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ZERO-EMISSION SHIPPING MISSION

Safety of Crew in Low/Zero-Emission Ships

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This report refers to DNV report 2024-1344

Rev. no.	Date	Reason for issue
A	2024-04-04	First draft
0	2024-05-08	Second draft
1	2024-06-12	Third draft

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Glossary

SCILZS	Safety of Crew in Low/Zero Emission Ships project
MMMCZCS	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
LNG	Liquid natural gas
IGF code	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
PPE	Personal protective equipment
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
ISM code	The International Safety Management Code
SMS	Safety management system
EX-machinery	Equipment used in explosive atmospheres that meets the relevant international standards
TMSA	Tanker Management and Self-Assessment
HAZID	Hazard identification study
HAZOP	Hazard and operability study
SOx & NOx	Sulphur oxides and nitrogen oxides
TEU	Twenty-foot Equivalent Unit
LOHC	Liquid Organic Hydrogen Carriers

Executive summary

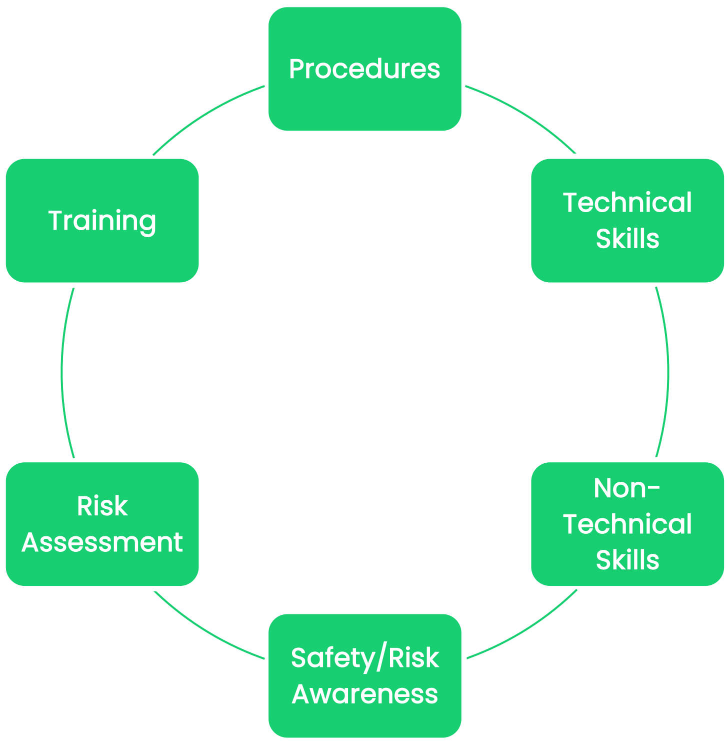
Background and method

The Safety of Crew in Low/Zero Emission Ships (SCILZS) project, has the following objectives:

1. Ensure knowledge sharing amongst first movers and other relevant stakeholders on how to develop crew training and procedures to ensure crew safety on ammonia-, hydrogen- or methanol-fuelled ships
2. Map the needed competencies and training for seafarers when operating ships using ammonia, methanol or hydrogen as a fuel
3. Contribute to the dissemination of the results from the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping's ammonia safety project on competences and training

The objectives were met by examining industry examples, interviewing representatives from relevant companies in the shipping value chain, and analysing relevant documentation provided by industry stakeholders. Key preliminary findings were subsequently reviewed in two workshops with stakeholders to validate and augment them as needed

This report presents the findings from industry examples, interviews, and workshops. The findings are not official positions of the Zero-Emission Shipping Mission.



Key findings

Key findings are summarised below:

•LNG/tanker basis	Previous experience from LNG carriers and tankers is essential for building future seafarer competence.
•General procedures	Experience from IGF vessels and technology suppliers, along with risk assessments, will act as a springboard for developing new procedures.
•Risk-based approach	Initial risk assessments will build on previous industry experiences to produce competence requirements and procedures.
•Role of technology suppliers	Technology suppliers will play an important role in developing procedures and training for alternative fuel systems.
•Extensive system knowledge	Deeper seafarer knowledge of technical systems will be required to compensate for potential unknown risks.
•Non-technical skills	Non-technical skills are necessary and should be incorporated into future training.
•Enhanced risk awareness	A common understanding of additional risk onboard is needed, along with a safety culture to mitigate it.
•Onboard risk assessments	Seafarers should use and be trained in conducting practical risk assessments, to be able to tailor procedures to the prevailing situation.
•Future training	The IGF code basic/advanced courses will form the basis for future competence, in addition to fuel-specific courses and familiarisation.

METHANOL

The approach taken to methanol training was a focus on IGF courses supplemented by an in-house methanol-specific course, which focused on the unique hazards of methanol as a fuel, including differences in firefighting, PPE usage, and maintenance procedures.

HYDROGEN

Experience with LNG was leveraged and adapted for liquid hydrogen. Training was approached through IGF courses, a hydrogen-specific course, and training from the manufacturer. High automation levels, and a specialised maintenance crew mitigated hazards.

Introduction

Emerging alternative fuels in the maritime industry, such as hydrogen and methanol, exhibit distinct properties compared to conventional marine fuels. Notably, these include aspects of toxicity, explosion hazards, and flammability. Consequently, the adoption of these fuels may necessitate the development of new competences, along with the implementation of training programs for crew members tasked with operating vessels powered by alternative fuels. These crew members are essential for ensuring safety onboard, as they are in large part responsible for the vessel's operation, maintenance, and responding to emergencies.

Background & objectives

The Zero-Emission Shipping Mission is an ambitious alliance between countries, the private sector, research institutes, and civil society, which aims to lay the foundation for a zero-emission shipping future and accelerate progress towards zero by 2050. The Mission will demonstrate commercially viable zero-emission ships by 2030 by focusing on the entire value chain: the ship, the fuel production, and the fuel infrastructure, driving the sector to a tipping point in its transition to well-to-wake zero-emission fuels as soon as possible. The Mission is co-led by the governments of Denmark, Norway, and the United States, along with the Global Maritime Forum and Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) as industry co-leads.

The *Safety of Crew in Low/Zero Emission Ships* (SCILZS) project has the following overall objectives:

1. Ensure knowledge sharing amongst first movers and other relevant stakeholders on how to develop crew training and procedures, to ensure crew safety on ammonia, hydrogen or methanol fuelled ships
2. Map the needed competencies and training for seafarers when operating ships using ammonia, methanol, or hydrogen as a fuel
3. Contribute to the dissemination of the results from the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping's ammonia safety project on competences and training

Initially, the project established a project team, stakeholders, and participants. A key early deliverable was the completion of a general mapping for seafarer competence needs regarding methanol, hydrogen, and ammonia. This mapping formed the preliminary competence framework.

Industry examples & interviews

General approach

SCILZS aims to provide input on tangible competence needs for seafarers operating on methanol-, hydrogen- and ammonia-fuelled vessels. The findings from this report provides input on crew training and procedures related to the safety of crew on vessels fuelled by methanol and hydrogen. The figure gives a general outline of the project's approach.

This approach has the following objectives:

1. To gather information, data, and experience on required/needed competencies for future seafarers to be able to safely operate on methanol/hydrogen fuelled vessels from participating ship owners and operators, as well as other relevant stakeholders
2. To facilitate knowledge sharing of the findings amongst project participants

These goals were accomplished by examining industry examples of vessels that already use methanol or hydrogen as fuels, interviewing relevant industry experts, and analysing relevant documentation provided by participants.

Workshops with stakeholders

Key preliminary findings from the industry examples and interviews were then discussed in two workshops with stakeholders. These workshops aimed to validate the preliminary findings and to augment them where necessary.

Report

This report presents the findings from the industry examples and interviews in addition to the outcomes of the workshops. The following limitations apply:

1. This report is limited to methanol and liquid hydrogen as alternative fuels
2. This report presents the findings from the industry examples, interviews, and workshops. The findings are the opinions of the participants

Findings

Findings from the interviews and workshops were thematically categorised under the main themes. Identified sub-themes are nested under these main themes.

Findings were split into general findings and findings specific to methanol and hydrogen.

The table below outlines the interview themes.

Themes	Definition
Procedures	A specific set of sequential actions required to operate a vessel. Split into standard procedures, such as: bunkering, operation, fuel transfer, storage, and maintenance; and emergency procedures, such as firefighting, leak mitigation, breakdown, machinery failures and exposure to toxicity.
Technical skills	Technical competence, specific knowledge or skills that are related to the operation, maintenance, or management of a vessel or maritime activity. For example, being competent in operating machinery or executing procedures.
Non-technical Skills	Qualities that are not related to specific technical knowledge or tasks, but rather to the way people interact with each other, manage themselves, and cope with challenges. For example: communication, leadership, problem-solving.
Safety/risk Awareness	Being aware of the potential hazards and risks resulting from operating with an alternative fuel and taking action to prevent or reduce the harm that may result from those hazards and risks. Meaning general safety culture and awareness of risks.
Risk assessment	The identifying of hazards and risks for alternative fuel technologies and steps taken to mitigate these. Meaning the specific application of using risk assessment as a tool.
Training	The development and training of operators to reach the required competence level.

General findings

This section will cover findings generally applicable to all alternative fuels under the identified themes.

Procedures

New procedures will have to be developed in tandem with the adoption of green technologies onboard. Procedures already used on **LNG or chemical tankers** will likely be a starting point for developing procedures on vessels that use alternative fuels, while considering the different properties of these fuels. **Technology suppliers** developing alternative fuel systems will have a crucial role in developing new procedures, as their understanding of their own system is advanced. **Risk assessments** play an essential role in the initial development of these new procedures, where identified risks can be mitigated by introducing new or updated procedures.

Procedures, within the context of this report, entails a specific set of sequential actions required to operate a vessel. Split into standard procedures, such as: bunkering, operation, fuel transfer, storage, and maintenance. Procedures also entail emergency procedures, such as firefighting, leak mitigation, breakdown, machinery failures and exposure to toxicity. Procedures are developed to reduce risks and the possibility of errors onboard. Procedures also facilitate standardised training, where seafarers are trained in performing a set of pre-determined actions. Procedures are thereby an essential aspect of seafarer competence.

Since many of these newly developed procedures are relatively untested some consider them to require an increased **level of detail** to lower the potential risk level. Detailed checklists are useful for potentially hazardous procedures, to further reduce potential risks.

To increase safety and reduce risk, the emphasis in developing procedures should be on safety-critical operations, such as: bunkering, emergency procedures, maintenance. System developers will play an important role here together with risk assessments.

Procedures	
LNG/Chemical Tanker Basis	- Experience from LNG carriers and chemical tankers will form the basis for determining procedures on alternative fuel vessels. Experience from LPG carriers may also contribute to future procedures in a similar manner. Procedures from these sectors could be adapted to fit the differences in characteristics of future alternative fuels. - To avoid introducing too many new procedures and to simplify the transition as much as possible, established and tested procedures should be used and revised where needed. For systems that differ significantly from traditional fuel systems, technology suppliers will play an important role.
Technology Suppliers	- As many technical systems for alternative fuels will be novel, or novel in some way, technology suppliers have an important role in developing procedures for their systems as they have the most understanding of their system. - Technology suppliers should focus more on user-centered design for their systems, including the systematic involvement of the end-user during the development of key procedures. Involving the seafarers as much as possible during system development ensures that procedures accompanying the systems are relevant. - Technology suppliers should strive to make procedures easily understandable and include the reasoning behind carrying out certain actions in their procedures during familiarisation. This allows for rapid training and adoption by seafarers.

Risk Assessment	- Procedures may be developed alongside systems by technology suppliers, but risk assessments will also play an important role in developing procedures. As hazards are identified in early risk assessments during the design-phase, procedures can be developed to directly mitigate specific hazards. These can then be iterated upon as experience is gained onboard.
Level of Detail	- During interviews two differing points of view came forward regarding the level of detail future procedures may need to tackle the industry inexperience regarding alternative fuel systems: ○ Some argue that procedures should initially be very detailed with every step clearly outlined in detailed checklists. Others argue that procedures should be simplified for seafarers, to limit the administrative burden, and facilitate flexibility in procedures. ○ There is general agreement that the approach for the level of detail is dependent on the procedure itself and the system/fuel type. The higher the risk involved in a procedure the more detailed it should be. The level of risk would be decided by a risk assessment.
Focus Points	- Some aspects require more focus than others: ○ Bunkering procedures, as it is a safety critical operation ○ Procedures for emergency operations, such as firefighting, leak mitigation etc. ○ Procedures for use of personal protective equipment (PPEs) ○ Use of EX-machinery during operation ○ Procedures for conducting maintenance operations, as risks are higher here when using alternative fuels and systems more complex ○ Operating procedures for new complicated machinery such as fuel cells ○ Handling of new, sensitive, materials. Especially in EX-machine spaces ○ New training procedures for maintaining crew competence onboard

Technical skills

Once again technical skills from **LNG-fuelled vessels and chemical tankers** will most likely form the basis for future technical skills. While the required technical skills are similar when it comes to, for example, LNG and liquid hydrogen, the differences must be considered. More advanced systems, such as **dual-fuel engines or fuel cells** will require seafarers to have additional technical skills. Additionally, the **higher level of automation** required to manage complex alternative fuelled systems will also demand more **digital skills** from seafarers.

Technical skills, within the context of this report, entails the specific knowledge or skills that are related to the operation, maintenance, or management of a vessel or maritime activity. For example, being competent in operating machinery or executing procedures. These skills are essential when it comes to the proper operation of vessels and will change as new technical skills are needed in the transition to green fuels and alternative fuel systems.

Given the industry's relative inexperience with alternative fuel systems, there is an increased likelihood of encountering unknown or unanticipated risks and hazards. To effectively troubleshoot and mitigate these failures, a **deeper understanding** of the entire technical system will be essential for the crew.

Technical skills may be distributed differently across onboard roles. Some roles may end up becoming more specialised, where a specialised maintenance crew may be called in to perform maintenance instead of the onboard crew. Deck and engineering **roles may overlap** more as similar safety essential technical skills are required from both groups.

With regards to technical skills the focus should be on leveraging the more mature LNG and chemical tanker-based technical skills to deliver up-to-date requirements for alternative fuel systems. Additional technical skills should thereby also focus on areas that differ, for example firefighting specific differences for specific alternative fuels and handling toxicity.

Technical Skills	
LNG/Chemical Tanker Basis	- Technical skills originating from LNG carriers and chemical tankers will form the basis for seafarer competence on alternative fuelled vessels as many aspects are similar. Experience from LPG carriers may also contribute in a similar manner. - The main challenge will be adapting these skills fit the differences in characteristics of future alternative fuels.
Dual-fuel and fuel cell/hybrid systems	- Some systems may be completely novel for most seafarers and may not have a similar equivalent to LNG. These novel systems will require additional focus and training. Examples include dual-fuel and fuel cell/hybrid systems as many alternative fuel systems integrate these. - Along with these systems vessels will be increasingly electrified. Additional technical competence is needed when it comes to understanding electrification onboard and power connections between ship and shore.

In-depth Understanding	- Due to industry inexperience with alternative fuel systems, there are many unknowns to operating them. A deep technical understanding of the system, how it integrates, operates and its technical safety barriers is essential for its safe operation as this facilitates troubleshooting of unknown failures, and assists seafarers in determining appropriate mitigation measures if an unanticipated hazard materialises. - More skills like those of process safety will be needed. Where the system as whole should be understood and not just its separate constituent parts. Seafarers should be able to determine the knock-on effects of an unknown failure and be able to mitigate the consequences through this deeper understanding of the system.
Overlap/Specialisation Between Crew Member Tasks	- As technical skill requirements change and increase, more tasks may become specialised onboard, such as the introduction of a dedicated bunkering crew. - Other onboard roles may overlap in technical skill needs where they traditionally did not. Deck and engineering officers may have tasks that overlap more, which will require additional technical skills for each party. - Some vessels may consider transferring onboard duties to a specialised external team. For example, a specialised maintenance crew for the technology supplier.
Digital Skills	- As alternative fuel systems will be technically more complex, they will rely on additional technical safety barriers where the seafarer is removed from the situation. These safety barriers will primarily be automated or operated remotely, ensuring that digital skills will be needed. - Due to a shift in a seafarer's role to more that of a monitoring role, they will need to be proficient in interpreting instrumentation and sensor data to ensure automated systems are working properly.
Focus Areas	- Some focus areas for technical competence are as follows: ○ Control/monitoring of pressure and temperature ○ Competences related to toxicity such as gas detection and leak mitigation ○ Technical skills related to handling, storage, transfer (including ship to ship), and fuel operation ○ Firefighting skills specific to the alternative fuel ○ Audits are needed to confirm that the crew has the required technical skills and competence

Non-technical skills

Competence needs and requirements should not only reflect technical skills. Technical, and **non-technical skills** should be approached in combination to account for complex/multidimensional human actions, such as decision making, leadership and attaining an understanding of what is going on.

Non-technical skills are essential for ensuring the proper application and training of technical skills. Seafarers should be trained in non-technical skills to **augment** their technical skills.

Enhancing seafarers' non-technical skills through training and courses is crucial. These skills complement their technical expertise and enable them to maximize its effectiveness. In addition to safety-related technical skills, seafarers should excel in teamwork, communication with shore personnel, and adaptability to handle unforeseen risks.

Anoter example of this is the non-technical skill of **flexibility**, seafarers will have to be increasingly flexible as new systems and potential new risks are introduced. This additional flexibility will allow seafarers to react to unanticipated scenarios resulting from relatively untested technologies.

Like the increasing need for seafarers to have a deeper technical understanding of the alternative fuel system, seafarers will need the ability to use their **insight** to interpret an unanticipated scenario and devise a solution.

The initial deployment of alternative-fuelled vessels presents a unique situation for seafarers. Cultivating a strong sense of **ownership** over their vessel and actively accumulating experience with the onboard systems will be crucial. This ownership mindset contributes to a deeper technical comprehension of the system and enhances their **awareness** of potential risks.

It is also important that vessel and shore have continuous dialogue, **communicating** potential hazards and learnings. Shore should support seafarers onboard in gaining the competences they require.

Non-Technical Skills	
Augmentation	- Non-technical skills augment technical skills. Seafarers need both to be able to operate safely on new alternative fuelled vessels. Non-technical skills help in this manner by assisting in the effective application of technical skills. - Non-technical skills should also be developed shoreside, as this will lead to improved communication and cooperation between ship and shore.
Flexibility/Adaptability	- As new systems are introduced onboard seafarers need to be flexible and adapt to their usage. This requires an open mindset, where seafarers are open to these changes and further development of technical competence. - Flexibility will allow seafarers to adapt to unanticipated hazards that may evolve from new alternative fuel systems.

Insight	- Insight entails a precise and deep understanding. As mentioned in the "Technical Skills" theme, increased insight allows seafarers to interpret deviations in system operations gained from that deeper knowledge. - Insight supports seafarers in seeing connections within a system to interpret a situation and create a solution.
Ownership	- Seafarers will gain a strong feeling of ownership over their vessel, especially in the early stages of the transition. This feeling of ownership supports seafarers in developing their technical competence of a new system and develop procedures to a deeper degree.
Awareness	- Awareness of the functioning of the technical system and happenings onboard supports a seafarer in being aware of where possible deviations and failures may occur in a system and how they could develop into a hazardous or critical event, as well as how these events could be prevented. Seafarers need to be even more acutely aware of their own limitations and the consequences of their actions.
Communication	- There will be an increased need for communication between vessels and shore. As vessels transition it is important that learnings are communicated so that the industry improves.
Focus Areas	- Some focus areas for non-technical competence are as follows: o Supporting seafarers in the development of their non-technical skills could be a top-down process led by shore-based management. Non-technical skills should be improved shoreside as well, to improve cooperation. o Seafarers should also be supported in developing their competence by being given time and space to mature their skills and familiarize themselves with the vessels. o Non-technical skills should be trained in a codified course.

Safety/risk awareness

The current level of safety culture on, for example **LNG carriers provides a solid baseline** from which experience can be leveraged for improving safety culture on other segments.

A common understanding of the potential risks onboard between vessels and shore is needed so that the overall **risk picture** is clear for all parties and can be addressed.

Being aware of the potential hazards resulting from operating with an alternative fuel and taking action to prevent or reduce the harm that may result from those hazards will be even more important going forward. In essence, a strong **safety culture, and general awareness of risks** onboard will be a key aspect for seafarers to prevent, anticipate and react to potential risks.

Additionally, it is crucial that there is a **shift in safety mindset**, so that there is a general level of understanding that alternative fuel systems are relatively new and untested. This should not only lead to a heightened level of cautiousness and safety mindset onboard, but also on shore.

Due to the higher levels of risk that come in tandem with these alternative fuel technologies, focus should be less on attaining a minimum in compliance and more on achieving a strong safety culture through appropriate application of **safety management**.

Focus should lie on raising safety culture to the levels of LNG carriers, ensuring a common awareness of risks onboard for both ship and shore, in addition to the effective application of existing safety management systems.

Safety/Risk Awareness	
LNG/Tanker Basis	- Experience from LNG/tankers can support building a mature safety culture and improving risk awareness. As these segments, along with the cruise industry, generally have a mature safety culture. Addressing safety culture gaps is crucial. Integrating crew members with a mature safety culture into other segments can help disseminate best practices. Their experience and mindset can positively influence safety practices across the board, mitigating risks associated with new alternative vessels.
Risk Awareness	- It is important that seafarers are aware of the potential hazards and risks that may occur with an alternative fuel system, going beyond what is normally expected. From this risk awareness, seafarers can take proactive steps to take mitigating actions.
Common understanding of the risks	- Maintaining an open risk register for the crew is a valuable practice. By documenting identified hazards and corresponding mitigating actions, seafarers can enhance their risk awareness onboard. This proactive approach contributes to a safer and more informed operational environment. - The overall risk picture between ship and shore should be aligned, so that it is clear how the risks evolve over time as experience is gained and mitigation measures are implemented. - The development of "What If" scenarios, to simulate high-risk scenarios would improve safety culture and general risk awareness onboard. As the major hazardous scenarios would then be clear and could be prevented.

Avoid reverting to old habits	- There is a valid concern that onboard operations may persist without adequately considering the heightened risks. To address this, a shift in safety mindset is necessary—one that surpasses the minimum standards outlined by STCW. Given the increased risk associated with alternative-fuelled vessels and the industry's relative inexperience, exercising an added level of caution during alternative vessel operations is prudent until sufficient experience is gained. - A strong safety mindset is equally important for shore as onboard, as shore has an indirect influence on operation onboard. Safety mindsets should therefore align. - Detailed procedures are a strong foundation for building a safety mindset, as they outline the required actions, and mitigating measures needed. - Maritime segments with a traditionally less intense focus on a strong safety culture need to invest and focus on reaching a high level, similar to the current LNG/tanker segments.
Safety Management	- The ISM code and safety management systems (SMS) need to go further and be more thoroughly applied. The focus should be less on achieving the minimum in compliance, but on continuous improvement to safety culture. - Safety should not only focus on people, but also the environment and material. - Tanker Management and Self-Assessment (TMSA) may provide a way to improve safety management /2/. Especially for non-tanker/LNG segments.
Focus Areas	- The following areas require focus: o Effective application of existing safety management systems o Risks and mitigating measures awareness amongst all crewmembers

Risk assessment

Initial risk assessments during the development of alternative fuel systems will be needed for the further development of onboard procedures especially as mitigating measures.

Risk assessments play a crucial role during the transition to alternative fuel systems. Onboard, they should be actively employed before undertaking potentially hazardous procedures. This ensures that any variations in circumstances during a procedure (such as adverse weather conditions during bunkering) are accounted for, addressing potential increases in risk.

Risk assessment involves identifying hazards and risks associated with alternative fuel technologies and implementing measures to mitigate them. It serves as a valuable tool for recognizing potential hazards, particularly in cases where experience with a specific technology solution is limited. These risk assessments inform potential mitigation, allowing proactive responses to unforeseen hazards.

Focus should lie on increasing the applicability and usability of risk assessments within procedures onboard.

Risk Assessment	
Onboard Risk Assessment	- Current risk assessments conducted onboard, such as Safe Job Analysis, should be expanded, especially when it comes to bunkering and maintenance. This is mainly due to potential unknown hazards that can unsure under operation, especially in tandem with other technical deviations or external circumstances. - These risk assessments should not just be a checklist but should be a natural part of a procedure. It should be applicable, practical, and not just a paper exercise. Risk assessments should be a tool a seafarer actively uses that adapts procedures to the prevailing circumstances.
Initial Risk Assessments	- Initial HAZIDs and HAZOPs provide an essential initial risk picture before vessel commissioning and a vessel's future crew should participate if possible. Their insight could be invaluable in identifying additional hazards and mitigating measures. - Feedback loops to attend to observed risks during a vessel's lifetime should be included onboard. Crew should be aware of risks onboard, report new/modified risks and be supported in suggesting mitigating measures.
Risk Assessment Quality	- The quality of risk assessments should be improved in terms of practicality, and properly implemented. - Risk assessments onboard should be a standard tool that is operationalised and produces a follow-up plan for closing actions. This facilitates continuous learning onboard and the overall reduction of risk.
Focus Areas	- The following areas require focus: ○ Practical risk assessment with tangible application, avoiding risk assessment that purely focuses on "ticking boxes" ○ The inclusion of third-parties (for example bunkering team onshore) into the risk assessment process could be considered ○ A risk-based approach is essential initially, as practical experience lacks, but standard procedures will take over as experience is gained

Training

IGF code training courses will likely form the basis of any training regarding alternative fuels, with an additional modular course covering **fuel specific** aspects.

Initial crews will heavily rely on training provided by technology suppliers to become familiar with the onboard technology. Involving the initial crew during the commissioning phase of a newbuild vessel aids in their familiarity with the novel features.

Training programs should strike a balance between e-learning and practical training. Certification and examination of training are essential. Beyond procedures and technical skills, training should encompass non-technical skills and risk assessment. Addressing the shortage of trainers requires a focused effort to increase training capacity.

Training	
IGF code course	- IGF code courses (basic & advanced) will form the basis for future training. These courses align closely with the competence needs of alternative fuel systems.
Fuel specific course	- In addition to the IGF code courses a fuel specific course covering the characteristics of the fuel, firefighting, leak detection/mitigation should be introduced. Focus will be on where the specific fuel differs from conventional fuels and operation of fuel-specific machinery. - Training courses should incorporate practical elements whenever feasible, such as hands-on firefighting training, as it enhances learning effectiveness. For theory-heavy topics like understanding fuel characteristics, e-learning can be a suitable approach
Familiarisation	- Technology suppliers may have to facilitate initial familiarisation by providing training on how to operate their systems. - After the initial crew is familiarised with the fuel system, they can assist in familiarising replacement crewmembers onboard. - Including the initial crew in the commissioning phase of a vessel provides a solid foundation for familiarisation onboard
Focus Areas	- Some focus areas for training are as follows: o Additional trainers must be trained via train-the-trainer courses o There should be a balance between practical, simulator and online training. Where effective training should still be efficient o While pure e-learning should be minimised, it can be useful for skill upkeep or introductory courses when needed. A balanced approach that combines practical training with targeted e-learning ensures effective learning outcomes o Proper examination and certification of training will be required o Training should cover areas such as: emergency scenarios, procedures/normal operation, and maintenance o A course specific to non-technical skills and risk assessment should be considered o Training should be regular as to ensure maintenance of competence levels, onboard training quality should also be improved o Consider training for supporting shore personnel to increase ship/shore understanding

Methanol specific findings

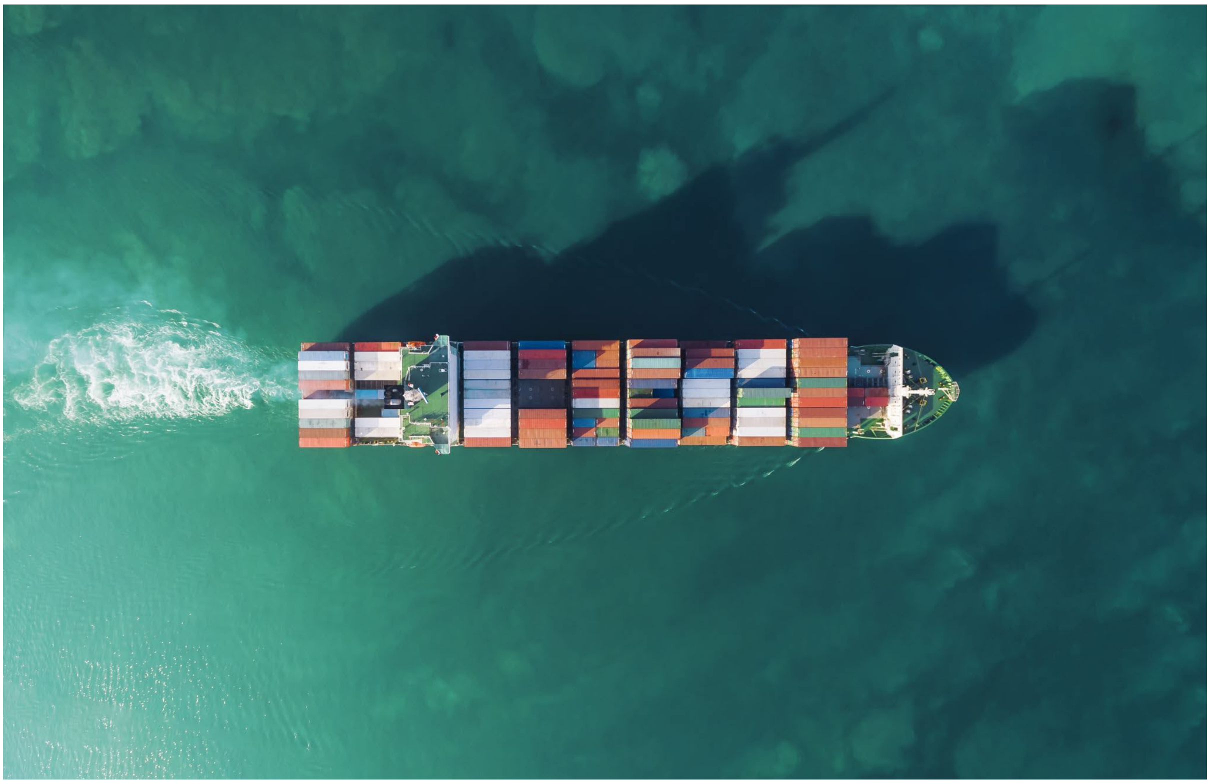
Methanol is a colourless liquid with high combustibility. Methanol produced with the use of renewable energy (e-methanol) is a popular alternative fuel due to its relative low emissions, compliance with regulations, safe handling, and fuel flexibility. When derived from renewable energy sources, its carbon emissions are 95 percent lower than conventional fuels, and it also has lower emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) compared to conventional marine fuels.

Methanol is a toxic substance that can lead to blindness, coma, or death if ingested and its vapors can cause asphyxiation. It is highly flammable, burns invisibly at low temperatures, and can create explosive atmospheres above 11°C, especially in confined spaces.

This section will cover findings specific to methanol, building on experiences from the methanol fuelled vessels, the Stena Germanica, and the Laura Mærsk.

The **MS Stena Germanica** was retrofitted with a methanol-fuel engine in 2015 and was the first large vessel to be able to run on methanol. It currently operates as a cruise ferry. It has a length of 240m and can host 1,300 passengers.

The **Laura Mærsk**, launched in 2023, is a feeder container ship owned by Mærsk. It is powered by a methanol-fuel engine and is the first methanol fuelled container vessel. It has a length of 172m and a 2100 TEU capacity.



Methanol – Key takeaways

Although methanol as a fuel is generally considered to have a lower risk profile than hydrogen, its unique characteristics necessitate a distinct approach compared to traditional fuels.

Industry examples typically relied on experience from LNG-fuelled vessels as a foundation for crew competence. The IGF basic and advanced courses served as the basis, supplemented by an in-house methanol-specific course. This specialised methanol training emphasised understanding the unique hazards related to using methanol as a fuel, including distinctions in firefighting (where methanol produces a nearly invisible flame), proper PPE usage, and maintenance procedures.

Methanol Findings	
Previous Experience	- Experience from offshore support ships' methanol cargo transfer can inform the refinement of methanol bunkering procedures.
Level of Risk	- Methanol has a generally accepted lower level of risk than, for example, hydrogen and ammonia. Due to it being less toxic when inhaled than ammonia, not cryogenic and less explosive/flammable than hydrogen. Procedures and required competences for methanol can thereby be considered less stringent than hydrogen or ammonia. - Industry examples included daily onboard briefings/debriefings to build awareness and understanding of the methanol system amongst the crew. - Focusing on increasing passive safety, including for example vessel layout, reduced the risks crewmembers faced and reduced complexity in handling risks. - Industry examples implemented dedicated work permits for crew members when working on the methanol fuel system. This practice ensured a general awareness of safety-critical activities onboard and promoted a safety-oriented mentality.
Firefighting	- Firefighting competences specific to methanol require practical training, providing seafarers with hands-on experience in dealing with methanol fires. Fighting a methanol fire differs significantly from handling conventional onboard fires. Industry examples collaborated with fire departments to develop specialised training for methanol firefighting.
Technical Skills	- Highlighted technical skills were the use of PPEs specific to methanol, bunkering and system operation/maintenance (purging/dismantling).

Industry example

The inhouse training course for Mærsk's' methanol fuelled vessels was provided as an example /3/. The training course follows a similar structure to the LNG basic/advanced course and is split in a similar way. The below table highlights the topics covered, including fuel characteristics, the methanol system, PPEs, procedures and risks/hazards.

Methanol Course	
Basic	**Advanced**
Methanol fuel properties, physics and chemistry, methanol safety - Interpret methanol Safety Data Sheet - Risks and hazards with methanol as a fuel - Hazard control measures to prevent personnel injuries/fatalities, minimise asset losses, and mitigate environmental pollution	Performing and monitoring operations on vessel (incl. SIM) - Fuel feed systems - Safety systems - Ventilation - Measurements - Piping and instrumentation diagrams of system parts
Operating and controlling propulsion plant - Methanol bunker station - construction - Bunker station - Storage system - Piping and instrumentation diagrams of system parts	Methanol engine systems - Main engine - Auxiliary systems
Response to emergencies to prevent fire, leakage, pollution of the environment and vapour intoxication through inhalation	Environmental impacts of a methanol spill and of gas plume dynamics to ensure precise evaluation of the correlated risks
Donning and functions of a Self-Contained Breathing Apparatus and PPE for methanol related incidents (leakage)	Methanol fuel systems and the handling of fuel in engine room operations, fuel storage, and piping system arrangement
Operation and management of methanol firefighting equipment and extinguishing agents	

Hydrogen specific findings

Hydrogen is a carbon-free fuel that can be used in an internal combustion engine or fuel cell. When produced from renewable sources hydrogen is a zero-emission fuel. Hydrogen's high energy density makes it a viable option for ships; however, it suffers from low volumetric density, often requiring liquefaction under even lower temperatures than LNG. Hydrogen can also be transported as a pressurised gas or via Liquid Organic Hydrogen Carriers (LOHC).

The hazards related to hydrogen differ depending on the storage method, but it is a colourless, odourless gas that's hard to detect, can embrittle materials, and causes severe cold when released as a liquid. It disperses quickly and can accumulate in enclosed spaces, presenting a high explosion risk due to its flammability and low ignition energy. The danger is amplified in confined areas where hydrogen's high diffusivity and explosive properties are particularly hazardous.

This section will cover findings specific to (liquid)-hydrogen. The industry example is the MF Hydra.

The **MF Hydra**, operational in 2023, is the world's first liquid hydrogen powered ferry. It is powered by two fuel cells and a liquid hydrogen fuel tank. Owned by Norled, it serves as a ferry in Norway for up to 300 passengers and has a length of 83m.

Hydrogen – Key takeaways

The industry example utilised liquid hydrogen. Liquid hydrogen is handled in a very similar way to LNG enabling the transfer of experience and competence from LNG to liquid hydrogen. As part of their safety measures, the industry example mandated that crew members possess experience in handling LNG.

The industry example generally took the approach of adapting procedures from LNG due to their similarity in operation. The crew underwent IGF advanced courses and a specialised in-house hydrogen course. Additionally, they received training directly from the fuel system manufacturer, which was crucial given the system's hybrid nature (fuel cell/battery). Safety measures heavily emphasized high automation levels, and maintenance risks were mitigated by having a separate specialised maintenance crew from the manufacturer.

Hydrogen Findings	
Previous Experience	- Experience from onshore hydrogen manipulation can be used to develop hydrogen competences and procedures onboard. - LNG experience can form a good competence basis, especially for liquid hydrogen due to their similarities in handling. Upcoming hydrogen guidelines should assist in adapting LNG competence to hydrogen. - For the liquid hydrogen industry example, experience with LNG was a prerequisite for new crewmembers.
Differences in Storage	- There are different competence and procedural requirements when it comes to the different ways hydrogen can be stored, for example liquid hydrogen vs. compressed hydrogen. This difference should be considered.
Firefighting	- Firefighting competence specific to hydrogen should be trained at a practical level, giving seafarers hands-on experience in dealing with a hydrogen fire.
Procedures	- Hydrogen procedures should be very detailed and risk assessments more in-depth due to the generally higher risk than, for example, methanol. - Bunkering procedures are very similar between LNG and liquid hydrogen as both are cryogenic bunkering methods. - The biggest difference in procedures compared to LNG was operation of the hybrid battery/fuel cell system on the industry example vessel. - Firefighting procedures for liquid hydrogen were deemed like those of fighting a fire in a battery room. With a focus on mitigation, tank flooding and pressure/temperature reduction.
Technical Skills	- Maintenance of liquid hydrogen technical systems on the industry example were left to an external specialised maintenance crew. - The industry example system was highly automated, so focus on skills lay in monitoring and automation control.

Conclusions

LNG/tanker basis

The interviews and industry examples underscored the importance of prior experience from LNG carriers and tankers as a foundation for developing seafarer competence. This experience extends beyond procedural knowledge, encompassing the ability to handle cryogenic fuels, manage double-walled piping, and cultivate a strong safety culture with heightened risk awareness. Industry stakeholders already using methanol or hydrogen as fuel consider LNG experience a prerequisite for crew members.

Risk-based approach

During the development process of alternative fuel vessels, a risk-based approach is commonly employed. This approach aids in identifying potential onboard hazards and determining effective mitigation strategies. It also informs the development of onboard procedures and helps identify the specific competences required for seafarers on a particular vessel. The industry examples from this study, where the vessels operate methanol and hydrogen respectively, have already utilised this risk-based approach for the technical design of the vessel and the establishment of procedures and seafarer competences for it.

Role of technology suppliers

Technology suppliers play a crucial role in developing procedures and training for alternative fuel systems. Close collaboration between technology suppliers, ship owners, and crews is essential to create safe procedures for new systems. User-centered design and involving users during development are key considerations. Initial crews on new-build vessels may require in-depth training on system operation, and ongoing training may be necessary as crews change. In the case of liquid hydrogen, the industry example not only relied on their technology supplier for fuel system training but also utilized a specialised maintenance crew provided by the supplier.

Extensive system knowledge

To mitigate potential unknown risks, seafarers must acquire a comprehensive technical understanding of alternative fuel systems. This includes knowledge of the entire system, rather than just its individual components, as well as an understanding of the fuel itself. Familiarity with how different aspects of the system interact, operate, and the safety measures involved is crucial. This deeper understanding enhances troubleshooting, risk awareness, and risk mitigation, ultimately reinforcing the onboard safety culture and promoting seafarer resilience.

Importance of non-technical skills

Non-technical skills complement the acquisition of new technical skills necessary for operating alternative-fueled vessels. These skills should be integrated into future training programs, ensuring that seafarers not only understand onboard safety from a technical standpoint but also excel in teamwork, communication with shore, and managing unforeseen challenges. Given the novelty of alternative-fueled vessels, seafarers must cultivate a strong sense of ownership and collaborate effectively as a cohesive team.

Enhanced risk awareness

To effectively address the additional risks onboard alternative-fuelled vessels, a shared understanding of said risks is vital. As these new systems are introduced, new risks emerge. Crew awareness enables proactive risk mitigation. Similarly, shoreside awareness fosters support and alignment. By promoting a learning culture and emphasising safety, seafarers can adapt to these changes. Industry examples, such as methanol and liquid hydrogen, demonstrate the value of common risk understanding and communication to all parties.

Risk assessments

Seafarers must utilise risk assessments as a practical tool, particularly before potentially hazardous procedures like bunkering or maintenance on alternative-fuelled vessels. These risk assessments should not be a paper-exercise or traditional checklist but should aim to adapt standard procedures to prevailing circumstances that may increase risk and include focus on mitigating actions. Methanol and liquid hydrogen industry examples used crew-conducted risk assessments to foster a shared understanding of the novel risks associated with alternative fuels. By tailoring procedures to actual conditions and implementing additional mitigating actions, seafarers can effectively reduce risk levels.

Future training

To ensure seafarer competence on alternative-fuelled vessels, the IGF code courses serve as a foundation. Additionally, specific fuel courses and onboard familiarisation are essential. Training should encompass both technical and non-technical skills, emphasising practical and simulator-based exercises. For alternative fuels, safety critical training, such as firefighting, must adapt to the unique characteristics of each fuel. Certification ensures transparent competence levels. Ongoing training and maintenance of competence onboard are crucial. Industry examples, particularly in methanol and liquid hydrogen, prioritise IGF code training alongside specialised in-house courses focusing on fuel characteristics and operational/emergency handling.

References

/1/ Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 77–101

/2/ OCIMF, (2017). Tanker Management and Self-Assessment 3 - A Best Practice Guide

/3/ Mærsk Fleet Management & Technology, (2024). Program Methanol Basic & Advanced

ANNEX I - Method

This covers the methodology used to acquire the findings.

Interviews

The interviews aimed to gather knowledge, experience, and information on required competencies for future seafarers from industry examples and experts.

Interview topics/method

The table below outlines the interview themes.

Themes	Definition
Procedures	A specific set of sequential actions required to operate a vessel. Split into standard procedures, such as: bunkering, operation, fuel transfer, storage and maintenance; and emergency procedures, such as firefighting, leak mitigation, breakdown, machinery failures and exposure to toxicity.
Technical Skills	Technical competence, specific knowledge or skills that are related to the operation, maintenance, or management of a vessel or maritime activity. For examples, being competent in operating machinery or executing procedures.
Non-Technical Skills	Qualities that are not related to specific technical knowledge or tasks, but rather to the way people interact with each other, manage themselves, and cope with challenges. For example: communication, leadership, problem-solving.
Safety/Risk Awareness	Being aware of the potential hazards and risks resulting from operating with an alternative fuel and taking action to prevent or reduce the harm that may result from those hazards and risks. Meaning general safety culture and awareness of risks.
Risk Assessment	The identifying of hazards and risks for alternative fuel technologies and steps taken to mitigate these. Meaning the specific application of using risk assessment as a tool.
Training	The development and training of operators to reach the required competence level.

Interview participants

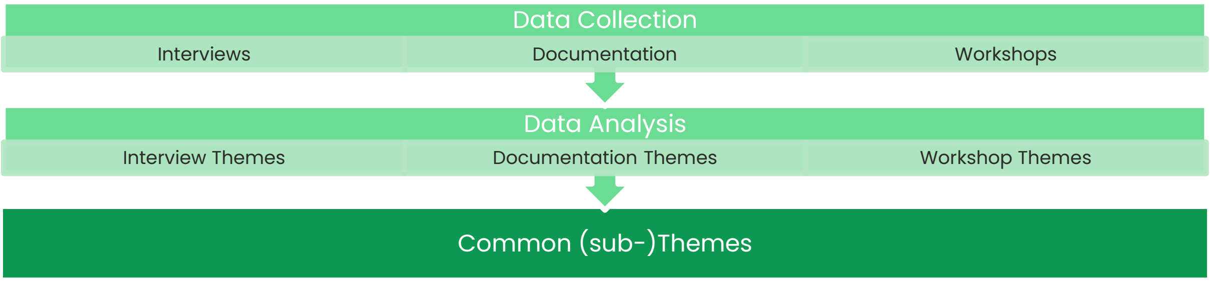
Participants were a combination of general crew safety experts, but also representatives from specific alternative fuel vessels. A total of 12 participants were interviewed. Participants were recruited by the SCILZS project team, based on expressions of interest and the project's network. The table below contains an overview of the participants. Organisations, rather than individuals, are listed to protect the privacy of the individual interviewees.

Participant Organisation	Expertise
A maritime safety agency	General maritime safety
British Petroleum	General experience with hydrogen & methanol
BunkerOne	Methanol experience
ClassNK	Crew training
DFDS	Methanol experience
Eltronic FuelTech	Methanol experience
Mærsk	Methanol fuelled industry example – Laura Mærsk

Minerva Marine	Crew training
NORLED	Liquid hydrogen fuelled industry example – MF HYDRA
Stena Line	Methanol fuelled industry example – Stena Germanica
Total Energies	General maritime safety
Woodside	General maritime safety

Interview analysis

Interviews were recorded and transcribed. After transcription, interviews were thematically analysed following the thematic analysis methodology set out by Braun & Clarke /1/. Thematic analysis is a method for identifying, analysing, and reporting patterns or themes within qualitative data. This approach allows for a flexible and detailed analysis of the data and can provide a rich and nuanced understanding of the information being studied.



A thematic analysis entails that if there are common topics (themes) that are repeated within the interviews. These repeated points can then be considered a theme and categorised accordingly. The more data points correspond, the stronger their consensus. Application of the thematic analysis methodology within this project is outlined in the figure above.

Preceding data collection, the 6 themes resulting from the project's mapping in phase 1 (theme table) were set as "main themes", where findings from phase 2 could then be categorised under as "sub-themes".

An example would be that: "the IGF code STCW courses should form the basis for alternative fuel crew training." This point was brought up multiple times amongst different participants, highlighting it as a strong sub-theme. This sub-theme could then be placed under the main theme, being "Training".

Some limitations to this method are that findings are limited to the knowledge and views of the participants, although findings are generally direct from industry and tangible due to their dependency on industry experts.

Workshops

Workshop objective

Two workshops with participants were organized to discuss preliminary findings, with the aim of validating them by coming to a consensus and augmenting findings where necessary.

Workshop topics/method

The workshops presented key findings from the industry examples. These findings were presented as statements open to discussion by workshop participants. Participants were urged to agree, disagree, comment and question.

Statements were presented on a per theme basis and were the same as in the interviews.

Any comments or additions were noted down for further analysis.

Workshop participants

Two identically structured online workshops were organised, to accommodate as many participants as possible within all times zones. Participants included representatives from vessel owners, oil and gas companies, maritime insurance, and crew training.

- Workshop 1 took place on March 6th, 2024, with 23 attendees.
- Workshop 2 took place on March 7th, 2024, with 12 attendees.

Workshop analysis

Themes brought up during the workshop were incorporated into the common themes. If a comment brought up during the workshop augmented an earlier finding from the interviews, that theme was expanded to reflect that. For example, if during the workshops the statement “LNG procedures will form the basis for future procedures” was presented and a response was received during the workshop that augmented this statement with “and chemical tankers” then this would expand the earlier statement to “LNG and chemical tanker procedures will form the basis for future procedures”. Disagreements were also noted down and incorporated where relevant, however, no substantial disagreements were identified during the workshops.

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