MARITIME TECHNOLOGIES FORUM

LEADING THE MARITIME WORLD FORWARD

GUIDELINES FOR CONDUCTING QUALITATIVE RISK ASSESSMENTS FOR ALTERNATIVE-FUELLED SHIPS: HAZID AND HAZOP

Executive Summary

The Maritime Technologies Forum (MTF) is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process. To accelerate a safe decarbonization of shipping, MTF considered the approval process for alternative-fuelled ships and developed guidance, based on the practices taken for a considerable number of vessels, for a more streamlined and uniform application of the required mandatory qualitative risk assessment and two of its main tools, HAZID (Hazard identification) and HAZOP (Hazard and operability).

The Net-Zero Framework of IMO [1] provides the mechanism for reducing carbon emissions to net-zero by or around 2050, as documented in the '2023 IMO Strategy on Reduction of GHG Emissions from Ships.' The use of alternative fuels will be key, and IMO has developed guidelines for design and operation of ships capable of using them.

For most alternative fuels, the Alternative Design and Approval process is required until mandatory regulations will be in place. This dictate using qualitative risk assessment to document an equivalent safety compared with a vessel designed to operate with conventional fuels. Existing guidelines, such as MSC.1/Circ.1455 [2] and IACS Rec. 146 [3], remain valuable references, particularly for approving vessels designed to operate with LNG as fuel. With the industry's expanding adoption of alternative fuels and lessons learned from recent projects, there is a need to broaden and update these documents to cover a wider range of fuels and technologies.

This report provides guidelines for conducting qualitative risk assessments as a core component of the approval process for alternative-fuelled ships. This addresses both HAZID and HAZOP studies, detailing qualification requirements for involved personnel and outlining the procedural steps involved. The guidelines also specify required input documents, reporting requirements and risk criteria. The guidelines support the identification of potential hazardous events and the development of preventive and mitigative safeguards to manage risks associated with the use of alternative fuels.

Proposed guidelines can be used in the approval process for alternative-fuelled ships.

While the new guidelines are a standalone guidance document, they also serve as a supplement to IMO MSC.1/Circ.1455 [2] and IACS Rec. 146 [3] when conducting HAZID and HAZOP studies for ships that are either under construction or undergoing a retrofitting process and are designed to operate using alternative fuels.

Increasing confidence in the execution of HAZIDs and HAZOPs is critical.

Consistent outcomes for qualitative risk assessments are necessary for ensuring the safety of alternative-fuelled ships. This requires standardised execution supported by a clear methodology, well-defined criteria, and a competent risk assessment team. Concise Terms of Reference (ToR) should be established prior to the workshop to ensure that all participants fully understand and agree on key elements.

Involved personnel should be competent on alternative fuels and risk assessments.

To ensure high quality outcomes from HAZID and HAZOP studies, involved facilitating risk assessment team and subject matter experts need to have competence on alternative fuels and knowledge on the relevant regulations / requirements, while the facilitation team needs to have competence on and be familiar with risk assessment methods and should have no direct involvement in the design.

Results from risk assessments can be integrated into the Safety Management System

Findings from the HAZID and HAZOP studies should serve as key input for the risk assessments to be conducted when the Safety Management System is developed.

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Abbreviations and Definitions

Abbreviation	Definition
ABS	American Bureau of Shipping
ESD	Emergency Shutdown
FPR	Fuel Preparation Room
HAZID	Hazard Identification (study)
HAZOP	Hazard and Operability (study)
IACS	International Association of Classification Societies
IGF	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMO	International Maritime Organization
LR	Lloyd’s Register
MSDS	Materials Safety Data Sheet
MPA	Maritime & Port Authority of Singapore
MTF	Maritime Technologies Forum
ClassNK	Nippon Kaiji Kyokai
NMA	Norwegian Maritime Authority
P&ID	Piping & Instrumentation Diagram
PPE	Personal Protective Equipment
PFD	Process Flow Diagrams
PSV	Pressure Safety Valve
RPT	Rapid Phase Transition
SIMOPS	Simultaneous Operations
SME	Subject Matter Expert
SMS	Safety Management System
SOLAS	(International Convention for the) Safety of Life at Sea
TCS	Tank Connection Space

Disclaimer

The findings and recommendations in this guidelines report represent a collaborative effort between participating MTF members.

No responsibility is accepted by MTF or its members for any consequences resulting directly or indirectly from the adoption of any of the recommendations in this guidelines report.

This guidelines report does not stop MTF members from having independent opinions or conclusions.

Reader is referred to the Acknowledgments section for the full list of contributors to this guidelines report.

Introduction

Rationale

The IGF Code mandates the execution of risk assessments to identify and eliminate or mitigate hazards associated with the installation of alternative fuel propulsion systems on seagoing vessels. Classification societies have, to varying extents, incorporated similar risk assessment practices into their own classification rules and guidelines. Qualitative risk assessment methods such as HAZIDs and HAZOPs are commonly used to detect hazards and operability concerns. These assessments also serve to validate that the prescribed requirements are achieving the intended safety expectations.

Existing non-Class-specific guidelines, such as MSC.1/Circ.1455 [2] and IACS Rec. 146 [3], remain valuable references, particularly for approving vessels designed to operate with LNG as fuel. With the industry's expanding adoption of alternative fuels and the lessons learned from recent projects, there is a clear need to broaden and update these documents to cover a wider range of fuels and technologies.

As the maritime sector continues to adopt alternative fuels and associated technologies, the complexity and risk profile of ship systems evolve. Traditional engineering and regulatory approaches must be adapted to address these emerging challenges. Robust and harmonized risk assessment methodologies are essential to ensure the safety and reliability of these fuel systems.

Confidence in the execution of HAZIDs and HAZOPs is critical, particularly in defining minimum risk criteria and ensuring consistent outcomes. The goal is to enhance the safety of alternative fuelled ships, leading to improved design integrity, operational safety, and public trust.

Furthermore, integrating the outcomes of these assessments into Safety Management Systems (SMS) will support the development of a comprehensive safety framework.

Risk assessments are required for all fuels covered under the IGF Code. The scope and depth of these assessments vary depending on the fuel type and its specific application. They may be conducted as part of an approval process for alternative design and arrangements as outlined in IMO MSC.1/Circ.1455 or used to determine whether additional safeguards are necessary beyond those prescribed in the IGF Code or relevant interim guidelines.

Currently, differing methodologies may be applied when conducting risk assessment workshops, potentially leading to inconsistencies in safety evaluations and approval outcomes. This report addresses that gap by proposing guidelines for conducting qualitative risk assessment studies, HAZID and HAZOP, for ships using alternative fuels, based on the practices taken for a considerable number of vessels.

By harmonizing risk assessment practices across shipowners, operators, regulators, classification societies, and other maritime stakeholders, the industry can achieve more consistent, transparent, and effective risk management. This alignment fosters trust, regulatory compliance, and supports innovation.

Until comprehensive prescriptive regulations are established for all alternative fuels, vessels must demonstrate an equivalent level of safety compared to those operating on conventional fuels. A harmonized methodology ensures that this equivalence is assessed consistently and credibly.

This report aims to bridge the gap between technological advancement and regulatory processes, enabling safer innovation and more efficient approval pathways for alternative-fuelled ships.

Objectives

These guidelines report will serve as a supplement to MSC.1/Circ.1455 [2], forming a standalone publication.

This report aims in stimulating proactive industry engagement to address safety and risk-related gaps associated with the adoption of alternative fuels, establish a robust industry reference report that will support effective qualitative risk assessments, and contribute to safer vessel designs and operations thereby fostering broader social acceptance of alternative-fuelled ships.

The guidelines provide clear instructions for conducting Hazard Identification (HAZID) and Hazard and Operability (HAZOP) qualitative risk assessments studies. Its purpose is to promote consistency in the application of these methodologies, ensuring that risks related to alternative fuels are properly identified, assessed, and mitigated as necessary.

The objectives are to:

- define qualification requirements for key personnel involved in the qualitative risk assessments;
- outline the general procedures for conducting HAZID and HAZOP studies;
- specify necessary input documents and reporting requirements for HAZID and HAZOP;
- assist in identifying potential hazardous events associated with the use of alternative fuels; and
- assist in identifying and proposing preventive and mitigative safeguards to eliminate or reduce the risks related to the use of alternative fuels.

Scope

The IGF Code [4] requires that a documented risk assessment be conducted to identify and mitigate hazards related to the use of low-flashpoint fuels, using recognised risk analysis techniques and to the satisfaction of the Administration.

According to IGF code (4.2.1):

> *"A risk assessment shall be conducted to ensure that risks arising from the use of low- flashpoint fuels affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed. Consideration shall be given to the hazards associated with physical layout, operation and maintenance, following any reasonably foreseeable failure."*

For vessels operating on LNG, the IGF Code permits the scope of the risk assessment to be limited to specific items outlined in paragraph 4.2.2. These include aspects such as drip tray sizing, airlock design, containment system evaluation, ventilation arrangements in tank connection spaces, permanent gas detection at ventilation inlets, and the design of novel containment systems.

In recent years, IMO has issued interim guidelines that require risk assessments to be adapted to the specific characteristics and operational scenarios for other alternative fuels and propulsion technologies.

- methanol/ethanol [8];
- LPG [9];
- ammonia as fuel [10]; and
- fuel cells installations [11].

Each of these guidelines explicitly requires a vessel-specific risk assessment for the installed fuel system. The extent of the risk assessment depends on the complexity and novelty of the fuel system installation, as well as the hazards associated with the chosen fuel.

Based on the requirements in the interim guidelines, the scope of the HAZID covers all reasonably foreseeable hazards associated with the design, operation, and maintenance of the alternative fuel system, including:

- **Fuel reception, storage, conditioning, and transfer systems:** bunker manifolds, tanks, pumps, compressors, valves, piping/lines, heat exchangers, and associated instrumentation from bunker manifold to consumers;
- **Control and monitoring systems:** pressure and temperature regulators, flow controllers, signal processors, and control panels;
- **Detection and safety systems:** gas and fire detectors, alarm functions, and automatic initiation of safety actions such as emergency shutdown;
- **Vent, containment, and abnormal operation handling:** vent lines, masts, overflow tanks, secondary containment, and ventilation arrangements;

- **Fire protection systems:** water spray, water curtain, and fire damper arrangements to prevent escalation and protect exposed surfaces;
- **Purging and inerting systems:** nitrogen storage and supply arrangements for safe inerting and disposal of fuel from bunker and process lines; and
- **Associated spaces and structures:** fuel storage hold spaces, tank connection spaces, and fuel preparation rooms.

The objective is to ensure that all hazards leading to loss of function, component damage, fire, explosion, electric shock, or toxic exposure are systematically identified, and that risks to personnel, the environment, and the ship are either eliminated or reduced to a level acceptable to the Administration.

IACS [3] provides guidance on the typical time required for the required risk assessments:

> *"The time expended by the team depends upon the agreed scope and the design complexity. For example, a qualitative risk assessment workshop for a new design might require two or three working days, whereas a minor variation to a previously assessed and approved design might require only half a day."*

The HAZID scope refers to the boundaries and focus of the hazard identification process, which includes:

- The design and arrangement of alternative fuel system with all components, controls, software, and structural elements involved;
- Operational and Environmental Conditions;
- Interfaces with Other Ship Systems;
- Emergency response and Evacuation;
- Failure Modes and Consequences; and
- Maintenance and Inspection.

Introduction to the Guidelines

Use

This guidelines report has been developed as a supplement to MSC.1/Circ.1455 [2] and Rec 146 [3] to provide easy to use guidance for conducting qualitative risk assessments for alternative fuelled ships, using HAZID and HAZOP as tools, as part of the approval process.

Consequently, the guidelines report is structured to provide two main chapters, one addressing HAZID and one addressing HAZOP methods, and a set of annexes common to both methods.
Each main chapter covers:

- Approach;
- Scope;
- Input documentation;
- Nodes identification;
- Terms of Reference;
- Procedure (the core steps of the method);
- Risk assessment team;
- Reporting; and
- Follow up.

The guidelines report is not providing fuel specific guidance and, therefore, it is necessary that the intended risk assessment workshop also addresses the necessary risk analysis that each specific fuel requires.

1. HAZID Risk Assessment

1.1 Approach

HAZID (Hazard Identification) is a structured, workshop-based technique used to identify potential hazards preferably at an early design stage. It involves the use of HAZID guidewords to explore hazardous events, causes, consequences, existing safeguards, and opportunities for further risk reduction.

HAZID is widely applied as a recognized risk assessment method as mentioned in IMO MSC-MEPC.2/Circ.12/Rev.2 [7] and MSC.1/Circ.1455 [2], among other risk assessment methods available in the industry. Its purpose is to ensure that all potential hazards associated with the use of low-flashpoint and gaseous fuels are identified as comprehensively as possible, and to demonstrate that the associated risks are either eliminated or mitigated as necessary.

In the HAZID procedure, the overall flow follows the concept of Inputs, Process, and Outputs.

More specifically,

- The **Inputs** consist of input documents and the assembly of Subject Matter Experts (SMEs) who are part of the HAZID risk assessment team, as defined in Section 1.6
- The HAZID **Process** involves conducting a technical workshop in which hazard identification, consequence analysis, and risk evaluation are conducted. Within this process, based on specific risk criteria, risks are to be mitigated as necessary to ensure that the alternative fuel system design provides an equivalent level of integrity in terms of safety and reliability as that which can be achieved with conventional oil-fueled machinery system.
- The **Outputs** are the action items, including preventive and mitigative safeguards, which were identified as necessary for risk mitigation and recorded in a worksheet during the risk assessment process. In most cases these are part of the Risk Report.

It is strongly recommended to conduct the HAZID at an early stage of the project, using high-level documents such as layout drawings and a Process Flow Diagram (PFD), to allow the findings to be reflected in the design with minimal impact on the project.

Before the workshop begins, however, the facilitator, as defined in Section 1.6, must confirm that adequate drawings and information have been supplied by all stakeholders since insufficient detail can prevent the risk assessment team from recognising key hazards.

Conducting the HAZID at an early stage of the project also provides the following benefits:

- Identifies all relevant hazards and their potential consequences for consideration in later design phases.
- Recognizes mitigating measures already included in the design and proposes additional ones should the risk level exceeds allowable level.
- Allows administration representatives to point out issues relevant for approval, leveraging their expertise and thereby reducing potential misunderstandings during later review stages.
- Determines, depending on the degree of novelty of the design, if a more detailed qualitative, semi-quantitative or quantitative risk analysis is necessary.
- Eliminates risks wherever possible and mitigate them as necessary, provided such actions are feasible and cost-effective.

1.2 Input Documentation

The following documents should be prepared and available prior to a HAZID workshop depending on specific fuel applicability requirements:

- General arrangement including muster stations and escape routes;
- Hazardous Area Plan, including Air Lock Arrangements;

- Toxic Areas Plan;
- Equipment Arrangements for:
  - Containment System;
  - Bunker station;
  - Tank connection space;
  - Fuel preparation room; and
  - Engine room.
- Ventilation arrangements;
- Bilge System;
- Process flow diagrams (PFDs);
- Piping and instrumentation diagrams (P&IDs), including Venting System;
- Operating, control, and shutdown philosophies; and
- Fire Fighting System Arrangement.

Based on requests made during the risk assessment workshop, relevant SMEs should be prepared to explain or provide the corresponding drawings or documents.

Note that documents not listed in this section may be requested additionally by the workshop facilitator or the SMEs, if necessary.

1.3 Nodes Identification

Prior to the workshop, the facilitator divides the fuel system into discrete sections with respect to equipment function and location. This helps the HAZID risk assessment team systematically consider each section of the system and focus on section specific causes and consequences.

Typical system divisions can include:

- Bunkering Station;
- Fuel Delivery Lines & Piping;
- Fuel Containment System and fuel storage hold space;
- Tank Connection Space;
- Fuel Preparation Room (including reforming, cracking);
- Fuel delivery lines;
- Fuel Consumer Spaces (Internal Combustion Engines, Steam & Gas Turbines, Fuel Cells, Gas Combustion Units, Boilers); and
- Vent Lines and Vent Mast.

Depending on the available time for conducting a risk workshop, it is to be decided by the facilitating team whether the utility systems, such as the bilge system, ventilation system, instrumentation etc of a vessel, are to be examined as separate nodes or rather can be considered as distinct hazards according to the consequences their malfunction can create.

Examples include mechanical ventilation that can contribute as a preventive safeguard or the bilge system that acts as a mitigative safeguard.

1.4 Terms of Reference

Terms of Reference (ToR) play a significant role in facilitating structured and effective workshops.

The ToR serves as a pre-workshop document that outlines the assessment's scope, objectives, schedule, methodologies, risk criteria, and participants. A well-prepared ToR ensures clarity of purpose, defines the scope of assessment, and aligns the expectations of all participants.

This document ensures all participants understand the design context and assessment approach and serves as a foundation for consistency and clarity during the workshop.

As a minimum, the ToR should include:

- Objectives and scope; Technical description of the proposed design and arrangements;
- Overview of the potential consequences associated with concerned fuel;
- Risk assessment methodology;
- HAZID prompts and guidewords;
- Node identification;
- Consequence and likelihood categories and risk criteria;
- HAZID worksheet template – according to risk team preferences;
- Intended workshop schedule; and
- Name, role, responsibility, area of expertise and experience of each SME.

The ToR should be reviewed and agreed by the relevant parties prior to the workshop.

For a successful HAZID, it should be confirmed that:

- The HAZID risk assessment team is composed of suitably qualified and experienced members;
- The proposed HAZID procedure is appropriate;
- Sufficient time is allocated for the completion of the HAZID; and
- The proposed risk acceptance criteria are suitable.

1.5 Procedure

The following section describes the procedures by which HAZID workshops are conducted in practice.

HAZID studies are typically conducted in a physical or virtual manner. For the workshop conducted remotely, with some or all participants joining via online platforms, offering this way participation flexibility, the workshop facilities are to be supportive.

1.5.1 Hazards Identification

At the initial phase of every HAZID study, two distinct processes are undertaken:

- Identification of potential hazards; and
- Identification of the Consequences and the corresponding Likelihood of the hazards.

The hazard identification process focuses on the identification of hazardous materials, systems, processes, and vessel characteristics that could lead to hazardous events. To facilitate this, the HAZID facilitator uses structured guidewords to prompt discussion and systematically identify potential hazardous scenarios. These guidewords are applied in reference to design documentation, such as Process Flow Diagrams (PFDs) and layout drawings.

To ensure productive and focused discussions, the facilitator should prepare relevant prompts in advance, tailored to the specific design and operational aspects of the gas-fuel system. Other members of the risk assessment team may also propose additional guidewords, either beforehand or during the workshop, subject to risk assessment team agreement, to support a comprehensive review.

Hazards should be considered in relation to:

- The physical layout of the system;
- Operational context;
- Maintenance activities; and
- Any reasonably foreseeable failures.

Hazardous events must be evaluated based on the properties and characteristics of the fuel, as well as the fundamental hazards associated with the system. The identification process typically combines analytical and creative techniques to ensure a thorough evaluation of potential risks.

The analytical component draws on past experiences and established knowledge, incorporating sources such as relevant regulations, industry codes, and statistical data. The facilitator uses structured guidewords to prompt discussion and systematically identify potential hazardous events and their consequences. These guidewords are applied with reference to design documents, such as PFDs and layout drawings.

Hazards should be considered in relation to physical layout, operational context, maintenance activities, and any reasonably foreseeable failures.

Example guidewords for a HAZID analysis are provided in Table 1.

Table 1, HAZID Guidewords

Prompt	Description
Equipment	
Loss of containment[1]	Fatigue, stress, heat, cold, collapse, disintegration, incorrect construction materials, installation or commissioning, operation outside of design intent, maintenance failure, vibration, external impact, liquefied gas-expansion, or sealing failure.
Equipment failure	Termination of intended function, or operation outside of design intent.
Control system failure	If the control system (total or part) failed what would happen? Loss of power, control fault, software failure, erratic operation, and spurious operation.
Electrical system failure	Are there electrical hazards with the equipment being used? Are electrical supplies present in the area? Black-out, loss of power, short circuit, earth fault, excessive harmonics, and ignition source.
Utility failure	If utilities were lost (power, air, etc.) would this lead to a dangerous situation? Loss of instrument air, loss of cooling medium, loss of steam supply, loss of hydraulic pressure, failure of ship-shore link /communication.
Operating Parameters	
Temperature	Are temperatures very high or low, above boiling point, flash point or auto ignition point? Can decomposition occur? Burns to personnel, damage to equipment? Ice formation. Solidification of materials?
Pressure	High pressure, low pressure or vacuum, pressure difference at interface, high differential pressure, and pressure surges.
Flow	High, low, no or reverse flow?
Level	High or low levels – can tanks be overfilled or pumps run dry?
Location/Environment	
Location hazards	Are there hazards associated with the work location? e.g. access, working at height, confined spaces, working over water, escape routes, etc.
Ambient conditions / extreme weather conditions	Could extremes in ambient conditions or weather be a problem? Hot / cold weather outside of operating limits, lightning, icing, green water, excessive ship motions
External hazards	Collison, impact, grounding, fire, explosion, flooding, etc.
Other activities	Would any other activities be taking place in the area or at the same time? Could they present a hazard? Dropped object, hot work.

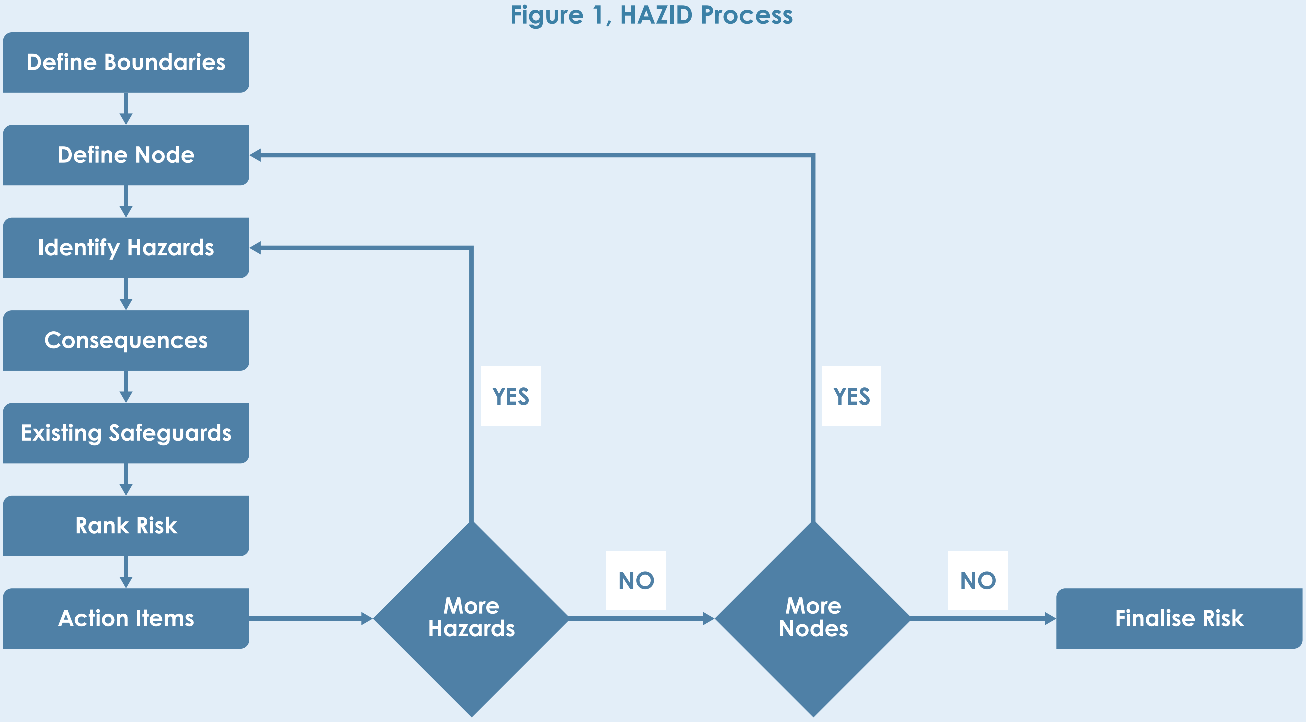
[1] Unplanned or uncontrolled release of a substance

Prompt	Description
Materials	
Flammable/oxidising materials	Are flammable or oxidising materials within the system or used/stored nearby, Vapour, liquid, solid, residues, chemical reaction.
Toxic materials	Are toxic materials within the system or used/stored nearby, Vapour, liquid, solid, residues, chemical reaction. Including eco-toxic materials?
Corrosive materials	Are corrosive materials within the system or used/stored nearby? Vapour, liquid, solid, residues, chemical reaction?
Inert materials	Are inert materials within the system or used/stored nearby (e.g. N_2, CO_2, etc.), asphyxiation hazards
Operating Modes	
Operation at sea	Normal operation, start-up, normal shutdown, emergency shutdown, and emergency situations
Operation in port	Normal operation, start-up, normal shutdown, emergency shutdown, emergency situations, Bunkering, and SIMOPS

Complementing this, the creative element encourages an initiative-taking approach, allowing for the identification of hazards beyond those already known from the past.

Figure 1 depicts the procedure followed during a HAZID risk workshop.

Figure 1, HAZID Process



It is of assistance to the HAZID risk assessment team if the potential hazards and properties of the concerned fuel are listed. Sources include public information resources, industrial groups, association manufacturers and/or suppliers, and material safety data sheets (MSDSs).

Table 10 adopted from the literature [12] in Annex A.2 tabulates common material properties for hazards identification.

1.5.2 Consequence and Likelihood Evaluation

For each identified hazardous event, the risk assessment team determines a credible worst-case scenario and assigns a consequence rating based on a predefined severity scale, such as:

- A: Major injury;
- B: Single fatality or multiple major injuries; or
- C: Multiple fatalities.

When assigning consequence levels, consider:

- fuel characteristics and inherent hazards (2.9 Annex A:);
- process conditions (pressure, temperature, phase, etc.);
- release location and dispersion pathways;
- ignition sources;
- presence of people;
- proximity of vulnerable receptors;
- expected effectiveness of existing safeguards; and
- outcomes from relevant supporting studies if necessary (e.g., gas dispersion analysis, and fire & explosion analysis).

Where uncertainties remain, further supporting studies may be proposed to determine the severity of consequences.

Using the agreed worst-case scenario and the consequence rating, the likelihood of the consequence occurring is estimated.

The likelihood is typically categorised as follows:

- Remote: 1 in a million per year or less (≤10-6/year);
- Extremely unlikely: 1 in 100,000 per year or less (≤10-5/year);
- Very unlikely: 1 in 10,000 per year or less (≤10-4/year);
- Unlikely: 1 in 1,000 per year or less (≤10-3/year); and
- Likely: 1 in 100 per year or less (≤10-2/year).

The risk assessment team should assess the likelihood of the final consequence, such as impacts on persons on board, environment, or ship assets, rather than the likelihood of the initiating event.

The following factors may be considered in estimating Likelihood:

- Likelihood of initiating event, e.g., number of leak sources and their leak frequencies, and operational cycles;
- Ignition probability;
- Presence of people;
- Vulnerability of people and/or structures; and
- Existing safeguards.

The definition of these scales can be seen in Table 2 and Table 3 respectively, while in Figure 2 the two categories are depicted on a Risk Matrix, with the vertical axis presenting the Consequence of the hazards and the horizontal the Likelihood.

Table 2: Consequence Scale Definitions (HAZID)

Consequence	People	Environment	Property
C	Multiple fatalities	Catastrophic	Extensive damage
B	Single fatality or multiple major injury	Major	Major damage
A	Major injury	Localised	Localised damage

Table 3: Likelihood Scale Definitions (HAZID)

Likelihood	Higher Bound	Lower Bound
Remotely	One in a million years or less	
Extremely Unlikely	One in a million years	One in 100.000 per year
Very Unlikely	One in 100.000 per year	One in 10.000 per year
Unlikely	One in 10.000 per year	One in 1.000 per year
Likely	One in 1.000 per year	One in 100 per year

1.5.3 Safeguards

For each identified hazardous event, the HAZID risk assessment team should identify and review existing safeguards. In reviewing safeguards, priority is given to physical as opposed to operational and procedural measures, and to measures that prevent releases rather than provide mitigation post-leak. This prioritisation promotes an inherently safer design by reducing reliance on crew to take actions to prevent or react to a release.

Prevention measures may include:

- minimising leak sources;
- improved reliability;
- equipment and operation simplification;
- periodic inspection and maintenance;
- lower pressures and temperatures[2] ; and
- minimised flow rates, inventories, and pipe runs.

Mitigation measures may include:

- detection and isolation;
- ventilation;
- containment;
- safely vent or treat the released fuel;
- limiting ignition;
- separation;
- physical protection; and
- firefighting.

[2] For the case of gases, higher temperature may prove to be a more effective prevention measure

Examples of safeguards can be found in Annex C:

1.5.4 Risk Evaluation

The HAZID risk assessment team should identify and assess all potential consequences associated with each cause.

Typical categories of consequences include:

- Effect on crew and passenger;
- Effect on surrounding public;
- Damage to ship;
- Effect on other sub-systems or the wider system; and
- Environmental impact.

Consequences should be evaluated without taking safeguards into account, to establish the full, unmitigated impact. This ensures that the ultimate effects of each deviation are understood before considering the adequacy of safeguards.

It can be useful to examine how consequences evolve over time, including when alarms and trips are triggered and how operators are notified, as this provides a more realistic view of the likelihood and impact of operator intervention.

Particular attention should be given to scenarios that could lead to severe outcomes, such as fatalities, major fire or explosion, toxic releases, or substantial plant and ship damage.
If available, supporting studies such as gas dispersion or explosion analysis, may be used to enhance understanding of the full range of potential consequences.

Risk Matrix

Once the likelihood and the consequence of a hazard are identified, the Risk Rating is evaluated. To visualise the ranking a consequence vs likelihood matrix is used, otherwise called a heat map or more commonly referred to as a risk matrix [13].

As the description implies, a risk matrix combines the likelihood of a hazard occurring together with the magnitude of implications such an event would have on the safety of the humans, the vessel and the environment. As a result, a risk ranking yields, categorising each hazard under consideration.

To be noted is that the evaluated risk refers to the one hazardous scenario under consideration and does not represent the concept of an overall risk.

It is essential that the risk matrix is agreed upon by all stakeholders prior to use, and the proposed risk criteria should not result in an underestimation of risks.

Once the analysis for each hazard is concluded, the corresponding risk ranking is identified on the Risk Matrix as a set of coordinates defined by a Likelihood, Consequence pair.

The grammatical, numerical or combined method with which the Matrix will characterise each risk ranking levels depends on the choice of the risk assessment team.

For the purposes of the HAZID report, for the indices the identification method proposed is with the letter defining the Consequence level, followed by the number defining the Likelihood level.

Figure 1: Risk Matrix - HAZID.

Consequence						
	C	C1	C2	C3	C4	C5
	B	B1	B2	B3	B4	B5
	A	A1	A2	A3	A4	A5
		Remote (1)	Ext. Unlikely (2)	V. Unlikely (3)	Unlikely (4)	Likely (5)
		Likelihood				

High	C4, C5, B5
Medium	C1, C2, C3, B2, B3, B4, A4, A5
Low	B1, A1, A2, A3

Risk Criteria

A second tool that the Risk Matrix should provide is the visualization of the Risk Ranking magnitude so that upon completion of the study to be in position to identify hazards of higher risk levels and threat them with priority.

The number of risk categories with which the rankings will be divided into depends on the choice of the risk assessment team. For the purposes of the HAZID, three risk categories are proposed namely,

- **Low Risk (Acceptable)**: The risk can be accepted. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.
- **Medium Risk (Tolerable)**: The risk is tolerable and considered 'mitigated as necessary'. This assumes that all reasonably practicable mitigation measures have been implemented. That is, additional or alternative mitigation measures have been identified and implemented unless judged impractical or the cost of implementation would be disproportionate to the reduction in risk.
- **High Risk (Unacceptable)**: The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation

1.5.5 ALARP Demonstration

While demonstrating an equivalent level of risk compared to conventional ships is generally sufficient for most alternative fuels, this report also introduces the ALARP tool as a supplementary method for the risk assessment team to show that a design can achieve an equivalent level of safety.

The IGF Code [4] uses the term "mitigated as necessary," aligning with the ALARP (As Low as Reasonably Practicable) principle.

A risk is ALARP if further reduction is impractical or the cost of doing so is grossly disproportionate to the benefit. If a risk is not demonstrably ALARP, additional mitigation measures must be considered, and the risk re-evaluated.

The risk cannot be accepted until this condition is met.

To demonstrate ALARP, the HAZID risk assessment team should identify preventive and mitigative risk safeguards for all hazardous scenarios classified as Medium Risk and implement all reasonably practicable measures, considering potential risk reduction, time, cost, and stakeholder views.

1.5.6 Workshop Recording

The details of HAZID discussion should be thoroughly documented using the HAZID worksheet. This guidelines report should capture the hazards identified, including also the full context of the discussion such as the systems or operations involved, associated scenarios, the specific deviations or failure modes considered, their causes and potential consequences, and the existing safeguards and control measures in place.

Furthermore, the rationale behind risk rankings and the selection of proposed control measures or mitigation actions should be clearly recorded. The level of details should be sufficient to serve as a robust foundation for subsequent steps in the risk assessment process, including quantitative analysis if required.

The HAZID worksheet should enable stakeholders to understand the risks involved, verify that appropriate risk reduction strategies have been identified, and ensure that the alternative design achieves a level of safety equivalent to or greater than the prescriptive regulatory requirements.

The identified hazardous scenarios, including their causes, safeguards (prevention and mitigation), risk ratings, and proposed actions should be recorded using a worksheet format shown in the example tabulated in Table 4.

Table 4, HAZID Recording Worksheet

Node:	Fuel Preparation Room								
Hazards	Hazardous event	Cause	Consequence	Safeguards	C	L	R	Action	By
Loss of containment	Release of pressurised ammonia from equipment and piping	Wear and tear	1. Potential toxic gas exposure to crew, potentially resulting in 1–2 fatalities. 2. Potential toxic gas dispersion into accommodation, potentially resulting in multiple crew injuries.	1. Gas detection system in the FPR with local gas alarm indication at 25 ppm 2. Periodic inspection and maintenance	B	4	M	1. Perform a gas dispersion analysis to demonstrate that ammonia concentrations exceeding 220 ppm do not reach any openings into the accommodation, service and machinery spaces, control stations, and other non-toxic spaces in the vessel.	AA

1.6 Risk Assessment Team

The success of a qualitative risk assessment relies heavily on the collective expertise of its participants. The risk assessment team's qualifications and experience must be sufficient to fully understand the design and operational aspects of the system under review.

The optimal risk assessment team size and composition may vary depending on the complexity of the study. In general, a HAZID risk assessment team includes eight to ten members. This size helps maintain focus and efficiency while avoiding communication overload. In certain cases, participation may expand to up to twenty individuals, provided that effective facilitation is maintained.

A typical HAZID risk assessment team includes:

Facilitating Team:

- Facilitator; and
- Scribe

The facilitator plays a central role in directing and organizing the analysis. He is responsible for guiding the risk assessment team through the structured risk assessment process, ensuring effective execution and collaboration.

To fulfil this role effectively, the facilitator should possess a strong understanding of risk assessment methodologies, proven experience in leading collaborative hazard reviews, and independence from the project, with no direct involvement in the system's design, to maintain impartiality.

The scribe is designated to formally document the discussions and outcomes of the HAZID workshop. Ideally, the scribe supports the facilitator by ensuring accurate and efficient recording of identified hazards, safeguards, and proposed actions.

This role requires strong language and organizational skills and the ability to process and structure large volumes of information in real time.
Consequently, the qualifications of all personnel participating in a Risk Workshop must be submitted in advance of the session as also dictated in MSC.1/Circ. 1455 [2] and elaborated in the following section.

Subject matter experts (SMEs):
The remainder of the HAZID risk assessment team should consist of subject matter experts (SMEs) with practical experience in the design, operation, and maintenance of the fuel system and vessel under evaluation. Risk assessment team members should be qualified professionals whose competencies and ability to contribute meaningfully to the risk assessment are verified and documented in accordance with MSC.1/Circ.1455 (6.6.2.1.4) [2].

MSC.1/Circ.1455 states that:

> *"details of the qualifications of the HAZID team members as well as the project team members (to ensure the application of sound operational principles and adequate expertise within the team)" shall be provided.*

Document requirements of the above mentioned circular need to be included in the risk assessment report.

Typical members include:

- Ship and system designers – Provide detailed knowledge of the system's design, including drawings, specifications, and operational intent;
- Safety Specialists – Ensure that regulatory requirements, safety standards, and risk management principles are considered;
- Operations Personnel – Offer practical insights into how the system is operated under normal and abnormal conditions;
- Maintenance Experts – Contribute understanding of maintenance procedures, potential failure modes, and access limitations;
- Subject Matter Experts (SMEs) – May be included as needed to address specific technical areas such as fuel properties, control systems, or environmental impacts;
- Classification society representatives; and
- Additional experts on call.

Flag Administration & Classification Society
In addition to the core disciplines previously mentioned, and depending on the novelty and complexity of the system under review, it is highly recommended to invite Class and/or Flag Administration representatives to attend the workshop for close communication with the Submitter (e.g. designer, shipyard, and shipowner) as this is the best chance for them to evaluate the quality of the HAZID workshop. Their involvement can enhance regulatory alignment and ensure that emerging risks are adequately addressed.

However, careful consideration should be given for the case of the Classification society to ensure that their independence from the design team is maintained.

1.7 Report

A written report documenting the risk assessment should be prepared. It must be sufficiently detailed to support the results, conclusions, recommendations, and any actions taken.

This level of detail is necessary because the assessment will inform important design and operational decisions.

Furthermore, the report serves as a formal record to demonstrate that risks have been mitigated as necessary (ALARP). A report consisting only of a completed worksheet is insufficient.
An example of specific report contents is provided below in Table 5.

Table 5, HAZID Report Contents

Executive summary
An overview of the HAZID and main results and conclusions.
1. Introduction
A brief statement on the purpose of HAZID and the parties involved.
2. Scope and objectives
The principal objective is, for example, to demonstrate that the safety-risk is, or can be made acceptable/ tolerable for Class approval. The scope is, for example, limited to the design/arrangement, the specific environment/location and the intended modes of operation.
3. System overview (including nodes)
A simple explanation of the design and arrangement with respect to its intended operation and process conditions.
4. HAZID procedure (methodology)
Overview of the HAZID technique/method. This includes how the design was divided into sections for assessment, how hazard identification was undertaken (including documentation in support of any assumptions made and the existing safeguards and control measures), the selection of risk criteria, and the mechanism of risk rating and recording the plans and means for proposed safeguards and control measures. In addition, a note on the actual workshop schedule illustrating the time expended on each section.
5. HAZID risk assessment team
The names, job titles, relevant qualifications, expertise and experience of the facilitating risk assessment team and SMEs. This can be recorded in a table, together with a record of workshop attendance. If this information is particularly large and would detract from the approach and results, the information can be included as an appendix.
6. Results
Discussion of the main findings and issues, including further analysis and applicable techniques, the needs for further in-depth examination of historical evidence / expert judgement or calculations, and the sources of information. Results of the risk assessment are to include: • a discussion and illustration of the hazards, how they can be realised, the consequences, the likelihood of occurrence, the 'level' of risk in relation to agreed criteria, and the main contributors to that risk. • a listing of key prevention and mitigation measures. • a discussion and listing of actions and recommendations to address the risk and, for example, meet good design practice, and inform safe operation, inspection and maintenance. • identification of supporting studies to better understand the risk, investigate risk reduction and control measures (i.e. safeguards), and/or confirm design suitability.
7. Conclusions
A summary judgement on whether the risks are 'mitigated as necessary (ALARP)'.
8. Actions
A listing of additional/alternative safeguards, and consideration of additional supporting studies, including who is responsible and expected completion date.
Appendices
Worksheets (as recorded in the workshop, including guidewords and phrases i.e. prompts). Input documents/drawings, process information and reference documents including the Terms of Reference (ToR) (if necessary)

1.8 Follow up

The outcome of the HAZID is normally recommendations that are to be followed up by the key stakeholders to ensure that identified risks are properly addressed and mitigated. The stakeholders include the individuals, teams or project manager assigned the responsibility of monitoring the risks, Implementing the mitigation strategies or reporting on the project progress.

The submitter, who is seeking the approval from the classification society and flag administration, should maintain a register of all actions identified in the HAZID and regularly update it. The register may include:

- Status of each action (open/closed);
- Responsible party;
- Brief description of action outcomes and supporting evidence; and
- Closed-out signatures by relevant parties.

The Submitter should ensure that all actions are addressed in a timely manner and tracked until closure. Actions should be assigned to a responsible party with a target completion date for follow-up. The timeline of the follow-up should be agreed among the interested stakeholders ensuring that crucial milestone dates are respected for the completion of each project.

All actions identified for hazardous scenarios with medium or high risk shall be tracked and closed out appropriately to demonstrate ALARP. This does not mean that every action must be implemented; each action should be evaluated for practicality, effectiveness in reducing risk, cost, and stakeholders' views. Alternative measures may also be considered and adopted subject to stakeholder consensus.

The safeguards recorded in the worksheet - whether planned, additional, or alternative - are to be implemented.

As a next step, implementation of these safeguards is to be confirmed through class and statutory surveys wherever applicable.

A formal check should be conducted before commissioning to ensure that all identified actions have been completed or otherwise resolved.

2. HAZOP Risk Assessment

2.1 Approach

A HAZOP (Hazard and Operability Study) is a structured review method used by a multidisciplinary HAZOP risk assessment team to identify hazards and operability issues in a process design by examining deviations from design intent. This technique can be used for continuous or batch processes and can be adapted to evaluate written procedures.

HAZOP is applied at an early stage of the detailed design of the alternative fuel system, using documents such as layout drawings, Process Flow Diagram (PFD), Piping and Instrumentation Diagrams (P&ID), methods of operation, including start-up, normal operations, and shutdown to allow the findings to be reflected in the design with minimal impact on the project.

Before the workshop begins, however, the facilitator, as defined in Section 2.7.1, must confirm that adequate drawings and information have been supplied by all stakeholders since insufficient detail can prevent the risk assessment team from recognising key hazards.

Conducting the HAZOP at an early stage of the project also provides the following benefits:

- Identifies design relevant hazards and their potential consequences;
- Recognizes mitigating measures already included in the design and proposes additional ones should the risk level exceeds allowable level;
- Allows administration representatives to point out issues relevant for approval, leveraging their expertise and thereby reducing potential misunderstandings during later review stages;
- Determines, depending on the degree of novelty of the design, if a more detailed semi-quantitative or quantitative risk analysis is necessary; and
- Eliminates risks wherever possible, as it is feasible and cost-effective for such an action to take place during the design phase.

2.2 Scope

International conventions and the IMO Guidelines applicable to alternative fuel ships do not clearly require a HAZOP risk assessment.

Under these circumstances, when implementing risk assessment of alternative fuel ships, it is recommended that HAZOP be conducted for fuel supply systems, particularly where manufacturers have limited experience with such systems or technologies, novel technologies are involved, or field history is limited, to confirm the soundness of their systems. Such an approach is referred as a *System HAZOP* [14].

In addition, to address potential hazards in operating procedures and human error, it is recommended that HAZOP be implemented for the combination of operators who manage the system for the first time when the instructions have been prepared. Such an approach is referred as a *Procedure HAZOP* [14].

2.3 Input documentation

The following documents should be prepared and available prior to a HAZOP workshop:

- Process description / design basis;
- Process flow diagrams;
- Heat and mass balances;
- Piping and instrumentation diagram (P&IDs), including piping specification;
- Cause and Effect diagram;
- Equipment data sheet;
- Operational and control philosophy;
- General arrangement and system layout;

- Material Safety Data Sheets; and
- Wiring Diagrams.

All input documentation used for the HAZOP must be the latest approved revision, clearly showing revision numbers and dates to avoid confusion during the study. Incomplete documents should be avoided, as missing information such as interlock logic or equipment specifications can result in excessive pending action items and hinder the progress of the workshop.

To ensure effective preparation, all input documentation should be distributed to the HAZOP risk assessment team well in advance.

2.4 Node Identification

A node is the basic unit of analysis in a HAZOP. The facilitator should divide the system into appropriate nodes before the HAZOP to enable effective discussion.

Nodes should be defined so that the design intent of each can be clearly and easily understood, considering:

- Change in design intent;
- Change in process condition (pressure, temperature, phase, etc.);
- Major equipment; and
- Operating modes.

If nodes are defined too narrowly, the analysis becomes excessive and inefficient. If defined too broadly, specific hazards may be diluted or overlooked. The key is to define nodes at a practical size that enables effective hazard identification.

Nodes should be clearly indicated on the relevant P&IDs using distinct colours. The marked-up P&IDs should be shared with the risk assessment team in advance and used throughout the HAZOP workshop.

Prior to the HAZOP review, an appropriate person, typically the system designer, should introduce each node, explaining the overall design concept, key design features, design and operating parameters, and safeguarding arrangements.

2.5 Terms of Reference

The facilitating HAZOP risk assessment team must prepare a Terms of Reference (ToR) before the workshop. This document ensures all participants understand the design intent and assessment approach and serves as a foundation for consistency and clarity during the workshop.

As a minimum, the ToR should include:

- objectives and scope;
- technical description of the proposed design and arrangements;
- overview of the potential consequences associated with concerned fuel;
- risk assessment methodology;
- HAZOP parameters and guidewords for the study;
- node identification with marked-up P&IDs;
- HAZOP worksheet template;
- intended workshop schedule; and
- name, job title, relevant qualifications, expertise, and experience of each SME.

2.6 Procedure

The HAZOP follows the following steps:

- Define the design intention: Clearly describe the section or step under review, including its intended operation and boundaries.
- Generate deviations: Apply guidewords systematically to process parameters or procedural steps to highlight possible deviations.
- Identify causes: Brainstorm credible initiating events, including equipment failures, human errors, or external influences.
- Evaluate consequences: Assess the potential outcomes of each deviation, considering safety, environmental, and operational impacts.
- Review safeguards: Document existing protective measures such as alarms, interlocks, relief systems, and operator responses.
- Assess risk (if applied): Use a qualitative or semi-quantitative approach (e.g., risk matrix) to rank deviations where appropriate.
- Recommend actions: Develop and agree on additional safeguards or procedural improvements where risks are not tolerable.
- Record and close out: Document findings comprehensively in the HAZOP worksheets and ensure action items are tracked to closure.

HAZOP studies are typically conducted in a physical or virtual manner. For the meetings conducted remotely, with some or all participants joining via online platforms, offering this way participation flexibility, the workshop facilities are to be supportive.

2.6.1 Description & Design Intention

The HAZOP risk assessment team should begin with a clear understanding of the section or stage under review, supported by sufficient information. It is recommended that a full description, including key parameters, be recorded in the HAZOP report.

A design intention should then be formulated, defining the intended operational range (envelope) so that deviations outside this range can be recognised. The design intention should be comprehensive, clearly linked to drawings, and cover equipment, materials, conditions, sources and destinations, transfers, control means, and timing.

Recording must provide enough detail for later users to understand the basis of the risk assessment team's analysis.

2.6.2 Deviations Identification

Deviations are key to the HAZOP process. For each selected node, the risk assessment team systematically generates potential deviations by combining process parameters with guidewords. This structured approach enables the identification of hazards and operability problems that may arise from departures from the design intent.

An example of deviations used in a HAZOP workshop are shown in Table 6 and the Guidewords that are used in a HAZOP session are tabulated in Table 7.

Table 6, HAZOP Deviations

Parameters	Guideword					
	No	Less	More	Reverse	Part of	As well as
Flow	No flow	Less flow	More flow	Reverse flow	Composition on change	Contamination
Pressure	Vacuum	Low pressure	High pressure			
Temperature		Low temperature	High temperature			
Level	No level	Low level	High level			
Other considerations: Utility failures, maintenance, relief, corrosion/erosion, toxic, static, interface, etc.						

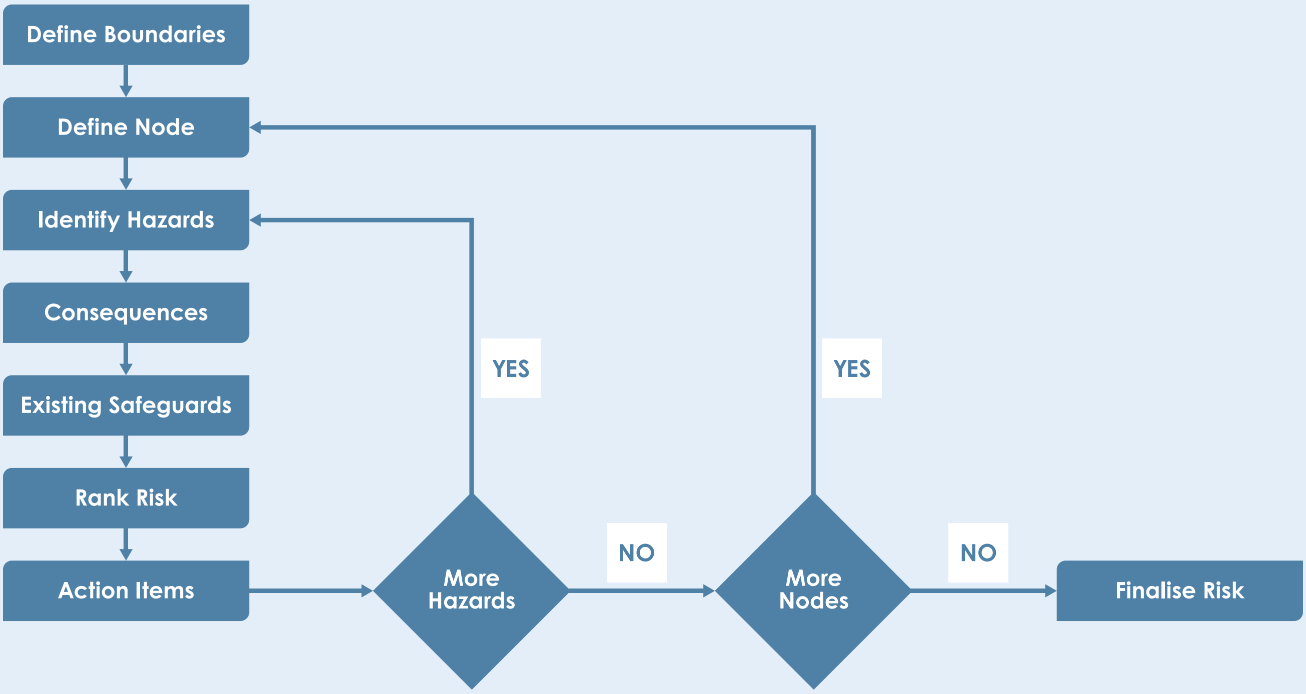
Table 7, HAZOP Guidewords

Guidewords	Parameter	Causes
Low	*Flow*	Restriction (valve, filter, depositions, etc.), pump failure, connection error, leak out (rupture, valve), change in density, control error, high viscosity, competing pump heads and flows
No		Blockage, pump failure, connection error, no differential pressure, control error, block valve closed, control valve fails closed
High		Pump, high DP, leak in/out (rupture or valve), change in density, low viscosity, control error, bypass valve open, increased pumping capacity
Reverse		Pump failure, negative differential pressure, suction
High	*Pressure*	Boiling, freezing, viscosity, density, fire, leak, gas blow-by, control error (PSH, PSV, CV), pump, temperature, blocked discharge, gas expansion, surge, PSV isolated, vent,
Low		Condensation, gas leak, density, suction by drainage, density, control error, damaged restriction (FO, CV), vacuum
High	*Temperature*	Boiling, weather, fire, leak in heat exchanger, loss of cooling, control error
Low		Weather, degassing, JT effect, leak in heat exchanger, loss of heating medium, control error
High	*Level*	High flow in, low flow out, control failure, filling operation
Low		Low flow in, high flow out, control failure, draining
Composition		Water entrainment, fuel quality, purity, leak, nitrogen, connection/mixing error, decomposition, chemical reaction
Contamination		Leak, hydrate, wax, sand, solids, wrong feed, corrosion/erosion, scale, foam, emulsion, leak
Operation		Start-up, shutdown, connection error, overrides, equipment access
Maintenance		Bypass operation, access, drain/vent, flushing, purging, isolation, entry, surveillance, spare parts, lift and manual handling
Instrumentation		Location, set point, adequate, correct principle, response time, redundancy, correct control system (SIS vs PCS).
Utilities		Loss of instrument air, heating medium, cooling medium, steam, electrical power, HVAC, controller, hydraulic pressure, nitrogen, etc.
Piping		Corrosion/erosion, fluid service, pipe class, stress corrosion cracking
Safety		Fire (insulation, relief), F&G detection, ESD arrangement, blow down, firefighting, noise, MSDS

Complementing this, the creative element encourages an initiative-taking approach, allowing for the identification of hazards beyond those already known from the past.

Figure 3 depicts the procedure followed during a HAZOP risk workshop.

Figure 3, HAZOP Process



It is of assistance to the HAZOP risk assessment team if the potential hazards and properties of the concerned fuel are listed. Sources include public information resources, industrial groups, association manufacturers and/or suppliers, and material safety data sheets (MSDSs).
Table 10 adopted from the literature [12] in Annex A.2 tabulates common material properties for hazards identification.

2.6.3 Causes Identification

Once a meaningful deviation has been identified, the HAZOP risk assessment team will brainstorm all credible causes. Causes may arise from both technical and human sources and should be described clearly and precisely. Typical categories of causes include:

- Equipment or component failure;
- Human error (operation, maintenance, or procedural mistakes);
- Control or instrumentation failure;
- Influence from other system, e.g. deviations from upstream and downstream;
- External events, such as fire and explosion, collision, grounding, and dropped objects; and
- Extreme environmental conditions.

Causes should be recorded using the correct equipment, instrumentation, and piping identifiers, ensuring clarity and traceability. While the cause is identified within the node under review, its resulting consequence may extend throughout the process.

In general, double jeopardy, the occurrence of two simultaneous and independent failures, is not considered in a HAZOP. However, simultaneous failures should be examined when there is a potential for common mode failure, common cause failure, or hidden failure.

2.6.4 Safeguards

In the next step, the HAZOP risk assessment team should identify the safeguards that can prevent the occurrence of hazardous events or mitigate their consequences. This may include:

- Prevention:
  - Compliance with design standards (e.g. pressure / temperature rating, material selection, etc.);
  - Control loops and instrumentation;
  - Interlocks;

    - Alarm and shutdown systems;
    - Safety Instrumented Systems (SIS);
    - Operating procedures; and
    - Preventive maintenance
- Mitigation:
    - Pressure safety valves;
    - Drip trays, bunds and dikes;
    - Gas detection;
    - Fire detection;
    - Firefighting;
    - Fire insulation and passive fire protection;
    - Emergency Shutdown System (ESD); and
    - Emergency Response Plans and procedures

Safeguards may only be documented if they are already in place or formally planned. Where the identified safeguards are judged to be inadequate by the HAZOP risk assessment team, then recommendations should be developed to propose additional safeguards. All recommendations and actions must be unambiguous and clearly recorded so they are understandable to those that were not present at the meeting.

2.6.5 Consequences Evaluation

The HAZOP risk assessment team should identify and assess all potential consequences associated with each cause.

Typical categories of consequences include:

- Effect on crew and passenger;
- Effect on surrounding public;
- Damage to ship;
- Effect on other sub-systems or the wider system; and
- Environmental impact.

Consequences should be evaluated without taking safeguards into account, to establish the full, unmitigated impact. This ensures that the ultimate effects of each deviation are understood before considering the adequacy of safeguards.

It can be useful to examine how consequences evolve over time, including when alarms and trips are triggered and how operators are notified, as this provides a more realistic view of the likelihood and impact of operator intervention.

Particular attention should be given to scenarios that could lead to severe outcomes, such as fatalities, major fire or explosion, toxic releases, or substantial plant and ship damage.

These must be clearly recorded in the HAZOP worksheet, as they often provide the basis for further analysis (e.g. Layer of Protection Analysis, LOPA).

If available, supporting studies such as gas dispersion or explosion analysis, may be used to enhance understanding of the full range of potential consequences.

Risk Matrix

Once the likelihood and the consequence of a hazard are identified, the Risk Rating is evaluated. To visualise the ranking a consequence vs likelihood matrix is used, otherwise called a heat map or more commonly referred to as a risk matrix [13].

As the description implies, a risk matrix combines the likelihood of a hazard occurring together with the magnitude of implications such an event would have on the safety of the humans, the vessel and the environment. As a result, a risk ranking yields, categorising each hazard under consideration.

To be noted is that the evaluated risk refers to the one hazardous scenario under consideration and does not represent the concept of an overall risk.

It is essential that the risk matrix is agreed upon by all stakeholders prior to use, and the proposed risk criteria should not result in an underestimation of risks.

Once the analysis for each hazard is concluded, the corresponding risk ranking is identified on the Risk Matrix as a set of coordinates defined by a Likelihood, Consequence pair.

The grammatical, numerical or combined method with which the Matrix will characterise each risk ranking levels depends on the choice of the risk assessment team.

For the purposes of the HAZID report, for the indices the identification method proposed is with the letter defining the Consequence level, followed by the number defining the Likelihood level.

Table 8, Risk Matrix - HAZOP

Consequence						
	C	C1	C2	C3	C4	C5
	B	B1	B2	B3	B4	B5
	A	A1	A2	A3	A4	A5
		Remote (1)	Ext. Unlikely (2)	V. Unlikely (3)	Unlikely (4)	Likely (5)
		Likelihood				

High
Medium
Low

Risk Criteria

A second tool that the Risk Matrix should provide is the visualization of the Risk Ranking magnitude so that upon completion of the study to be in position to identify hazards of higher risk levels and treat them with priority.

The number of risk categories with which the rankings will be divided into depends on the choice of the risk HAZOP risk assessment team. For the purposes of the HAZID, three risk categories were proposed namely,

- Low Risk (Acceptable): The risk can be accepted. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.
- Medium Risk (Tolerable): The risk is tolerable and considered 'mitigated as necessary'. This assumes that all reasonably practicable mitigation measures have been implemented. That is, additional or alternative mitigation measures have been identified and implemented unless judged impractical or the cost of implementation would be disproportionate to the reduction in risk.
- High Risk (Unacceptable): The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

2.6.6 ALARP Demonstration

While demonstrating an equivalent level of risk compared to conventional ships is generally sufficient for most alternative fuels, this report also introduces the ALARP tool as a supplementary method for the risk assessment team to show that a design can achieve an equivalent level of safety.

The IGF Code [4] uses the term "mitigated as necessary," aligning with the ALARP (As Low as Reasonably Practicable) principle.
A risk is ALARP if further reduction is impractical or the cost of doing so is grossly disproportionate to the

benefit. If a risk is not demonstrably ALARP, additional mitigation measures must be considered, and the risk re-evaluated.

The risk cannot be accepted until this condition is met.

To demonstrate ALARP, the HAZOP risk assessment team should identify preventive and mitigative risk safeguards for all hazardous scenarios classified as Medium Risk and implement all reasonably racticable measures, considering potential risk reduction, time, cost, and stakeholder views.

2.6.7 Workshop Recording

The details of HAZOP discussion should be thoroughly documented using the HAZOP worksheet. This documentation should capture the hazards identified, including also the full context of the discussion such as the systems or operations involved, associated scenarios, the specific deviations or failure modes considered, their causes and potential consequences, and the existing safeguards and control measures in place.Furthermore, the rationale behind risk rankings and the selection of proposed control measures or mitigation actions should be clearly recorded. The level of details should be sufficient to serve as a robust foundation for subsequent steps in the risk assessment process, including quantitative analysis if required.

The HAZOP worksheet should enable stakeholders to understand the risks involved, verify that appropriate risk reduction strategies have been identified, and ensure that the alternative design achieves a level of safety equivalent to or greater than the prescriptive regulatory requirements.

The identified hazardous scenarios, including their causes, safeguards (prevention and mitigation), risk ratings, and proposed actions should be recorded using a worksheet format shown in the example tabulated in Table 9.

Table 9, HAZOP Recording Worksheet

Node:								
Deviation	Cause	Consequence	Safeguards	C	L	R	Action	By
No Flow	Pressure controller PIC-001 failure, driving PCV-001 fully closed	Potential over-pressurisation of the piping downstream of the fuel supply pump, potentially leading to fuel release and subsequent fire and/or explosion. Potential for personnel injury or fatality and major asset damage.	1. Pressure safety valve (PSV-001) downstream of the fuel supply pump 2. Gas detection system which initiates the fuel supply system shutdown 3. Ignition source control and use of ex-proof equipment in the FPR	B	4	M	Provide an independent pressure transmitter downstream of the fuel supply pump with high pressure alarm and high-high pressure shutdown that shuts down the fuel supply pump.	AA

2.7 Risk Assessment Team

The success of a qualitative risk assessment relies heavily on the collective expertise of its participants. The team's qualifications and experience must be sufficient to fully understand the design and operational aspects of the system under review.

The optimal HAZOP risk assessment team size and composition may vary depending on the complexity of the study. In general, a HAZOP risk assessment team includes eight to ten members. This size helps maintain focus and efficiency while avoiding communication overload. In certain cases, participation may expand to up to twenty individuals, provided that effective facilitation is maintained.

A typical HAZOP risk assessment team includes:

2.7.1 Facilitating Team

- Facilitator; and
- Scribe.

The facilitator plays a leading role in directing and organizing the analysis. He is responsible for guiding the HAZOP risk assessment team through the structured risk assessment process, ensuring effective execution and collaboration.

To fulfil this role effectively, the facilitator should possess a strong understanding of risk assessment methodologies, proven experience in leading collaborative hazard reviews, and independence from the project, with no direct involvement in the system's design, to maintain impartiality.

The scribe is designated to formally document the discussions and outcomes of the HAZOP workshop. Ideally, the scribe supports the facilitator by ensuring accurate and efficient recording of identified hazards, safeguards, and proposed actions. This role requires strong language and organizational skills and the ability to process and structure large volumes of information in real time.

2.7.2 Subject matter experts (SMEs):

The remainder of the HAZOP risk assessment team should consist of subject matter experts (SMEs) with practical experience in the design, operation, and maintenance of the fuel system and vessel under evaluation. HAZOP risk assessment team members should be qualified professionals whose competencies and ability to contribute meaningfully to the risk assessment are verified and documented in accordance with MSC.1/Circ.1455 (6.6.2.1.4) [2].

Typical members include:

- Ship and system designers – Provide detailed knowledge of the system's design, including drawings, specifications, and operational intent.
- Safety Specialists – Ensure that regulatory requirements, safety standards, and risk management principles are considered.
- Operations Personnel – Offer practical insights into how the system is operated under normal and abnormal conditions.
- Maintenance Experts – Contribute understanding of maintenance procedures, potential failure modes, and access limitations.
- Subject Matter Experts (SMEs) – May be included as needed to address specific technical areas such as fuel properties, control systems, or environmental impacts.
- Process Engineers;
- Classification society representatives, with above mentioned qualifications; and
- Additional experts on call.

2.7.3 Flag Administration & Classification Society

In addition to the core disciplines previously mentioned, and depending on the novelty and complexity of the system under review, it is highly recommended to invite Class and/or Flag Administration representatives to attend the workshop for close communication with the Submitter (e.g. designer, shipyard, and shipowner). Their involvement can enhance regulatory alignment and ensure that emerging risks are adequately addressed.

However, careful consideration should be given for the case of the Classification society to ensure that their independence from the design team is maintained.

2.8 Report

The HAZOP report is the final record of the study and may serve many future purposes (e.g. audits, regulatory review, design modifications, incident investigations). Therefore, it must be complete, clear, and understandable even to those not involved in the workshop.

A comprehensive HAZOP report should include:

- Executive summary;
- Introduction;
- Scope and objectives;
- System overview;
- HAZOP procedure;
- HAZOP risk assessment team;
- Results;
- Conclusion;
- Actions;
- HAZOP worksheet;
- List of the drawings and documentation referred to; and
- Marked-up design representation (P&ID).

2.9 Follow-up

The outcome of the HAZOP is normally several recommendations that are to be followed up by the key stakeholders to ensure that identified risks are properly addressed and mitigated. The stakeholders include the individuals, teams or project manager assigned the responsibility of monitoring the risks, Implementing the mitigation strategies, or reporting on the project progress.

The submitter, who is seeking the approval from the classification society and flag administration, should maintain a register of all actions identified in the HAZOP and regularly update it. The register may include:

- Status of each action (open/closed);
- Responsible party;
- Brief description of action outcomes and supporting evidence; and
- Closed-out signatures by relevant parties.

The Submitter should ensure that all actions are addressed in a timely manner and tracked until closure. Actions should be assigned to a responsible party with a target completion date for follow-up. The timeline of the follow-up should be agreed among the interested stakeholders ensuring that crucial milestone dates are respected for the completion of each project.

All actions identified for hazardous scenarios with medium or high risk shall be tracked and closed out appropriately to demonstrate ALARP. This does not mean that every action must be implemented; each action should be evaluated for practicality, effectiveness in reducing risk, cost, and stakeholders' views. Alternative measures may also be considered and adopted subject to stakeholder consensus.

The safeguards recorded in the worksheet - whether planned, additional, or alternative - are to be implemented.

As a next step, implementation of these safeguards is to be confirmed through class and statutory surveys wherever applicable.

A formal check should be carried out before commissioning to ensure that all identified actions have been completed or otherwise resolved.

Annex A: Alternative Fuel Hazards

A.1 Fuels [15], [16], [17], [18]

LNG

Natural gas is a mixture of gaseous hydrocarbons, primarily methane. At ambient temperature and pressure, methane can ignite when mixed with air in concentrations between 4.4-17%, requiring a minimum ignition energy of 0.29 mJ. Consequently, any leaks or discharges from the fuel system pose a significant fire and explosion risk onboard a ship.

When methane is liquefied at atmospheric pressure to be converted to LNG, its volume is reduced by 600 times. The low boiling temperature of -161°C presents a safety challenge. Normal ship steel hulls are unsuitable for such low temperatures as they become brittle and can crack. Leakages of liquid natural gas may therefore damage load-carrying structures and compromise the gas tightness of safety barriers.

Additionally, large, pressurized storage tanks contain high energy content, which will be released if the tank experiences a substantial rupture.

Managing boil-off gas (BOG) is crucial to avoid over-pressurization and gas venting to atmosphere.

LPG

Liquefied Petroleum Gas (LPG) is a mixture of light hydrocarbons, primarily propane and butane. At ambient temperature and pressure, these gases can form flammable mixtures with air within concentration ranges of approximately 1.7–10.9% for propane and 1.4–9.3% for butane, with minimum ignition energies around 0.25 mJ. As such, leaks or discharges from the fuel system represent a serious fire and explosion hazard onboard a ship.

LPG is commonly stored as a liquid under moderate pressure and/or at low temperatures (pressurised, fully refrigerated, or semi-refrigerated). In the event of a tank failure or external fire (e.g., jet fire or pool fire), a rapid release of LPG can lead to a BLEVE (Boiling Liquid Expanding Vapour Explosion), resulting in catastrophic consequences.

Additionally, LPG is heavier than air in its gaseous form, which increases the likelihood of vapour accumulation in enclosed or low-lying areas, thereby heightening the risk of delayed ignition explosions. Ensuring proper ventilation, leak detection, and pressure relief is therefore critical to maintaining system safety and preventing accidental releases.

Methanol

Methanol is a liquid at normal conditions and can be stored in integral hull tanks similar to conventional fuel oil tanks. However, its storage and handling require careful management to prevent leaks and ensure safety.

Methanol is a liquid with a flashpoint of 9°C, meaning it can create ignitable vapours at temperatures above this point. Given that ambient temperatures onboard are typically above 9°C, methanol vapours pose a constant fire risk. At ambient temperature and pressure, methanol can ignite when mixed with air in concentrations between 6-36%, requiring a minimum ignition energy of 0.2 mJ.

Accumulation of methanol vapours, which is heavier than air, in confined spaces can lead to explosions if ignited. Methanol leakages introduce both fire and explosion hazards.

Methanol is toxic and can cause severe health issues, including blindness, coma, and death if ingested in large quantities. It is poisonous to the central nervous system and can be absorbed through the skin. High vapor concentrations can also cause asphyxiation. The United States National Institute for Occupational Safety and Health (NIOSH) specifies an Immediately Dangerous to Life or Health Concentrations (IDLH) value of 6000 ppm, while the Occupational Safety and Health Administration (OSHA) has a Permissible Exposure Limit of 200 ppm time-weighted average (TWA).

Ethanol

Ethanol is a liquid at normal conditions and can be stored in integral hull tanks similar to conventional fuel oil tanks. However, its storage and handling require careful management to prevent leaks and ensure safety.

Ethanol is a liquid with a flashpoint of 12°C, meaning it can create ignitable vapours at temperatures above this point. Given that ambient temperatures onboard are typically above 9°C, ethanol vapours pose a constant fire risk. At ambient temperature and pressure, ethanol can ignite when mixed with air in concentrations between 3-19%, requiring a minimum ignition energy of 0.3 mJ.

Accumulation of ethanol vapours, which is heavier than air, in confined spaces can lead to explosions if ignited. Ethanol leakages introduce both fire and explosion hazards.

Ammonia

At ambient temperature and pressure, ammonia can ignite when mixed with air in concentrations between 15 - 33.6%, requiring a minimum ignition energy of 14 mJ [17]. There are no reports of anhydrous gaseous ammonia explosions in open air.

Although anhydrous ammonia is lighter than air, rapid evaporation after a sudden release can cause liquid carry-over, forming a cloud that may be heavier than air. Depending on the airborne liquid fraction, ammonia can behave in buoyant, neutral, or dense fashion.

Toxicity is the key hazard of ammonia, harmful at concentrations well below its LFL and life-threatening at 0.5% in air. Small leakages are hazardous due to ammonia's harmful concentrations, necessitating careful consideration in ship design, including passenger and crew areas, escape ways, and safety equipment. NIOSH specifies an IDLH value of 300 ppm, and OSHA's Permissible Exposure Limit is 50 ppm TWA. Ammonia is transported in liquid state, either compressed or refrigerated. Fully refrigerated ammonia is stored at -33°C, while liquefied ammonia requires tanks designed for 18 bars at 45°C. Materials must be selected to avoid brittle fracture at low temperatures. Ammonia is corrosive, requiring careful material selection for direct contact and potential exposure during leakages.

Hydrogen

Hydrogen presents several safety challenges when used as ship fuel. Its wide flammability range (4 - 77%) and low ignition energy (0.017mJ) make it highly flammable and prone to severe explosions, with a high burning velocity that can escalate explosions into detonations.

The low boiling point of hydrogen (-253°C) complicates its storage and distribution. Managing boil-off gas and preventing the condensation of other gases (e.g., nitrogen, oxygen) are critical to avoid equipment malfunction and potential explosion hazards.

Hydrogen's low density causes it to rise and disperse quickly in open environments. In confined spaces, it can accumulate in high spots, increasing the risk of ignition from sources like ceiling lights. Effective gas detection and ventilation systems are essential.

High-pressure storage (250-700 bar) of hydrogen creates potential energy that, upon release, can cause significant pressure effects even without combustion. Sudden releases can ignite spontaneously, posing immediate risks to personnel and equipment.

Hydrogen can cause significant deterioration in the mechanical properties of metals, known as hydrogen embrittlement. This necessitates careful material selection and design considerations to ensure structural integrity.

Significant hydrogen leaks pose risks of asphyxiation due to oxygen depletion, alongside risks of frostbites and burn injuries due to low temperatures.

A.2 Properties

Critical properties from alternative fuels are given in Table 10 [16], [17], [19], [20]

When handling highly acute toxins like ammonia in work environments, it appears to be frequent practice to indicate the TLV-TWA and TLV-STEL values based on U.S. standards. While TLV-TWA, TLV-STEL, along with IDLH, AEGL standards are helpful for identifying the possibility of injury, they cannot be used to assess the potential for fatalities. To determine possibility of fatality in QRA, probit functions are also recommended to be used.

Table 10, Properties of Fuels

Properties	Methane	Hydrogen	Ammonia	Methanol	Ethanol	Butane	Propane
Relative density (air =1) [a]	0.55	0.07	0.59	1.11	1.59	2.05	1.56
Boiling point (Deg C) [a]	-162	-253	-33	65	78	-1	-42
Boiling point [3] (Deg C) [a]	gas	gas	gas	9.0	12.0	gas	gas
Flammable Limit, Lower (Vol. %) [a]	4.4	4.0	15.0	6.0	3.1	1.4	1.7
Flammable Limit, Higher (Vol. %) [a]	17.0	77.0	33.6	36.0	19.0	9.3	10.9
Auto ignition temperature [4] (Deg C) [a]	600	560	630	440	400	372	340
Minimum ignition energy (mJ) [b]	0.29	0.017	14.0	0.20	0.28	0.25	0.24
Laminar burning velocity (m/s) [c]	0.40	3.12	0.07	0.56	0.40	0.45	0.46
Molecular weight (kg/kmol) [c]	16.0425	2.01588	17.0305	32.0419	46.0684	58.1222	44.0956
Heat of combustion (kJ/kg)	50,000	120,000	18,604	19,918	26808	45,720	46,334
LC01 in 10 min (ppm)	na[5]	na	6,648 (0.66%)	53,533 (5.35%)	na	na	na
LC50 in 10 min (ppm)	na	na	21,129 (2.11%)	171,330 (17.13%)	na	na	na
LC01 in 30 min (ppm)	na	na	3,819 (0.38%)	23,300 (2.30%)	na	na	na
LC50 in 30 min (ppm)	na	na	12,263 (1.23%)	98,974 (9.89%)	na	na	na

[3] Temperature above which a material can vaporize to form a flammable mixture.
[4] The lowest temperature at which a fluid mixture can ignite without a source of ignition
[5] na: not applicable

Properties	Methane	Hydrogen	Ammonia	Methanol	Ethanol	Butane	Propane
Toxicity based on ACGIH, TLV-TWA[6] (ppm)	na	na	25	200	na	na	na
Toxicity based on ACGIH, TLV-STEL (ppm)	na	na	35	250	na	na	na

A.3 Hazards [21]

Table 11 tabulates typical hazards associated with the alternative fuels under consideration.

Table 11, Fuel Hazards

Hazards	LNG	Hydrogen	Ammonia	Methanol	Ethanol	LPG	Fuel Oil
Flammable hazards	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pool Fire	Yes	Unlikely	Yes	Yes	Yes	Yes	Yes
Smoke	No	No	No	No	No	No	Yes
Jet Fire	Yes	Yes	Yes	Unlikely	Unlikely	Yes	No
Flash Fire	Yes	Yes	Yes	Yes	Yes	Yes	Unlikely
Explosion	Yes	Yes	Yes	Yes	Yes	Yes	Unlikely
Boiling Liquid Expanding Vapour Explosion (BLEVE) [7]	Yes	Yes	Yes	Yes	Yes	Yes	No
Toxic hazards	No	No	Yes	Yes	No	No	Unlikely
Other Hazards							
Condensation	No	No	No	No	No	Yes	No
Asphyxiation	Yes	Yes	Yes	Unlikely	Unlikely	Yes	Unlikely
Cryogenic / Cold Contact	Yes	Yes	Yes	No	No	Yes	No
Gas expansion	Yes	Yes	Yes	No	No	Yes	No
Low Temperature Embrittlement	Yes	Yes	Unlikely	No	No	Unlikely	No
Rapid Phase Transition (RPT)	Yes	Unlikely [8]	No	No	No	Yes	No
Rollover	Yes	Yes	Unlikely	No	No	Yes	No

[6] When working with highly acute toxins such as ammonia, it is common practice to reference TLV-TWA and TLV-STEL values based on U.S. standards. While these thresholds, along with IDLH and AEGL levels, are useful for identifying the potential for injury, they are not sufficient for assessing the likelihood of fatalities. In Quantitative Risk Assessment (QRA), probit functions are recommended as an additional tool to evaluate the probability of fatal outcomes.

[7] An event that occurs from the sudden release of a large mass of pressurized liquid (above the boiling point) to the atmosphere. A primary cause is an external flame impinging on the shell of a vessel above the liquid level, weakening the shell and resulting in sudden rupture.

[8] A study by Lars H. [31] concluded that LH2 RPT event as a consequence of an accidental spill on water is an issue of only minor concern.

Annex B: Likelihood Reference Data

B.1 Fuel Release Likelihood

There is no applicable leak frequency database in the maritime industry. As an alternative, utilising leak frequency databases from the oil and gas industry, such as IOGP (2019) [22], may be considered as discussed in the literature [23].

To address uncertainties and different operating environment, e.g. ship motions, hull deflection, and vibrations, and operating practice in ships, more conservative data set based on data between 1992-2015 is suggested.

N.B.: This data table is indicative purpose only and includes uncertainties. All values raised to E-3. Additionally, large, pressurized storage tanks contain high energy content, which will be released if the tank experiences a substantial rupture.

Table 12, Likelihood of Fuel Releases

Equipment type	Hole diameter				
	1–3 mm	3–10 mm	10–50 mm	50-150mm	FBR[9]
Equipment diameter, 50 mm					
Pipe (per m length)	0.0360	0.0150	0.0067	-	0.0024
Flange	0.0130	0.0060	0.0028	-	0.0011
Valve, Manual	0.0240	0.0130	0.0075	-	0.0044
Valve, Actuated	0.2400	0.9700	0.0390	-	0.0012
Instrument	0.2100	0.0850	0.0350	-	0.0110
Pressure Vessel	0.5100	0.2600	0.1400	-	0.0740
Pump, Centrifugal	5.9	1.4	0.3	-	0.0390
Pump, Reciprocating	0.8100	0.5500	0.4200	-	0.4500
Compressor, Centrifugal	3.7	1.6	0.72	-	0.27
Compressor, Reciprocating	16	7.1	3.2	-	1.3
HEX, S&T (Shell)	1.2	0.6	0.3	-	0.14
HEX, S&T (Tube)	0.48	0.29	0.18	-	0.14
HEX, Plate	6.8	2.4	0.83	-	0.21
Filter	2.3	0.83	0.29	-	0.0740
Equipment diameter, 150 mm					
Pipe (1m)	0.017	0.0069	0.0028	0.000570	0.00036
Flange	0.021	0.0095	0.0043	0.000098	0.00017
Valve, Manual	0.028	0.0130	0.0062	0.001500	0.00120
Valve, Actuated	0.130	0.0620	0.0030	0.007200	0.00600
Instrument	-	-	-	-	-
Pressure Vessel	0.51	0.26	0.14	0.038	0.036

[9] **F**ull **B**ody **R**upture

Equipment type	Hole diameter				
	1–3 mm	3–10 mm	10–50 mm	50-150mm	FBR[9]
Pump, Centrifugal	5.9	1.4	0.3	0.03	0.0089
Pump, Reciprocating	0.81	0.55	0.42	0.16	0.28
Compressor, Centrifugal	3.7	1.6	0.72	0.16	0.11
Compressor, Reciprocating	16	7.1	3.2	0.74	0.55
HEX, S&T (Shell)	1.2	0.6	0.3	0.074	0.062
HEX, S&T (Tube)	0.48	0.29	0.18	0.061	0.077
HEX, Plate	6.8	2.4	0.83	0.14	0.071
Filter	2.3	0.83	0.29	0.049	0.025

B.2 Ignition Likelihood

Ignition probability refers to the likelihood that flammable materials will ignite following a leak. It is a critical factor in risk assessments for facilities handling flammable liquids and gases.

Ignition events are typically classified into two categories:

- Immediate Ignition: Occurs when flammable substances ignite instantly after a leak, triggered by auto-ignition or nearby accidental ignition sources.
- Delayed Ignition: Happens when a flammable gas cloud disperses and is later ignited by a remote source. This can lead to flash fires, explosions, or secondary fires such as jet fires or pool fires if the flame burns back to the leak origin.

Table 13 and Table 14 give indicative probability values for immediate and delayed ignition.

Table 13: Indicative ignition likelihood: immediate ignition [24]

Release rate	Hydrogen, LPG, Flammable gas with high & average reactivity	LNG, Ammonia, Flammable gas with low reactivity	Methanol, Ethanol, Flammable liquid with flash point < 21°C
< 10 kg/s	0.2	0.02	0.065
10 – 100 kg/s	0.5	0.04	0.065
> 100 kg/s	0.7	0.09	0.065

Table 14: Indicative ignition likelihood: delayed ignition (process plant, non-hazardous area) [25]

Source	Probability of ignition in one minute
High equipment density (non-classified)	0.5
Medium equipment density (non-classified)	0.25
Low equipment density (non-classified)	0.1
Confined space with no equipment	0.02

Annex C: Safeguards

IACS Rec 146 + additional measures for ammonia / hydrogen/methanol/LPG/Ethanol

Safeguards	LNG	LPG	Methanol Ethanol	Ammonia	Hydrogen
I. Engineering Mitigation Measures					
Structural/Design Measures					
Protection from impact damage (*collision, dropped object*)	✓	✓	✓	✓	✓
Vibration monitoring, Vibration Protection Measures	✓	✓	✓	✓	✓
Protection from wind, waves, and weather	✓	✓	✓	✓	✓
Thermal Insulation	✓	-	-	-	✓
Increased separation or increased physical protection from collision / grounding	✓	✓	✓	✓	✓
Secondary containment (*double-walled pipework*)	✓	✓	✓	✓	✓
Welded connections in preference to flanged connections	✓	✓	✓	✓	✓
Alarmed Doors	✓	✓	✓	✓	✓
Self-Closing Doors	✓	✓	✓	✓	✓
Bulkhead separation / cofferdam	✓	✓	✓	✓	✓
Pressure Relief Gaseous fuels	✓	✓	-	✓	✓
Pressure/Vacuum Relief Valve	-	-	✓	-	-
Venting	✓	✓	-	-	✓
Venting (*emergency only*)	✓	✓	-	✓	✓
Liquid Detection (*drip trays or annulus or interbarrier space*)	✓	✓	✓	✓	✓
Spray shield coverage	✓	✓	✓	✓	✓
Structural Thermal Protection (*cryogenic temperatures, vapour pressure*)	✓	-	-	-	✓
Drip Tray	✓	✓	✓	✓	✓
Bilge System (*independent*)	✓	✓	✓	✓	✓
Pressure and temperature detection, audible / visual monitoring, alarm, and shutdown	✓	✓	✓	✓	✓
Forced / natural ventilation - airlock	✓	✓	✓	✓	✓

Safeguards	LNG	LPG	Methanol Ethanol	Ammonia	Hydrogen
Minimisation of ignition sources - Ex proof electrical & mechanical equipment	✓	✓	✓	✓	✓
Separation of spaces	✓	✓	✓	✓	✓
Access arrangements	✓	✓	✓	✓	✓
Mooring tension monitoring / alarm	✓	✓	✓	✓	✓
Fatigue monitoring of mechanical supports	✓	✓	✓	✓	✓
Buffer / overflow tank - Fuel recycling	✓	✓	✓	✓	✓
Safety Instrumented System (*in accordance with IEC 61508* [26])	✓	✓	✓	✓	✓
Service fluid detection	✓	✓	✓	✓	✓
Fuel Level detection	✓	✓	✓	✓	✓
Monitoring & Detection					
Gas Detection (*audible / visual alarms*)	✓	✓	✓	✓	✓
Temperature Monitoring	✓	✓	-	✓	✓
Pressure Monitoring	✓	✓	✓	✓	✓
Flow Monitoring	✓	✓	✓	✓	✓
Independent control and safety system	✓	✓	✓	✓	✓
Remote/local emergency stop	✓	✓	✓	✓	✓
Emergency Shut Down	✓	✓	✓	✓	✓
Toxic Protection					
Safe Haven	-	-	-	✓	-
Water Sealing System	-	-	-	✓	-
Release Mitigating System (*Ammonia*)	-	-	-	✓	-
Fire Protection					
Fire dampers	✓	✓	✓	✓	✓
Flame arrestor	✓	✓	✓	✓	✓
Fire Detection, (*audible / visual alarms*)	✓	✓	✓	✓	✓
Water Mist System	✓	✓	✓	✓	✓

Safeguards	LNG	LPG	Methanol Ethanol	Ammonia	Hydrogen
Fire Fighting System	✓	✓	✓	✓	✓
Inert gas	✓	✓	✓	✓[10]	✓
Dilution of fuel to increase flash point	-	-	✓	-	-
Extraction ventilation	✓	✓	✓	✓	✓
Material selection	✓	✓	✓	✓	✓
Double block and bleed arrangement in fuel supply lines	✓	✓	-	✓	✓
Low temperature detection	✓	✓	✓	✓	✓
PPE	✓	✓	✓	✓	✓
Decontamination showers and eyewashes	-	-	✓	✓	-
Non-sparking fan	✓	✓	✓	✓	✓
Air intake shut-off devices	✓	✓	✓	✓	✓
HVAC with recirculation mode	✓	✓	✓	✓	✓
II. Procedural Mitigation Measures					
Increased frequency of inspection *(and maintenance)*	✓	✓	✓	✓	✓
Reduced parts replacement frequency	✓	✓	✓	✓	✓
Specific training for low-flashpoint fuels	✓	✓	✓	✓	✓
Restricted access	✓	✓	✓	✓	✓
Monitoring	✓	✓	✓	✓	✓
Operational procedures, emergency procedures	✓	✓	✓	✓	✓
Crew competency assessment and training	✓	✓	✓	✓	✓

[10] Carbon dioxide may form carbonates in contact with ammonia and is therefore not permitted for use as an inert gas.

Conclusions

The shift toward alternative fuels in maritime operations is a vital step in meeting the IMO target of net-zero greenhouse gas emissions by or around 2050. However, this transition brings new safety challenges, as fuels like LNG, LPG, methanol, ethanol, ammonia, and hydrogen introduce hazards that differ significantly from those of conventional marine fuels.

As a result, shipping companies must prepare to adopt a diverse range of alternative fuels through a transition process in which technological innovation often precedes the development of international regulatory frameworks. Currently, existing IMO guidelines primarily address the safe use of LNG as a marine fuel with the organization actively working on developing safety guidelines for the design and operation of ships using alternative fuels. A key priority in this effort is the identification and mitigation of associated risks, which is essential for ensuring safe operations and fostering a robust safety culture across the industry.

This report offers comprehensive guidelines on conducting qualitative risk assessments using HAZID and HAZOP methodologies. When applied effectively, these tools are critical for identifying potential hazards and operability issues early in the design or retrofit process. This enables stakeholders to implement appropriate safeguards and demonstrate that alternative-fueled vessels achieve safety levels equivalent to traditional ships.

By guiding a more standardizing application of HAZID and HAZOP, MTF aims to promote consistency, transparency, and trust among stakeholders—including shipowners, designers, classification societies, and flag administrations. The guidelines emphasize early-stage risk identification, structured workshop facilitation, and integration of findings into the SMS. They also stress the importance of qualified personnel, clear Terms of Reference, and well-defined risk criteria to ensure meaningful outcomes.

While the new guidelines are a standalone document, they serve as a supplement to IMO MSC.1/Circ.1455 [2] and IACS Rec. 146 [3] when conducting HAZID and HAZOP studies for ships that are either under construction or undergoing a retrofitting process and are designed to operate using alternative fuels. This dual applicability supports both prescriptive and alternative design approval processes, especially for fuels and technologies, not yet fully addressed by international regulations. The inclusion of fuel-specific hazard profiles, likelihood reference data, and safeguard strategies further enhances the guidelines' practical value.

The adoption of alternative fuels presents both challenges and opportunities for the maritime sector. By embracing structured, transparent, and collaborative risk assessment practices, the industry can manage this transition safely and responsibly. The guidelines in this report provide a strong foundation for supporting innovation while protecting people, assets, and the environment. MTF encourages all stakeholders to apply these practices rigorously and contribute to their continuous improvement through shared learning and feedback.

Recommendation on Future Work

MTF has revised the framework for conducting risk assessments related to the use of alternative fuels onboard vessels. While the framework presented in this guidelines report reflects current best practices, it is acknowledged that future revisions may be necessary as technologies and operational experience evolve.

It is recommended that a future edition of this guidelines report could incorporate additional risk assessment tools that enhance the depth and reliability of Hazard Identification (HAZID) and Hazard and Operability (HAZOP) studies.

These may include methodologies such as Layers of Protection Analysis (LOPA), which helps evaluate the effectiveness of existing safeguards, and quantitative techniques like Failure Mode, Effects, and Criticality Analysis (FMECA), which systematically assess potential failure modes and their impact on safety and operations.

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