

MissionGreenFuels

Guideline for Safe Storage, Bunkering and Usage of Green Fuels in Port Facilities

Authors:

DBI

Robert McTaggart
Mohammad Ahli-Gharamaleki
Leonard Tuei

Force Technology

Rian Holdstock
Jens Thomsen
Frej Anton Alwerud
Christian Sig Overgård

Aalborg University

Nanna Finne Skovrup
Cathrine Winther Skytte
Kristian Borch

Reviewers:

DBI

Robert McTaggart
Mohammad Ahli-Gharamaleki
Nicklas Sjøgren Koch
Michelle Padul Jensen

Force Technology

Rian Holdstock
Jens Thomsen
Frej Anton Alwerud

Aalborg University

Nanna Finne Skovrup

Contributors:

DBI (Bunkering)
FORCE Technology (Storage/Usage)
Aalborg University (Societal and Public Perception)
Complete Solutions
Rønne Havn
MHO-Co

Document Identification

Project acronym	SafeSBU
Full title	Mission: II Green Fuels in Transport and Industry
Grant agreement number	1150-00001A
Funding scheme	Grand Solutions
Project start date	01-09-2023
Project duration	60 months

Executive Summary

The transition to green marine fuels is creating new requirements for ports, which form the interface between fuel production and transport, port-based storage, bunkering operations and onboard fuel use. The introduction of fuels such as methanol, ammonia and hydrogen brings different hazard profiles, technical and operational requirements, and regulatory challenges compared with conventional marine fuels. Safe implementation therefore requires coordination across technical systems, organisations, authorities, emergency services and the wider port community.

The SafeSBU guideline has been developed as part of MissionGreenFuels to support this transition. It draws on existing legislation, standards and international guidance, site visits to the ports of Rotterdam and Rønne, a hazard identification (HAZID) workshop involving relevant technical and operational stakeholders, and stakeholder engagement activities addressing societal and public perception.

Objectives

The overall objective of the guideline is to support the fast and safe implementation of green fuel activities in ports by providing practical guidance for the storage, bunkering and usage of green marine fuels.

The guideline is intended to help ports and other stakeholders:

- understand the fuel-specific hazards associated with green marine fuels;
- identify and evaluate credible hazardous scenarios;
- establish appropriate technical, operational and organisational safety barriers;
- define safe operational procedures and interfaces between organisations;
- establish appropriate competence and training requirements;
- prepare integrated emergency response arrangements;
- navigate governance, regulatory and approval processes;
- consider societal and public acceptance as part of project implementation; and
- assess and develop port readiness using the Port Readiness Level for Marine Fuels (PRL-MF) framework.

Structure and Approach

The guideline is based on a layered, risk-based safety system approach. Compliance with legislation, codes and standards remains an essential foundation, but emerging fuels and operating concepts may not always be fully covered by prescriptive requirements. The guideline therefore supplements a traditional compliance-based approach with an approach based on systematic hazard identification and risk evaluation. The shared safety-system model consists of eight interconnected layers:

1. Hazard understanding
2. Risk evaluation

3. Safety barriers
4. Operational control
5. Emergency preparedness
6. Competence and organisation
7. Governance and external interfaces
8. Societal and public perception.

This structure provides a common logic across storage, bunkering and usage and allows hazards to be traced through to the barriers, procedures, competence requirements and documentation needed to demonstrate that risks are adequately managed.

The guideline combines cross-cutting guidance, applicable across all green fuel handling activities, with dedicated chapters providing specific guidance for bunkering, storage and usage. The chapter on bunkering provides the most detailed illustration of how the layered, risk-based safety system approach is translated into practical technical, operational and organisational requirements. Storage focuses primarily on containment, material compatibility and associated technical safety considerations, while usage focuses on competence and training.

Contents

DOCUMENT IDENTIFICATION	2
EXECUTIVE SUMMARY	3
CONTENTS	5
LEGAL NOTICE	10
ACKNOWLEDGEMENTS	10
1. INTRODUCTION	11
1.1. PURPOSE	11
1.2. SCOPE	11
1.3. METHODOLOGY	11
1.4. PRIMARY USERS	12
1.5. HOW TO READ THE GUIDELINE	12
2. ABBREVIATIONS	14
3. GUIDANCE FRAMEWORK	16
3.1. HAZARD UNDERSTANDING	17
3.2. RISK EVALUATION	17
3.3. SAFETY BARRIERS	18
3.4. OPERATIONAL CONTROL	18
3.5. EMERGENCY PREPAREDNESS	19
3.6. COMPETENCE AND ORGANISATION	19
3.7. GOVERNANCE AND EXTERNAL INTERFACES	20
3.8. SOCIETAL AND PUBLIC PERCEPTION	21
4. FUEL PROPERTIES AND KEY HAZARD DRIVERS	22
4.1. GENERAL	22
4.2. METHANOL	23
4.3. AMMONIA	23
4.4. HYDROGEN	24
4.5. SUMMARY	25
5. HAZARD IDENTIFICATION AND RISK EVALUATION	26
5.1. HAZARD IDENTIFICATION	27
5.2. RISK EVALUATION	28
5.2.1 Qualitative Risk Assessment	28
5.2.2 Consequence Modelling and QRA	29
5.3. RISK CONTROL AND MITIGATION	29
5.4. DEMONSTRATION OF RISK ACCEPTANCE	30
5.5. RISK REVIEW	30

5.6. PROJECT HAZID	31
6. BUNKERING	41
6.1. INTRODUCTION	41
6.2. SCOPE, DEFINITION AND SYSTEM BOUNDARIES	41
6.3. GOVERNANCE, ROLES AND APPROVAL CONTEXT	42
6.4. BUNKERING CONCEPTS AND OPERATIONAL INTERFACES	43
6.5. HAZARD IDENTIFICATION FRAMEWORK	44
6.5.1 Methodology.....	44
6.5.2 Participants and Inputs	45
6.5.3 Inclusion of human and organisational factors	45
6.5.4 Normal, non-routine, and abnormal operations.....	46
6.5.5 Output and use of hazard identification results.....	46
6.6. BUNKERING HAZARD CATEGORIES	46
6.6.1 Non-fuel-specific hazards.....	46
6.6.2 Fuel-specific hazards	48
6.6.3 Use of hazard categories in bunkering.....	49
6.7. RISK EVALUATION AND SAFETY BARRIER PHILOSOPHY	49
6.7.1 Principles of risk evaluation	50
6.7.2 Safety barrier concept.....	50
6.7.3 Technical safety barriers	50
6.7.4 Operational safety barriers	50
6.7.5 Organisational safety barriers	51
6.7.6 Barrier independence and robustness.....	51
6.7.7 Traceability from hazards to controls	51
6.8. TECHNICAL SAFETY REQUIREMENTS FOR BUNKERING	52
6.8.1 Transfer equipment and material compatibility	52
6.8.2 Isolation, shutdown, and emergency release.....	52
6.8.3 Detection and monitoring systems	53
6.8.4 Electrical equipment and ignition source control.....	53
6.8.5 Area classification and controlled zones.....	53
6.8.6 Spill containment and drainage.....	54
6.8.7 Inspection, testing, and maintenance.....	54
6.9. OPERATIONAL CONTROL AND BUNKERING PROCEDURES.....	54
6.9.1 Planning and coordination.....	54
6.9.2 Pre-arrival and pre-transfer preparation	55
6.9.3 Connection and integrity checks	55
6.9.4 Control during transfer	56
6.9.5 Hold points and decision points	56
6.9.6 Stop work and deviation management.....	56
6.9.7 Completion, disconnection, and close-out	56
6.10. HUMAN FACTORS AND ORGANISATIONAL INTERFACES.....	57
6.10.1 Human-machine interface considerations.....	57
6.10.2 Workload, fatigue, and time pressure.....	57
6.10.3 Roles, responsibilities, and authority	58
6.10.4 Communication and coordination.....	58
6.10.5 Contractor and third-party management	58

6.10.6	<i>Learning, feedback, and continuous improvement</i>	58
6.11.	EMERGENCY PREPAREDNESS AND RESPONSE	59
6.11.1	<i>Emergency scenarios considered</i>	59
6.11.2	<i>Emergency shutdown philosophy</i>	59
6.11.3	<i>Response to leaks, fires, and toxic releases</i>	60
6.11.4	<i>Interface with port emergency services</i>	60
6.11.5	<i>Evacuation, muster, and exclusion zones</i>	61
6.11.6	<i>Drills, exercises, and readiness assurance</i>	61
6.12.	TRAINING, COMPETENCE AND ORGANISATIONAL READINESS	61
6.12.1	<i>Identification of roles requiring competence</i>	61
6.12.2	<i>Competence requirements and knowledge areas</i>	62
6.12.3	<i>Alignment with existing training frameworks</i>	62
6.12.4	<i>Practical training, drills, and exercises</i>	62
6.12.5	<i>Verification, records, and refresher training</i>	62
6.12.6	<i>Organisational readiness and maturity</i>	63
6.13.	INTERFACES WITH STORAGE AND USAGE DOMAINS	63
6.13.1	<i>Interface with Storage</i>	63
6.13.2	<i>Interface with Usage</i>	63
7.	STORAGE	65
7.1.	INTRODUCTION	65
7.2.	AMMONIA STORAGE	65
7.2.1	<i>Anhydrous and Aqueous Ammonia</i>	65
7.2.2	<i>Temperature and Pressure in Ammonia Storage</i>	66
7.2.3	<i>Vapour Space</i>	66
7.2.4	<i>Material Interactions</i>	67
7.2.5	<i>Metallic Materials</i>	67
7.2.6	<i>Stress Corrosion Cracking</i>	67
7.2.7	<i>Polymers, Seals and Gaskets</i>	68
7.3.	METHANOL STORAGE	68
7.3.1	<i>Vapour Space</i>	69
7.3.2	<i>Stress Corrosion Cracking</i>	69
7.3.3	<i>Galvanic Corrosion</i>	69
7.3.4	<i>Metallic Materials</i>	69
7.3.5	<i>Polymers, Seals and Gaskets</i>	69
7.4.	DIRECTIVES, REGULATIONS AND EXECUTIVE ORDERS	70
7.5.	CONCLUSIONS FOR STORAGE	73
8.	USAGE	75
8.1.	INTRODUCTION	75
8.2.	REGULATORY AND LEGISLATIVE FRAMEWORK	75
8.2.1	<i>STCW and IGF framework as training baseline</i>	76
8.2.2	<i>Interim guidance and equivalency approaches</i>	76
8.2.3	<i>Current regulatory position for ammonia and methanol</i>	76
8.3.	ALTERNATIVE MARINE FUELS AND HAZARD DRIVERS	76
8.3.1	<i>LNG framework as baseline</i>	76

8.4. GENERIC TRAINING REQUIREMENTS FOR SEAFARERS.....	77
8.4.1 Basic training – generic.....	77
8.4.2 Advanced training – generic.....	77
8.5. HAZARD PROFILES AND TRAINING REQUIREMENTS.....	78
8.5.1 Specialist training – ammonia.....	78
8.5.2 Specialist training – methanol.....	79
8.5.3 Role groups.....	79
8.6. CONCLUSIONS FOR USAGE.....	80
9. INTEGRATED EMERGENCY PREPAREDNESS, RESPONSE AND RECOVERY.....	82
9.1. INTRODUCTION	82
9.2. EMERGENCY PLANNING PROCESS.....	83
9.3. DANISH EMERGENCY RESPONSE INTERFACES	84
9.3.1 Municipal rescue service.....	84
9.3.2 Incident command.....	84
9.3.3 Chemical Emergency Response.....	85
9.3.4 Major accident establishments.....	85
9.3.5 Pollution within ports.....	85
9.4. ALARM, NOTIFICATION AND ESCALATION	85
9.5. SHUTDOWN AND ISOLATION	86
9.6. PROTECTION OF PERSONNEL AND PUBLIC	87
9.7. FUEL-SPECIFIC RESPONSE REQUIREMENTS.....	88
9.7.1 Methanol.....	88
9.7.2 Ammonia.....	88
9.7.3 Hydrogen.....	89
9.8. FIREFIGHTING, SPILL AND ENVIRONMENTAL RESPONSE	89
9.9. EMERGENCY EQUIPMENT AND RESPONDER INFORMATION.....	90
9.10. DRILLS, READINESS AND RECOVERY.....	91
9.11. REQUIRED OUTPUTS	92
10. GOVERNANCE, REGULATORY INTERFACES, DOCUMENTATION AND APPROVAL READINESS.....	93
10.1. INTRODUCTION.....	93
10.2. GOVERNANCE AND STAKEHOLDER MATRIX.....	93
10.3. DANISH REGULATORY AND APPROVAL SCREENING	94
10.3.1 Port requirements.....	95
10.3.2 Environmental approval.....	95
10.3.3 Workplace and ATEX requirements.....	95
10.3.4 Major accident requirements.....	95
10.4. ROLES AND DECISION RIGHTS	96
10.5. AUTHORITY ENGAGEMENT AND APPROVAL ROADMAP	97
10.6. DOCUMENTATION AND SAFETY JUSTIFICATION.....	98
10.7. INTERFACE AND SIMOPS MANAGEMENT.....	100

10.8. MANAGEMENT OF CHANGE	101
10.9. READINESS, AUDIT AND CONTINUED OPERATION	101
10.10. MINIMUM APPROVAL READINESS PACKAGE	102
10.11. RELATIONSHIP TO PRL-MF	103
11. SOCIETAL AND PUBLIC PERCEPTION	104
11.1. CURRENT STATUS.....	104
11.2. BUILDING INVOLVEMENT.....	105
11.3. CURRENT PERCEPTION.....	105
11.4. DEVELOPMENT OF INFORMATION STRATEGIES	106
11.5. CONCLUSIONS AND RECOMMENDATIONS.....	107
12. PORT READINESS LEVEL FOR MARINE FUELS.....	108
13. REFERENCES.....	110
ANNEX A.....	113
ANNEX B.....	114

List of Figures

<i>Figure 1 Risk Management Flowchart.....</i>	<i>27</i>
<i>Figure 2 Risk Assessment Matrix</i>	<i>29</i>

List of Tables

Table 1 Safety System Model	16
Table 2 Comparison of Key Properties of Green Fuels.....	22
Table 3 List of HAZID Actions.....	32
Table 4 Typical Compatibility of Gasket Materials.....	68
Table 5 Governance Table for Marine Fuel Storage.....	71
Table 6 Reference Table for Marine Fuel Storage.....	73
Table 7 List of Generic Basic Training Requirements	77
Table 8 List of Generic Advanced Training Requirements.....	78
Table 9 Comparative Hazard Drivers for Training	78
Table 10 List of Ammonia-specific Training Requirements	79
Table 11 List of Methanol-specific Training Requirements	79
Table 12 List of Role Groups and Key Competence Requirements	80
Table 13 Emergency Scenario and Response Matrix.....	83
Table 14: Emergency Escalation Model.....	86
Table 15: Emergency Exercise Program	91
Table 16 Typical Danish Port Stakeholders	93
Table 17: Applicability and Approval Register.....	96
Table 18: Approval Gates	98
Table 19: Hazard-to-Evidence Matrix	99
Table 20: Governance Outputs by PRL stage	103
Table 21 Port Readiness Level for Marine Fuels.....	108

Legal Notice

Neither DBI, FORCE Technology, Complete Solutions, Rønne Havn, MHO-Co and Aalborg University, nor any third-party contributors to the guideline is responsible for the use that may be made based on the information contained in this guideline.

Acknowledgements

This recommended practice guide was produced by the partnership in Innomission2, “Safe and Faster PtX implementation pathways” reporting to administration in Energy Cluster Denmark. The project has been a collaboration between DBI, FORCE Technology and four partners from the PtX industry.

The following is a list of companies/organisations who have contributed and who are acknowledged for their effort in the development of this guideline:

DBI, FORCE Technology, Complete Solutions, Rønne Havn, MHO-Co and Aalborg University.



1. Introduction

1.1. Purpose

The purpose of this guideline is to support fast and safe implementation of green fuel activities in ports by giving practical guidance for safe storage, bunkering and usage of methanol, ammonia and hydrogen-related fuel systems. It focuses on midstream and downstream port activities, including storage facilities, transfer systems, bunkering interfaces, operational controls, emergency preparedness, competence and approval evidence.

1.2. Scope

The scope of the guideline includes the following:

- Port-based storage of green fuels and related intermediate handling systems.
- Bunkering operations from truck, terminal, barge or other port-side supply arrangements to vessels.
- Port-relevant aspects of onboard fuel use, including the ship/shore interface, operational restrictions while alongside and crew/port coordination.
- Health, safety and environmental risk considerations for methanol, ammonia and hydrogen as relevant.
- Training, competence, emergency preparedness, public perception and stakeholder communication.
- Implementation planning using the port readiness tool PRL-MF as a self-assessment and maturity roadmap.

The following are not covered by the guideline:

- Use of fuels already covered by existing guidelines, including IMO (e.g. biodiesel, LNG).
- Detailed ship design approval, except where it affects port interface and bunkering safety.
- Detailed process plant design for upstream fuel production, except where production variability affects storage and logistics.
- Commercial fuel contracting, custody transfer disputes and market design beyond their safety relevance.
- A complete legal interpretation of Danish, EU or IMO requirements.

1.3. Methodology

The guideline was developed through the following:

- A comprehensive review of applicable legislation, relevant standards, and existing national and international guidance relating to the storage, bunkering, and use of green marine fuels.

- Site visits to the Port of Rotterdam, where discussions focused on the development and application of Port Readiness Levels (PRLs) for green marine fuel bunkering (see Chapter 12), and to the Port of Rønne, where practical arrangements for the storage, bunkering, and use of green fuels at a typical Danish port were examined.
- Adoption of a risk-based approach, as explained in Chapters 3 and 5 and informed by a Hazard Identification (HAZID) workshop (see Section 5.6) involving key stakeholders with practical experience in the design, operation, and regulation of port facilities. The workshop systematically identified and assessed how the properties and key hazard drivers associated with the green fuels considered within the project scope resulted in specific hazards during storage, bunkering and usage and thus providing the basis for the SafeSBU Guideline.
- Guidance on societal and public perception were developed from a review of the literature, existing public engagement initiatives, and local media coverage, supported by interviews and participatory workshops with port stakeholders, authorities, emergency services, and citizens' organisations. This evidence was used to develop the practical guidance found in Chapter 11 for transparent, effective communication and stakeholder engagement to support public confidence and societal readiness.

1.4. Primary Users

User group	How they should use this guideline
Port authority / port operator	Plan port policy, approval pathway, emergency coordination, zoning, public communication and PRL roadmap.
Storage / facility owner	Define storage design basis, safety barriers, inspection regimes, maintenance and approval evidence.
Bunker operator / supplier	Develop bunkering method statements, HAZID, procedures, SIMOPS controls and emergency response.
Shipowner / vessel operator	Align ship readiness, crew competence, receiving procedures and port interface requirements.
Authority / regulator	Review traceability from hazards to controls, approval evidence and stakeholder roles.
Emergency services	Understand scenarios, exclusion zones, response interfaces, drills and competence needs.
Training provider	Translate hazard profiles, procedures and role groups into training modules and drills.

1.5. How to Read the Guideline

This document presents a combination of cross-cutting guidance relevant across all port infrastructure and operations associated with green fuels (Chapters 4, 5, 9 to 12) and specific requirements associated with each domain of operations - bunkering, storage and usage respectively (Chapters 6, 7 and 8), although the overall approach to risk management and the barrier philosophy described in Chapter 6 is also applicable for all domains.

The content of each chapter is as follows:

- Chapter 3 describes the guidance framework, including the logic of the shared safety systems and common vocabulary.
- Chapter 4 outlines the key properties and associated hazard drivers associated with each of the fuels considered in this guideline.
- Chapter 5 summarises the risk management provides more detail on the risk-based approach to ensuring safe design and operations, including the HAZID workshop undertaken for the project.
- Chapters 6, 7 and 8 describe the specific requirements associated with bunkering, storage and usage respectively. It should be borne in mind that the focus and level of detail in each of the domain chapters is different. Chapter 6 provides guidance on how the shared system logic is applied, with specific reference to bunkering operations. Chapter 7 is focused on the technical requirements for containment in storage, while Chapter 8 describes the operational requirements for competence and training associated with the usage of the green fuels in ports.
- Chapter 9 summarises the overall requirements for integrated emergency response planning across domains.
- Chapter 10 provide guidance on governance and interfaces with external stakeholders
- Chapter 11 provides detailed guidance on managing societal and public perception across all domains.
- Chapter 12 provides guidance on planning and assessing port readiness, implementation, and preparing approval submissions.

2. Abbreviations

Abbreviation	Meaning
AB	Able Seafarer
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
ALARP	As Low as Reasonably Practicable
AR-AFFF	Alcohol Resistant Aqueous Film Forming Foam
ATEX	Explosive atmospheres (atmosphères explosibles)
AXBK	Specialised respirator cartridge designed to protect the user from a broad spectrum of hazardous gases and vapours
BEK	Danish Executive Order (Bekendtgørelse)
BLEVE	Boiling Liquid Expanding Vapour Explosion
BPR	Biocidal Products Regulation
CEN	Comité Européen de Normalisation
CLP	Classification, Labelling and Packaging
CMRD	Carcinogens, Mutagens and Reprotoxic Substances Directive
CPR	Cardiopulmonary Resuscitation
DK	Denmark / Danish
EMC	Electromagnetic Compatibility
EMSA	European Maritime Safety Agency
EPDM	Ethylene Propylene Diene Monomer
ETO	Electro-Technical Officer
EU	European Union
Ex	Explosion protection
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HDPE/LDPE	High/Low Density Polyethylene
HTW	Human element, Training and Watchkeeping
IAPH	International Association of Ports and Harbors
IGF Code	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
IMO	International Maritime Organization
IMPCA	International Methanol Producers and Consumers Association
ISPS	International Ship and Port Facility Security
LEL	Lower Explosion Limit
LHV	Lower Heating Value (Net Calorific Value)
LNG	Liquefied Natural Gas
LVD	Low Voltage Directive
MARPOL	International Convention for the Prevention of Pollution from Ships
MeOH	Methanol

Abbreviation	Meaning
MDO	Marine Diesel Oil
MD	Machinery Directive
MGO	Marine Gas Oil
MoC	Management of Change
MSC	Maritime Safety Committee
NFPA	National Fire Protection Association
NOx	Nitrogen Oxide
PPE	Personal Protective Equipment
PED	Pressure Equipment Directive
PP	Polypropylene
ppm	Parts per million
PRL-MF	Port Readiness Level for Marine Fuels
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
QRA	Quantitative Risk Assessment
RACI	Responsible, Accountable, Consulted, and Informed
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
SBU	Storage, Bunkering and Usage
SCBA	Self-Contained Breathing Apparatus
SCC	Stress Corrosion Cracking
SDS	Safety Data Sheet
SOLAS	International Convention for the Safety of Life at Sea
SGMF	Society for Gas as a Marine Fuel
SIMOPS	Simultaneous Operations
SOP	Standard Operating Procedure
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TCS	Tank Connection Space
TWA	Time Weighted Average
UEL	Upper Explosion Limit

3. Guidance Framework

This guideline should be read as a description of a system comprising continuously active layers. Safe and effective port fuel operation is achieved by the interaction of hazard understanding, risk evaluation, barriers, operational controls, emergency preparedness, competence, governance and public trust. These layers are defined in Table 1 below.

Storage, bunkering and usage have different technical and operational emphases, but they must operate as one safety system. The shared model makes the logic visible and allows stakeholders to trace hazards through to barriers, procedures, competence and approval evidence, as well as addressing societal and public perception.

While implementation of legislation, codes and standards gives good coverage for well-understood hazards and applications, however, they may not be sufficiently prescriptive for new or developing technologies or for specific applications, including the handling of green fuels discussed in this guideline. Furthermore, even a purely compliance-based approach contains requirements for hazard identification and assessment, to ensure that the requirements are implemented specifically for their application. A risk-based approach shall therefore be taken as part of the demonstration that the storage, bunkering and usage of green fuels is safe.

Table 1 Safety System Model

Layer	Meaning in SafeSBU	Typical evidence
1. Hazard understanding	Fuel properties, source terms, toxicity, flammability, pressure/temperature behaviour, material compatibility and operational deviations.	Fuel data, HAZID worksheets, SDS review, learnings from previous incidents.
2. Risk evaluation	Credible scenarios, consequence and likelihood assessment, acceptance criteria, ALARP or equivalent decision logic.	HAZID worksheets/risk register, QRA/consequence modelling, risk assessment matrix, decision records.
3. Safety barriers	Technical, operational and organisational barriers preventing, detecting, controlling or mitigating unwanted events.	Risk register, bowtie analysis, design documentation, inspection/maintenance plan.
4. Operational control	Procedures, permits, SIMOPS control, communication, stop work authority and management of change.	SOPs, SIMOPS plan, toolbox talk records, MoC logs.
5. Emergency preparedness	Scenario-based response, escalation, isolation, evacuation, firefighting/toxic cloud response and recovery.	Emergency response plan, drills, mutual aid arrangements.
6. Competence and organisation	Role definition, training, authority, supervision, contractor management and organisational readiness.	Training matrix, competence records, role descriptions.

Layer	Meaning in SafeSBU	Typical evidence
7. Governance and external interfaces	Regulation, approvals, class/authority/port conditions, stakeholder responsibility and compliance evidence.	Approval roadmap, permits, interface agreements, audit trail.
8. Societal and public perception	Cross-cutting layer affecting legitimacy, transparency, trust and acceptance of port fuel activities.	Stakeholder plan, public information, complaints/feedback process.

Each of the layers is summarised in the following sections, while Chapter 6 provides a detailed illustration of how the shared system logic is applied with specific reference to bunkering operations.

3.1. Hazard Understanding

Systematic hazard identification is a fundamental element of risk management, as it provides the basis for defining safety barriers, operational limits, procedures, and competence requirements, based on the hazards present. The objective of the hazard identification framework is to ensure that all credible hazards are identified in a systematic and transparent manner.

In this way, hazard identification forms a continuous thread through port operations, ensuring traceability from the identified hazards to concrete risk controls and operational guidance. Proactive, systematic and timely identification of hazards enables the application of the most effective control measures in order to achieve acceptable risks.

The output of the hazard identification process should be a structured set of identified hazards linked to specific plant areas and operational phases, interfaces, and contributing factors. These outputs are used directly as inputs to:

- evaluation of risks,
- definition of safety barriers,
- specification of technical and operational requirements,
- development of procedures, training, and emergency preparedness.

Chapter 4 provides an overview of the properties and key hazard drivers associated with methanol, ammonia and hydrogen. The overall risk management process is described in more detail in Chapter 5, including a summary of a HAZID study undertaken as part of the SafeSBU project.

3.2. Risk Evaluation

Risk evaluation is part of a structured decision-making process to determine how the hazardous scenarios identified (see Section 3.1) can be effectively managed to an acceptable level. Risk evaluation considers both the credible consequences of the identified hazardous events (taking into account potential escalation) and the likelihood of their occurrence.

The results of the risk evaluation process are used to inform the requirements for the safety barriers described in the following section. Risk evaluation is described as part of the overall risk management process in Chapter 5

3.3. Safety Barriers

In the layered safety philosophy described in this guideline, safety is achieved through multiple, complementary safety barriers designed to prevent the occurrence of hazardous events and to mitigate their consequences should prevention fail.

Safety barriers are grouped into three main categories:

- Technical barriers, which rely on physical or engineered features (e.g. facility layout, materials, ignition control, firefighting, emergency equipment);
- Operational barriers, which rely on procedures and active control during operations (e.g. planning, SOPs, MoC, stop work authority);
- Organisational barriers, which rely on management systems, competence, and governance (e.g. role definition, training and qualifications, safety management systems).

There shall be a clear link between the identified hazards (see Sections 3.1 and 3.2) and the barriers intended to control them. This ensures that the requirements for these barriers are based on a systematic understanding of risks rather than relying on generic best practice.

Chapter 6 provides an illustration of how safety barriers have been applied to bunkering activities, while Chapter 7 provides more information on application of technical barriers for storage, with a focus on preventative controls.

3.4. Operational Control

Operational control ensures that technical systems and safety barriers are used within their intended operating limits and that activities are carried out in a planned, coordinated and repeatable manner. Operational controls are particularly important for green fuel activities because storage, transfer, bunkering and onboard operations involve interfaces between different systems, organisations and personnel.

Operational controls should be developed from the results of the hazard identification and risk evaluation and should address normal, non-routine and abnormal operating conditions. These may include:

- Standard operating procedures (SOPs) and checklists;
- Defined operating limits and operational envelopes;
- Permits to work and activity-specific authorisations;
- Planning and coordination of simultaneous operations;
- Pre-operation meetings, toolbox talks and readiness checks;
- Defined hold points requiring positive confirmation before proceeding;
- Continuous monitoring and communication during safety-critical activities;
- Stop work authority;
- Management of deviations, interruptions and abnormal conditions;
- Safe shutdown, completion and return to normal operation;
- Management of change (MoC).

Responsibilities for implementing and verifying operational controls should be clearly allocated. All parties involved in an activity should have a common understanding of the operating sequence, applicable limits, communication arrangements and conditions requiring the activity to be stopped.

Operational controls should be reviewed following incidents, near misses, significant deviations, changes to equipment or procedures, and lessons learned from operations.

Chapter 6 provides a detailed illustration of how operational control is applied to bunkering activities.

3.5. Emergency Preparedness

Emergency preparedness provides the arrangements required to limit the consequences of a hazardous event where preventive and control barriers are unsuccessful. Emergency arrangements should be based on the credible scenarios identified through the hazard identification and risk evaluation process and reflect the properties of the fuel, the facility layout, the operating concept and the potential effects on personnel, neighbouring activities, the environment and members of the public.

Emergency preparedness should be integrated across storage, bunkering and usage, as well as with the overall emergency arrangements of the port. The objective is not necessarily to establish a single emergency plan for all organisations, but to ensure that individual plans are compatible and that responsibilities are clearly defined. The arrangements should identify:

- Who raises the alarm and initiates emergency shutdown;
- Who isolates the fuel and places the system in a safe condition;
- Who commands the initial response;
- Who evacuates or shelters personnel and accounts for them;
- Who contacts the port, authorities and external emergency services;
- Who manages environmental consequences;
- Who communicates with neighbouring facilities and the public;
- Who authorises recovery and restart.

Emergency response measures should be fuel-specific. Methanol scenarios may require ignition control, detection of low-visibility flames, alcohol-resistant foam and contaminated-water management. Ammonia scenarios require particular emphasis on toxic cloud monitoring, respiratory protection, evacuation or sheltering, decontamination and control of contaminated water. Hydrogen scenarios require rapid isolation, ignition control, gas detection, ventilation and prevention of escalation from leaks or jet fires.

In the Danish context, emergency arrangements should be coordinated with the relevant municipal rescue service, port emergency arrangements, police, health services and environmental or pollution response organisations, as applicable. Emergency preparedness should be demonstrated through training, functional testing, drills and joint exercises. Chapter 9 provides further guidance on integrated emergency preparedness, response and recovery.

3.6. Competence and Organisation

Competence and organisational readiness are essential for ensuring that technical and operational safety barriers function as intended. The effectiveness of procedures, detection systems, emergency shutdown arrangements and emergency plans ultimately depends on personnel being able to understand the hazards, recognise deviations and take appropriate action.

Competence requirements should be defined for all roles that can influence the safety of green fuel activities. These may include:

- Storage and terminal personnel;
- Bunkering operators and fuel suppliers;
- Shipboard personnel;
- Supervisors and responsible managers;
- Port authority or port operator personnel;
- Contractors and temporary personnel;
- Maintenance and inspection personnel;
- Emergency responders.

Training should be role-based and proportionate to the responsibilities of the individual. It should include, as relevant:

- Fuel-specific properties and hazards;
- Operating limits and safety barriers;
- Normal and abnormal operating procedures;
- Use of PPE and emergency equipment;
- Detection, alarms, shutdown and isolation;
- Communication and coordination at organisational interfaces;
- Stop-work and escalation arrangements;
- Emergency response, evacuation and sheltering;
- Environmental response requirements.

Existing maritime, port and company training frameworks should be used where applicable, with supplementary training provided where they do not adequately address the properties of methanol, ammonia or hydrogen or the specific port–ship interfaces.

Competence should be verified before personnel undertake safety-critical activities and should be maintained through practical training, supervision, drills, exercises and periodic refresher training. Training and competence records should be maintained, and additional training provided following significant changes, incidents, near misses or identified performance gaps. Chapters 6 and 8 provide more detailed guidance on competence requirements for bunkering and onboard fuel usage.

3.7. Governance and External Interfaces

Governance ensures that responsibilities, decision rights, approvals and external interfaces are clearly defined throughout the lifecycle of a green fuel project. This is particularly important in ports, where storage, transport, bunkering, ship operations and emergency response may be managed by separate organisations operating under different regulatory and contractual arrangements.

The governance arrangements should identify:

- The project owner, asset owner, and operating organisation;
- The port authority or port operator;
- The storage and terminal operator;
- The bunker supplier and bunkering operator;
- The shipowner, master, and shipboard representatives;

- Owners of hazards and safety barriers;
- Persons authorised to approve, stop and restart operations;
- Relevant authorities, emergency services, and independent verifiers.

A responsibility matrix, such as a RACI matrix, should be used where appropriate to distinguish between the party carrying out an activity, the party accountable for the result, parties that must be consulted and parties that must be informed.

Regulatory and approval requirements should be identified at an early stage and reviewed as the project develops. In the Danish context, relevant interfaces may include the port, municipality, environmental authorities, municipal rescue service, Beredskabsstyrelsen, Danish Working Environment Authority, Danish Maritime Authority, flag State and classification society, depending on the activity and its regulatory classification.

Governance should also address:

- Authority engagement and approval planning;
- Port-specific conditions and operating permissions;
- Ship/shore and organisational interface agreements;
- SIMOPS approval;
- Emergency response interfaces;
- Access control and security responsibilities;
- Documentation and compliance evidence;
- Management of change;
- Audit, assurance and continued operational readiness.

Regulatory or port approval does not transfer responsibility for safe operation to the approving authority. Each operator remains responsible for managing its activities safely and complying with applicable approval conditions. Chapter 10 provides further guidance on governance, documentation, external interfaces and approval readiness.

3.8. Societal and Public Perception

Societal and public perception is a cross-cutting layer that influences trust, transparency, and the social legitimacy of port fuel activities. While it does not directly reduce technical risk, it shapes how stakeholders and members of the public understand and accept safety measures, risk management, and operational decisions.

A case study based on interviews and workshops undertaken around the Port of Rønne shows that citizens are generally supportive of the green transition but are concerned about potential impacts, including noise, traffic, air quality, and the impact of future developments. The study also revealed that citizens tend to view the port as a single entity rather than as separate projects and operators. As a result, trust depends not only on technical safety performance but also on clear, continuous, and coordinated communication.

Within the SafeSBU framework, public perception should therefore be considered an integral part of safety governance, linking technical and operational safety with transparency, stakeholder engagement, and public acceptance. Chapter 11 provides more details of the methodology and conclusions of the societal and public perception study undertaken for the SafeSBU Project.

4. Fuel Properties and Key Hazard Drivers

4.1. General

The physical and chemical properties of a fuel largely determine the hazards associated with its storage, transfer, bunkering, and onboard use. Consequently, the selection of safety measures, operational procedures, emergency response arrangements, and technical barriers should be based on the intrinsic properties of the fuel, rather than simply applying a common approach for all fuels.

Although methanol, ammonia, and hydrogen are all considered promising low or zero-carbon marine fuels, their hazard profiles differ significantly. Methanol is primarily characterised by its low flash point and toxicity, ammonia by its high toxicity and corrosive properties, and hydrogen by its high flammability, low ignition energy, and storage requirements. These differences require fuel-specific risk assessments and corresponding engineering and operational controls.

Table 2 below summarises the principal physical and safety-related properties of the fuels considered in this guideline. The data are intended to illustrate the key hazard characteristics influencing safe storage, bunkering, and onboard usage. The values are indicative only and should not replace verified design data during engineering, risk assessment, or regulatory approval.

Table 2 Comparison of Key Properties of Green Fuels

Property	Methanol	Ammonia	Hydrogen
Chemical formula	CH ₃ OH	NH ₃	H ₂
Typical storage condition	Liquid at ambient temperature and atmospheric pressure	Fully refrigerated liquid (-33°C and 1bar), or semi-refrigerated liquid (-9~to 4°C and 2~4 bar), or pressurised (Ambient temperature and 7~18 bar)	Compressed gas or cryogenic liquid
Boiling point (°C at 1 bar)	64.7	-33.3	-252.9
Lower heating value (MJ/kg)	19.9	18.6	120
Flash point (°C)	11–12	Not generally considered applicable for safety design	Not applicable (gas)
Flammable range in air (vol.%)	6–36	15–28	4–75
Auto-ignition temperature (°C)	~470	~650	~585
Minimum ignition energy (mJ)	Moderate (0.14)	Relatively high (380 to 680)	Extremely low (~0.02)

Property	Methanol	Ammonia	Hydrogen
Vapour behaviour after release	Vapours may accumulate in poorly ventilated spaces	Cold vapour cloud may remain near ground before dispersing	Rapid upward dispersion outdoors; accumulation possible in enclosed high-level spaces
Toxicity	Toxic	Highly toxic	Non-toxic (asphyxiation hazard in confined spaces)
Corrosivity	Low	High toward certain materials	May cause hydrogen embrittlement
Principal safety concern	Fire and toxic exposure	Toxic release	Fire and explosion

4.2. Methanol

Methanol is a low-flashpoint, toxic, water-miscible liquid that can be stored and transferred at ambient temperature and atmospheric pressure. Compared with conventional marine fuels, its relatively low flash point increases the likelihood of forming flammable vapour-air mixtures, requiring effective ignition control during storage and bunkering operations.

The principal hazards associated with methanol include:

- ignition of flammable vapours;
- low-visibility flames during combustion;
- toxic exposure through inhalation, ingestion, eye contact, or skin absorption;
- spill migration due to complete miscibility with water;
- accumulation of vapours in enclosed or poorly ventilated spaces;
- static electricity generated during fuel transfer; and
- incompatibility with certain materials, seals, coatings, and gaskets.

Consequently, methanol facilities should incorporate effective ignition source control, bonding and earthing of transfer equipment where applicable, leak detection, ventilation, compatible materials, spill containment, suitable firefighting systems using alcohol-resistant foam, and appropriate personal protective equipment (PPE). Operational procedures should include controlled connection and disconnection, emergency shutdown, spill response, and medical treatment arrangements.

4.3. Ammonia

Ammonia is a toxic, corrosive chemical which is normally stored either as a fully refrigerated liquid, under semi-refrigerated conditions, or pressurised. Unlike methanol, the dominant hazard associated with ammonia is not flammability but the potential release of toxic vapour capable of affecting personnel onsite (or onboard) or outside the facility.

Additional hazards include corrosive effects on materials and human tissue, cold burns caused by refrigerated liquid, pressure increase due to boil-off and limited, but credible, fire and explosion hazards under certain conditions.

The principal hazards associated with ammonia include:

- toxic vapour release,
- inhalation exposure,
- chemical and cold burns,
- pressure and temperature management,
- boil-off gas generation,
- release from pressure relief systems,
- material compatibility issues,
- environmental contamination following accidental release,
- potential consequences for surrounding communities.

Accordingly, ammonia installations should prioritise prevention of loss of containment through robust system design, secondary containment and leak mitigation measures, toxic gas detection, automatic isolation, controlled ventilation and dispersion, compatible construction materials, emergency shutdown systems, respiratory protection, decontamination facilities, and comprehensive emergency response planning. Because toxic effects may occur at concentrations significantly below the flammable range, prevention and control of toxic releases constitute the primary safety objective.

4.4. Hydrogen

Hydrogen may be stored as compressed gas, cryogenic liquid, or in other engineered storage systems depending on the application. Although hydrogen offers significant potential as a zero-carbon energy carrier, its physical properties introduce hazards that differ substantially from those associated with liquid fuels.

Hydrogen is characterised by an extremely low ignition energy, a wide flammable range, high flame propagation speed, and a strong tendency to leak through very small openings because of its low molecular weight. When stored as a liquid, additional cryogenic hazards arise, while high-pressure storage systems introduce mechanical hazards and specific material compatibility considerations, including hydrogen embrittlement.

The principal hazards associated with hydrogen include:

- high-pressure releases;
- rapid formation of flammable mixtures;
- jet fires;
- flame invisibility;
- accumulation in enclosed or elevated spaces;
- cryogenic hazards associated with liquid hydrogen;
- material degradation caused by hydrogen embrittlement; and
- rapid pressure rise in confined spaces.

Safe hydrogen installations should therefore emphasise leak prevention, suitable material selection, effective ventilation, hydrogen-specific gas detection, ignition source control, pressure relief systems, emergency isolation, separation distances, and appropriate operational competence and training.

While hydrogen has the potential to be used as a fuel in the maritime sector, the large storage volumes required for its use as fuel may limit its application on a larger scale. For this reason, the specific requirements related to hydrogen and its properties have not been considered in detail in this guideline. Nevertheless, the general guidance for the safe storage, bunkering and use of green fuels described in this document also applies to hydrogen.

4.5. Summary

Although methanol, ammonia, and hydrogen are all considered alternative marine fuels, their dominant hazards differ considerably and therefore require different safety philosophies.

Methanol safety primarily focuses on preventing ignition and managing toxic liquid spills. Ammonia safety is governed by preventing and mitigating toxic releases and ensuring effective emergency response. Hydrogen safety is dominated by leak prevention and control of fire and explosion hazards associated with high-pressure or cryogenic systems.

Accordingly, risk assessments, implementation of technical safeguards, operational procedures, and emergency preparedness should be developed based on the properties of the fuel rather than applying identical safety measures across all fuel types.

5. Hazard Identification and Risk Evaluation

This section describes the application of a risk-based approach to informing and optimising the design and operations associated with the storage, bunkering and usage of green fuels in port facilities, and how a systematic process of hazard identification, risk assessment and risk management may be used to demonstrate safety.

There are two basic approaches to demonstrating safety:

- Prescriptive (compliance-based) approach
- Risk-based approach.

The first of these involves ensuring that design and operations are compliant with applicable legislation codes and standards and the incorporation of best engineering practice. While this approach gives good coverage for well-understood hazards and applications, however, it may not be sufficiently prescriptive for new or developing technologies or for specific applications and interactions with other systems. Furthermore, even a prescriptive approach contains requirements for hazard identification and risk assessment, to ensure that the requirements are implemented correctly for their specific application. A systematic risk-based approach should therefore be taken to ensuring that hazards understood and risks are managed. The principles of this risk-based approach are as follows:

- All hazards shall be identified, assessed, understood and controlled.
- A suitable combination of risk reduction measures (prevention, detection, control and mitigation, both technical and operational/organisational) shall be provided to manage risks at an acceptable level throughout the operational lifecycle.
- All systems provided to protect people, and the environment shall be suitable for the expected hazardous scenarios against which they are designed to protect.
- Adequate means of escape shall be available for personnel in all circumstances.
- Any changes to the design or operation which may impact the risk, or introduce new hazards, shall be assessed as part of a robust Management of Change (MoC) process.

A risk-based approach should be an integral part of the design and operational planning process and not used simply to confirm decisions already made.

The steps involved in the risk management process are summarised below and described in the following sections.

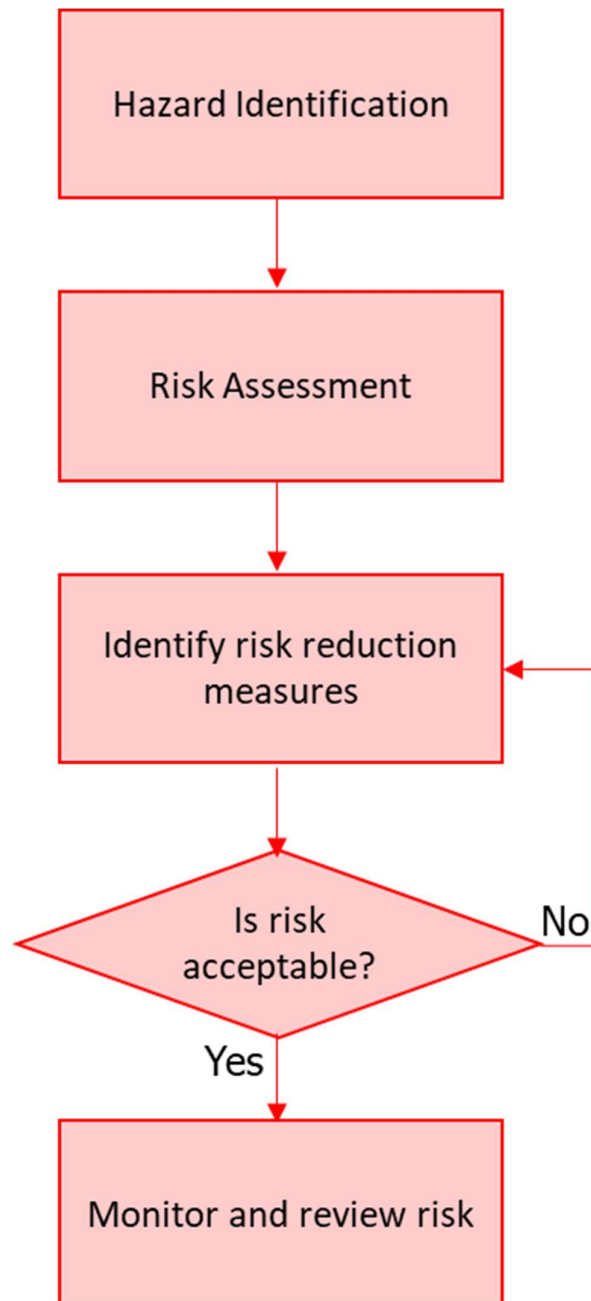


Figure 1 Risk Management Flowchart

5.1. Hazard Identification

The aim of this step is to ensure that all hazards associated with a system (e.g. plant or operation) are identified and the associated risks assessed, and to identify potential measures for risk reduction.

The process begins by defining the system to be studied and its boundaries and interfaces. The process is then used to identify the following:

- The causes of a hazardous event (including technical causes and human or organisational contributors, as well as external hazards and more general threats, such as sabotage and IT security which, while not explicitly associated with the introduction of green fuels, could lead to hazardous events involving a loss of containment of such fuels.
- The consequences of a hazardous event (e.g. fire or explosion, toxic release, as well as possible escalation to other areas of the port, ships, the environment, or neighbouring facilities or members of the public).
- The barriers for preventing a hazardous event or mitigate the consequences of such an event should it occur.

Various methods for hazard identification may be used (e.g. HAZID, HAZOP, as well as lessons learned from previous incidents). Hazard identification should not be undertaken solely as a desktop exercise but should involve a dialogue between suitably experienced subject matter experts, typically in the form of a workshop to ensure a systematic and focused approach and ensure collaboration between relevant disciplines.

Early identification of hazards enables the application of the most effective control measures to achieve acceptable risks. A hazard identification study conducted during the early phases can be used to identify significant hazards and thus provide early input to layout and the requirements for fire and explosion protection and emergency response. It can also be used to plan further risk evaluation activities where more detail is required, including modelling of the consequences of fires, explosions or toxic releases.

A HAZID study was undertaken as part of the SafeSBU project to provide an illustration of the hazard identification process to be followed by designers and operators of port facilities handling green fuels. The HAZID is summarised in Section 5.6 and described in detail in Annex A.

5.2. Risk Evaluation

Two types of risk evaluation may be used, namely (i) qualitative risk assessment and (ii) quantitative risk assessment (QRA), depending on the level of details required.

5.2.1 Qualitative Risk Assessment

A risk assessment matrix is typically used during hazard identification studies to provide a risk scoring for each hazard. This is a simple matrix used to define the level of risk associated a hazardous event by considering its likelihood and consequence and thus to provide a qualitative assessment of the risk. This enables the most significant risks to be prioritised and to identify the need for preventative or mitigative barriers.

A typical risk assessment matrix is shown in Figure 2 below. Clear definitions should be provided for the likelihood, consequence, and risk categories to reduce subjectivity and ensure consistency.

			Frequency				
			F1	F2	F3	F4	F5
Consequences			Unlikely	Less likely	Possible	Likely	Very likely
Consequences	C5	Catastrophic					
	C4	Serious					
	C3	Significant					
	C2	Less significant					
	C1	Negligible					

Figure 2 Risk Assessment Matrix

5.2.2 Consequence Modelling and QRA

While qualitative assessment described in the previous section can enable the most significant risks to be prioritised and provide an indication of whether risks have been reduced to an acceptable level, major accident hazards (e.g. fire, explosion, toxic release) may be subject to detailed consequence analysis or quantitative risk assessment (QRA).

Modelling of the potential consequences of significant hazardous events (e.g. gas dispersion, heat radiation, explosion overpressure etc.) may be used to determine possible impact on workers, adjacent or neighbouring infrastructure, third parties and members of the public.

QRA may also be used to combine the consequences of a hazardous event with analysis of the frequency and the probabilities that an event escalates leading to different consequences, to assess the overall risk to workers or to third parties.

The layout, spacing and orientation of a plant can have a significant effect on the consequences of fires, explosions and toxic releases, including the possibility of escalation, as well as the availability and effectiveness of risk reduction measures. Possible layout options should therefore be evaluated, using consequence modelling and/or QRA where appropriate, and the results used to optimise the layout and orientation (including spacing of equipment, location of escape routes), and to inform the requirements for safety systems (e.g. ventilation to safe location, fire and gas detection, fire and explosion protection).

Various approaches are available for consequence analysis and QRA from the use of simple dynamics equations to use of modelling tools. Software is available to model the effects of a hazardous event and illustrate the consequences of a hazardous event at different locations which can be translated into the effects on humans, assets or equipment. The choice of approach depends on the level of accuracy required.

5.3. Risk Control and Mitigation

Once hazards have been identified and the associated risk assessed, preventative and mitigative controls should be identified to reduce to an acceptable level. Risks shall be managed using the following hierarchy of controls, arranged from the most effective to the least.

- 1 Eliminate: Remove the hazard completely.
- 2 Substitute: Replace the hazard with something less dangerous (e.g. less toxicity, lower operating parameters (temperature, pressure etc.) or optimise the layout to reduce the risk.
- 3 Engineering Controls: Use technical measures or safeguards to control the hazard or limit its consequences (e.g. ignition source control ventilation, fire and gas detection, suppression systems).
- 4 Operational controls: Change the way work is carried out through procedures, training or emergency response.
- 5 Personal Protective Equipment (PPE): Provide equipment that offers individual protection.

5.4. Demonstration of Risk Acceptance

Some risk is inherent to the design and operation and cannot be eliminated entirely. It is therefore necessary to determine whether the risk is acceptable, or whether further risk reduction is required. To do this, the estimated risk should be compared with defined risk acceptance criteria. These criteria may be defined by applicable legislation, by the operating company or for a specific project, and may be expressed qualitatively (using a risk acceptance matrix) or quantitatively, in terms of risk to individual workers or to third parties or members of the public. If the risk does not meet the defined criteria, then further risk reduction measures must be implemented to reduce the risk further.

One criterion for determining whether a risk is acceptable is by demonstrating that the risk is as low as reasonably practicable (ALARP). For a risk to be ALARP, it must be demonstrated that the cost of implementing further barriers, in terms of money, time and effort, is grossly disproportionate to the benefit gained, in terms of lifetime risk reduction (i.e. the benefit gained does not justify the cost). Compliance with applicable legislative requirements and use of best engineering practice must also be demonstrated for a risk to be ALARP.

In simple terms, if the assessment has been through the process of identifying risk reduction measures in line with the hierarchy of controls described in Section 5.3 and no further risk reduction measures can be identified, then the risk may be considered ALARP. If there is doubt as to whether a risk reduction measure is justified on safety cost benefit grounds, then detailed more detailed risk assessment and cost benefit analysis may be required.

5.5. Risk Review

The final step in the risk management process is the continued monitoring and review of the preventative and mitigating barriers during the system lifecycle to ensure that they remain operational and are able to meet their requirements effectively. These barriers should also be reviewed in the event of any changes to plant and its operation, as part of a robust MoC process. This applies to non-technical systems for prevention and mitigation of accident scenarios (e.g. processes and instructions, competency and training of personnel) as well as technical systems (e.g. layout, equipment, safeguarding systems).

5.6. Project HAZID

A HAZID study was undertaken as part of the SafeSBU project to identify and qualitatively assess hazards associated with the storage, bunkering and usage of green fuels in ports and green-fuelled ships within the port area. The scope, methodology and the results of the HAZID are described in detail in Annex A and summarised below.

The scope of the HAZID was the identification and qualitative assessment of major accident hazards (i.e. those with the potential to result in fires, explosions or releases of hazardous (e.g. flammable or toxic) inventories, leading to possible fatalities or serious (i.e. irreversible) injuries, major environmental impact, major asset damage/long-term shutdown or significant reputational impact) associated with the storage, bunkering and usage of methanol and ammonia in ports and in methanol or ammonia-fuelled ships within the port area, along with the associated causes and consequences of a loss of control of such hazards, and the identification of measures for prevention or mitigation of such a loss of control.

Hazard identification should also consider general hazards such as security (e.g. sabotage and IT security), which, while not explicitly associated with the introduction of green fuels, could lead to hazardous events involving a loss of control of such fuels. Suitable controls (include access control, security responsibility, and functional risk assessment to identify required cybersecurity controls) should be implemented to ensure such risks are managed.

The objective of the HAZID was to provide a systematic approach to hazard identification and assessment, to identify the issues which define the requirements for the prevention or mitigation of a loss of control of those hazards, with the aim of providing a risk-based foundation for the development of this guideline for safe storage, bunkering and usage of green fuels. The HAZID also provides an illustration of the hazard identification process to be followed by designers and operators of port facilities or operations associated with the scope.

The HAZID was attended by key subject matter experts involved in the design and operation of storage, bunkering and usage of green fuels in ports.

It should be emphasised that the HAZID was undertaken at a generic level, based on a typical port facility, and is not intended to be an exhaustive assessment of hazards which could arise at specific facilities or during specific operations. It should not be used as a substitute for undertaking a specific HAZID for each port facility or operation.

A number of actions were raised during the HAZID as examples of areas where more specific preventative controls or mitigation may be required, or where more detailed risk evaluation should be used to define specific requirements for port operations. These actions are summarised in Table 3 below, together with references to relevant sections of the guideline.

Table 3 List of HAZID Actions

No.	HAZID action	Relevant section(s)	Why the reference is relevant
1. Storage			
1	Provide oil company procedures for fuel receipt.	6.9.1 Planning and coordination; 6.9.2 Pre-arrival and pre-transfer preparation; 6.9.3 Connection and integrity checks	These sections describe planning, verification of documentation and equipment, pre-transfer meetings and connection checks. Although written for bunkering, the same operational control logic is relevant to ship-to-storage receipt. The procedures themselves were provided as supporting information rather than a guideline requirement.
2	Specify requirements for security restrictions for fuel receipt area and ensure receipt is within an ISPS area.	3.7 Governance and External Interfaces; 6.3 Governance, Roles and Approval Context; 7.4 Directives, Regulations and Executive Orders; 10 Governance, Documentation and Approval Readiness	The action concerns access restrictions, port security boundaries and approval responsibility rather than fuel properties which are described as part of governance.
3	Specify undertaking of consequence modelling of tanker BLEVE.	5.2.2 Consequence Modelling and QRA; 7.2.2 Temperature and Pressure in Ammonia Storage	Section 5.2.2 establishes the need for consequence modelling for fire, explosion, toxic dispersion and layout decisions. Section 7.2.2 explains temperature rise, pressure escalation, refrigeration failure and that such incidents should be subject to risk assessment.
4	Provide example drawings of transfer schematics for fuel receipt.	6.2 Scope, Definition and System Boundaries; 6.4 Bunkering Concepts and Operational Interfaces; 6.8.1 Transfer Equipment and Material Compatibility	These sections define transfer-system boundaries and interfaces. The drawings were provided as supporting project input, rather than a guideline requirement.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
5	Specify use of risk assessment to identify requirements for additional gas detection/monitoring (general requirement throughout port).	5.1 Hazard Identification; 5.2 Risk Evaluation; 5.3 Risk Control and Mitigation; 6.8.3 Detection and Monitoring Systems; 7.1 Introduction	The guideline states that detection should depend on the fuel and bunkering concept and include gas/vapour detection, leak detection and monitoring. Referencing the risk assessment sections makes it clear that detector type, number and location must arise from credible release scenarios rather than generic provision.
6	Investigate possible means of suppressing ammonia leakage during transfer from tanker to storage (e.g. water curtains, dry fog).	4.3 Ammonia; 5.3 Risk Control and Mitigation; 6.11.3 Response to Leaks, Fires and Toxic Releases; 7.1 Introduction, 9 Integrated Emergency Preparedness	The fuel properties chapter establishes toxic cloud and corrosive hazards, while the risk control and emergency sections provide the decision framework for engineered suppression.
7	Specify the need to ensure dispersion modelling is undertaken to identify safe location for venting (general requirement throughout port).	5.2.2 Consequence Modelling and QRA; 7.2.2 Temperature and Pressure; 7.2.3 Vapour Space; 9 Integrated Emergency Preparedness	Section 5.2.2 identifies gas dispersion modelling as a means of assessing impacts on workers, infrastructure and the public.
8	Consideration to be given to possibility of underground storage.	5.2.2 Consequence Modelling and QRA; 5.3 Risk Control and Mitigation; 7.1 Storage Introduction; 7.4 Directives, Regulations and Executive Orders	Underground storage is a layout and substitution/engineering-control option. Its suitability should be evaluated against leak detection, secondary containment, access, inspection and applicable Danish requirements.
9	Specify that requirements for gas detection in storage area are to be based on assessment of likely leak sources.	3.1 Hazard Understanding; 5.1 Hazard Identification; 5.2.2 Consequence Modelling and QRA; 7.1 Introduction.	As Action 5

No.	HAZID action	Relevant section(s)	Why the reference is relevant
10	Consider requirements for ESD on gas detection in storage area (how initiated, necessary actions - e.g. stop all activities and ignition sources).	3.3 Safety Barriers; 5.3 Risk Control and Mitigation; 6.8.2 Isolation, Shutdown and Emergency Release; 6.11.2 Emergency Shutdown Philosophy	Sections 6.8.2 and 6.11.2 address isolation, shutdown initiation, fail-safe behaviour and integration with procedures. These principles are transferable to storage.
11	Define requirements for suitable firefighting measures in storage area (e.g. including AR-AFFF and required water capacity).	4.2 Methanol; Key Hazard Drivers and Associated Technical Barriers; 6.11.3 Response to leaks, fires, and toxic releases; 9 Integrated Emergency Preparedness	The guideline identifies AR-AFFF as a key methanol barrier and notes that methanol storage requires foam-type protection.
12	Investigate possible solutions for ammonia suppression in storage area (e.g. water curtains), including requirements for effluent disposal.	4.3 Ammonia; 6.8.6 Spill Containment and Drainage; 6.11.3 Response to leaks, fires, and toxic releases; 7.2 Ammonia Storage; 9 Integrated Emergency Preparedness	Suppression can reduce airborne ammonia but creates contaminated liquid requiring containment and disposal. Referencing both emergency response and drainage is necessary, so the measure is not treated independently of its secondary environmental consequences.
13	Investigate possible requirements for ammonia shelter in storage area.	4.3 Ammonia; 5.2.2 Consequence Modelling and QRA; 6.11.3 Response to leaks, fires, and toxic releases; 6.11.5 Evacuation, Muster and Exclusion Zones; 9 Integrated Emergency Preparedness	Whether a shelter should be put in place is appropriate depends on toxic-cloud scenarios, warning time, escape feasibility and shelter location. It is therefore linked to the outcome of dispersion modelling and emergency strategy selection rather than specifically prescribed.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
14	Consider requirements for redundancy of ammonia storage cooling system.	5.3 Risk Control and Mitigation; 7.2.2 Temperature and Pressure in Ammonia Storage; 7.2.3 Vapour Space	Section 7.2.2 explains that refrigeration failure raises evaporation and tank pressure and may contribute to BLEVE. This directly supports a risk-based determination of redundancy, backup power, alternative heat removal and relief capacity.
15	Specify undertaking of consequence modelling of storage BLEVE.	5.2.2 Consequence Modelling and QRA; 7.2.2 Temperature and Pressure.	See Action 3.
16	Consider requirements for disposal of liquid effluents used for firefighting/toxic release suppression.	5.3 Risk Control and Mitigation; 6.8.6 Spill Containment and Drainage; 7.2/7.3 Storage; 9 Integrated Emergency Preparedness	The bunkering chapter specifies requirement for controlled drainage and safe collection and disposal of contaminated material.
Bunkering			
17	Investigate whether provision of the double wall piping is mandatory for fuel transfer to bunkering stations.	6.7 Risk Evaluation and Safety Barrier Philosophy; 6.8.1 Transfer Equipment and Material Compatibility.	Double-walled piping is a containment barrier decision which should be selected through risk assessment based on location, release consequences, detection and inspectability.
18	Investigate the instrumentation in the fixed pipeline from the storage to the bunkering station, including pressure relief valves.	6.8.2 Isolation, Shutdown and Emergency Release; 6.8.3 Detection and Monitoring; 6.9.4 Control During Transfer	These sections describe requirements for pressure relief, isolation, ESD and monitoring of pressure, temperature and flow.
19	Investigate requirements for gas detection in vicinity of transfer pipeline to bunkering station.	6.8.3 Detection and Monitoring Systems; 6.8.5 Area Classification and Controlled Zones	The guideline describes requirement for gas/vapour detection in the bunkering area.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
20	Investigate the classification and size of the ATEX classification zone around transfer pipelines.	6.8.4 Electrical Equipment and Ignition Source Control; 6.8.5 Area Classification and Controlled Zones; 7.4 Directives, Regulations and Executive Orders	Sections 6.8.4 and 6.8.5 explicitly link hazardous area classification to equipment selection, ignition source control, access and exclusion distances. Section 7.4 references the ATEX product and workplace framework.
21	Consider requirements for flame detection systems in place to detect methanol fires in the event of a leakage from transfer pipelines.	4.2 Methanol; 6.6.2 Fuel-specific Hazards; 6.8.3 Detection and Monitoring Systems; 6.11.3 Response to Leaks, Fires and Toxic Releases	Methanol's low-visibility flame is identified as a key hazard. Flame detection is therefore relevant where visual detection cannot be relied upon, with need and positioning determined by the release and fire scenarios.
22	Investigate whether ESD is required to be operated automatically or manually in the event of leak detection during ammonia transfer.	6.8.2 Isolation, Shutdown and Emergency Release; 6.8.3 Detection and Monitoring; 6.11.2 Emergency Shutdown Philosophy	These sections cover rapid isolation, detection, response time, fail-safe behaviour and ship/shore interfaces.
23	Investigate the minimum requirements and procedures to ensure appropriate mooring.	6.4 Bunkering Concepts and Operational Interfaces; 6.9.1 Planning and Coordination; 6.9.2 Pre-transfer Preparation; 6.9.6 Stop work and Deviation Management	The guideline identifies relative movement, weather and sea-state as operational limits, and describes checks and verification of mooring arrangements.
24	Investigate the need for tugboats during ship-to-ship bunkering.	5.2 Risk Evaluation; 6.4 Bunkering Concepts and Operational Interfaces; 6.9.1 Planning and Coordination	Tug assistance is a concept and location-specific risk control decision involving vessel movement, weather, traffic and consequence severity. It should be considered as part of planning and operating envelope determination, rather than a prescribed requirement.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
25	Review the requirements of the IGF Code with respect to the bunkering station on the ship.	6.2 Scope and System Boundaries; 6.3 Governance and Approval Context; 6.13.2 Interface with Usage; 8.2 Regulatory and Legislative Framework	The guideline recognises that IMO and class requirements govern onboard systems and that the ship/shore interface must be compatible with approved ship arrangements.
26	Investigate the competency requirements for bunkering operations personnel, including certifications.	6.10 Human Factors and Organisational Interfaces; 6.12 Training, Competence and Organisational Readiness; 8.4 Generic Training Requirements; 8.5 Hazard Profiles and Training Requirements	These sections provide structure for identifying safety-critical roles, knowledge, certification, practical training, verification and refresher training.
27	Investigate the requirements for inerting prior to bunkering.	6.5.4 Normal, Non-routine and Abnormal Operations; 6.8.1 Transfer Equipment; 6.9.2 Preparation; 6.9.7 Completion and Disconnection 7.2.3 Vapour space.	Inerting affects atmosphere control, material integrity and safe connection/disconnection. The guideline describes purging at completion and nitrogen padding in ammonia storage.
28	Consider the use of fixed flame detection in bunkering area (subject to risk assessment)	4.2 Methanol; 6.8.3 Detection and Monitoring; 6.11.3 Emergency Response	The technical justification is the low visibility of methanol flames. The guideline states that fixed detection shall be subject to risk assessment.
29	Specify that requirements for firefighting systems in bunkering area should be based on risk assessment.	5.2 Risk Evaluation; 5.3 Risk Control; 6.7 Safety Barrier Philosophy; 6.11.3 Response to Leaks, Fires and Toxic Releases	These sections establish that barriers must respond to credible scenarios and fuel properties, based on risk evaluation, including determination of suitable active firefighting measures.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
30	Investigate possible means of suppressing ammonia leakage in bunkering area (e.g. water curtains, dry fog).	4.3 Ammonia; 6.8.6 Spill Containment and Drainage; 6.11.3 Response to Leaks, Fires and Toxic Releases	The measure relates directly to toxic release mitigation. It must be integrated with drainage, contaminated-water control, responder safety and the risk of spreading ammonia rather than considered only as emergency equipment. This is described in the relevant sections.
31	Investigate requirements for ammonia leak detection during bunkering.	6.6.2 Fuel-specific Hazards; 6.8.3 Detection and Monitoring; 6.9.4 Control During Transfer	Section 6.8.3 states the requirement for requires rapid identification of toxic vapour and cold cloud formation during ammonia bunkering.
32	Ensure that there are means to measure the temperature and pressure inside the hose during bunkering.	6.8.3 Detection and Monitoring; 6.9.4 Control During Transfer	Both sections explicitly include monitoring of pressure and temperature during transfer.
33	Investigate possible pressure relief solutions during bunkering of ammonia.	6.8.1 Transfer Equipment; 6.8.2 Isolation and Shutdown; 6.9.4 Control During Transfer; 6.9.7 Completion and Disconnection	Isolation can trap refrigerated liquid and generate thermal overpressure. The relevant sections describe determination of requirements for pressure relief.
34	Specify that purging should be appropriate for the fuel being purged.	4.2 Methanol; 4.3 Ammonia; 6.9.7 Completion, Disconnection and Close-out; 6.13.2 Interface with Usage	Section 6.9.7 states requirements for purging where appropriate and safe management of residual fuel.
Usage			
35	Investigate requirement for switching to a higher extraction air flow in case of gas detection inside the fuel preparation room / TCS.	4.3 Ammonia; 5.3 Risk Control; 8.3 Alternative Marine Fuels and Hazard Drivers	The action concerns detection-initiated ventilation as an engineered mitigation.
36	Investigate whether shutdown of fuel transfer onboard is automatic or done manually by the operator.	5.3 Risk Control; 6.8.2 Isolation and Shutdown; 6.13.2 Interface with Usage	The ship/shore interface must have compatible shutdown logic. Section 6.8.2 provides a transferable philosophy.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
37	Investigate the requirements for the secondary containment in case of ammonia release inside the fuel preparation room / TCS.	4.3 Ammonia; 5.3 Risk Control; 6.8.6 Spill Containment and Drainage	Secondary containment limits spread and supports detection, drainage and safe recovery. (Also see action 40).
38	Review onboard pressure relief requirements for ammonia.	4.3 Ammonia; 5.2.2 Consequence Modelling; 6.13.2 Interface with Usage; 8.2 Regulatory and Legislative Framework	Relief discharge affects both onboard safety and the port while the vessel is alongside. The topic should be linked to ship rules and to port-side dispersion, exclusion-zone and emergency-planning assumptions.
39	Investigate the redundancy requirements for onboard cooling system for ammonia.	4.3 Ammonia; 5.3 Risk Control; 7.2.2 Temperature and Pressure; 8.3 Hazard Drivers	The storage chapter explains why loss of cooling can increase boil-off and pressure. The same physical dependency makes redundancy relevant onboard, but the actual onboard requirement must be governed by ship design rules and risk assessment.
40	Investigate secondary containment requirements in case of ammonia release onboard.	As Action 37	As Action 37
41	Investigate requirements for redundancy of the nitrogen system onboard.	5 Hazard identification and Risk Assessment; 7.2.3 Vapour Space; 7.2.3.3 Stress Corrosion Cracking; 8.3 Hazard Drivers	The storage chapter links nitrogen padding and purging to oxygen control and SCC prevention. Risk assessment. Risk assessment should address loss of nitrogen as a safety system failure and determine necessary redundancy from the functions it supports.
42	Investigate requirements for ventilation inside the engine room in event of a release of fuel.	4.2 Methanol; 4.3 Ammonia; 5.3 Risk Control; 8.3 Hazard Drivers;	Methanol and ammonia require different responses because of flammability, toxicity and dispersion. Risk control should address ventilation requirements.
43	Investigate requirements for fixed and portable ammonia release suppression systems onboard.	4.3 Ammonia; 8.5.1 Specialist Training—Ammonia	This combines technical equipment, emergency procedures and competence. Chapter 8 covers onboard equipment and trained use.

No.	HAZID action	Relevant section(s)	Why the reference is relevant
General actions			
44	Specify that emergency equipment, escape routes, emergency access and assembly points should be determined based on risk assessment.	5.1–5.3 Hazard Identification, Evaluation and Control; 6.11.1 Emergency Scenarios; 6.11.5 Evacuation, Muster and Exclusion Zones; 9 Integrated Emergency Preparedness	Section 6.11.5 addresses muster points, escape routes and access management during bunkering. Chapter 5 ensures their number, location and protection are based on identified release, fire, explosion and escalation scenarios.
45	Specify that emergency response procedures and training (including emergency exercises) need to reflect specific responses to hazardous release or fire/explosion involving methanol/ammonia.	4.2–4.4 Fuel Hazards; 6.11.3 Response; 6.11.6 Drills and Exercises; 6.12 Training and Competence; 8.5 Hazard Profiles and Training; 9 Integrated Emergency Preparedness	The guideline requires fuel-specific scenarios in drills and distinguishes ammonia toxic-release response from methanol fire and ignition response. These sections collectively provide the hazard-to-procedure-to-competence chain required by the action.
46	While sabotage is not specifically related to the use of green fuels, it should be considered as a potential cause of the hazardous events identified within the HAZID and therefore suitable risk reduction measures should be implemented to reduce its likelihood.	5.1 Hazard Identification; 5.6 Project HAZID; 6.3 Governance and Approval Context; 10 Governance, Documentation and Approval Readiness	Chapter 5 states that sabotage should be considered as a potential cause of loss of containment. Chapter 10 refers to need for governance on port security.
47	While IT Security is not specifically related to the use of green fuels, it should be considered as a potential cause of many of the hazardous events identified within the HAZID and therefore suitable risk reduction measures should be implemented to reduce its likelihood.	5.1 Hazard Identification; 5.6 Project HAZID; 6.8.2 Isolation and Shutdown; 6.8.3 Detection and Monitoring; 10 Governance, Documentation and Approval Readiness	Chapter 5 identifies IT security as a possible initiating cause. Referencing control, detection and ESD sections is relevant because compromise or loss of digital systems can affect monitoring and protective functions. The guideline does not yet provide detailed cybersecurity controls, so the guideline should retain a functional risk-assessment requirement rather than inventing a separate cyber standard.

6. Bunkering

6.1. Introduction

The introduction of alternative fuels such as methanol and ammonia in maritime transport places bunkering operations at the centre of port safety and operational readiness. Bunkering represents a time-limited but highly safety-critical activity in which fuel properties, transfer systems, vessels, port infrastructure, and personnel from multiple organisations interact within a shared operational space. Experience from early demonstration projects and pilot operations shows that safe bunkering cannot be ensured by technical measures alone, but requires a coherent combination of governance, operational control, risk management, and competence.

The objective of this chapter is to provide structured guidance for the safe execution of bunkering operations for green fuels in ports. It focuses on defining the scope and boundaries of bunkering, clarifying roles and approval contexts, and establishing a common framework for identifying hazards, evaluating risks, and implementing effective technical, operational, and organisational safety measures. Rather than prescribing specific technologies or layouts, it adopts a functional and risk-based approach that can be applied across different ports, bunkering concepts, and levels of maturity.

In line with the overall SafeSBU approach, this chapter uses Port Readiness Level (PRL) thinking as an underlying structuring principle to ensure that bunkering operations are not only technically feasible, but also operationally defined, organisationally supported, and ready for safe implementation. This means that attention is given to interfaces between stakeholders, clarity of responsibilities, robustness of procedures, and availability of competent personnel, in addition to physical safety barriers.

Bunkering is closely linked to the other domains within SafeSBU. Interfaces with storage ensure that constraints and safety principles related to fuel storage are reflected in bunkering operations, while interfaces with usage ensure compatibility with shipboard fuel systems and operational practices.

The guidance developed for bunkering section is intended to support ports, bunkering operators, ship operators, and authorities in planning, approving, and executing bunkering operations in a safe, consistent, and repeatable manner, while allowing flexibility for local conditions and future developments.

6.2. Scope, Definition and System Boundaries

Bunkering of green fuels is defined in SafeSBU as the controlled transfer of fuel from a shore-based or mobile supply system to a ship, including all preparatory, execution, and close-out activities required to return both ship and port systems to a safe state. In contrast to conventional marine fuels, bunkering of ammonia and methanol introduces new hazard mechanisms and operational dependencies that require explicit definition of scope and boundaries.

The guidance provided in this chapter addresses bunkering of the following fuels when used as marine energy carriers:

- Methanol
- Ammonia (ammonia bunkering is assumed to involve refrigerated liquid, ammonia handled at or near atmospheric pressure, unless otherwise specified).

The scope includes the operational phases of bunkering, namely:

- pre-bunkering planning and coordination,
- preparation and verification of systems,
- connection and integrity checks,
- fuel transfer and monitoring,
- completion, depressurisation or purging, and disconnection,
- immediate post-bunkering verification and documentation.

The bunkering modes considered include ship-to-ship, ship-to-shore, and truck or portable tank supply. These modes are treated functionally rather than prescriptively, recognising that ports may implement different technical solutions depending on layout, traffic patterns, operational constraints, and maturity level. This approach is consistent with international guidance and industry best practice, including IMO interim guidance and circulars [1,2], recommendations from the Society for Gas as a Marine Fuel (SGMF) [3,4], relevant Danish Standards (DS) [5], and other applicable standards, technical guidelines, and literature related to alternative fuel bunkering safety and operational flexibility [6–16].

The system boundary is defined across three interacting layers. The primary boundary includes the transfer system itself, from the fuel supply outlet (terminal manifold, bunker vessel manifold, or truck connection) to the receiving ship's bunker connection, including hoses, arms, couplings, valves, emergency shutdown interfaces, and associated instrumentation. The secondary boundary covers the immediate operational area around the bunkering interface, including controlled or exclusion zones, access control, ventilation considerations, and ignition source management. The tertiary boundary concerns operational control and decision-making, including command hierarchy, communication interfaces, and coordination with port services.

6.3. Governance, Roles and Approval Context

Safe bunkering of green fuels depends as much on governance and organisational clarity as on technical safeguards. Bunkering operations typically involve several independent organisations operating under different regulatory regimes, including ship operators, fuel suppliers, port authorities, and emergency services. Experience from pilot projects and early deployments shows that unclear allocation of roles and approval responsibilities is a significant contributor to operational uncertainty and risk.

At the international level, bunkering of ammonia and methanol is informed by IMO interim guidelines for ships using these fuels (MSC.1/Circ.1687 for ammonia and MSC.1/Circ.1621 for methanol). These documents primarily address onboard systems and ship safety functions and do not define detailed port-side bunkering procedures. Similarly, classification society rules and technical advisories (e.g. ABS, DNV, Lloyd's Register, ClassNK) provide requirements for fuel system integrity and interfaces but leave port operational governance largely to national and local authorities.

Within this framework, a governance model is adopted in which bunkering safety is achieved through clearly defined responsibilities and approval processes rather than centralised prescriptive rules. As a minimum, the following roles should be explicitly defined for each bunkering operation:

- the receiving ship, represented by the master and designated fuel handling personnel, responsible for onboard readiness and acceptance of fuel transfer;
- the bunkering operator or fuel supplier, responsible for custody of the fuel during supply, integrity of transfer equipment, and execution of the operation;
- the port authority or terminal operator, responsible for granting permission to operate, enforcing port rules, and coordinating marine traffic and safety zones;
- supporting services, including traffic control, mooring services, and emergency response organisations.

A key governance principle is the clear allocation of authority to stop bunkering operations. Any party involved in the operation who identifies an unsafe condition must have the authority to call an immediate stop. The process for confirming a stop, investigating the cause, and authorising restart must be clearly defined in advance and reflected in procedures and permits.

Approval of bunkering operations typically follows a layered process. At an early stage, ports and operators establish an approved operational envelope for specific fuels and bunkering concepts. For each individual operation, a permit-to-work or bunkering permit is issued based on verification of readiness, agreement of operating limits, and completion of a pre-transfer coordination meeting. Documentation and reporting following completion of bunkering support traceability and learning. This governance logic aligns with practices observed in leading ports and pilot projects, such as those documented by SGMF, GCMD, and port-specific regulations (e.g. Port of Gothenburg methanol bunkering rules).

6.4. Bunkering Concepts and Operational Interfaces

Bunkering concepts for green fuels vary across ports depending on infrastructure, traffic patterns, and maturity. Within this scope, bunkering concepts are described in functional terms, focusing on interfaces and operational dependencies rather than detailed equipment design. Typical concepts include fixed terminal supply, bunker vessel supply, and truck or portable tank supply. Each concept introduces different interface challenges related to motion, access, and control.

Bunkering operations are conducted through a sequence of defined phases, which form the basis for both hazard identification and operational control. These phases include preparation and verification, connection and integrity checks, controlled transfer, and completion with disconnection and close-out. Existing guidance and operational experience from hazardous fluid transfer operations indicate that risk is often concentrated at phase transitions, particularly during connection, start-up, shutdown, and abnormal interruptions.

Interfaces are treated as primary risk drivers in bunkering operations. Physical interfaces include manifold geometry, hose or arm compatibility, emergency release arrangements, and grounding or bonding considerations where relevant. Control and information interfaces concern who controls flow, pressure, and temperature, how alarms are presented and acknowledged, and how deviations are communicated between ship and shore. Organisational interfaces include handover of responsibility between companies, use of contractors, and coordination with port services.

Simultaneous operations (SIMOPS) represent a critical interface challenge. Activities such as cargo handling, passenger movements, hot work, or adjacent bunkering can introduce ignition sources, traffic conflicts, or distractions. Consistent with industry guidance from SGMF and class societies, bunkering operations adopts the principle that SIMOPS are permitted only when explicitly assessed and controlled as part of the bunkering planning process.

Operational limits form an essential part of bunkering concepts. These include weather and sea-state limits, particularly for ship-to-ship operations; pressure, temperature, and flow envelopes for transfer systems; and requirements for controlled zones around the bunkering interface. While specific limits may vary between ports and fuels, the principle of defining and respecting an approved operating envelope is fundamental to safe and repeatable operations.

Finally, the use of defined hold points within the bunkering sequence is introduced. Hold points require positive confirmation before proceeding and are typically applied before connection, before start of transfer, before significant changes in transfer rate, and before disconnection. These hold points provide a practical mechanism for enforcing governance decisions at the operational level.

6.5. Hazard Identification Framework

As previously stated in Section 5.1, systematic hazard identification is a fundamental element of risk management and is of particular importance to the safe bunkering of green fuels, as it provides the basis for defining operational limits, safety barriers, procedures, and competence requirements. Hazard identification should not be treated as a generic or one-off exercise, but as a structured process tailored to the specific characteristics of bunkering operations, including their time-limited nature, multiple interfaces, and strong dependence on human actions.

The objective of the hazard identification framework is to ensure that all credible hazards associated with bunkering operations are identified in a systematic and transparent manner, covering both technical failures and human or organisational contributors. This approach is consistent with international practice for hazardous operations and aligns with methodologies applied in industry guidance from organisations such as SGMF, classification societies, and pilot projects for methanol and ammonia bunkering. Several industry organisations and technical bodies have developed publications relevant to methanol and ammonia bunkering.

A HAZID study was undertaken as part of the SafeSBU project with the aim of providing the basis for the development of this guideline for safe storage, bunkering and usage of green fuels, as well as providing an illustration of the hazard identification framework to be followed by designers and operators of facilities or operations. The HAZID is summarised in Section 5 and described in detail in Annex A.

6.5.1 Methodology

A structured HAZID-based methodology shall be applied, adapted specifically for bunkering operations. The methodology combines a phase-based and interface-based perspective to ensure completeness and relevance. Rather than analysing individual components in isolation, the focus is on how hazards arise during the execution of bunkering activities and at the boundaries between systems and organisations. Hazard identification is performed by reviewing the bunkering operation step by step across defined operational phases, including:

- pre-bunkering planning and readiness,
- pre-transfer checks and connection,
- controlled transfer and monitoring,
- completion, depressurisation or purging where applicable, and disconnection,
- post-bunkering close-out and verification.

For each phase, deviations from intended operation shall be considered, including late changes, interruptions, equipment malfunction, and emergency shutdown and restart. This phase-based structure reflects experience from methanol and ammonia pilot projects, where incidents and near-misses have frequently occurred during transitions between phases rather than during steady-state transfer.

In parallel, the methodology explicitly considers interfaces as a primary source of hazards. These include physical interfaces between ship and shore equipment, control and information interfaces related to monitoring and decision-making, and organisational interfaces between different companies and authorities involved in the operation.

6.5.2 Participants and Inputs

Effective hazard identification requires participation from all key stakeholders involved in bunkering operations. HAZID activities should be led by an experienced facilitator and conducted with representatives from:

- the receiving ship, including personnel responsible for fuel handling,
- the bunkering operator or fuel supplier,
- the port authority or terminal operator, as applicable,
- technical specialists with knowledge of the fuel properties and transfer systems, as well as the systems in place for control and mitigation of the associated risks.

Typical inputs to the hazard identification process include the bunkering concept and layout, descriptions of the operational sequence, specifications of transfer equipment, proposed operating envelopes and limits, and relevant experience from similar operations. Guidance from IMO interim circulars, class rules, and industry recommendations provides an important reference framework, but site and operation-specific conditions are always considered.

6.5.3 Inclusion of human and organisational factors

A key element of the hazard identification is the explicit inclusion of human and organisational factors. Experience from early green fuel bunkering operations shows that hazards often arise not from single technical failures, but from combinations of human actions, assumptions, and organisational interfaces.

Hazard identification should therefore consider factors such as:

- clarity of roles and responsibilities during each bunkering phase,
- authority to make decisions and stop operations,
- communication protocols between ship and shore,
- workload, time pressure, and staffing levels,
- use of contractors and temporary personnel,
- reliance on manual actions during connection, monitoring, and disconnection.

This approach is consistent with recommendations in the SGMF bunkering guidelines [3,4] which emphasise that human performance and organisational alignment are critical to managing the risks associated with new marine fuels.

6.5.4 Normal, non-routine, and abnormal operations

Hazard identification in bunkering explicitly covers three categories of operating conditions:

- normal operations conducted within the approved operating envelope,
- non-routine operations such as changes in transfer rate, temporary interruptions, or maintenance-related deviations,
- abnormal and emergency conditions, including equipment failure, loss of containment, emergency shutdown, and restart after a stop.

By considering these conditions together, the hazard identification framework supports the development of robust safety barriers and procedures that remain effective beyond steady-state operation. This principle reflects lessons learned from ammonia and methanol bunkering pilot studies, where the ability to manage deviations and recover safely has proven as important as preventing incidents during normal transfer.

6.5.5 Output and use of hazard identification results

The output of the hazard identification process should be a structured set of identified hazards linked to specific operational phases, interfaces, and contributing factors. These outputs are used directly as inputs to:

- categorisation of bunkering hazards (see Section 6.6),
- evaluation of risks and definition of safety barriers (see Section 6.7),
- specification of technical requirements (see Section 6.8),
- development of procedures, training, and emergency preparedness (see Sections 6.9 to 6.12).

In this way, hazard identification forms a continuous thread through bunkering, ensuring traceability from identified hazards to concrete risk controls and operational guidance.

6.6. Bunkering Hazard Categories

Based on the hazard identification framework described in Section 6.5, as well as the HAZID study described in Annex A, SafeSBU bunkering groups identified hazards within a structured set of categories. This categorisation supports consistency across fuels and bunkering concepts, while allowing fuel-specific characteristics to be addressed in a transparent and controlled manner. The categorisation reflects common practice in industry guidance, including SGMF bunkering guidelines, class society advisories, and lessons learned from pilot bunkering operations.

6.6.1 Non-fuel-specific hazards

The following hazard categories apply to bunkering operations irrespective of the specific fuel used. They represent the common risk landscape associated with transferring hazardous substances in a port environment.

Loss of containment

Loss of containment represents a primary initiating event for many bunkering incidents. It may result from:

- failure of hoses, arms, couplings, flanges, or valves,
- incorrect connection or incomplete engagement of couplings,
- seal degradation or material incompatibility,
- mechanical damage due to vessel movement, impact, or excessive loading,
- inadvertent disconnection during transfer or emergency shutdown.

Loss of containment can occur during any phase of bunkering, but experience shows that connection, start-up, shutdown, and disconnection are particularly sensitive phases.

Fire and explosion

Fire and explosion hazards arise when a released fuel forms a flammable mixture and encounters an ignition source. Relevant mechanisms include:

- accumulation of flammable vapours within controlled or enclosed areas,
- ignition from electrical equipment, hot surfaces, static electricity, or external activities,
- escalation from small releases to pool fires, or vapour cloud events,
- delayed ignition following release and dispersion.

While the manifestation of fire and explosion differs between fuels, the basic hazard category applies to all bunkering operations and requires systematic control.

Toxic exposure

Toxic exposure hazards affect personnel involved in bunkering and potentially third parties in the vicinity. These hazards include:

- acute exposure during release, particularly during connection and disconnection,
- delayed detection of hazardous concentrations,
- exposure during emergency response or clean-up,
- inadequate escape routes or sheltering options.

Toxic exposure is a central concern for some fuels but is considered as a generic hazard category to ensure appropriate controls are identified.

Overpressure and system integrity failure

Overpressure hazards may arise from:

- blocked-in sections of piping,
- thermal expansion of trapped liquid,
- malfunction or incorrect setting of pressure relief systems,
- incorrect valve line-up or sequencing.
- overfilling of methanol fuel tanks or inadequate tank venting, resulting in excessive tank pressure.

System integrity failures related to pressure can lead directly to loss of containment and escalation.

Manual handling and ergonomic hazards

Manual handling hazards are common in bunkering operations and include:

- handling of heavy or stiff hoses,
- awkward working postures during connection and disconnection,
- slips, trips, and falls in the bunkering area,
- fatigue during prolonged or repeated operations.

These hazards can contribute directly to injury or indirectly to loss of containment and procedural errors.

Environmental release

Environmental hazards arise when fuel is released to water, ground, or drainage systems. Relevant scenarios include:

- spills during connection, disconnection, or hose draining,
- failure of secondary containment,
- uncontrolled spread through drainage or surface water,
- delayed detection or ineffective clean-up.

Environmental release is considered separately from toxic exposure and fire to ensure appropriate mitigation and response measures are addressed.

External and third-party interference

Bunkering operations can be affected by external factors beyond the immediate control of the bunkering team, including:

- vessel movement, wake effects, or mooring failure,
- weather conditions exceeding operational limits,
- interference from port traffic or nearby activities,
- unauthorised access to controlled or exclusion zones,
- simultaneous operations introducing ignition or impact hazards.

These hazards emphasise the importance of coordination with port authorities and other stakeholders.

6.6.2 Fuel-specific hazards

In addition to the non-fuel specific core hazards described in the previous section, each fuel introduces specific hazard mechanisms that require additional consideration. These are treated as deltas to the common hazard set, rather than as separate hazard systems.

Ammonia-specific hazards

For refrigerated liquid ammonia handled at or near atmospheric pressure, fuel-specific hazards are primarily associated with toxicity, cryogenic effects, and vapour dispersion rather than high-pressure release. Relevant hazard mechanisms include:

- severe acute toxicity at low concentrations, with immediate health effects,
- rapid vaporisation and formation of dense, cold vapour clouds following release;
- potential for downwind exposure beyond the immediate bunkering area;

- cryogenic burns and material embrittlement due to low temperatures;
- corrosion and strict material compatibility requirements;
- limited tolerance for human intervention during releases, affecting emergency response strategies.

These characteristics are reflected in IMO interim guidelines [1] for ammonia-fuelled ships, class rules, and safety handbooks [17], and influence detection, personal protective equipment, and emergency response planning during bunkering.

Methanol-specific hazards

Methanol bunkering hazards are dominated by flammability and handling characteristics, including:

- low flash point and wide flammability range,
- difficulty of visually detecting methanol flames,
- potential for static electricity during transfer,
- health effects from skin contact and inhalation.

These aspects are addressed in IMO interim guidelines [2], SGMF methanol bunkering guidance [4], and operational experience from early methanol bunkering ports, and influence ignition control, grounding practices, and monitoring during transfer.

These characteristics influence detection strategies, exclusion zone design, and emergency response considerations during bunkering.

6.6.3 Use of hazard categories in bunkering

The hazard categories defined in this section provide a structured basis for:

- evaluation of risks and prioritisation of controls (Section 6.7),
- definition of technical safety requirements,
- development of operational procedures and hold points,
- identification of training and competence needs,
- preparation for emergency response scenarios.

By combining a common hazard core with clearly defined fuel-specific deltas, the approach supports consistency across fuels while ensuring that unique hazard mechanisms are explicitly addressed.

6.7. Risk Evaluation and Safety Barrier Philosophy

The purpose of risk evaluation is to determine how the identified bunkering hazards can be effectively controlled through an appropriate combination of technical, operational, and organisational safety measures. Risk evaluation is not applied to optimise numerical risk metrics and thus to justify decisions already made, but as part of a structured decision-making on operating limits, safety barrier design, procedures, and competence requirements necessary for safe bunkering operations.

This approach is consistent with the goal-based philosophy applied in IMO interim guidelines, classification society rules, and industry guidance for bunkering of alternative fuels, where emphasis is placed on demonstrating that risks are understood and managed to an acceptable level.

6.7.1 Principles of risk evaluation

Risk evaluation considers both the credible consequences of identified hazards and the likelihood of their occurrence under intended operating conditions. Particular attention is given to:

- potential consequences to personnel, including acute health effects and injury,
- potential escalation to major incidents affecting vessels, port infrastructure, or the environment,
- sensitivity of bunkering operations to deviations, interruptions, and human actions.

Risk evaluation explicitly considers the time-limited and interface-intensive nature of bunkering. Hazards that may be well controlled during steady-state operation can become critical during start-up, shutdown, emergency stop, or restart. These conditions are therefore treated as integral parts of the risk picture rather than exceptional cases.

6.7.2 Safety barrier concept

A layered safety philosophy is adopted in which no single measure is relied upon to control risk. Instead, safety is achieved through multiple, complementary safety barriers designed to prevent the occurrence of hazardous events and to mitigate their consequences should prevention fail.

Safety barriers are grouped into three main categories:

- Technical barriers, which rely on physical or engineered features;
- Operational barriers, which rely on procedures and active control during operations;
- Organisational barriers, which rely on management systems, competence, and governance.

This barrier-based approach is widely applied in hazardous industries and is reflected in bunkering guidance from SGMF, classification societies, and national authorities.

6.7.3 Technical safety barriers

Technical safety barriers are intended to prevent loss of containment, detect abnormal conditions at an early stage, and limit escalation. Examples include:

- design and specification of transfer equipment suitable for the fuel and operating conditions,
- material compatibility and corrosion control,
- isolation and emergency shutdown systems,
- emergency release mechanisms where applicable,
- detection systems for leaks, vapours, or abnormal concentrations,
- physical separation, controlled zones, and ignition source control.

Technical barriers are expected to be effective under both normal and abnormal conditions, including vessel movement, environmental influences, and emergency shutdown scenarios.

6.7.4 Operational safety barriers

Operational barriers rely on defined procedures and active control during bunkering operations. These barriers include:

- planning and coordination activities prior to bunkering,
- pre-transfer meetings and verification of readiness,
- checklists and stepwise execution of critical tasks,

- defined hold points requiring positive confirmation before proceeding,
- monitoring of key parameters during transfer,
- stop work authority and escalation procedures.

Operational barriers play a critical role in managing interface-related hazards and in ensuring that technical barriers are used as intended. Experience from pilot bunkering operations shows that well-defined operational controls are particularly important during non-routine situations and deviations.

6.7.5 Organisational safety barriers

Organisational barriers support the effectiveness of technical and operational measures by ensuring that the necessary capability and governance are in place. These barriers include:

- clear definition of roles, responsibilities, and authority,
- competence requirements for personnel involved in bunkering,
- training and qualification programmes,
- safety management systems and permit-to-work frameworks,
- incident reporting, learning, and continuous improvement processes.

Organisational barriers are essential for managing the multi-actor nature of bunkering operations and for ensuring consistent application of safety measures across different ports and operators.

6.7.6 Barrier independence and robustness

A key consideration in this approach is the robustness and independence of safety barriers. Where practicable, barriers should not rely on the same component, system, or human action to function. For example, reliance solely on procedural compliance without supporting technical safeguards is not considered sufficient, particularly for fuels with high toxicity or flammability.

Risk evaluation therefore considers:

- potential common-cause failures,
- dependency on human performance under stress,
- degradation of barriers over time,
- effectiveness of barriers during emergency conditions.

This consideration supports the development of resilient bunkering operations capable of tolerating single failures or deviations without leading to major incidents.

6.7.7 Traceability from hazards to controls

The outcome of risk evaluation is a clear linkage between identified hazards and the safety barriers intended to control them. This traceability supports:

- definition of technical safety requirements (Section 6.8),
- development of operational procedures and controls (Section 6.9),
- identification of human factors considerations (Section 6.10),
- specification of emergency preparedness measures (Section 6.11),
- definition of training and competence requirements (Section 6.12).

By maintaining this traceability, the approach ensures that guidance provided in later sections is grounded in a systematic understanding of bunkering risks rather than generic best practice.

6.8. Technical Safety Requirements for Bunkering

Technical safety requirements for bunkering provide the physical foundation for preventing loss of containment, detecting abnormal conditions, and limiting escalation should an incident occur. In this context, technical requirements are defined in functional terms, recognising that specific equipment solutions may vary between ports, fuels, and bunkering concepts. The intent is to ensure that transfer systems and supporting infrastructure are fit for purpose, compatible with the fuel handled, and robust under both normal and abnormal operating conditions.

The technical requirements described in this section are informed by IMO interim guidelines, classification society rules, and industry guidance from organisations such as SGMF and ABS, as well as experience from pilot bunkering operations for ammonia and methanol.

6.8.1 Transfer equipment and material compatibility

Transfer equipment, including hoses, arms, couplings, valves, and associated fittings, shall be suitable for the fuel, pressure, temperature, and flow conditions expected during bunkering. Material compatibility with the fuel is a fundamental requirement and shall account for chemical properties, potential corrosion, embrittlement, and permeation effects.

For ammonia, particular attention shall be given to material selection and sealing arrangements due to toxicity and leakage sensitivity. For methanol, compatibility with elastomers and potential degradation due to prolonged exposure shall be considered. Transfer equipment shall be designed to withstand mechanical loads arising from vessel movement, thermal expansion, and handling during connection and disconnection.

Where flexible hoses are used, requirements for inspection, testing, certification, and retirement criteria shall be defined. These practices are consistent with recommendations in SGMF bunkering guidelines and class society advisories.

6.8.2 Isolation, shutdown, and emergency release

Bunkering systems shall be equipped with means to rapidly isolate the fuel transfer in the event of abnormal conditions or emergencies. This includes:

- remotely or locally actuated isolation valves,
- emergency shutdown (ESD) systems capable of stopping fuel flow,
- defined interfaces between ship and shore ESD systems, where applicable.

For bunkering concepts involving relative motion between supply and receiving units, emergency release mechanisms may be required to prevent excessive loads on transfer equipment. The functionality, response time, and fail-safe behaviour of isolation and shutdown systems shall be compatible with the hazards of the fuel and the dynamics of the bunkering operation.

Shutdown and isolation systems shall be designed to operate reliably during loss of power or control signals, in line with common practice described in class rules and industry guidance.

Where liquefied fuels such as ammonia are transferred, the isolation philosophy shall consider the potential for liquid to become trapped between closed isolation valves. Appropriate pressure relief arrangements shall be provided to prevent overpressure resulting from thermal expansion of trapped liquid or other abnormal pressure conditions. Where applicable, provisions for controlled depressurisation, recirculation or discharge to a safe location shall be incorporated into the system design to enable safe isolation and maintenance of the transfer system.

6.8.3 Detection and monitoring systems

Early detection of abnormal conditions is a key technical barrier in bunkering operations. Depending on the fuel and bunkering concept, detection systems may include:

- leak detection within transfer systems,
- gas or vapour detection in the bunkering area,
- monitoring of pressure, temperature, and flow parameters,
- alarms for deviation from normal operating envelopes.

For ammonia bunkering, detection systems shall prioritise rapid identification of toxic vapour releases and cold vapour cloud formation rather than pressure-related anomalies.

Detection systems shall be designed to provide timely and unambiguous information to personnel responsible for controlling the operation, both on ship and ashore. Alarm thresholds and presentation shall support rapid decision-making and avoid unnecessary nuisance alarms that could undermine operator trust.

Guidance from IMO interim circulars and class societies highlights the importance of detection systems for fuels with low odour thresholds, invisible flames, or rapid dispersion characteristics.

6.8.4 Electrical equipment and ignition source control

Bunkering areas shall be assessed for potential ignition sources, and appropriate controls shall be implemented to prevent ignition of flammable atmospheres. This includes:

- selection and certification of electrical equipment suitable for the hazardous area classification,
- control of hot surfaces and mechanical ignition sources,
- grounding and bonding arrangements to manage static electricity, particularly relevant for methanol bunkering,
- procedural controls for non-certified equipment and temporary installations.

Ignition source control shall extend beyond the immediate transfer equipment to include adjacent activities and temporary equipment within the defined bunkering and exclusion zones.

6.8.5 Area classification and controlled zones

The area around the bunkering interface shall be assessed to define hazardous or controlled zones based on the fuel properties, transfer conditions, and potential release scenarios. These zones provide the basis for:

- ignition source control,
- access restrictions,

- definition of exclusion distances,
- planning of emergency response and evacuation.

While specific zone extents may vary, the principle of defining and enforcing controlled areas during bunkering is consistently reflected in class rules, SGMF guidance, and port regulations.

6.8.6 Spill containment and drainage

Technical measures shall be provided to prevent uncontrolled spread of spilled fuel and to support effective clean-up. This may include:

- drip trays and local containment at connection points,
- closed or controlled drainage systems in the bunkering area,
- barriers to prevent release to water or sensitive areas,
- facilities for safe collection and disposal of contaminated material.

Spill containment arrangements shall be compatible with the fuel handled and integrated with port environmental response plans.

6.8.7 Inspection, testing, and maintenance

The integrity of technical safety barriers depends on systematic inspection, testing, and maintenance. The need for the following is therefore emphasised:

- defined inspection and test intervals for transfer equipment and safety systems,
- verification of functionality of isolation, shutdown, and detection systems,
- maintenance procedures aligned with manufacturer recommendations and class requirements,
- management of change (MoC) and repairs to bunkering equipment.

These activities support continued confidence in technical barriers and provide assurance to authorities and operators that bunkering systems remain fit for service.

6.9. Operational Control and Bunkering Procedures

Operational control is a critical element of safe bunkering, as bunkering operations are time-limited, interface-intensive, and strongly influenced by human actions and coordination between organisations. In this context, bunkering procedures are treated as operational safety barriers that ensure technical systems are used within their intended limits and that deviations are detected and managed in a controlled manner.

The guidance in this section reflects common principles from industry bunkering practices, including those described by SGMF, class society advisories, and operational experience from ammonia and methanol bunkering pilot projects, while remaining adaptable to local port arrangements.

6.9.1 Planning and coordination

Bunkering operations shall be planned in advance and coordinated between all parties involved. Planning activities typically include:

- confirmation of bunkering concept, fuel type, and quantities,
- verification that the operation falls within the approved operational envelope,

- identification of simultaneous operations and potential conflicts,
- confirmation of weather and environmental conditions.

Planning shall ensure that responsibilities are clearly allocated and that all participants have a common understanding of the operation to be performed.

6.9.2 Pre-arrival and pre-transfer preparation

Prior to commencement of bunkering, preparatory activities are required to confirm readiness of both ship and shore systems. These activities may include:

- verification of documentation, permits, and approvals,
- confirmation of equipment availability and condition,
- verification of communication systems and emergency arrangements,
- establishment of controlled and exclusion zones.

A pre-transfer meeting involving ship and shore representatives is typically used to confirm readiness, agree on operating limits, and review emergency and stop work procedures. Such meetings are a common feature of industry guidance and pilot operations and provide an important opportunity to align expectations and assumptions.

Prior to commencing bunkering, the adequacy of the mooring arrangements shall be verified, taking account of the vessel characteristics, berth configuration, expected environmental conditions and the anticipated loads imposed by the transfer equipment. During bunkering, vessel movement and mooring integrity should be monitored to ensure that the operational limits established for the transfer system are not exceeded. Predefined stop work criteria shall be established to suspend or terminate bunkering where excessive vessel movement, deterioration of mooring conditions or environmental conditions could compromise the integrity of transfer hoses, loading arms or associated equipment.

6.9.3 Connection and integrity checks

Connection of transfer equipment is a critical phase of bunkering and requires careful control. Procedures shall ensure that:

- correct equipment is selected and properly connected,
- couplings and seals are fully engaged and verified,
- grounding or bonding arrangements are in place where required,
- integrity checks, such as pressure or leak tests, are performed as appropriate.

Only after successful completion of connection and integrity checks should authorisation be given to proceed to fuel transfer.

Before fuel transfer commences, the connected bunkering lines and associated transfer equipment should be prepared in accordance with the approved fuel-specific bunkering procedure. Where required, air should be displaced using an inert gas (typically dry nitrogen) before leak or pressure testing is completed. For ammonia systems, inerting should be followed by gassing-up with ammonia vapour before liquid transfer.

6.9.4 Control during transfer

During fuel transfer, continuous monitoring is required to ensure that operating conditions remain within defined limits. Operational controls during this phase typically include:

- monitoring of pressure, temperature, and flow parameters,
- observation of transfer equipment and connection points,
- verification that exclusion zones and ignition source controls are maintained,
- maintenance of continuous communication between ship and shore.

Transfer rates may be increased in a controlled manner following initial stabilisation. Any deviation from expected behaviour shall trigger predefined response actions, including potential reduction or cessation of transfer.

6.9.5 Hold points and decision points

The use of defined hold points within the bunkering sequence is introduced. Hold points require positive confirmation before proceeding and serve as practical enforcement points for operational control. Typical hold points include:

- before commencement of connection,
- before start of fuel transfer,
- before significant changes in transfer rate,
- before completion and disconnection.

Hold points provide an opportunity to verify conditions, confirm readiness, and address uncertainties before progressing to the next phase.

6.9.6 Stop work and deviation management

A clear and consistently applied stop work principle is essential for safe bunkering. Procedures shall specify:

- conditions under which bunkering must be stopped,
- authority to initiate a stop, applicable to all parties,
- communication protocols during a stop,
- criteria and approval process for restarting operations.

Deviation management includes handling of non-routine situations such as temporary interruptions, equipment malfunction, or environmental changes. Experience from pilot operations highlights the importance of predefined responses to deviations to avoid improvised actions under time pressure.

6.9.7 Completion, disconnection, and close-out

The completion phase of bunkering includes controlled shutdown of transfer, depressurisation or purging where appropriate, and safe disconnection of transfer equipment. Procedures shall ensure that:

- fuel flow is fully stopped and isolated,
- residual fuel in hoses or arms is safely managed,
- connection points are secured and protected,

- controlled zones are lifted only after confirmation of safe conditions.

Where purging or inerting is required, the procedures shall be appropriate for the fuel being handled and the transfer configuration. The selected purge medium, purge sequence and completion criteria shall be defined in the operating procedures. The effectiveness of purging or inerting should be verified using appropriate process parameters, such as oxygen concentration, gas composition or other suitable verification methods, before transfer equipment is disconnected or opened. Post-bunkering close-out activities include documentation of the operation, reporting of deviations or incidents, and confirmation that both ship and port systems are returned to normal operation. These activities support traceability, learning, and continuous improvement.

6.10. Human Factors and Organisational Interfaces

Human performance and organisational interfaces play a decisive role in the safety of bunkering operations for green fuels. Bunkering is characterised by time pressure, coordination between multiple organisations, and reliance on manual actions during critical phases such as connection, start-up, shutdown, and disconnection. Experience from pilot bunkering operations and incident investigations in conventional fuel bunkering shows that weaknesses in human–system interaction and organisational alignment are frequent contributors to unsafe conditions.

Human factors are treated as an integral part of bunkering safety rather than as a secondary consideration. The objective is to ensure that bunkering systems, procedures, and organisational arrangements are designed to support correct human performance under both normal and abnormal conditions.

6.10.1 Human–machine interface considerations

The design and arrangement of bunkering equipment and control systems shall support intuitive and unambiguous operation. Key considerations include:

- clear visibility and accessibility of connection points, valves, and emergency devices,
- consistent layout and labelling of controls on ship and shore,
- clear distinction between normal operation controls and emergency controls,
- alarm presentation that supports rapid recognition and prioritisation.

Poorly designed interfaces can increase cognitive workload and the likelihood of error, particularly during time-critical situations. Guidance from class societies and human-centred design principles highlights the importance of designing for the operator rather than relying solely on procedural compliance.

6.10.2 Workload, fatigue, and time pressure

Bunkering operations may be conducted under constraints related to port schedules, vessel turnaround times, and weather windows. These factors can contribute to increased workload and time pressure, particularly during preparation and completion phases.

The need to address the following is emphasised:

- ensure adequate staffing levels for bunkering operations,
- avoid excessive reliance on extended working hours,
- recognise that fatigue can impair situational awareness and decision-making,

- plan operations to allow sufficient time for verification and hold points.

Managing workload and fatigue is an important organisational barrier that supports the effectiveness of technical and operational controls.

6.10.3 Roles, responsibilities, and authority

Clear definition of roles and responsibilities is essential for safe bunkering. This includes:

- identification of personnel responsible for controlling transfer on ship and shore,
- clear allocation of responsibility for monitoring and decision-making,
- unambiguous authority to stop operations when unsafe conditions are observed.

The authority to stop work shall apply to all parties involved in bunkering, regardless of organisational affiliation. This principle is consistently emphasised in industry guidance and is particularly important in multi-actor operations involving new fuels.

6.10.4 Communication and coordination

Effective communication between ship and shore is critical throughout the bunkering operation. The importance of the following is highlighted:

- agreed communication protocols and terminology,
- confirmation of critical information through closed-loop communication,
- reliable ship/shore communication available throughout the transfer,
- clear procedures for communicating abnormal conditions and decisions to stop or resume operations.

Communication failures are a common contributor to incidents in bunkering and other hazardous operations. Consistent communication practices help maintain shared situational awareness and reduce misunderstandings at organisational interfaces.

6.10.5 Contractor and third-party management

Bunkering operations primarily involve the fuel supplier and receiving vessel but may also involve contractors, temporary personnel, or service providers which are not part of regular organisations of either the port or the ship. It is recognised that:

- contractors may have different safety cultures or operating practices,
- unfamiliarity with local procedures can increase risk,
- clear induction and briefing are essential before participation in bunkering.

Organisational arrangements shall ensure that contractors are integrated into the bunkering operation, understand their roles, and are subject to the same safety and stop work principles as permanent personnel.

6.10.6 Learning, feedback, and continuous improvement

Human and organisational performance improves through learning from experience. The following are therefore encouraged:

- reporting of incidents, near-misses, and deviations,
- structured review of bunkering operations,

- sharing of lessons learned within and between organisations,
- periodic review and update of procedures and training.

This learning loop supports gradual improvement in operational maturity and aligns with the PRL-inspired objective of moving from initial implementation to routine, well-controlled bunkering operations.

6.11. Emergency Preparedness and Response

Emergency preparedness is a critical component of safe bunkering of green fuels, as bunkering operations involve the transfer of hazardous substances in proximity to personnel, vessels, and port infrastructure. Despite preventive measures and operational controls, residual risk remains, and the ability to respond effectively to abnormal and emergency situations is essential to limit consequences and prevent escalation.

Emergency preparedness and response are addressed as integral elements of bunkering readiness, ensuring that technical systems, procedures, and organisational arrangements support timely and effective action during incidents. This approach is consistent with principles outlined in IMO interim guidelines, classification society rules, and industry guidance for bunkering of alternative fuels.

6.11.1 Emergency scenarios considered

Emergency preparedness covers a range of credible scenarios identified through the hazard identification and risk evaluation processes, including:

- loss of containment with release of fuel,
- fire or explosion in the bunkering area,
- toxic release affecting personnel or adjacent areas,
- failure of transfer equipment or emergency shutdown systems,
- external events such as vessel movement, collision, or extreme weather during bunkering.

These scenarios are considered across all bunkering phases, with particular attention to connection, transfer, shutdown, and disconnection.

6.11.2 Emergency shutdown philosophy

Bunkering systems shall be designed and operated to allow rapid and reliable shutdown of fuel transfer in emergency situations. The emergency shutdown philosophy includes:

- clear definition of conditions requiring emergency shutdown,
- availability of emergency shutdown devices at appropriate locations on ship and shore,
- defined interfaces between ship and shore shutdown systems,
- fail-safe behaviour in the event of power or control system failure.

Emergency shutdown actions shall be clearly integrated into operational procedures and training, ensuring that personnel can act decisively under stress. This philosophy aligns with guidance from classification societies and industry organisations, which emphasise simplicity and reliability of emergency actions.

6.11.3 Response to leaks, fires, and toxic releases

Emergency response procedures shall be defined for credible incident scenarios and tailored to the properties of the fuel handled. These procedures typically address:

- immediate actions by bunkering personnel, including stopping transfer and raising alarms,
- protection of personnel through evacuation, sheltering, or use of personal protective equipment,
- establishment and enforcement of exclusion zones,
- coordination with port emergency services and responders.

Fuel-specific considerations influence response strategies. For example, toxic release scenarios for ammonia require rapid evacuation and protection against inhalation, while methanol and hydrogen incidents may prioritise ignition control and fire response. These considerations are reflected in IMO interim guidelines and safety handbooks.

Where justified by the project-specific risk assessment, additional mitigation measures may be provided to reduce the consequences of accidental releases. For ammonia bunkering, such measures may include water spray, water curtain or dry-fog systems to assist in reducing airborne ammonia concentrations and protecting personnel or adjacent equipment. The selection and design of such systems should consider their effectiveness under the expected release conditions, local meteorological conditions, drainage arrangements, contaminated firewater management, and responder safety.

Active firefighting measures for bunkering facilities shall be determined through the project-specific risk assessment. The assessment should consider the properties of the fuel, credible fire and release scenarios, bunkering configuration, potential escalation mechanisms, personnel exposure, and the capabilities of the port emergency response. Arrangements for retention, collection and disposal of contaminated firefighting water, release mitigation media and other liquid effluents should be determined through the project-specific hazard identification and risk evaluation process. The required containment capacity and disposal arrangements should be compatible with the foreseeable emergency scenarios and response measures. Where active firefighting systems are required, their type, capacity and performance should be justified as part of the safety barrier strategy.

The selected firefighting strategy should also consider potential secondary consequences, such as contaminated firewater, toxic vapour dispersion, and compatibility of the extinguishing media with the fuel involved.

6.11.4 Interface with port emergency services

Effective emergency response during bunkering relies on close coordination with port emergency services, including fire brigades, medical services, and traffic control. The importance of the following is emphasised:

- clear communication pathways between bunkering personnel and emergency responders,
- predefined roles and responsibilities during emergency response,
- compatibility of emergency response plans between ship, port, and bunkering operator.

Ports with experience from pilot bunkering projects have highlighted the value of joint planning and familiarisation between operators and emergency services prior to commencing routine operations.

6.11.5 Evacuation, muster, and exclusion zones

Emergency preparedness includes arrangements for evacuation and muster of personnel in the event of an incident. This involves:

- predefined muster points and escape routes,
- management of access and traffic within the port during emergencies,
- enforcement of exclusion zones to protect third parties and responders.

The size and management of exclusion zones depend on the fuel, bunkering concept, and local conditions, but the principle of defining and rehearsing these arrangements is common across industry guidance.

6.11.6 Drills, exercises, and readiness assurance

Preparedness for emergencies is demonstrated through drills and exercises rather than solely through documentation. The following are therefore encouraged:

- regular drills involving ship and shore personnel,
- inclusion of fuel-specific emergency scenarios,
- participation of port emergency services where practicable,
- review of drill outcomes and incorporation of lessons learned.

Drills and exercises support confidence in emergency response arrangements and provide valuable feedback for improving procedures, training, and technical systems.

6.12. Training, Competence and Organisational Readiness

Training and competence are essential enablers for safe bunkering of green fuels. The effectiveness of technical systems, operational procedures, and emergency arrangements ultimately depends on the ability of personnel to understand hazards, recognise deviations, and take appropriate action. Training and competence are therefore treated as core organisational safety barriers rather than supplementary measures.

This approach is consistent with IMO interim guidelines, classification society requirements, and industry guidance for bunkering of alternative fuels, all of which emphasise competence as a prerequisite for approval and routine operation.

6.12.1 Identification of roles requiring competence

Bunkering operations involve multiple roles with different responsibilities and competence needs. As a minimum, competence requirements should be defined for:

- shipboard personnel involved in fuel handling, monitoring, and emergency response,
- bunkering operator personnel responsible for transfer operations and equipment,
- supervisory personnel overseeing bunkering activities,
- port authority or terminal personnel with approval or oversight responsibilities,
- emergency responders involved in bunkering-related incidents.

Clear identification of roles supports targeted training and avoids assumptions that generic maritime or port experience is sufficient for handling new fuels.

6.12.2 Competence requirements and knowledge areas

Competence for bunkering of green fuels extends beyond familiarity with procedures and includes understanding of:

- fuel-specific properties and hazard mechanisms,
- operational limits and safety barriers,
- emergency shutdown and response actions,
- communication and coordination during bunkering,
- human factors relevant to time-critical and interface-intensive operations.

For fuels such as ammonia, additional emphasis is required on toxicity, dispersion behaviour, and personal protection. For methanol, competence in ignition control, static electricity management, and detection of fires is particularly important.

6.12.3 Alignment with existing training frameworks

This approach builds on existing training and certification frameworks rather than proposing parallel systems. Where applicable, existing maritime training standards, port safety training, and company-specific competence schemes should be used as a foundation.

Experience from pilot projects indicates, however, that existing training often does not fully address fuel-specific bunkering hazards or port–ship interfaces. The approach therefore identifies the need for supplementary training and certification focused specifically on:

- bunkering operations for alternative fuels,
- ship/shore interface management,
- emergency response during bunkering.

This approach aligns with recommendations from industry organisations such as SGMF and guidance developed by classification societies and national authorities.

6.12.4 Practical training, drills, and exercises

Competence development for bunkering of green fuels should include practical elements in addition to classroom-based training. This approach emphasises the importance of:

- hands-on training with bunkering equipment,
- participation in simulated or real bunkering operations under supervision,
- regular drills addressing abnormal and emergency scenarios,
- joint exercises involving ship, shore, and port emergency services.

Practical training and drills support retention of knowledge, build confidence, and help identify weaknesses in procedures and interfaces before incidents occur.

6.12.5 Verification, records, and refresher training

Organisational readiness requires that competence is not only developed but also verified and maintained. In this context, the following are encouraged:

- formal verification of competence prior to participation in bunkering operations,
- maintenance of training and competence records,
- periodic refresher training, particularly when procedures or equipment change,
- additional training following incidents, near-misses, or significant deviations.

This approach supports continuous improvement and aligns with safety management system principles applied in both maritime and port environments.

6.12.6 Organisational readiness and maturity

Training and competence form part of a broader concept of organisational readiness. In this context, organisations involved in bunkering are encouraged to periodically assess whether:

- sufficient competent personnel are available,
- roles and responsibilities remain clear as operations evolve,
- training content reflects current hazards and operating experience,
- lessons learned are effectively fed back into training and procedures.

This supports gradual progression from pilot or demonstration operations to routine bunkering activities conducted with a high and consistent level of safety.

6.13. Interfaces with Storage and Usage Domains

Safe bunkering of green fuels cannot be considered in isolation from upstream storage systems or downstream onboard fuel use. Bunkering therefore explicitly addresses the interfaces with storage and usage to ensure continuity of safety philosophy and to avoid gaps or overlaps in responsibility.

6.13.1 Interface with Storage

The interface between storage systems and bunkering operations is a critical boundary where responsibilities and safety measures must be clearly aligned. The guidance provided for this domain assumes that storage systems described in Chapter 7 provide fuel to the bunkering operation within a defined and approved operating envelope. Constraints related to storage pressure, temperature, inventory management, and isolation capability directly influence bunkering procedures and operating limits.

The guidance provided for bunkering reflects these constraints by:

- ensuring that bunkering operating envelopes are compatible with storage system limits,
- aligning emergency shutdown and isolation philosophy between storage and bunkering systems,
- recognising dependencies related to fuel quality, availability, and transfer readiness.
- Any assumptions regarding storage system behaviour during bunkering are explicitly stated to support safe integration and clear allocation of responsibilities.

6.13.2 Interface with Usage

The interface between bunkering and fuel usage is equally important, as bunkering operations must be compatible with shipboard fuel systems and operational practices addressed in Chapter 8. The guidance provided for this domain assumes that receiving ships are designed, approved, and operated in accordance with applicable rules and guidelines for the specific fuel.

The guidance provided for bunkering supports this interface by:

- ensuring compatibility of bunkering connections, procedures, and safety systems with shipboard arrangements,
- aligning communication, authority, and emergency response expectations between ship and shore,
- recognising the role of shipboard readiness and fuel system status as prerequisites for bunkering.

Clear definition of this interface ensures that bunkering operations do not introduce hazards that compromise onboard fuel system safety or operational integrity.

7. Storage

7.1. Introduction

Compared with conventional ammonia and methanol, green ammonia and green methanol do not introduce different thermodynamic behaviour or material compatibility requirements when equivalent product specifications and impurity limits are maintained. The main difference is operational. Green production is linked to variable renewable energy supply, so storage systems are less likely to operate at steady state and may need to handle greater variability in production rates, inventory levels, filling and emptying patterns, and logistics interfaces [18,19].

This chapter explains what that means for storage safety in port facilities. It first introduces how flexible green-fuel supply can affect storage design and operation. It then considers ammonia storage, including storage condition, temperature and pressure control, vapour space management, toxicity, stress corrosion cracking, material compatibility and sealing performance. The chapter then considers methanol storage, including ambient storage, flammability, vapour management, moisture uptake, galvanic corrosion, stress corrosion cracking and compatibility of metallic and non-metallic materials.

A further focus is the wider safety system around the tank. More variable operation may influence pressure relief arrangements, fire and gas detection, emergency shutdown and isolation, ventilation, release mitigation, firefighting systems, refrigeration or inerting, secondary containment, inspection intervals and emergency response.

Required barriers and cause-and-effect actions should be defined through project-specific hazard identification and risk evaluation, taking into account the hazard drivers described in Chapter 4, credible release scenarios and locations, supported by consequence assessment where appropriate [20]

Finally, the chapter links the technical storage topics to the applicable governance framework, including EU Regulations, EU Directives and Danish Executive Orders. The intention is to give the reader a practical overview of the main technical safety issues before moving into the more detailed ammonia and methanol storage sections.

7.2. Ammonia Storage

7.2.1 Anhydrous and Aqueous Ammonia

Anhydrous ammonia is pure ammonia and stored as a high-pressure liquid at ambient temperatures. It is widely considered one of the most critical alternative green fuels, particularly for decarbonising heavy industries and global shipping [21].

Aqueous ammonia (ammonia dissolved in water) is stored in atmospheric containers and not used directly as a fuel, but it has a “behind the scenes” role in the green fuel ecosystem. Examples include urea, which is used to clean up and neutralise nitrogen oxide emissions (NO_x). Urea is also used as a liquid fertiliser. Due to not being pressurised and because it is mostly water, aqueous ammonia will have a much larger storage footprint when compared to anhydrous ammonia [21].

7.2.2 Temperature and Pressure in Ammonia Storage

Ammonia is typically stored in one of three ways: as a refrigerated liquid at approximately -33°C and near atmospheric pressure, as a pressurised liquid (roughly 8–15 bar) at ambient temperature, or as a combination of these (semi-refrigerated). Temperature control is achieved by cooling systems (water spray and refrigeration), pressure control and by insulation.

Stored ammonia is sensitive to temperature, and even small temperature increases can lead to a significant pressure rise. The temperature-pressure relationship is nonlinear, which means that over-pressurisation can develop quickly if heat input, boil-off gas and pressure relief are not controlled. Safe ammonia storage therefore depends on continuous management of both temperature and pressure.

The ammonia storage system will breathe due to both normal operational conditions and fluctuations in weather patterns. If heat is absorbed during this breathing process, then liquid ammonia will vaporise, producing boil-off gas. To keep the tank pressure stable and to prevent venting of the toxic ammonia gas, the boil-off gas will continuously be collected, compressed, cooled, and then returned to the tank.

Ammonia refrigeration operates continuously to return vapour and maintain storage temperature and pressure. If refrigeration fails, evaporation increases and tank pressure will rise. In a severe case, uncontrolled warming could contribute to a boiling liquid expanding vapour explosion (BLEVE), combining mechanical failure with a toxic release.

External events can also influence refrigeration and relief system requirements. For example, a fire in a neighbouring storage tank may increase heat input and the pressure relief system must be capable of handling the resulting emergency gas flow. Such scenarios should be included in quantitative risk assessment, as they may influence storage location, separation distances and emergency response planning.

7.2.3 Vapour Space

The vapour space is located directly above the stored ammonia. It helps manage internal pressure changes by providing space for liquid thermal expansion and by collecting returned boil-off gas. This reduces the likelihood of over-pressurisation during normal storage and operating cycles.

Ammonia vapour is lighter than air and will rise. As liquid ammonia expands with increasing temperature, the vapour space will absorb the change before other pressure relief systems need to activate. The vapour space is also connected to emergency relief valves and scrubbers, which handle more severe over-pressurisation events when the vapour space capacity is exceeded. Due to ammonia's toxicity, any release will be captured and fed back into the storage system, or passed through scrubbers, which force the released vapours through an acidic or aqueous spray and neutralise the ammonia gas.

In PGS-12, inert gas padding is applied as a risk control measure to maintain a low-oxygen atmosphere in the vapour space of ammonia storage systems, thereby limiting oxygen-driven degradation mechanisms such as stress corrosion cracking and reducing the likelihood of loss of containment [22].

The location and design of vent, relief and release management systems should be supported by consequence assessment or dispersion modelling, as appropriate, to demonstrate that the resulting impacts on personnel, neighbouring facilities, the public and the environment are understood and adequately managed.

7.2.4 Material Interactions

The role of pressure and temperature on material interactions (corrosion) was briefly introduced during Section 7.2.2. The following text will discuss material interactions in more detail, focusing on material selection and specific failure mechanisms for ammonia storage.

Material behaviour is strongly influenced by environmental conditions, particularly the presence of water, with wet ammonia storage systems exhibiting more aggressive corrosion compared to dry ammonia storage systems [21].

7.2.5 Metallic Materials

Ammonia compatibility is driven mainly by susceptibility to stress corrosion cracking (SCC). As general starting points, low-temperature carbon steels are preferred, stainless steels may be suitable, and copper- or zinc-containing materials should generally not be used where they are in contact with ammonia.

Although ammonia is alkaline rather than strongly acidic, it can still drive material degradation through specific mechanisms. These mechanisms depend on the material, the presence of oxygen or moisture, the stress state and whether the ammonia is dry or wet.

7.2.6 Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the dominant material degradation mechanism found in ammonia storage. Oxygen is a strong SCC enabler, because it allows electrochemical reactions to take place on the material surface that in time create the corrosion. The core conditions for stress corrosion cracking of both carbon steels and copper alloys are the simultaneous presence of tensile stress, a susceptible material, and a specific corrosive environment. Carbon steels typically crack in anhydrous ammonia (no water), while copper alloys crack in aqueous ammonia. The chemical nature of the corrosion and the internal cracking mechanisms will therefore be different, when comparing carbon steels to copper and its alloys.

The most frequent places for SCC to occur in ammonia storage systems are those where air can accumulate, such as in the vapour spaces (the areas above the liquid ammonia). The use of nitrogen purging, either during routine maintenance or used as a continuous slight overpressure during storage is an established method to keep the oxygen levels very low.

The drivers for SCC in carbon steel are contaminants, such as air and carbon dioxide, while the driver for SCC in copper alloys is moisture. For both, oxygen is also required.

7.2.7 Polymers, Seals and Gaskets

Ammonia is moderately aggressive to polymers, and the effects depend on the polymer chemistry, the ammonia concentration and the ammonia water content. Typical effects of ammonia on polymers include swelling, softening and loss of strength. Polypropylene (PP), Polyethylene (HDPE / LDPE) and PTFE tend to show little to no damage [23].

Ammonia failure often occurs at the gaskets because ammonia diffuses into the gasket material and changes its properties through swelling or degradation, which then reduces the sealing force and ultimately results in leakage. Table 4 gives a summary of typical compatibility of gasket materials for use in ammonia storage systems.

Table 4 Typical Compatibility of Gasket Materials

Good resistance	Poor resistance
EPDM	Natural rubber
PTFE	Polyurethane
Neoprene	Some silicones
Butyl rubber	Some nitriles

The discussion in Section 7.3.5 provides additional context on how variable green-fuel operating conditions may affect polymers, seals and gaskets.

7.3. Methanol Storage

Methanol is stored as a liquid at ambient temperature and typically does not require refrigeration or high-pressure tanks. However, because methanol storage systems are sealed, temperature changes can still result in pressure changes. These temperature influences may come from atmospheric conditions, such as day-night cycles and weather systems, or from operational conditions such as filling and emptying. Managing this temperature-pressure relationship is therefore important for both safety and efficiency.

From a flammability perspective, temperature control can also include avoidance of ignition sources, particularly in areas where methanol vapour can accumulate. Methanol vapour forms explosive mixtures with air over a wide concentration range and, because it is heavier than air, will sink to the ground during a leak. From there, it then migrates to depressions or confined zones. Examples include low-lying areas, tank head spaces, confined spaces, and poorly ventilated locations.

Another aspect to consider for temperature and pressure control, is that the normal operational breathing cycles may introduce unwanted chemical elements into the inner storage system. Methanol is hygroscopic and absorbs moisture from the air that enters the tank during normal operational activities. In coastal environments, where the air carries dissolved chlorides, the chloride contaminated moisture could accelerate internal corrosion. Pressure and temperature control is therefore more than just controlling the methanol vapours.

7.3.1 Vapour Space

Methanol storage tanks include a vapour space above the liquid methanol. This space accommodates liquid expansion and supports vent management. The vapour space will typically be sealed and filled with an inert gas, such as argon or nitrogen. This will displace oxygen and reduce the ignition risk, and it will also lower the water vapour in the storage tank. Because methanol is hygroscopic, it easily absorbs moisture. The ability of inerting to lower the water vapour will also reduce the uptake of moisture by methanol, further reducing the corrosion risk. Inerting is not only done during active storage, but also when the storage system is emptied. The inert gas will then replace the extracted air that was once in the vapour space.

7.3.2 Stress Corrosion Cracking

Stress corrosion cracking (SCC) is also a degradation mechanism found in methanol storage. Pure methanol rarely causes SCC, but the addition of small amounts of water will greatly accelerate the onset of stress corrosion cracking. Water is then the SCC enabler, often when combined with chlorides. Purging and inerting reduce moisture uptake.

7.3.3 Galvanic Corrosion

Because methanol is a polar solvent, galvanic corrosion is more prevalent than in other commonly used motor fuels. Materials particularly susceptible include aluminium, lead, magnesium, copper, zinc, and platinum alloys.

Methanol is a polar solvent, meaning that its electronic arrangement helps to dissolve other substances. This specific property speeds up galvanic corrosion due to the following:

- It removes and transports impurities, such as water, chlorides and oxygen.
- It destabilises protective surface films.
- It can create galvanic currents (act like an electrolyte) and speed up localised corrosion.

7.3.4 Metallic Materials

Besides galvanised steel, there is no universal rule that can be used to exclude certain metallic materials, as was the case for copper and its alloys in ammonia storage. The general idea is to prevent both stress corrosion cracking and oxidation driven corrosion mechanisms, the latter being a conversion of methanol into corrosive organic acids in the presence of oxygen and moisture.

According to the Methanol Institute, methanol tanks can be constructed of either carbon steel or 300 series austenitic stainless steel. Carbon steel will be cheaper, but will have more maintenance and corrosion protection costs, when compared to 300 series austenitic stainless steels [24]. Regular inspection and cathodic protection are two key requirements to prevent methanol related corrosion failure.

7.3.5 Polymers, Seals and Gaskets

Methanol presents a demanding service environment due to its behaviour as a small, polar solvent, which enables it to penetrate polymer structures and interact with sealing materials more aggressively than non-polar fuels, such as petrol, diesel and jet fuel.

Performance of polymers and gaskets is therefore highly dependent on chemical compatibility, temperature, pressure, and service conditions, and these components are often a limiting factor in the operational reliability of storage and transfer systems.

Gasket failure in methanol systems is typically driven by material degradation and loss of sealing function, rather than purely mechanical failure. The most common causes include:

- Excessive swelling of elastomers: Methanol diffuses into elastomer matrices due to its polarity and small molecular size, causing volume expansion and mechanical distortion. In confined sealing geometries, this can result in rupture or extrusion.
- Chemical degradation: Methanol can alter the chemical structure of certain polymers, leading to loss of physical properties and progressive degradation of the sealing material.
- Explosive decompression: Absorbed methanol vapour may rapidly expand during pressure changes, generating internal stresses that can damage, crack or eject the seal from its seating.
- Loss of elasticity due to temperature effects: At low temperatures, elastomers may harden and lose elasticity, while elevated temperatures accelerate chemical degradation and ageing.

Gaskets and seals are therefore selected for their resistance to swelling and chemical attack, while at the same time being able to maintain their mechanical integrity across the operational temperature and pressure range. Material suitability will not be uniform across all methanol storage conditions and compatibility will vary, depending on the chemical environment and operating conditions. The following are, however, commonly used:

- PTFE and fluoropolymers
- Perfluoro elastomers
- Synthetic rubbers, such as neoprene and those based on ethylene propylene
- Fluorosilicone.

There are also materials that have reduced performance or are not normally recommended for methanol service. These are:

- Polyurethanes
- Polycarbonates
- PVCs
- Nitrile rubbers.

7.4. Directives, Regulations and Executive Orders

Storage systems and the equipment in the storage system need to meet specific technical safety expectations. These expectations are found in EU Regulations, EU Directives and Danish Executive Orders [See Table 5 and Table 6].

Technical safety can be explained as the initial application and continuous refinement of safety requirements to equipment and systems, based on systematic hazard identification and risk evaluation (see Chapter 5), demonstrated through documented verification, maintained through lifecycle control, and assessed against potential failure scenarios. In other words, technical safety follows all aspects of the storage system, from design through fabrication, installation, commissioning, operation, repair, modification and, eventually, decommissioning.

EU Regulations are directly applicable in all Member States and are compulsory in their entirety without the need for national transposition. They apply as they were written and create a common legal baseline across the EU. EU Directives are also compulsory, but in a different way. They define the result that must be achieved, while leaving each Member State flexibility to decide how the requirement is implemented in national law. In Denmark this is done by Executive Orders, also known as “bekendtgørelser”. The Danish Executive Orders provide the national mechanism that turns the objectives of EU Directives into practical and enforceable requirements.

Danish Executive Orders serve an essential role in technical safety. They connect European legal intent with Danish operational reality by specifying how requirements are applied, supervised and enforced in practice. Even where an EU Regulation already applies directly, national rules may still be needed to define competent authorities, supervisory arrangements or supplementary obligations.

A governance overview has been created below in Table 5, to show an example of how EU directives and DK executive orders fit together.

The table is intended as a navigation aid and does not replace a project-specific legal, regulatory and contractual review. The contractual documentation for the marine fuel storage system should be reviewed to confirm the applicable requirements.

Table 5 Governance Table for Marine Fuel Storage

EU Governance	DK Governance	Design	Installation	Operation	Decommissioning
PED ¹	BEK 190	✓	✓	X	X
Seveso III ¹	BEK 372 BEK 1254 BEK 1257 BEK 1639	✓	✓	✓	X
ATEX ¹ (Product)	BEK 289	✓	✓	X ²	X ²
ATEX ¹ (Workplace)	BEK 478 BEK 1639 BEK 590	✓	✓	✓	✓
Machinery ¹ Directive	BEK 1094	✓	✓	X ²	X ²

EU Governance	DK Governance	Design	Installation	Operation	Decommissioning
EMC	—	✓	✓	X ⁴	X ⁴
LVD	—	✓	✓	X ⁴	X ⁴
—	BEK 99	✓	✓	✓	X
CLP ³	—	✓	✓	✓	✓
REACH ³	—	✓	✓	✓	✓
CMRD ³	—	✓	✓	✓	✓
BPR ³	—	✓	✓	✓	✓

Notes

1. Storage-specific Danish Executive Orders may apply alongside the EU governance framework. They support implementation of requirements related to environmental protection, hazardous substances, fire and explosion safety, and safe storage and handling of hazardous materials.
2. Some instruments do not directly regulate operation or decommissioning, but influence these phases indirectly through risk assessment, technical documentation, instructions for use, maintenance requirements and dismantling assumptions.
3. CLP, REACH, CMRD and BPR define hazard classification, substance properties, exposure limits and conditions of use. They act as an input layer to the governance framework and influence technical safety decisions across the lifecycle.
4. EMC, LVD and ATEX Product requirements influence operation indirectly through electrical safety, reliability, electromagnetic compatibility and ignition-prevention requirements incorporated into equipment during design and manufacture.

PED, ATEX Product, EMC, LVD and the Machinery Directive sit mainly on the product side of the regulatory landscape. They are concerned with safe design, manufacture, conformity assessment and the conditions that must be satisfied before equipment is placed on the market or put into service.

Seveso III and ATEX Workplace extend further into the system context and operational environment. They address how hazardous substances, explosive atmospheres and major accident scenarios are managed at installation level. BEK 99 also has an important role in Denmark because it covers repair, modification and continued safe use of pressure equipment after it has entered service.

In simple terms, the EU layer helps determine whether equipment can be placed on the market, while the Danish layer defines how it must be controlled, used, repaired and modified safely in practice. Regulations such as CLP and REACH apply directly in all Member States and provide important substance and hazard information. Together, these instruments define the boundary conditions within which directives such as PED, ATEX and the Machinery Directive, and Danish Executive Orders, are applied. Table 6 collects the governance references to give an overview of the regulations and instruments considered.

Table 6 Reference Table for Marine Fuel Storage

Executive Order	Application
BEK 99	Use, repair and modification of pressure equipment
BEK 190	Implementing the Pressure Equipment Directive
BEK 289	Implementing ATEX product requirements for equipment used in explosive atmospheres
BEK 372	Control of major accident hazards involving dangerous substances
BEK 478	Work in connection with explosive atmospheres
BEK 590	Classification of areas with explosive atmospheres
BEK 1094	Machinery safety requirements
BEK 1639	Fire safety requirements for storage and handling of flammable substances
PED	Pressure Equipment Directive
Seveso III	Major Accident Hazards Directive
ATEX - Product	Equipment for Explosive Atmospheres Directive
ATEX - Workplace	Explosive Atmospheres Workplace Directive
MD	Machinery Directive
EMC	Electromagnetic Compatibility Directive
LVD	Low Voltage Directive
CLP	Classification, Labelling and Packaging Regulation
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
CMRD	Carcinogens, Mutagens and Reprotoxic Substances Directive

7.5. Conclusions for Storage

- Green ammonia and green methanol do not fundamentally change the storage chemistry, but they are expected to change storage operations through increased variability in production, inventory levels and cycling associated with renewable energy supply.
- Future storage systems may need to be designed for greater operational flexibility, with increased attention to transient conditions, material degradation mechanisms, inspection strategies and system integration.
- For ammonia, the dominant technical safety challenges are management of temperature and pressure, toxicity, stress corrosion cracking and material compatibility.
- For methanol, the dominant technical safety challenges are flammability, moisture uptake, stress corrosion cracking, galvanic corrosion and long-term compatibility of polymers, seals and gaskets.
- Storage cannot be considered in isolation. Safe implementation depends on the integration of storage, logistics, bunkering operations, emergency preparedness and the wider port environment.

- Technical safety requirements are governed through a combination of EU legislation and Danish Executive Orders, with European legislation primarily influencing design and conformity assessment, while Danish requirements extend governance into operation, modification and continued safe use. Additional required barriers and cause-and-effect actions shall be defined through project-specific hazard identification and risk evaluation, supported by consequence assessment where appropriate.
- Some specifications from oil and gas are specific and do not automatically qualify in their scope for ammonia and methanol use. SafeSBU did not manage to review all relevant documentation, and the activity is left to the reader where relevant.

8. Usage

8.1. Introduction

This chapter defines competency and training requirements for the safe use of alternative marine fuels, with particular focus on ammonia and methanol. It uses the existing STCW Code [25], IGF Code [26] and the IMO interim guidance framework as the starting point and then considers where additional fuel-specific competence is needed because of the different hazard profiles of ammonia and methanol.

The chapter first summarises the regulatory and legislative framework that currently shapes training requirements, including the use of interim guidance, equivalency and risk-based approaches where prescriptive requirements are still developing. It then explains why the LNG-based training framework provides a useful baseline but cannot be applied without modification to ammonia and methanol.

The chapter then sets out generic basic and advanced training requirement for seafarers before considering additional ammonia-specific and methanol-specific training needs. For ammonia, the emphasis is on toxicity management, vapour dispersion, respiratory protection, material compatibility and emergency response. For methanol, the emphasis is on low-flashpoint behaviour, invisible flames, bunkering and transfer safety, spill response, exposure management and suitable firefighting methods.

Finally, the chapter considers the wider role groups involved in safe fuel use. Safe operation depends not only on the ship's crew, but also on ship management, shoreside organisations, terminal personnel, port authorities and support functions that influence planning, supervision, emergency preparedness and operational interfaces.

8.2. Regulatory and Legislative Framework

Training for crew members sailing on vessels using methanol or ammonia is regulated by both the IMO and the relevant flag-state authority. During the latest Maritime Safety Committee session (MSC 111), from 13–22 May 2026, the sub-committee on human element, training and watchkeeping (HTW 12) approved interim guidelines, STCW.7/Circ.26 and STCW.7/Circ.27, on training for seafarers on ships using alternative fuels and new technologies, covering methyl/ethyl alcohol and ammonia as fuel.

The IMO separates traditional petroleum products (such as diesel, gas oil, and heavy fuel oil) from alternative fuels. Although the fuel types considered in this guideline share this common denominator, their properties and characteristics vary significantly. For example, minor leaks can result in small concentrations of ammonia that nearby personnel may notice as a stinging or burning sensation in the nose. However, the body quickly adapts to these low levels and stops reacting, which is dangerous because ammonia is highly toxic. Without proper monitoring, an increased concentration can go undetected, posing a significant risk. Methanol, while not toxic in the same way as ammonia, poses its own challenges. If ignited, methanol burns without a visible flame, making fire detection and firefighting more difficult.

8.2.1 STCW and IGF framework as training baseline

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) sets minimum standards of competence for seafarers. For ships using low-flashpoint fuels under the IGF Code, STCW Section A-V/3 provides the primary baseline for training and certification. This framework was originally developed for LNG but is currently used as the reference point for alternative fuels through equivalency and interim guidance.

8.2.2 Interim guidance and equivalency approaches

Because prescriptive competence requirements for fuels such as ammonia and methanol are still developing, training is currently shaped through interim IMO guidance, equivalency arrangements and risk-based safety assessments. In practice, this means operators often use the STCW and IGF Code frameworks as a baseline and then supplement them with additional fuel-specific competencies based on the hazards of the fuel and the ship design.

8.2.3 Current regulatory position for ammonia and methanol

Ammonia is not yet covered by prescriptive IGF Code or STCW competence requirements and therefore relies on equivalency, interim guidance and risk-based approaches. Methanol is supported by IMO interim safety guidelines, which reference the IGF Code and STCW Section A-V/3, but competence requirements remain largely derived from LNG-based structures rather than fuel-specific tables.

8.3. Alternative Marine Fuels and Hazard Drivers

8.3.1 LNG framework as baseline

The existing STCW/IGF framework was developed around LNG and cannot be transferred directly to ammonia and methanol. It is still a practical starting point because these fuels also rely on dedicated fuel systems, bunkering procedures, operating controls and emergency response planning. The training framework therefore needs a common baseline, with targeted additions that reflect the distinct hazard profiles and operational challenges of ammonia and methanol.

Although this chapter focuses on competence and training, safe use of ammonia and methanol also depends on onboard technical safety systems. Depending on the fuel concept and vessel design, these may include ventilation, gas detection, emergency shutdown functions, pressure relief arrangements, secondary containment, inert-gas systems and fuel-specific emergency response measures.

These technical systems are generally governed through ship design rules, classification requirements and IMO instruments. Competence requirements then ensure that personnel can operate, monitor and respond to the conditions created by those systems, including alarms, ventilation changes, shutdown actions and emergency response measures.

Additional technical safety measures may be required depending on the fuel, operating concept and identified hazards. For toxic or environmentally harmful fuels, this may include secondary containment, drainage control and recovery arrangements. Where inert-gas or nitrogen systems perform safety-critical functions, the project should assess the consequences of loss of supply and determine whether redundancy, backup supply or additional safeguards are required.

8.4. Generic Training Requirements for Seafarers

Regardless of the fuel type, there are two generic training levels. The first is “basic training” which applies to all seafarers with designated safety duties and focuses on hazard awareness, safe working practices and immediate response actions.

The second generic training level is “advanced training” which applies to masters, engineer officers and personnel with immediate responsibility for fuel systems and operations. This advanced level includes details of the fuel system, risk assessment and emergency leadership.

8.4.1 Basic training – generic

Table 7 applies to all seafarers assigned duties on ships using alternative fuels. It builds on existing STCW requirements and includes safe operation of alternative-fuelled ships, hazard awareness, occupational health and safety, fire awareness, emergency response and pollution prevention [27]. This level integrates fuel-specific hazard awareness for ammonia and methanol.

Table 7 List of Generic Basic Training Requirements

Training area	Focus	Applies to
Safe operation	Basic awareness of operations	All crew members
Hazard awareness	Awareness of ammonia and methanol risks	All crew members
Emergency response	Actions, alarms, mustering and first response	All crew members
Health and safety	Working practices, PPE and exposure	All crew members
Fire awareness	Fire risks, alarms and firefighting	All crew members
Pollution prevention	Environmental protection and spill reporting	All crew members

8.4.2 Advanced training – generic

Table 8 applies to personnel with immediate responsibility for fuel systems and operations. It includes detailed understanding of fuel properties, propulsion and fuel supply systems, bunkering planning and supervision, risk assessment, regulatory compliance and emergency leadership [27].

Table 8 List of Generic Advanced Training Requirements

Advanced training area	Focus	Applies to
Fuel systems knowledge	Detailed understanding of fuel properties, system design and operation	Officers and engineers
Bunkering supervision	Planning, coordination and monitoring of bunkering operations	Responsible personnel
Risk management	Hazard control, compliance and operational risk assessment	Senior officers
Emergency leadership	Decision-making and coordination during incidents and emergencies	Master mariners and chief engineers

8.5. Hazard Profiles and Training Requirements

As discussed in Chapter 4, ammonia presents a hazard profile dominated by toxicity, corrosivity, material incompatibility and specific fire and explosion scenarios. These hazards drive the need for enhanced training in toxicity management, use of specialised PPE, leak detection, dispersion behaviour and emergency response, including practical drills for high-consequence events.

Methanol is a low-flashpoint liquid fuel stored at ambient conditions. Its primary hazards include flammability with invisible flames, toxicity by ingestion and inhalation, and material compatibility considerations. These characteristics require targeted training in ignition control, flame detection, bunkering operations, spill response and appropriate firefighting techniques. A comparison of hazard drivers for both ammonia and methanol is available in Table 9 [28,29].

Table 9 Comparative Hazard Drivers for Training

Aspect	Ammonia	Methanol	Training implication
Primary hazard	Inhalation toxicity (IDLH context)	Flammability (invisible flame) + ingestion	Different PPE, detection and emergency drills
Flame visibility	Visible	Often invisible in daylight	Enhanced detection training for methanol
Storage context	Cryogenic/pressurised	Ambient liquid	Different handling and emergency planning
Material risks	Copper and zinc alloys; SCC	Aluminium/Zinc; some elastomers	Fuel-specific materials training

8.5.1 Specialist training – ammonia

Additional ammonia-specific training is required to address hazards not fully covered by LNG-based frameworks (Table 10). This includes toxicity management, respiratory protection, vapour dispersion awareness, material compatibility, ammonia-specific firefighting strategies and regular practical emergency drills [30].

Table 10 List of Ammonia-specific Training Requirements

Ammonia-specific training area	Focus	Applies to
Toxicity management	Exposure awareness, respiratory protection and immediate first response	All relevant personnel
Respiratory protection	Selection, use and limitations of breathing apparatus and PPE	Emergency teams and operators
Vapour dispersion awareness	Gas behaviour, detection zones and release consequences	Watchkeepers and officers
Emergency drills	Practical response to leaks, toxic exposure and evacuation scenarios	All crew members

8.5.2 Specialist training – methanol

Additional methanol-specific training (Table 11) focuses on low-flashpoint fuel behaviour, invisible flame detection, safe bunkering and transfer operations, spill response for a water-soluble fuel, ingestion first aid and use of appropriate firefighting media such as alcohol-resistant foams [28,29].

Table 11 List of Methanol-specific Training Requirements

Methanol-specific training area	Focus	Applies to
Invisible flame awareness	Recognition of low-visibility fires and appropriate detection methods	All relevant personnel
Bunkering and transfer safety	Safe handling, connection procedures and ignition source control	Operators and responsible personnel
Spill and exposure response	Response to leaks, skin contact, inhalation and ingestion hazards	All crew members
Methanol firefighting	Use of suitable media such as alcohol-resistant foams and flame detection support	Emergency teams and officers

8.5.3 Role groups

A consulted report [30] identified seven port community stakeholder groups for maritime operations, reflecting the fact that safe fuel operation depends on more than the ship's crew alone.

The port community has a layered responsibility structure, starting with onboard ship management and operational personnel, extending to onboard support functions, and then moving outward to company corporate staff, port authorities, terminal management and finally to other onshore support. Competencies will be distributed across the full maritime operational chain, rather than concentrated in the seagoing roles. The shoreside rows show that safe use of ammonia and methanol also depends on organisational and interface competence beyond the vessel.

The management group carries the broadest responsibility because it combines regulatory compliance, operational decision-making, supervision of storage and transfer, and emergency leadership. The operational personnel then translate those requirements into day-to-day execution through watchkeeping, system monitoring and other safety-critical tasks. Operational personnel typically do not manage fuel systems directly, but they still need to have hazard awareness, know what PPE to apply, and know how to respond during emergencies and alarms. Table 12 provides a list of key functions in the port community and the associated responsibilities needed to manage the risks associated with ammonia and methanol.

Table 12 List of Role Groups and Key Competence Requirements

Role group	Personnel	Summary of key requirements
Ship management	Master, Chief Officer, Chief Engineer, First Engineer	Regulatory compliance; supervision of storage/transfer; emergency leadership; hazard management
Ship operations	Junior Officers, Junior Engineers, ETO	Safety-critical tasks under supervision; watchkeeping in alternative-fuel risk context; automation interfaces
Ship support	Bosun, AB, OS, Motorman, Oiler, Pumpman, Hotel functions	Hazard awareness; PPE discipline; support during drills and emergencies
Company	Operations, Technical, HSSEQ, Procurement	Management system updates; procedures; shoreside support
Port authorities	Government port entry/operations entity	Port planning; emergency response coordination
Terminal management	Terminal managers, supervisors, local fire teams	Protect workers; support bunkering; assist emergency response
Support	Bunker barges, tugs, salvage companies	Support alternative-fuel operations; emergency response role

8.6. Conclusions for Usage

- Competence and training for ammonia and methanol should be built from a common STCW/IGF baseline but also supplemented with fuel-specific requirements.
- The existing LNG-based framework is a useful starting point, but it does not fully address the different hazard profiles, operating conditions and emergency response needs associated with ammonia and methanol.
- Prescriptive competence requirements for ammonia and methanol are still developing, so interim guidance, equivalency arrangements and risk-based approaches remain important.
- Generic basic and advanced training provide a common structure for all seafarers working with alternative fuels.

- Ammonia requires additional competence in toxicity management, respiratory protection, vapour dispersion, material compatibility, leak response and emergency preparedness.
- Methanol requires additional competence in low-flashpoint behaviour, invisible flame detection, bunkering and transfer safety, spill response, exposure management and alcohol-resistant firefighting methods.
- Training must reflect both fuel properties and the technical safety systems installed on board, including detection, ventilation, shutdown, containment and emergency response arrangements.
- Safe use depends on more than the ship's crew. Competence requirements should also cover ship management, shoreside organisations, port authorities, terminal personnel and support functions involved in planning, supervision and emergency response.

9. Integrated Emergency Preparedness, Response and Recovery

9.1. Introduction

Emergency preparedness is an essential part of the safety system for the storage, bunkering and usage of green fuels in ports. Technical barriers reduce the likelihood and consequences of an accident, but they cannot eliminate all risk. Ports, facility operators, bunker operators and ships shall therefore be prepared to detect abnormal conditions, stop and isolate fuel systems, protect people and the environment, support public emergency services and recover safely following an incident.

Emergency arrangements shall be based on the hazards and scenarios identified through the risk-management process described in Chapter 5. They shall cover:

- Port-based fuel storage and receipt;
- Transfer and bunkering operations;
- Ship/shore interfaces;
- Onboard incidents that may affect the port;
- Neighbouring port activities;
- Environmental and marine-pollution response;
- Coordination with public emergency services.

While individual organisations may maintain separate emergency plans, such plans shall connect at their interfaces and clearly identify:

- Who raises the alarm;
- Who stops and isolates the fuel;
- Who commands the initial response;
- Who contacts external emergency services;
- Who evacuates or shelters personnel;
- Who accounts for personnel;
- Who informs neighbouring facilities and authorities;
- Who manages environmental consequences;
- Who authorises recovery and restart.

Detailed bunkering-specific requirements for ESD, isolation, emergency release and ship/shore response are provided in Chapter 6.

9.2. Emergency Planning Process

Before operations commence, the port or project operator shall:

- 1 Identify credible emergency scenarios.
- 2 Define the immediate response for each scenario.
- 3 Allocate responsibilities between the port, facility, bunker operator, ship and emergency services.
- 4 Establish alarm, notification and escalation procedures.
- 5 Verify the availability of isolation, firefighting, monitoring, protective and environmental response equipment.
- 6 Prepare evacuation, sheltering, muster and personnel-accountability arrangements.
- 7 Consult the relevant Danish authorities and emergency services.
- 8 Train personnel and conduct exercises.
- 9 Close significant findings before first operation.
- 10 Review the arrangements following changes, incidents and exercises.

The output shall be in the form of an emergency scenario and response matrix, an example of which is illustrated below.

Table 13 Emergency Scenario and Response Matrix

Scenario	Immediate actions	Protection of people	External support	Environmental actions
Methanol spill	Stop transfer, isolate the source, remove ignition sources and monitor vapours	Establish an exclusion zone, use suitable PPE and assess exposure	Contact the rescue service if the release cannot be safely controlled	Close drains, contain and recover the material
Methanol fire	Activate ESD, isolate the inventory and apply the approved firefighting strategy	Evacuate the affected area and protect responders	Municipal rescue service	Retain foam and contaminated firewater
Ammonia release	Stop transfer, isolate, raise the alarm and determine wind direction	Evacuate or shelter based on dispersion and local conditions	Rescue service, police and chemical response advice	Prevent contaminated water from entering drains or port water
Hydrogen leak	Isolate, ventilate, control ignition sources and monitor gas	Establish an exclusion zone	Rescue service where escalation is possible	Normally limited unless other substances are involved

Scenario	Immediate actions	Protection of people	External support	Environmental actions
Hydrogen jet fire	Isolate the source and cool exposed equipment	Protect responders and evacuate the escalation area	Rescue service	Manage firefighting runoff where relevant
Loss of power or control	Initiate fail-safe shutdown and manual isolation	Account for personnel and restrict access	Technical and emergency support as required	Monitor containment and drainage systems
Vessel or vehicle impact	Stop operations, isolate systems and inspect damage	Establish an exclusion zone	Rescue and marine services as relevant	Contain any release
Release to port water	Stop the source and notify port control	Restrict access to the affected area	Municipality and relevant pollution response organisations	Activate the port pollution response plan

9.3. Danish Emergency Response Interfaces

The project shall identify the relevant Danish emergency organisations and agree how they will be involved.

9.3.1 Municipal rescue service

The municipal rescue service should be consulted during planning where a new activity introduces significant fire, explosion, toxic release or rescue requirements.

Danish municipal rescue services are dimensioned according to the local risk profile, including the required organisation, alarm arrangements, response capability, equipment and resources. Early engagement allows the project and the rescue service to identify capability, familiarisation, firewater, foam, monitoring or specialist equipment gaps before operations commence [31].

9.3.2 Incident command

The emergency plan shall recognise the Danish incident command arrangement:

- The rescue service incident commander directs the technical response at the incident site;
- The police incident commander manages the area outside the incident site and coordinates the overall multi-agency response;
- The health service incident commander manages the medical response;
- The port and operators provide technical information, specialist advice, access and support for plant isolation.

A competent operator representative shall be available to support the incident commander throughout the emergency [32].

9.3.3 Chemical Emergency Response

For significant ammonia or other chemical release scenarios, the plan should identify how advice or support from Beredskabsstyrelsen's chemical emergency response may be requested.

Available support includes:

- Chemical advice;
- Safety distance assessment;
- Dispersion forecasts;
- Field measurements and analysis;
- Decontamination advice;
- Advice on contaminated casualties;
- Specialist HazMat assistance.

The local rescue service remains responsible for requesting and coordinating such assistance [33].

9.3.4 Major accident establishments

Where the activity falls within the Danish major accident regime, the operator shall prepare and maintain the required internal emergency plan.

For applicable establishments, the internal plan shall:

- Control and limit major accidents;
- Protect employees;
- Be submitted before establishment or significant modification;
- Be implemented during a major accident or an uncontrolled event that could reasonably lead to one;
- Be reviewed, tested and updated as necessary at least every three years.

More frequent operational exercises may be required according to the risks and operating conditions [34].

9.3.5 Pollution within ports

Environmental emergency arrangements shall be coordinated with the municipality and the port's pollution response arrangements.

Under Danish law, the municipality is responsible for combating oil and chemical pollution within ports. The municipality may require the port board to prepare a port pollution response plan and ensure that the necessary response equipment is available [35].

9.4. Alarm, Notification and Escalation

The emergency plan shall define:

- Alarm types and their meaning;

- Manual and automatic alarm initiation;
- Who contacts port control;
- Who calls 112;
- Who notifies the ship, bunker operator and neighbouring facilities;
- Who notifies environmental and other relevant authorities;
- Backup communications;
- Escalation criteria;
- Communication during power, control-system or IT failure.

A four-level escalation model may be used, as illustrated below.

Table 14: Emergency Escalation Model

Level	Description	Required action
Level 1 – Local event	The event can be controlled within the immediate work area	Stop the affected activity and apply the local procedure
Level 2 – Site emergency	The facility emergency organisation is required	Activate the site plan and account for personnel
Level 3 – Port emergency	The event affects several operators or requires external response	Activate port coordination and call 112
Level 4 – Potential off-site impact	The event may affect public areas, neighbouring facilities or the environment	Support police-led coordination and assessment of public warning

The terminology may be adapted to the port, but the activation criteria and required actions shall be documented.

9.5. Shutdown and Isolation

Emergency procedures shall specify:

- Conditions requiring immediate ESD;
- Conditions requiring controlled shutdown;
- Locations of manual and remote shutdown controls;
- Ship/shore ESD interfaces;
- Isolation of storage and transfer inventories;
- Emergency-release arrangements;
- Response to loss of power or control;
- Management of trapped liquid or pressure;
- Safe depressurisation, draining, purging or venting;

- Confirmation that isolation has been achieved.

Personnel shall not approach a release point for manual isolation unless:

- The task has been risk assessed;
- They are trained and authorised;
- Suitable protective equipment is available;
- Atmospheric conditions are monitored;
- Withdrawal criteria are defined.

9.6. Protection of Personnel and Public

Emergency arrangements shall include:

- Primary and alternative escape routes;
- Primary and alternative muster points;
- Personnel accountability arrangements;
- Management of contractors, visitors, drivers and ship personnel;
- Evacuation procedures;
- Shelter-in-place procedures;
- Exclusion zones;
- Responder access and staging areas;
- Re-entry criteria.

Muster points and escape routes shall be selected using the identified fire, explosion and toxic-dispersion scenarios and informed by the consequence modelling. A single fixed muster point may not be suitable for ammonia because the safe direction depends on the wind and release location.

For toxic releases, the plan shall determine when sheltering may be safer than evacuation. Shelter arrangements shall address:

- Closure of doors and windows;
- Ventilation shutdown or recirculation;
- Communication with persons sheltering;
- Monitoring of shelter conditions;
- Maximum safe shelter duration;
- Criteria for evacuation or all clear.

Public warning is determined by the Danish authorities. The police may use physical sirens, the S!RENEN mobile-warning system and emergency messages through DR, TV 2 and official communication channels. The port and operators shall provide timely and accurate technical information to support public-warning decisions [36].

9.7. Fuel-specific Response Requirements

9.7.1 Methanol

The emergency plan shall address:

- Low-visibility flames;
- Ignition source control;
- Alcohol-resistant foam;
- Fixed or portable flame detection where visual confirmation is unreliable;
- Toxic inhalation, ingestion and skin exposure;
- Cooling of exposed equipment;
- Drainage isolation;
- Collection of spilled fuel;
- Retention and disposal of contaminated firefighting water.

9.7.2 Ammonia

The emergency plan shall address:

- Rapid isolation;
- Wind direction and toxic-cloud monitoring;
- Upwind and crosswind access;
- Respiratory and chemical protection;
- Evacuation versus sheltering;
- Casualty decontamination;
- Contaminated PPE and equipment;
- Public-warning implications;
- Atmospheric monitoring before re-entry.

Water spray, fog or curtains shall only be used where justified by the risk assessment and responder capability. The assessment shall consider:

- Effectiveness for the release type;
- Responder exposure;
- Risk of spreading the release;
- Quantity of contaminated water generated;
- Available retention capacity;
- Disposal requirements.

The SafeSBU project HAZID (Section 5.6) identifies that ammonia suppression, if implemented, and contaminated water disposal must be considered together, rather than treating vapour suppression as an independent measure.

9.7.3 Hydrogen

Where hydrogen is in scope, the emergency plan shall address:

- High pressure release;
- Ignition and jet fire;
- Accumulation in enclosed or high-level spaces;
- Isolation and ventilation;
- Pressure relief discharge;
- Cryogenic exposure where relevant;
- Cooling of exposed equipment.

A hydrogen flame should normally not be extinguished while the release continues unless extinguishment is required to save life or prevent escalation and the fuel source can be controlled.

9.8. Firefighting, Spill and Environmental Response

The operator shall determine firefighting and release mitigation requirements based on the identified scenarios.

The assessment shall define:

- Response objective;
- Required water supply;
- Foam type and quantity;
- Fixed and mobile equipment;
- Cooling requirements;
- Gas and flame monitoring;
- Suitable PPE;
- Drainage isolation;
- Retention capacity;
- External response time;
- Compatibility between port and municipal response equipment.

For methanol, the project shall verify that sufficient compatible alcohol-resistant foam is available.

For ammonia, water-based mitigation shall be linked to containment and disposal of contaminated water.

The environmental response plan shall identify:

- Drainage routes and isolation points;
- Available retention volume;
- Temporary containment arrangements;
- Protection of port water;
- Monitoring and sampling;
- Authority notification;
- Storage and disposal routes for contaminated materials.

Conventional oil spill equipment shall not automatically be assumed suitable for water-soluble fuels.

9.9. Emergency Equipment and Responder Information

Required equipment shall be identified based on the identified emergency scenarios and may include:

- Fixed and portable gas detection;
- Flame detection;
- Wind indicators;
- ESD and isolation controls;
- Firefighting equipment and foam;
- Respiratory and chemical protective equipment;
- Emergency showers and eyewash;
- Decontamination equipment;
- First aid equipment;
- Drain covers and spill control equipment;
- Intrinsically safe communications;
- Emergency lighting and backup power.

The port or operator shall provide an Emergency Response Information Pack containing:

- Site and berth plan;
- Maximum fuel inventories;
- Safety data sheets;
- ESD and isolation locations;
- Vent and relief discharge locations;
- Detection and firefighting systems;

- Drainage and retention layout;
- Access routes and staging areas;
- Emergency contacts;
- Fuel-specific response limitations.

The pack shall remain available during loss of normal electronic systems.

9.10. Drills, Readiness and Recovery

Emergency readiness shall be verified through the following activities, as a minimum.

Table 15: Emergency Exercise Program

Project Stage	Required Activity
Concept and design	Emergency scenario workshop with relevant stakeholders
Detailed design	Table-top exercise and emergency-services review
Commissioning	Functional testing of alarms, communications, ESD and isolation
Before first pilot operation	Integrated table-top exercise and muster or evacuation drill
Before routine operation	Joint exercise with the port and relevant external responders
Routine operation	Periodic fuel-specific drills
After significant change or incident	Targeted exercise and revalidation

Each exercise shall have:

- Defined objectives;
- An agreed scenario;
- Recorded observations;
- Identified deficiencies;
- Responsible action owners;
- Completion dates;
- Verification of action closure.

Operations shall not commence until:

- Emergency plans are approved;
- Relevant personnel are trained;
- Critical emergency equipment is available;
- Alarms, ESD and isolation have been tested;
- Relevant emergency services have been consulted;
- Required exercises have been completed;

- Significant findings have been closed or formally controlled.

Danish workplace requirements also require employers to provide appropriate first-aid, firefighting and evacuation arrangements and to prepare emergency, evacuation and exercise plans where there is a particular risk of hazardous releases, fire, explosion or similar accidents [37].

Following an incident, restart shall require:

- Confirmation that the source is isolated;
- Atmospheric and environmental monitoring;
- Equipment and structural inspection;
- Restoration of safety systems;
- Incident investigation;
- Risk reassessment;
- Closure of immediate safety actions;
- Formal restart approval.

9.11. Required Outputs

Application of this chapter shall produce the following:

- 1 Emergency Scenario and Response Matrix.
- 2 Emergency responsibility matrix.
- 3 Alarm and notification matrix.
- 4 Integrated emergency plan.
- 5 Evacuation, shelter and muster plan.
- 6 Environmental and port water response arrangements.
- 7 Emergency Response Information Pack.
- 8 Emergency equipment register.
- 9 Training and exercise programme.
- 10 Pre-operation emergency readiness record.
- 11 Recovery and restart checklist.

10. Governance, Regulatory Interfaces, Documentation and Approval Readiness

10.1. Introduction

Safe implementation of green fuel activities in ports requires clear governance as well as safe technical design. Storage, bunkering and ship operations within ports commonly involve several independent organisations, multiple authorities and interfaces between land-based and maritime requirements.

The project shall therefore establish governance arrangements that clearly define:

- Accountable organisations
- Regulatory and port approval requirements
- Decision rights
- Ownership of safety barriers
- Organisational and technical interfaces
- Required documentation and evidence
- Readiness and authorisation to operate.

This chapter provides the organisational link between the risk management process (Chapter 5), the storage, bunkering and usage chapters (Chapters 6 to 8), integrated emergency preparedness (Chapter 9) and the PRL-MF implementation process (Chapter 12).

The chapter does not provide a complete legal interpretation of Danish, EU or international requirements. Applicability shall be confirmed for each project based on the fuel, quantity, location, equipment and operating concept.

10.2. Governance and Stakeholder Matrix

The project shall identify all relevant stakeholders and document their roles, which may include the following:

Table 16 Typical Danish Port Stakeholders

Stakeholder	Required project action
Port authority or port operator	Confirm berth, land-use, port-rule, traffic, security and emergency requirements
Facility or terminal operator	Define responsibility for design, operation, maintenance and workplace safety
Storage operator	Define inventory, containment, receipt and integrity responsibilities
Bunker supplier or operator	Define responsibility for fuel quality, supply equipment and transfer
Shipowner and master	Confirm ship approval, receiving limits, crew competence and ship/shore compatibility

Stakeholder	Required project action
Municipality	Confirm planning, environmental, wastewater and emergency interfaces
Danish Environmental Protection Agency	Confirm whether it is the competent environmental authority
Municipal rescue service	Confirm fire-prevention and response requirements
Beredskabsstyrelsen	Confirm applicable fire, major accident and specialist response interfaces
Danish Working Environment Authority	Confirm workplace, chemical-risk and ATEX requirements
Danish Maritime Authority, flag State and class	Confirm ship-side regulatory and technical requirements
Police and health services	Address public protection and multi-agency emergency interfaces
Utility and infrastructure providers	Confirm availability and backup arrangements for power, water, drainage and communications
Neighbouring operators	Identify domino, SIMOPS and emergency interfaces

The project shall prepare a RACI matrix identifying who is:

- **Responsible** for carrying out the activity;
- **Accountable** for owning and approving the result;
- **Consulted** before the activity or decision is completed;
- **Informed** of the activity or decision.

Each significant activity should normally have one clearly identified Accountable party.

10.3. Danish Regulatory and Approval Screening

The project shall perform an early applicability screening using the current fuel, inventory, location, equipment and operating concept.

The screening shall consider:

- Port and port-specific operating requirements;
- Environmental approval;
- Planning and environmental assessment;
- Building requirements;
- Wastewater and waste;
- Fire and explosion requirements;
- Major accident requirements;
- Workplace chemical requirements;
- ATEX workplace and equipment requirements;

- Pressure equipment and machinery;
- Transport of dangerous goods;
- Port security and ISPS;
- Ship and maritime requirements;
- Marine pollution response.

10.3.1 Port requirements

Under the Danish Ports Act, port-security requirements and individual port regulations may apply in addition to other statutory approvals. Port permission shall therefore be treated separately from environmental, workplace, fire and ship-side approvals [38].

10.3.2 Environmental approval

Activities classified as listed activities under the Danish environmental approval system shall receive approval before establishment or before changes that may increase pollution are implemented.

The competent approval authority may be the municipality or the Danish Environmental Protection Agency. The authority determines the applicable list entry, and applications for listed activities are normally submitted through the Byg og Miljø digital system [39,40].

10.3.3 Workplace and ATEX requirements

Where employees may be exposed to an explosive atmosphere, the employer shall prepare an ATEX workplace assessment as part of the statutory workplace assessment.

The ATEX-APV shall identify:

- Possible explosive atmospheres;
- Zone classifications;
- Ignition sources;
- Technical and organisational protective measures;
- Safety systems;
- Trained personnel;
- Coordination between employers working in the same area.

The measures and equipment selected shall be compatible with the relevant hazardous-area classification [41].

10.3.4 Major accident requirements

Where applicable major accident thresholds are reached, the environmental authority coordinates the case with the other relevant authorities. Each authority retains responsibility for decisions within its own area.

The municipal rescue service and Beredskabsstyrelsen are involved where substances with the potential to result in fire and explosion hazards fall under the emergency management legislation [42].

The table below illustrates a register of the applicability of approvals required.

Table 17: Applicability and Approval Register

Requirement	Applicable?	Responsible party	Authority	Required evidence	Status
Port permission			Port	Operating application	
Environmental approval			Municipality or EPA	Environmental application	
Fire and explosion approval			Rescue service/Beredskabsstyrelsen	Fire-safety documentation	
Major accident requirements			Coordinated authorities	Notification or safety documentation	
ATEX workplace assessment			Employer/Working Environment Authority	ATEX-APV	
Ship-side approval			Flag/class/Danish Maritime Authority	Ship certificates and compatibility evidence	

The register shall be updated when the design, fuel, inventory or operation changes.

10.4. Roles and Decision Rights

The project shall define:

- Project owner;
- Asset owner;
- Operator;
- Environmental permit holder;
- Storage operator;
- Bunkering operator;
- Ship representative;
- Hazard owners;
- Safety barrier owners;
- Document owners;

- Internal approvers;
- Independent verifiers;
- Stop work authority;
- Restart authority.

For each significant hazard or barrier, the project shall identify:

- Who owns the hazard;
- Who implements the barrier;
- Who maintains and tests the barrier;
- Who verifies its performance;
- Who accepts the remaining risk.

Any person directly involved in an operation shall have authority to stop the activity where an immediate unsafe condition is identified. Restart authority and the required checks shall be defined in advance.

Regulatory approval shall not be treated as a transfer of operational accountability. The operator remains responsible for safe and compliant operation even where an authority, port or classification society has reviewed or approved the activity.

10.5. Authority Engagement and Approval Roadmap

The project shall appoint one responsible coordinator for authority engagement.

Before detailed design, the project should arrange early dialogue with the relevant authorities to confirm:

- Project boundaries;
- Relevant authorities;
- Regulatory classification;
- Required applications;
- Required risk studies;
- Consequence-modelling expectations;
- Emergency-planning requirements;
- Public-consultation requirements;
- Sequence and timing of approvals;
- Arrangements for pilot or temporary operation.

All authority comments, conditions and commitments shall be recorded and tracked.

The table below illustrates the approval gates to be reached, together with the evidence required to gain approval.

Table 18: Approval Gates

Gate	Minimum evidence
Initial feasibility	Activity description, stakeholders, preliminary regulatory screening and initial hazards
Concept selection	Preferred concept, preliminary HAZID, site constraints and authority feedback
Basis of design	Inventories, operating conditions, system boundaries, applicable requirements and safety philosophies
Detailed design readiness	Completed risk studies, barrier register, approval applications and verification plan
Commissioning readiness	Mechanical completion, test procedures, trained personnel and approved emergency arrangements
Pilot-operation readiness	Pre-start-up review, closed critical actions, port permission and pilot restrictions
Routine operation readiness	Pilot review, final procedures, maintenance programme and operating authorisation
Continued operation	Audits, permit compliance, barrier performance and periodic revalidation

Each gate decision shall record:

- Evidence reviewed;
- Decision-maker;
- Outstanding actions;
- Operating conditions or restrictions;
- Approval date;
- Review or expiry date.

10.6. Documentation and Safety Justification

The project shall maintain a controlled document register covering:

- Design basis;
- System descriptions and drawings;
- Fuel specifications and safety data sheets;
- HAZID, HAZOP and risk registers;
- Consequence modelling or QRA;
- Hazardous area documentation;
- Safety barrier register;

- Equipment certificates;
- Inspection and test records;
- Operating procedures;
- Bunkering procedures;
- SIMOPS assessments;
- Training and competence;
- Emergency plans and exercise records;
- Authority correspondence and approvals;
- Management of change records.

A concise safety justification shall demonstrate:

- What activity is proposed;
- Which requirements apply;
- Which hazards have been identified;
- Which barriers control those hazards;
- Who owns each barrier;
- How barrier performance has been verified;
- How operations and emergencies will be managed;
- Which risks remain;
- Which approvals and conditions apply;
- Whether the activity is ready to proceed.

An illustration of the evidence required to demonstrate barrier verification is presented in the table below for typical hazardous scenarios.

Table 19: Hazard-to-Evidence Matrix

Hazard or scenario	Required barrier	Barrier owner	Verification evidence	Approval status
Ammonia hose failure	Ship and shore ESD	Ship and bunker operator	Functional test	
Methanol spill fire	Detection, isolation and foam response	Terminal operator	Design review and exercise	
Loss of control power	Fail-safe shutdown and manual isolation	System operator	Failure mode test	

10.7. Interface and SIMOPS Management

Written interface agreements shall be established where two or more organisations share responsibility.

Agreements shall define:

- Physical boundaries;
- Equipment ownership;
- Control of valves and transfer;
- ESD and alarm interfaces;
- Operating limits;
- Inspection and maintenance;
- Communication;
- Emergency actions;
- Drainage and environmental responsibility;
- Stop work authority;
- Restart authority;
- Change notification.

The SIMOPS assessment shall address, where relevant:

- Bunkering and cargo handling;
- Passenger or vehicle movements;
- Hot work;
- Maintenance;
- Lifting;
- Construction;
- Adjacent fuel receipt or bunkering;
- Tug, pilot and mooring operations;
- Neighbouring terminal activities.

The assessment shall state whether each concurrent activity is:

- Permitted;
- Permitted subject to controls;
- Prohibited.

10.8. Management of Change

A formal Management of Change (MoC) review shall be initiated for changes to:

- Fuel type or composition;
- Maximum inventory;
- Transfer rate;
- Operating pressure or temperature;
- Equipment or pipework;
- ESD, alarm or control logic;
- Operating procedures;
- Storage or bunkering location;
- Vessel or supplier;
- Staffing or contractor arrangements;
- Emergency response;
- Neighbouring activities.

The MoC review shall include:

- Description of the change;
- Risk assessment;
- Regulatory screening;
- Approval requirements;
- Technical and operational review;
- Documentation updates;
- Training requirements;
- Testing;
- Implementation approval;
- Close-out.

Temporary changes shall have a responsible owner, compensating measures and an expiry date.

10.9. Readiness, Audit and Continued Operation

Before first operation, the project shall verify that:

- Required approvals are in place;
- Approval conditions have been addressed;
- Systems match the approved design;

- Critical equipment has been inspected and tested;
- Procedures are approved;
- Personnel are competent;
- Emergency arrangements have been exercised;
- Significant risk actions are closed;
- Interface agreements are signed;
- Current documentation is available.

The operation shall then be formally classified as:

- Ready;
- Ready with defined restrictions;
- Not ready.

Routine assurance shall include:

- Compliance audits;
- Safety barrier testing;
- Inspection and maintenance monitoring;
- Permit status tracking;
- Incident and near-miss review;
- Training compliance;
- Exercise findings;
- Management review;
- Periodic revalidation of the Safety Justification.

10.10. Minimum Approval Readiness Package

The minimum package should contain:

- 1 Activity and system description.
- 2 Governance and stakeholder matrix.
- 3 RACI matrix.
- 4 Applicability and Approval Register.
- 5 Authority engagement and commitment register.
- 6 Approval roadmap.
- 7 Design basis and interface drawings.
- 8 Fuel specifications and safety data sheets.

- 9 HAZID and risk register.
- 10 Consequence modelling or QRA, where required.
- 11 Safety-barrier register.
- 12 ATEX and hazardous-area documentation.
- 13 Equipment and material-compatibility evidence.
- 14 Operating and bunkering procedures.
- 15 Ship/shore compatibility evidence.
- 16 Interface agreements.
- 17 SIMOPS assessment.
- 18 Inspection and maintenance plan.
- 19 Training and competence records.
- 20 Integrated emergency plan.
- 21 Exercise and readiness evidence.
- 22 Environmental response arrangements.
- 23 Management of change procedure.
- 24 Pre-start-up safety review.
- 25 Authority decisions and conditions.
- 26 Formal authorisation to operate.

10.11. Relationship to PRL-MF

The PRL-MF tool described in Chapter 12 can be used to assess maturity and implementation level although it should not be considered a replacement for statutory approval. The table below presents a list of governance output required to achieve each readiness level.

Table 20: Governance Outputs by PRL stage

PRL stage	Required governance output
PRL 1–2	Initial activity description and stakeholder map
PRL 3	Preliminary hazards and applicability screening
PRL 4	Governance model and approval roadmap
PRL 5	Risk studies, procedures and draft approval package
PRL 6	Commissioning tests and exercise evidence
PRL 7	Pilot approval, restrictions and monitoring plan
PRL 8	Routine operating authorisation and assurance programme
PRL 9	Audits, performance monitoring and periodic revalidation

11. Societal and Public Perception

Public acceptance is recognised as a critical enabling factor in the successful deployment of green fuels and associated port infrastructure. As the transition to green fuels extends across storage, bunkering and operational use in port facilities, public perception is a cross-cutting issue that influences all stages of implementation.

This Chapter examines how safety perceptions shape public acceptance and how structured engagement can improve understanding, trust and social acceptance of energy transition projects. A case study undertaken at the Port of Rønne (Bornholm) provides practical evidence to support recommendations for future stakeholder engagement and communication strategies. Further details of the case study are presented in Annex B.

11.1. Current Status

Current literature consistently identifies the transition to green fuels as a socio-technical transformation in which technical performance alone is not sufficient to secure successful implementation. Public confidence depends not only on objective safety, but also on perceived risk, institutional trust, transparency and effective communication.

Existing research highlights two complementary approaches to achieving public acceptance, namely:

- robust technical governance through clear regulatory frameworks, recognised safety standards and effective risk management;
- meaningful stakeholder engagement through early, transparent and participatory communication.

Although policy increasingly advocates co-creation and participatory governance, current practice within the maritime sector remains dominated by information provision and consultation, with relatively few examples of genuine citizen involvement. Existing engagement frequently occurs late in project development, increasing the potential for mistrust and conflict. The literature therefore recommends combining strong technical safety governance with earlier and more meaningful public engagement to strengthen legitimacy and long-term acceptance

The case study identified a number of existing initiatives used by Danish ports to engage local communities, including:

- Open Port (Åben Havn) events that increase transparency through exhibitions, guided visits and informal engagement;
- Town hall meetings, providing opportunities for questions and feedback; and
- Exhibitions and communication material explaining port developments and future projects.

These initiatives broadly reflect three recognised levels of public engagement:

1. Inform – one-way provision of information to improve awareness.
2. Communicate – information with opportunities for feedback and clarification.
3. Involve – collaborative dialogue and co-creation in which citizens can influence communication and project development.

The study concludes that while information provision remains essential, the greatest long-term public acceptance is achieved where stakeholders are actively involved through collaborative processes that build ownership and trust.

11.2. Building Involvement

The Rønne case study adopted three complementary approaches to understanding current public perceptions and develop improved communication strategies.

i. Consultation with local stakeholders

Semi-structured interviews and workshops were undertaken with port stakeholders, technical experts, emergency services and local authorities. These explored perceptions of safety, communication challenges and governance arrangements, while identifying opportunities to strengthen stakeholder engagement and public trust.

ii. Review of media coverage

A systematic review of over 200 local newspaper and television articles examined how energy transition projects are presented publicly and how citizen concerns are reflected in local debate. This provided insight into recurring issues influencing public opinion.

iii. Workshops with citizens' organisations

Participatory workshops with local citizens' organisations explored community expectations, communication needs and preferred methods for public involvement. These formed the basis for developing practical information strategies tailored to local concerns.

11.3. Current Perception

Across all stakeholder groups there is broad acceptance of the need for green fuel infrastructure and port development. Maintaining this acceptance depends, however, on addressing several important constraints:

- limited public understanding of technical safety systems
- uncertainty regarding governance and decision-making responsibilities;
- insufficient transparency;
- inconsistent communication; and
- concerns with respect to noise, traffic, emissions and visual impacts.

The study found no evidence of widespread opposition to the use of green fuels themselves. Rather, public concerns arise primarily from knowledge gaps and uncertainty.

While it was noted that technical safety is managed through well-established regulatory frameworks, inter-agency approval processes and structured risk management systems (see Chapter 5). Nevertheless, these robust safety arrangements are not always understood by the public. Consequently, effective communication should focus on translating technical safety management into accessible information that builds confidence and trust through greater transparency and "demystification" of complex technologies.

11.4. Development of Information Strategies

Building on the findings of the previous phases of the case study, a participatory workshop was undertaken to develop practical information strategies.

The workshop followed three sequential stages:

i. Review of current challenges

Participants reviewed previously identified issues and prioritised the most significant barriers to public acceptance. The principal concerns related to:

- communication
- transparency
- knowledge
- political participation
- pollution
- public involvement.

ii. Identifying best practice

- Participants then defined effective communication strategies around three key questions:
- Who should communicate?
- How should information be communicated?
- When should communication occur?

Key recommendations included:

- Involving municipalities, port operators, emergency services and citizens' organisations.
- Restoring regular newsletters, public meetings and visible information materials.
- Expanding 'Open Port' events and guided visits.
- Communicating both positive developments and potential impacts.
- Providing information early, throughout project development and into operational phases.

iii. Implementation

The final stage translated these principles into practical implementation measures. Participants concluded that future information strategies should:

- provide continuous rather than one-off communication;
- explain both benefits and impacts;
- present long-term development plans;
- coordinate communication across all port stakeholders;
- utilise citizens' organisations as trusted intermediaries; and
- proactively address concerns relating to noise, emissions and safety before they generate opposition.

11.5. Conclusions and Recommendations

The case study demonstrates that successful deployment of green fuel infrastructure depends on integrating technical safety management with effective stakeholder engagement and communication.

The principal conclusions are:

- Public acceptance of the green transition is generally high, but remains conditional upon transparency, trust and effective communication.
- Existing regulatory approval processes and safety management systems provide a robust framework for managing technical risks, but these systems require clearer public explanation.
- Knowledge gaps and environmental concerns (e.g. noise, traffic, emissions, visual impact), rather than technical safety deficiencies, represent the primary barriers to public confidence.
- Early, continuous and coordinated communication is more effective than isolated consultation exercises.
- Citizens' organisations can play an important role as trusted intermediaries in disseminating information and strengthening local ownership.
- Information strategies should focus on explaining future developments, anticipated impacts and control measures in accessible language, while demonstrating how safety risks are assessed and managed.

Overall, the study recommends adopting coordinated, long-term information strategies that combine transparent communication, trusted local partnerships and clear and accessible explanation of technical safety systems. Such approaches will help bridge the gap between technical risk management and public understanding, thereby supporting socially acceptable implementation of future e-fuel infrastructure.

12. Port Readiness Level for Marine Fuels

The Port Readiness Level for Marine Fuels (PRL-MF) tool [43] provides a structured and scalable self-assessment tool which port communities can use to assess, plan and develop how they handle alternative marine fuels such as methanol and ammonia. It is organised into nine readiness levels, centred around four key focus points for each readiness level, namely governance, safety, infrastructure and market readiness.

The suitability of the PRL-MF for alternative fuels is reinforced when considering the hazard drivers for methanol and ammonia, e.g. toxicity, flammability, gas dispersion, ignition prevention, fuel handling and advanced emergency response. Safe operations involving these fuels will depend on the combined readiness of vessels and port communities, with training, infrastructure and organisational preparedness aligned.

Table 21 illustrates how ports, and those conducting activities around alternative fuels, can progressively build capability for green fuels, following the readiness levels from initial assessment through to routine commercial deployment.

Table 21 Port Readiness Level for Marine Fuels

Port Readiness Level	Level Name	Example usage activity
PRL 1	Initial assessment	Review whether methanol or ammonia fuelled vessels are likely to call at its berths.
PRL 2	Stakeholder interest determined	Surveys conducted to gauge demand for methanol or ammonia.
PRL 3	Sufficient information gathered	Compile technical data on methanol flammability and ammonia toxicity. Evaluate and establish a go/no-go decision.
PRL 4	Policy decided, roadmap developed	Formally commit to supporting methanol or ammonia vessel operations. Publish a phased roadmap.
PRL 5	Framework designed	Operational procedures, checklists, PPE protocols and emergency response plans are drafted. These are then reviewed through a process of hazard identification and risk assessment (see Chapter 5).
PRL 6	Framework demonstrated in protected environment	A controlled real-life example is created in relevant settings.

Port Readiness Level	Level Name	Example usage activity
PRL 7	Project-based operations in operating environment	A first project is established, with dedicated safety monitoring, pre-job briefings and incident standby arrangements in place.
PRL 8	System complete and qualified	Full system capability for the target fuel is established. Continuous safety management in place.
PRL 9	Routine commercial deployment	The fuel or alternative fuel activity is fully integrated into normal port operations.

13. References

- [1] International Maritime Organization (IMO) MSC. MSC.1/Circ.1687: Interim Guidelines for the Safety of Ships Using Ammonia as Fuel. London, UK: 2025.
- [2] International Maritime Organization (IMO) MSC. MSC.1/Circ.1621: Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel. London, UK: 2020.
- [3] Society for Gas as a Marine Fuel (SGMF). Ammonia Safety and Operational Guidelines – Bunkering. 2024.
- [4] Society for Gas as a Marine Fuel (SGMF). Methanol Safety and Operational Guidelines- Bunkering. 2024.
- [5] European Committee for Standardization (CEN). Inland navigation vessels – Methanol bunkering. 2025.
- [6] Yang M, Ng C, Liu M. Ammonia as a marine fuel - bunkering, safety and release simulations. 2022.
- [7] Hammer LS, Eide MS, Leisner M, Endresen Ø, Gravir G, Hustad H, et al. Ammonia in Shipping - Tracing the emergence of a new fuel. 2022.
- [8] Lloyd's Register. Barge Supplier – Checklist Pack 2020. <https://www.lr.org/en/> (accessed July 10, 2026).
- [9] Lloyd's Register. Lloyd's Register, Technical Reference 2020. <https://www.lr.org/en/> (accessed July 10, 2026).
- [10] Port of Gothenburg. Methanol Bunker Operating Regulations. 2023.
- [11] Singapore: Global Centre for Maritime Decarbonisation. Safety and operational guidelines for piloting ammonia bunkering in Singapore. 2023.
- [12] Lloyd's Register. Ship Bunker Loading – Checklist Pack n.d. <https://www.lr.org/> (accessed July 10, 2026).
- [13] Lloyd's Register. Ship Portable Tank Loading – Checklist Pack n.d. <https://www.lr.org/> (accessed July 10, 2026).
- [14] Lloyd's Register. Truck Portable Tank Supply – Checklist Pack n.d. <https://www.lr.org/> (accessed July 10, 2026).
- [15] Schotman H V. Ammonia bunkering and storage for the maritime industry during a global ammonia transition. n.d.
- [16] Lloyd's Register. Terminal Supplier – Checklist Pack n.d. <https://www.lr.org/> (accessed July 10, 2026).
- [17] DNV GL. Ammonia as a Marine Fuel Safety Handbook. Norway: n.d.
- [18] Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. E-methanol n.d. <https://www.zerocarbonshipping.com/files/alternative-maritime-fuel-information-sheets-e-methanol.pdf> (accessed September 3, 2026).
- [19] Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. E-Ammonia n.d. <https://www.zerocarbonshipping.com/files/alternative-maritime-fuel-information-sheets-e-ammonia.pdf> (accessed September 3, 2026).
- [20] Methanol Institute. Compatibility of Elastomers in Neat Methanol Service n.d. <https://methanol.org/wp-content/uploads/2016/06/Compatibility-of-Elastomers-in-Neat-Methanol-Service.pdf> (accessed September 3, 2026).
- [21] Laursen R, Karageorgos V, Collazos V, Monterde N, Semiz O, Ge Z, et al. Study Investigating the Safety of Ammonia as Fuel on Ships - Part 1. Lisbon, Portugal: ABS; 2023.

- [22] Publicatiereeks Gevaarlijke Stoffen (PGS). Ammoniak – Opslag en verlading (PGS 12: Ammonia – Storage and Offloading) 2026.
<https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs12/> (accessed September 3, 2026).
- [23] Minnesota Department of Agriculture. Anhydrous Ammonia System Piping Requirements 2019. <https://www.mda.state.mn.us/sites/default/files/2019-11/nh3pipingreqs.pdf> (accessed September 3, 2026).
- [24] Methanol Institute. Atmospheric Above Ground Tank Storage of Methanol. n.d.
- [25] International Maritime Organization. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) 2010.
<https://www.imo.org/en/ourwork/humanelement/pages/stcw-conv-link.aspx> (accessed September 4, 2026).
- [26] International Maritime Organization. International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code) n.d.
<https://www.imo.org/en/ourwork/safety/pages/igf-code.aspx> (accessed September 4, 2026).
- [27] International Maritime Organization (IMO). STCW.7/Circ.25: Generic Interim Guidelines on Training for Seafarers on Ships Using Alternative Fuels and New Technologies. London, UK: 2025.
- [28] Methanol Institute. Methanol Safe Handling Technical Bulletin n.d.
<https://methanol.org/what-safety-handling> (accessed September 3, 2026).
- [29] Maritime Just Transition Task Force. Considerations of Training Aspects for Seafarers on Ships Powered by Ammonia, Methanol and Hydrogen. 2024.
- [30] Lloyd's Register Maritime Decarbonisation Hub, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. Ammonia as Fuel Competencies and Training Project summary report. 2025.
- [31] Beredskabsstyrelsen. Vejledning om risikobaseret dimensionering og plan for det kommunale redningsberedskab 2025. https://www.brs.dk/da/nyheder-og-publikationer/publikationer2/alle-publikationer/2025/vejledning-om-risikobaseret-dimensionering/?_t_id=xIJARI6gmbAlfPG5iXBAGg%3d%3d&_t_uuid=GeUFg2X-Sxeizdk4Y7iWnA&_t_q=Vejledning+om+risikobaseret+dimensionering+og+plan+for+det+kommunale+redningsberedskab&_t_tags=siteid%3ab02411c9-26a8-4c35-a92d-24692f049409%2clanguage%3ada%2candquerymatch&_t_hit.id=KIP_Models_Pages_PublicationPage/_2402e3e0-46c6-4697-92eb-64e9971ca18d_da&_t_hit.pos=3 (accessed August 20, 2026).
- [32] Beredskabsstyrelsen. Indsatsledelse og -taktik 2023.
https://www.brs.dk/da/redningsberedskab-myndighed/dimensionering-og-indsats/Indsatsledelse-og-taktik/?_t_id=xIJARI6gmbAlfPG5iXBAGg%3d%3d&_t_uuid=nJ_O6mPpTvSaCW6e0Ta-aQ&_t_q=indsatsledelse+og+taktik&_t_tags=siteid%3ab02411c9-26a8-4c35-a92d-24692f049409%2clanguage%3ada%2candquerymatch&_t_hit.id=KIP_Models_Pages_ContentPage/_4b3b8128-eee1-48b6-b8da-37753838442f_da&_t_hit.pos=1 (accessed August 20, 2026).

- [33] Beredskabsstyrelsen. Redningsberedskabet 2020. <https://www.brs.dk/da/redningsberedskab-myndighed/assistance-fra-beredskabsstyrelsen/kemiske-haendelser-cbrn/redningsberedskab/> (accessed August 20, 2026).
- [34] Arbejdstilsynet. Bekendtgørelse om kontrol med arbejdsmiljøet ved risiko for større uheld med farlige stoffer 2026. <https://www.retsinformation.dk/eli/lta/2026/600> (accessed August 20, 2026).
- [35] Miljø- og Ligestillingsministeriet. Havmiljøloven 2023. <https://www.retsinformation.dk/eli/lta/2023/1032> (accessed August 20, 2026).
- [36] Rigspolitiet. Varsling n.d. <https://politi.dk/lov-og-information/kriseinformation/varsling> (accessed August 20, 2026).
- [37] Arbejdstilsynet. Bekendtgørelse om arbejdets udførelse 2026. <https://www.retsinformation.dk/eli/lta/2026/609> (accessed August 20, 2026).
- [38] By- Land- og Transportministeri. Havneloven 2024. <https://www.retsinformation.dk/eli/lta/2024/116> (accessed August 20, 2026).
- [39] Miljøstyrelsen. Miljøgodkendelse af listevirksomheder n.d. <https://mst.dk/erhverv/groen-produktion-og-affald/industri/miljoegodkendelse-af-listevirksomheder> (accessed August 20, 2026).
- [40] Miljøstyrelsen. Søg om miljøgodkendelse . Miljøstyrelsen n.d. <https://mst.dk/erhverv/groen-produktion-og-affald/industri/miljoestyrelsen-virksomheder/soeg-om-miljoegodkendelse> (accessed August 20, 2026).
- [41] Arbejdstilsynet. APV-krav ved fare fra eksplosiv atmosfære (ATEX) n.d. <https://at.dk/faa-viden/arbejde-med-kemi-og-biologi/arbejde-i-eksplosionsfarlig-atmosfaere-atex/apv-krav-ved-fare-fra-eksplosiv-atmosfaere-atex/> (accessed August 20, 2026).
- [42] Beredskabsstyrelsen. Risikovirksomheder 2023. <https://www.brs.dk/da/virksomhed-institution/brandfarlige-virksomheder-og-oplag/risikovirksomheder-seveso/> (accessed August 20, 2026).
- [43] International Association of Ports and Harbors (IAPH) and World Ports Climate Action Program (WPCAP). Port Readiness Level for Marine Fuels (PRL-MF) assessment tool for bunker ports. 2024.

Annex A
HAZID Study
(22 Pages)

Annex B
Societal and Public Perception – Case Study
(19 Pages)