Process Safety Considerations and Safety Management

The majority of process hazards related to ammonia as fuel revolve around the control of pressure and temperature to reduce the potential for consequences related to leaks or spills. These consequences would include exposures, corrosion, fires or explosions. Various safeguards, including engineering and administrative controls, would be present to prevent or reduce the potential impact of such consequences.

Within the context of safety management, including the ISM Code, some areas would not change in overall management while others would need to have modifications or updates. The table below provides an overview of the impacts of using ammonia as a fuel as it relates to the different sections of the ISM Code.

Table 3 – ISM Code

Section	Title	Notes
1	General	n/a
2	Safety and environmental protection policy	The related policy should be broad enough to include new hazards posed by ammonia
3	Company responsibilities and authority	Information should be broad enough to cover ammonia as fuel.
4	Designated person(s)	The Designated Person Ashore (DPA) role for oversight of management and/or operation of the vessel or fleet would not change.
5	Master's responsibility and authority	Master's role would not change. The Master will remain responsible for all ship operations.
6	Resources and personnel	This will change since personnel with different competencies and skill sets may be needed and at a minimum, new procedures and relevant training will be required.
7	Development of plans for shipboard operations	This will change and new procedures, plans and instructions, including checklists, will be needed.
8	Emergency preparedness	The response to emergency situations will change with the addition of a new set of hazards and response associated with ammonia. New drills and exercise should be incorporated.
9	Reports and analysis of non-conformities, accidents and hazardous occurrences	Reporting and analysis overall would not change since this area should be written broadly enough to take account of reporting events related to ammonia. With that said, new specific requirements and modified procedures are likely for ammonia related events.

Section	Title	Notes
10	Maintenance of the ship and equipment	New preventative, corrective and emergency maintenance regimes will be needed. New equipment and systems will need to be added to the maintenance program along with appropriate maintenance regimes. Given the nature of ammonia, maintenance is likely to be different, require new skills and be critical to maintaining safe operations. In addition, new metal and material, and potential special tools / techniques, requirements, would need to be updated for ammonia compatibility.
11	Documentation	The means for controlling documentation should not change.
12	Company verification, review and evaluation	The requirements for periodic reviews will remain though the new operations / equipment / systems etc will need to be reviewed as a part of the scheme.

Specific process safety concerns that the design and management of vessels using ammonia as a fuel can address include:

- By identifying sources, the potential for ammonia leaks can be reduced through including engineered safeguards such as process safety parameter information in the ECR, automated operations, design of valving in piping systems and relief systems. When leaks occur, personnel can address leaks via work practices like increasing ventilation, misting of water, using detoxification scrubbers and venting. Where local action is required by personnel, risk assessment and safe work practices can be applied for identification and repair of leaks to reduce the impacts. Such administrative processes, including the use of PPE, can minimize the impact of process hazards and the potential human exposure to ammonia. For example, the employment of personal ammonia detectors for those entering spaces could provide early warning and allow prompt action since ammonia odour is not a reliable indicator for the level of ammonia present.

- The potential for dropped objects or other impact damage (especially resulting from human error) would first be addressed via design features likely identified in risk studies and later through procedures, training and job planning including risk assessments for that work.

- For activities where risk potentials are higher, such as ship-to-ship mooring, bunkering and simultaneous operations, organizations would need to ensure that procedures, processes and related work practices are well documented, and personnel are well trained to reduce the potential for hazards and address any potential consequences. With the addition of support systems/ equipment (e.g., detox scrubbers, vents, SCRs), new chemicals and potential hazards could be present thus requiring an enhanced chemical management program.

- The planning processes for various activities, especially where there are interfaces with other organizations, would require updates to ensure the vessel and shipboard or other personnel are protected. It is also possible that less impactful operations would also require modification to take account of ammonia onboard. These may include port approach, mooring at a pier and replenishment of stores. In these cases, relevant interfaces would need to be properly informed of any requirements or actions needed from them.

- The maintenance practices and regimes of equipment associated with new ammonia related systems such as fuel injection, storage and management including support systems would be defined for new regimes or potentially modified practices for applicable existing maintenance processes. The incompatibility of ammonia with some metals and materials must be considered during maintenance. This must also be reflected in the maintenance system itself and Supply Chain processes to ensure inappropriate substitutions are not allowed where ammonia could have negative impacts. Ammonia work can require the use of new tools and techniques. Relevant personnel would need to be aware of these and be proficient.

- Evaluation should be undertaken to identify where human failure during the preparation, work, reinstatement and testing may affect process safety. This would include a focus upon various performance shaping factors of working on a vessel i.e., the availability of appropriate tools, work environment, divided attention etc. This is particularly important since maintenance systems, and administrative controls, can affect the operation of engineered controls, like relief systems, if tasks are not conducted properly.

- Emergency response plans, including for firefighting, will need to be updated to take account of any steps that could reduce the potential for ammonia involvement or the impact of ammonia hazards. For example, steps would be included in firefighting plans if an escalation of the fire occurs threatening ammonia sources. Leak or releases would be viewed within the context of dispersal. Emergency response plans would need to address the means for reducing potential exposures to ammonia for personnel on board as well as any organization or facilities that might be near the vessel if any emergency takes place. Planning activities for joint response in emergencies, such as leaks, spills, fires or explosions, could need to change as well as the various response plans themselves.

- Ammonia may require changes to recordkeeping and reporting. In most cases, current onboard practices should be able to accommodate most day-to-day recordkeeping via shipboard logs. There is a potential that the process for daily rounds and its associated recordkeeping could change to reduce potential personnel exposures to ammonia. The overall practice for recording incidents would be expected to be similar to current practices. Changes may be required as international, or flag Administration requirements are updated to accommodate ammonia as fuel. There is also the potential for change in reporting at the local level, such as ports. Relevant personnel would need to be cognizant of these regulations and any requirements related to the presence of ammonia and its potential impacts.

- There is the possibility that crew members may not respond to ammonia-specific exposure alarms and instrumentation in a desirable way due to challenges associated with alarm management and response (e.g., habituation, alarm risk perception, alarm perception etc). Training and familiarization would be enhanced to ensure personnel have training, knowledge and information related to any new substances. All would also come with SDS to outline precautions and safe handling. It should be noted that some vessels, carry hazardous chemicals currently as cargo.

Since the process hazards associated with ammonia differ from those of fuel oil, new or amended safeguards and safety management practices would be required. As a result, a vessel using ammonia as fuel and any organizational interfaces must ensure that safeguards are in place to prevent and if necessary, respond to events such as overpressures, releases, leaks and potential consequences including corrosion, fires and explosions. Information provided in this report can supplement that from the various project risk assessments and serve as an input to project / industry guidance.

3.8 Management of Change (MoC)

3.8.1 Overview

The introduction of ammonia fuel will present a challenge to industry as identified in previous sections. The aggregation of these changes will present different challenges depending upon the industry sectors maturity, experience and current methods of working either to the change itself (where you want to get to) and the process of change (how you get there).

3.8.2 MoC Considerations

The move from engines using fuel oil to dual fuel engines using both ammonia and fuel oil results in not just new equipment / system but new procedures, work processes, maintenance regimes. Officers and crew will need new training and familiarization. There is a potential that crew complements will changes as well as roles and responsibilities. This evolution will call for a Company Change Management program that addresses changes needed throughout the organization as well as at the ship level. The information in this report can provide some insight into the changes that will be required and serve as an input to project / industry guidance.

The aggregation of these changes will present different challenges depending upon the industry sectors maturity, experience and current methods of working either to the change itself (where you want to get to) and the process of change (how you get there). To this point, sectors with gas fuel and cargo experience, will be able to leverage their former experience, such as with LNG, to guide their approach to change management for ammonia fuel.

With the introduction of ammonia as a fuel, there will be large numbers of changes needed in most areas. The following details those changes.

- At a minimum, officers will need to be cognizant of the impact of change management for moving to ammonia as a fuel and able to lead any management of change efforts on board where tasks may need to be modified due to the presence of ammonia or changing conditions.
- Leadership skills held by officers will be emphasized to ensure the precautions needed for working with and around ammonia are used so that any negative impacts associated with ammonia are minimized during the conduct of various tasks.
- The introduction of ammonia as a fuel will require new, updated or modified procedures, practices, processes and reporting. Personnel's approach to hazards and risk assessment / management will need to be adapted to ensure safety, efficiency and environmentally sound operations.
- There will be ammonia-related systems and equipment added to the vessel as well as support systems for ammonia operations. This will result in the need to update drawings, databases, technical information, operational processes, manuals, vessel maintenance requirements as well as people’s technical knowledge.
- Consideration may also be needed about changing or upgrading existing equipment to account for the potential influence of ammonia. For example, TEMPSC / lifeboats may need to be upgraded to the type used on chemical tankers. Reviews of the effects of potential corrosion for components near ammonia areas. Personal gas detectors (multi-meters) may need to be checked for degradation if used for ammonia service.
- To monitor and control the new additions, human-machine interfaces will be updated. At a minimum, this will change the display / control information, both computerized and hardwired in various areas including the centralized computer system (DCS), the ECR, Bridge and in local areas.

Information will be needed for the ammonia related equipment and systems and support system such as SCRs, detox scrubbers, gas / fire detectors, water curtain / mist systems.

- With ammonia, increased automation, digitalization and technological changes are expected. It is likely that process information would be computerized, and that control and monitoring functions will use computer interfaces. Depending on the past experience of personnel, new or modified skills may be needed including new methods for analysing data to aid decision-making.

- New requirements for ammonia competencies and skills must be determined. Officers and crew will need updated familiarization and training related to ammonia as appropriate to their job duties. This could include familiarization with ammonia as a hazard as well as training for ammonia operations, bunkering, normal operations, off-normal operations, emergency response including spill management, mustering and abandonment. In all cases, personnel will need to understand how to protect themselves from ammonia based on exposure. Familiarity with dual fuel operations will be needed if past experience was for single fuel oil-only vessels. Those with dual fuel operations experience will still need enhanced training to address ammonia characteristics / requirements.

- With the addition of ammonia systems and equipment, new responsibilities will need to be assigned and there is a potential there could be new roles for personnel. For example, ship's personnel may not have past experience with ship-to-ship bunkering processes or with fuels other than fuel oil. Such operations will need to be reviewed within the context of available / minimum staffing. It could be that inputs from LNG fuel experience as well as ammonia carriers could provide insight into staffing needs.

To move to using ammonia as a fuel, overall management of change considerations will emerge from the introduction of ammonia and associated systems on vessels. The information in this report could serve as an input to the development of project / industry guidance related to the use of ammonia as a fuel. In fact, the information in this section points to the need for a Company Change Management program and /or process that addresses changes needed throughout the organization as well as at the ship level.

4. Conclusions

4.1 Overview

The marine industry has a long history of noteworthy innovation. Faced with the global need to reduce carbon emissions, a variety of low and no carbon fuels are being investigated. Both the on shore and marine industry have previous experience with the safe use of ammonia for industrial purposes. For example, gas tankers have successfully carried ammonia as a cargo for many years.

Using the information provided in this report, it is believed that if the marine industry develops the human factors considerations, builds upon existing marine industry experience with low flash point fuels / cargo and ensures sufficient engineering barriers and administrative safeguards are provided for the various ammonia risks then ammonia can provide an acceptable alternative to conventional fuel use. Such guidance would help the industry to move farther forward with its goal for using low carbon fuel alternatives.

4.2 Human Factors Summary

The section provides a synopsis of the anticipated impact on various human factors themes.

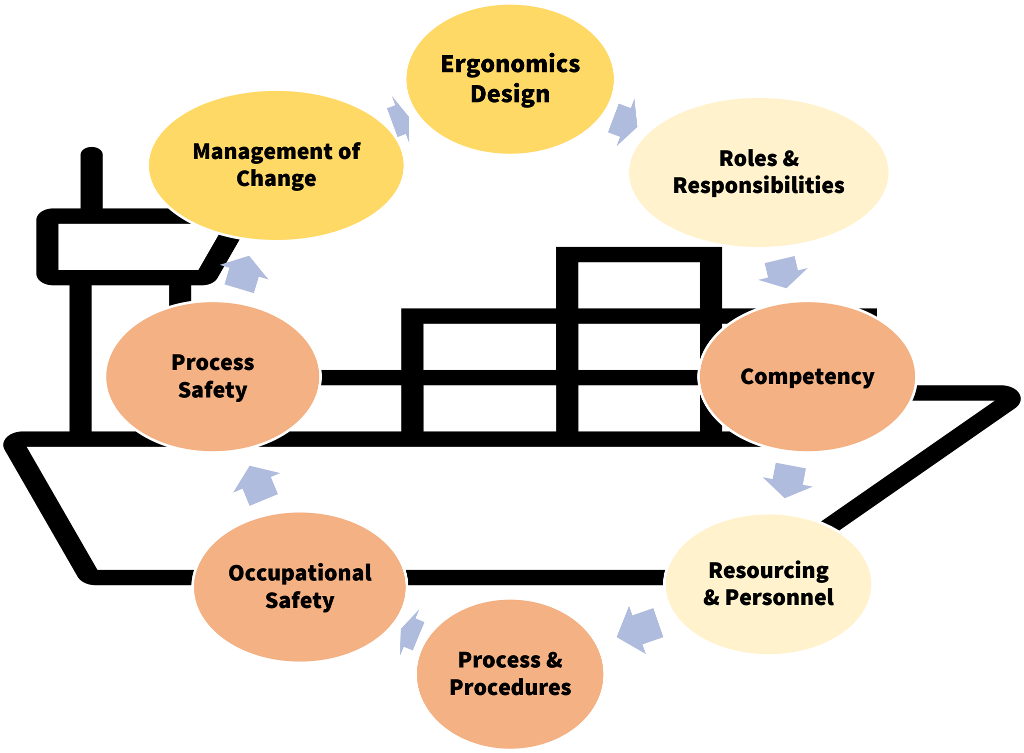

Figure 1 - Ratings of Human Factors impacts for Ammonia Fuel Use

Impact Key: Low Medium High

4.2.2 Ergonomics Design

'Automation, overseeing fuel process complexity and new safeguards will need to be addressed through user-centred design'

Application of specific user-centred ergonomics design would benefit the design of operability and maintainability of new ammonia related systems, equipment, components and spaces. This includes a focus on specific critical work areas which where seafarers would interact with safety critical systems. For example, the integration of new technology and its integration within the Engine Control Room, controlled access to certain areas (e.g., fuel preparation area, monitoring of vessel areas to permit remote maintenance/operations), and designing working environments and equipment which specifically takes into account physical constraints to the seafarer when donning PPE (e.g., wearing PPE will increase need for clearance space around equipment and controls, reduce visibility/hearing and response to alerts, impair their physical strength application and ability for precision work, and increase fatigue). The application of human factors design criteria and principles would also reduce the potential crew exposures around ammonia through ensuring usability, efficiency and safety.

It is recommended that a human-centred approach to design is undertaken that defines design criteria and specifications for key areas on the vessel which impact crew interaction. These include principally the deck & bunker stations, local engine and tank spaces (e.g., FPR, TCS) and fuel process control locations.

4.2.3 Roles and Responsibilities

'There will be minor impact to roles, some new responsibilities'

With ammonia as fuel, the organisational structure onboard a vessel would not be expected to change significantly compared to similar existing high-hazard vessel types (e.g., LNG, LPG). However, within the organisational structure, it could be expected that roles and responsibilities associated with ensuring safe methods of working and emergency response would need to be developed to account for the new emerging technical tasks and ensuring appropriate accountability for emergency response decision-making and implementation of plans.

It is recommended that as the design of reference vessels are matured, and operational requirements are better defined that an analysis takes place to confirm the onboard organisational structure and that new ammonia related roles and responsibilities are assigned appropriately. Experience from gas fuelled or gas cargo ships should serve as an input with compensations made based on hazard similarity and differences,

4.2.4 Competence and Training

'New skills and knowledge will need to be developed for all crew personnel"

The novelty of ammonia as a fuel and any associated new systems & equipment (e.g., automated process control systems, vents, detox scrubbers, SCR) will be disruptive and present new technical complexity.

There will be new and modified technical skills for those directly involved in managing the transfer or handling of the ammonia. All personnel will need to be aware of ammonia and its hazards though relevant officers will need to increase their knowledge of relevant regulations and any special requirements such as those for interfacing with flag Administrations and port personnel. There will also be further emphasis on the need for non-technical skills for all crew such as maintaining situation awareness and recognizing potential hazards which will affect decision-making and communication under various circumstances.

Companies and the marine industry can benefit from the information in this report as well as previous information, knowledge and experience gained from the successful use of other low flashpoint fuels / cargoes to identify competencies for crew members working with ammonia as a fuel. it likely that the amount of additional training or upskilling needed for tanker personnel will be less. Container ships or bulk carriers' personnel without such experience would need higher levels of upskilling, training and certification.

It is recommended that a training needs analysis for seafarers to identify key competence requirements for operations and maintenance is undertaken. Specific attention should be on not only developing the technical competencies of those personnel who undertake safety critical tasks (e.g., engineering team) but also the non-technical competencies of all crew members in sharing and motivating others to communicate hazard-related information. This may be delivered a tailored training programme course.

4.2.5 Resourcing and Personnel

'There will be impact to staffing levels and workload distribution'

Vessels must be staffed in a manner that allows for safe and environmentally sensitive operations while remaining efficient. Broadly, resourcing levels would be based around regulations as well as the Company's assessment of the time required (duration and frequency), complexity (including importance) and any conflicting circumstances which cause constraints on how work can be done.

The increase in the number of tasks to be completed for the use of ammonia and new chemicals related to ammonia support systems plus the increased use of permits would increase the workload associated with vessel operations and maintenance.

In particular for ammonia fuelled vessels, the areas that are most likely to impact resourcing levels compared to conventional fuel oil vessels would include:

- Maintaining the integrity of fuel machinery and spaces, as well as the wellbeing of personnel onboard, through safe systems of working e.g., increase the frequency with which formalized safe work practices. such as permitting, will be employed.
- New operational approaches to common tasks such as bunkering, ship-to-ship transfers, leak detection / response.
- Tasks associated with overseeing process control, including monitoring, intervention and alarm response.
- Preparedness and response for emergencies.

It is recommended that any industry guidance highlight that operational and maintenance tasks may require additional time and potentially personnel due to requirement for the use of additional protection, safe work practices, and risk assessments to control hazards. A workload assessment of key roles associated with ammonia fuel handling, operations and maintenance activities is necessary.

4.2.6 Work Practices and Procedures

'There will be numerous changes and increased reliance upon practices and procedures'

Ammonia presents numerous changes to work practices, procedures and plans. Onboard, there will be a more frequent need to use safe work practices including risk control methods such as job safety analysis, permits, confined space, lock-out tag-out, toolbox talk etc. to manage fuel risks as well as revision to processes which accompany the safe transit of ammonia-fuelled vessels, relating to flag State, port State, ports, pilots, vendors and contractors.

Their application will require operators to review how procedures are adhered to and incorporated with competence development.

It is recommended further guidance is produced that would assist companies in determining which particular operations would benefit from explicit procedures due to the level of complexity, crew experience and task frequency with which they occur. This is particularly critical for procedures that relate to safety critical operations and maintenance tasks where human error could occur and should be captured in work descriptions.

4.2.7 Occupational Health

'*Ammonia-fuel vessels will introduce new occupational health hazards not just related to toxicity*'

There are a range of occupational health effects of ammonia due to the nature and exposure levels and duration of the chemical when in contact with a person (e.g., acute & chronic toxic effects), the method of storage (e.g., high-pressure, low temperature, working at height, manual handling), its combination with other vessel chemicals (e.g., low-flash point with oil) and any accompanying high hazard systems in its processing (e.g., caustic acid for detoxification scrubbers) or support (e.g., chemicals for SCRs, use of methanol).

Providing safeguards for occupational health and safety hazards is recognized as a necessity for any industrial workplace. The potential side effects of some protections with regard to task performance and timings are not always initially recognized when large changes occur. e.g., physically incumbering the crew when donning additional PPE (respirators etc) for maintenance tasks, restricted flexibility in work/rest periods and fatigue due to the increased duration and complexity of bunkering.

It should also be noted that vessels with ammonia as fuel may also change the way interfaces with other organizations (e.g., ports, vendors, contractors, ships) occur to ensure appropriate safeguards are in place to protect for events such as leaks.

It is recommended that further guidance on specific PPE requirements is developed to define recommended PPE and other occupational safeguards for various, expected operating and maintenance scenarios.

4.2.8 Process Safety and Safety Management

'*Managing high standards of safety would require companies to develop their levels of commitment to sections of the ISM such as planning, emergency preparedness, maintenance*'.

A company's management of safety is fundamentally based upon its knowledge and assessment of risk on its vessels and the establishment of appropriate safeguards.

The properties of ammonia introduce different risks to those of fuel oil. In addition, there are potential support systems/ equipment (e.g., detox scrubbers, vents, SCRs) that may introduce new chemicals and hazards, as well. As a result, a vessel using ammonia as fuel and any organizational interfaces must ensure that safeguards are in place to prevent and if necessary, respond to events such as overpressures, releases, leaks, fires and explosions.

A company's commitment to addressing this risk is critical to safety and would necessitate a level of commitment to all safety management principles, with particular focus upon ISM areas, such as, emergency preparedness, maintenance philosophy, management of plans and competencies.

Information provided in this report can supplement that from the various project risk assessments and serve as an input to project and industry guidance.

It is recommended that all personnel supporting ammonia operations, shipboard and shoreside, have appropriate understanding and level of knowledge of potential ammonia process hazards and means to reduce or eliminate their impacts. In addition, the safety management processes and procedures, including emergency response measures, must outline necessary steps avoid or address negative outcomes such as exposures, releases, leaks or spills. The same procedures must consider any potential impacts that may extend beyond the boundary of the ship and potentially impact others. It should be determined if additional analytical tools may be needed for shoreside support or shipboard personnel to aid with ammonia risk assessment.

4.2.9 Management of Change

'Ammonia fuel and systems use will require a step change in safety culture and safe decision-making'

The move from engines using fuel oil to dual fuel engines using both ammonia and fuel oil results in not just new equipment & automated systems but also, new procedures, work processes, maintenance regimes. The aggregation of these changes will present different challenges depending upon the industry sectors maturity, experience and current methods of working.

This evolution will call for a Company Change Management program that addresses changes needed throughout the organization as well as at the ship level. The success by which a company sustains safe practices will be dependent upon a mature approach to safety culture, through principles related to good leadership, communications, procedure adherence, learning, crew engagement etc.

The information in this report can provide some insight into the changes that will be required and serve as an input to project / industry guidance.

It is recommended that each Company adopting the use of ammonia as fuel create a Change Management Plan that outlines what will be required to operate with ammonia in a safe, efficient and environmentally sound manner. The change plan will need to include not only changes to shipboard operations and maintenance practices but also determine updates or modifications that may be needed to provide shoreside support to ammonia fuelled vessels, outline adjustments for contractor / vendor / port agreements and interactions and determine where electronic systems may need to be upgraded or updated.

4.3 Further Studies

The following have been recognised as potential areas of further work but have not been addressed within the scope of this study.

- This work has focussed upon the seafarer challenges associated with new build vessels only (i.e., Container, Tanker & Bulk Carrier). Studies associated with different vessel types, and vessel retrofitment would identify new and additional challenges.
- The study has focussed upon crew members. Further work would be required to understand how others involved in vessel management and operation would be impacted e.g., shoreside activities, contractors, pilots, bunkering vessels etc.
- The introduction of ammonia fuel will be accompanied by various technical innovations which have partly been mentioned in this study. The expected application of automation, new maintenance regimes, principles of dual fuel systems, modernisation of process control etc., will mean that the seafarer will encounter challenges that require further attention with respect to human factors themes.

5. References and Bibliography

5.1 Class Rules, IMO Documents & Regulations

Source	Title	Year
ABS	Guide Ammonia Fuelled Vessels Spring, TX: September 2021.	2021
Class NK	Guidelines for Ships using Alternative Fuels. (Methyl/Ethyl Alcohol/LPG/Ammonia). Edition 2.0.	2022
DNV	Ammonia as fuel – Notation for Gas fuelled Ammonia.	2022
LR	Rule proposal – Specific Requirement for Ships using Ammonia as Fuel.	2021
LR	Guidance Notes for Fuel System Risk Assessments, Hazard Identification – Hydrogen and Ammonia.	2021
RINA	Ammonia as a fuel – Class Notation Ammonia Ready.	2021
IMO / Japan	Development of Guidelines for the Safety of Ships Using Ammonia as fuel: Issues to be considered and possible way forward for the development of guidelines for the safety of ships using ammonia as fuel.	TBD
IGF	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuel Code	2017

5.2 Industry and General Information on Ammonia

Source	Title	Year
ABS	Sustainability Whitepaper: Ammonia as Marine Fuel.	2021
Carmes, et al Oeko-Institut	Ammonia as a Marine Fuel. Risks and perspectives. Oeko-Institut (2021) - Ammonia as a marine fuel (nabu.de)	2021
DNV	White Paper: Ammonia as a Marine Fuel. https://www.dnv.com/publications/ammonia-as-a-marine-fuel-191385	2020
DNV	External safety study – bunkering of alternative marine fuel for seagoing vessels: Port of Amsterdam. Report Number 10288905.1. Rev 0	2021
DNV – Green Shipping Programme	Ammonia as Marine Fuel Safety Handbook. Version 01.	2021
Global Maritime Forum	Ammonia as a Shipping Fuel. https://www.globalmaritimeforum.org/news/ammonia-as-a-shipping-fuel	2022

Source	Title	Year
IAPH	LNG Bunker Checklist: Ship to Ship. Version 3.7A.	2019
LR / UMAS	Zero-Emission Vessels: Transition Pathways. https://www.lr.org/en/marine-shipping/maritime-decarbonisation-hub/about/our-story/research-library/	2019
KR	Report on Ammonia-Fuelled Ships. No. 2021-ETC-01.	2021
Maersk Mc-Kinney Moller Centre for Zero Carbon Shipping	Ammonia as Marine Fuel. Prospects for shipping industry. Documentation of assumptions for Navigate 1.0.	2021
Marine Technologies Forum	Preliminary Discussion Report on the Use of Ammonia as Fuel for Ships. https://www.maritimetechnologiesforum.com/documents/ammonia-report.pdf	2022
Navigator Gas Shipmanagement	Navigator Gas on Ammonia NH3 as Marine Fuel.	2019
Oil Companies International Marine Forum (OCIMF)	Linked Ship/Shore Emergency Shutdown Systems for Oil and Chemical Transfers. First edition.	2017
Pacific Northwest National Laboratory (US)	Ammonia as Maritime fuel.	2021
The Society for Gas as a Marine Fuel (SGMF)	Gas as a Marine Fuel: An introductory guide. Version 2.1	2017
The Society for Gas as a Marine Fuel (SGMF)	Gas as a marine fuel: Safety guidelines. Bunkering. Version 2.0.	2017
The Society for Gas as a Marine Fuel (SGMF)	Gas as a Marine Fuel: Simultaneous operations (SIMOPs) during LNG bunkering. Version 1.0.	2018
The Society for Gas as a Marine Fuel (SGMF)	LNG as a Marine Fuel: Safety and Operational Guidelines – Bunkering. Version 3.0.	2021
SIGTTO	ESD Arrangements & Linked Ship / Shore Systems for Liquefied Gas Carriers.	2009
The North of England P&I	Ship-to-Ship Transfer	2019
Together in Safety	Future Fuels Risk Assessment. Future-Fuels-Report.pdf (togetherinsafety.info)	--
Yadav, et al	Safety evaluation of using ammonia as marine fuel by analysing gas dispersion in a ship engine room using CFD. Journal of International Maritime Safety, Environmental Affairs and Shipping. 6:2-3, 99-116. 8 June 2022. https://doi.org/10.1080/25725084.2022.2.2083295.	2022

5.3 Ammonia Safety Information

Source	Title	Year
CDC NIOSH (US)	Ammonia solution, Ammonia, Anhydrous: Lung Damaging Agent. https://www.cdc.gov/niosh/ershdb/emergencyresponsecard_29750013.html	2011
CDC NIOSH (US)	Ammonia. Immediately Dangerous to Life or Heath Concentrations (IDHL). **https://www.cdc.gov/niosh/idlh/7664417.html**	1994
EPS (US)	Hazard of Ammonia Releases at Ammonia Refrigeration Facilities (Update August 2021)	2021
OSHA (US)	OSHA Occupational Chemical Database: AMMONIA. (Chemical Safety Data Sheet – CAS # 7664-4-7).	N/A
NRC (US)	Committee on Acute Exposure Guideline Levels. Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 6.	2008

5.4 Project Documents

Source	Title	Year
NYK-JK	NH3 Bunkering Operation Plan	2022
NYK	Ammonia Safety Project. Bulk Carrier. Rev. 11	2022
LR	Risk reduction measures (RRM) workshops: Containership, Tanker & Bulker	2022
LR	Tanker Specification 260722.	2022
LR	LR Container Specification 140622.	2022
LR	Ammonia Leak Scenarios for Venting Study.	2022
LR	Early Human Factors Screening Workshop: Terms of Reference document (LR220007 RT02 Rev01)	2022
LR	Human Factors Screening Analysis: Ammonia Fuel (LR220007 RT03 15_11_2022 v2.0)	2022
LR	Human Factors: Safety Critical Task and Work Environment Hazard Assessment (WP04/WP05) (LR 220007 RT05 Issue 01)	2022
LR	Competence Study for Ammonia-Fuelled Vessels (LR 220007 RT06 Rev 1.0)	2022

5.5 Human Factors Methods

Source	Title	Year
Energy Institute	Guidance on human factors safety critical task analysis	2020
Oil & Gas Producers	Human Factors Engineering in Projects (IOGP 454)	2020
NORSOK	S-002 Work Environment	2004

5.6 Industry Guidance on other Fuel Types

Source	Title	Year
ABS	LNG fuelled vessel; Crew Training and Competence. Presented at SUNY Maritime College, LNG Center of Excellence, 20 February 2020.	2020
DNV	Insights into seafarer training and skills needed to support a decarbonized shipping industry. Report Number 2022-0814. Rev 0	2022
IMO	International Convention on Standards of Training, Certification and Watching for Seafarers (STCW)	1978 2010
ITF	SCTW: A Guide for Seafarers. Taking into account the 2010 Manila Amendments.	2014
ITF	International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code)	2019
The Society for Gas as a Marine Fuel (SGMF)	Gas as a Marine Fuel: Operation of ships with Liquified Natural Gas (LNG) Competency and Assessment Guidelines. Version 1.0. FP14-01.	2021
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The Society for Gas as a Marine Fuel (SGMF)	Gas as a Marine Fuel: Work practices for maintenance, repair and dry-dock operations. Version 1.0 FP10-01.	2020
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The Society for Gas as a Marine Fuel (SGMF)	Gas as a Marine Fuel: Simultaneous operations (SIMOPs) during LNG bunkering. Version 1.0.	2018
SIGTTO	LNG and LPG Experience Matrix	2011
SIGTTO	LNG and LPG Experience Matrix: Guidelines for Use	2016
SIGTTO	LPG Shipping Suggested Competency Standards. Second Edition	2021
Tokic, T; Francic, V; Hanaspahic, N.; Rudan, I.	Training requirements for LNG Ship-to-Ship Transfer. Pomorski zbonik 60 (2021), 49-63. (ISSN: 0554-6397)	2021

Appendix A Operational Phases Impact

A.1 Overview

The figure below provides a synopsis of the anticipated human factors impact on various operational and maintenance phases. Impact is measured through criteria such as task novelty, frequency of human interaction, criticality and known issues.

Figure 2 – Human Factors Impact

Stages	Human Factors Impact	Key features
Port Approach	Low	Minimal additional impact to crew activities when compared with existing industry practices. There could be changes to planning and communications with port authorities, marine pilots and other organizations.
Mooring	Low	For standard mooring practices, minimal impact is expected. For ship-to-ship, mooring, associated with bunkering, there would be changes especially related to potential ammonia hazards. This impact would be greatest for vessel personnel without past STS mooring experience.
Bunkering / Transfer	High	Ammonia bunkering will introduce new hazards, safeguards and new crew activities including changes to interactions with other organizations. For example, the method to be used for ammonia fuel sampling will differ from that for conventional fuel. Overall, for those personnel with LNG / LPG, bunkering or ammonia cargo experience, the overall impact of the changes would be lower.
Fuel Storage	Medium	There will be a moderate level of new challenges related to ammonia storage for those with conventional fuel oil experience. The new tasks would relate to monitoring and control of pressure and temperature as well as tank levels.
System Start-up	Low	The process for system start-up will be largely automated with crew initiating the process and overseeing its performance and safe working. This is not expected to present a significant change to those with similar automation experience.
Fuel Transfer	Medium	The transfer of ammonia fuel will be initiated / monitored / intervened within the ECR. Although the transfer operation will differ between vessel types depending upon the fuel condition and process methods, the activity is projected to be automatic with control room operatives overseeing the transfer, as per conventional operations. As with other automated operations, personnel will need to understand required actions if automation is lost. New knowledge of ammonia and its characteristics will be paramount.
Steady state	Medium	The introduction of ammonia fuel is expected to impact human factors moderately when compared to current industry practice. The novelty of engine processes, such as dual fuel use, combined with general exposure to safe working around ammonia fuel would impact job / task characteristics.
System shutdown (automatic)	Low	As with system start-up, automated system shutdown, including automated fuel switchover, would have little impact changes to overall operations. The main impact would be additional monitoring of the automated aspect and responding to relevant alarms.
System shutdown (manual)	High	Manual shutdown could significantly impact the need for monitoring and intervention from various personnel. ECR personnel would need to control / monitor ammonia systems along with conventional systems. There is a potential that personnel would need to take actions locally and ensure precautions are taken to safely allow such interventions.

Leak Detection, Isolation & Repair	High	While personnel on conventional fuel oil vessels undertake leak detection, with the introduction of the toxic nature of ammonia, as well as explosivity and flammability, the task would be more complex and require additional safeguards to be used. For personnel with LNG / LPG or ammonia cargo experience, their experience would require less upskilling. Understanding of ammonia and its characteristics will influence all actions related to leaks.
General Maintenance	Medium	The introduction of ammonia for fuel use will increase the complexity of planning, conducting and recording maintenance. There will be new skills required for working with ammonia systems / equipment / components, as well as the potential for using new tools and maintenance techniques. Metal and materials incompatibilities will need to be understood.
Emergency Response	High	Emergency response processes and procedures will need to be updated to ensure that the novelty of dealing with occupation / process safety hazards and characteristics of ammonia fuel have been addressed. Complexity & criticality of decision-making under new circumstances will need to be considered. For example, firefighting regimes may need altering where ammonia could be present or if the systems could be affected. Changes to spill response would be required. Also, activities where outside organizations may be involved or impacted would have to be rethought and addressed.
Mustering & abandonment	High	With the potential for toxicity, mustering and abandonment procedures would need to be revised to reduce the potential for exposure of personnel to ammonia. Safe havens for sheltering / mustering would need to be engineered for potential ammonia impacts. To this point, the type of TEMPSC may need to be changed to those similar to those used on chemical tankers.
Personnel rescue	High	Various considerations would need to be addressed to ensure that personnel could be safely rescued after exposures to ammonia. This would include a review of high-risk space limitations (FRP, TCS), the use of PPE, suitability of rescue equipment and first aid items. Personnel participating in this operation would need understanding of ammonia and its characteristics / hazards.